EXCURSION TO THE CENTRAL PYRENEES, SEPTEMBER 1959

BY

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ABSTRACT

The account of a twelve day excursion is preceded by a short general description of the Central Pyrenees, their stratigraphy and structure and the regional metamorphism. The day by day description of the excursion follows the route which twice crosses the Paleozoic of the Pyrenees.

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PREFACE

In order to show our foreign colleagues something of the results of our work in the Central Pyrenees and with the hope to arrive at a better understanding of our problems by comparing their experience with ours, an excursion was arranged lasting from the 15th to the 27th of September 1959. Starting in Seo de Urgel we crossed the Pyrenees northwards through Andorra into France, then went westwards then south, entering the axial zone by following the Garonne river. We crossed the axial zone again going southwards by the Valle de Aran and the Pallaresa valley and finally went back to Viella by the tunnel through the Maladeta massif.

We had the pleasure of seeing among the participants during the whole or part of the excursion:

M. Bertraneu, B. R. G. G. M., Paris
Prof. Brindley, University of Dublin
Prof. Brinkmann, Bonn
Prof. Gill, Trinity College, Dublin
M. Guitard, B. R. G. G. M., Paris
Prof. Hollingworth, University College, London
Prof. Picard, Hebrew University, Jerusalem
Prof. Raguin, Ecole sup. des Mines, Paris
Prof. Sutton, Imperial College, London
Mrs. Sutton—Watson, Imperial College, London
Prof. R. Trümpy, Zürich
Prof. Wenk, Basel

and several young french and dutch geologists. To our regret several other colleagues, Spanish, French and Italian, were unfortunately prevented, some only at the last moment, to attend our meeting.

General leader of the excursion was Prof. de Sitter, who also was responsible for the explanation on all the non-crystalline rocks, Dr. Zwart was responsible for the metamorphic rocks seen on the 2nd to 6th day and 8th day and Prof. Brindley for the morning excursion to the Marimaña granite on the 10th day, which intrusive mass he has been mapping in 1958 and 1959.

Mr. Boschma from Leiden looked very efficiently after our well being in the field and in the villages where we passed the night.

Our excursion can be regarded as a sequence to the excursion of the Société géologique de France in the eastern Pyrenees (Bull. Soc. Géol. France, 6e sér. t. 8, fasc. 8, 1958) in September 1958, and we profited largely from the experience gathered there.

The excursion was mainly concerned with the structure of the Pyrenees as a Mountain chain and its metamorphic history. The stratigraphy of the Paleozoic received considerable attention but the lack of fossils in this highly cleaved region makes detailed knowledge unfortunately impossible.

As much of our detailed information about the 8000 km² which have been or are being mapped in the Central Pyrenees is, or will be published, in separate reports and in particular by 1 : 50.000 maps with explanation, of which three have been published already (sheet 3, de Sitter-Zwart, 1959; sheet 4, Kleinsmiede, 1960; sheet 5, Zandvliet, 1960), this account of the excursion will give only an introduction to the more important problems and a short description of the itinerary we followed.

INTRODUCTION

Since 1948 a group of varying composition, students and staff members, has been mapping the Central Pyrenees (Plate I). Various publications, mentioned in the reference list, have seen the light, other reports are deposited in our files. In recent years special petrographical and structural studies have been undertaken principally by Dr. Zwart (1958 a & b, 1959 a & b).

Our studies have mostly been restricted to the Paleozoic, the younger sediments have only been mapped as far as they constitue the boundaries or cover of the Paleozoic, and our structural analysis is mainly concerned with the Hercynian structures, although the Alpine deformation had to be analysed in so far as to understand how much must be subtracted from the present configuration to arrive at the Hercynian structure. The result of this latter study can be formulated very briefly in the concept that the Tertiary structure is partly an outward extension to the north and south of the Hercynian structure, and partly a morphogenetic arching combined with tilting of the whole mountain chain.

From a purely descriptive point of view the Pyrenean mountain chain consists of an axial zone, some 50 km wide, of Paleozoic rocks flanked on both sides by"sub-Pyrenean" zones, consisting of Paleozoic cores with a Mesozoic-Tertiary mantle. These internal zones are flanked again by Upper Cretaceous-Tertiary marginal troughs. Although the northern internal zone, the zone of the satellite massifs, is considerably broader (20 km) than its southern equivalent, the Nogueras zone (4—10 km), the whole structure is thus fundamentally symmetric and we can not talk about foreland and hinterland.

These two steps outwards from the axial zone, internal zone and marginal trough, have a profound significance. The axial zone is not only the centre of the Hercynian compression but has in its centre also the deepest and central part of the Paleozoic geocyncline. The two internal zones are the sites of the thickest Lowest Cretaceous deposits as a precursory phase of the Late Eocene Pyrenean phase of folding, mainly restricted to this zone. The marginal troughs are filled with Upper Cretaceous, and Lower Tertiary sediments and its outer borders are the sites of younger, Miocene, phases of folding, which have recently been studied in great detail by Mangin, 1959. The conclusion of this author that the most pronounced tectonic phase on the borders of the axial zone is also Lower-Miocene must certainly be regarded as erroneous, as long as the discordant Pobla de Segur conglomerates, which are generally regarded as Oligocene (see for instance Misch, 1934, and Hupé, 1954) are not proven to be Miocene.

Thus we see that both the formation of sedimentary basins and their subsequent deformations wander outwards from the centre since the onset in the Devonian. The Pyrenean mountain chain derives its fundamental symmetric structure from its situation between two cratonic blocks, the Aquitanian block in the north and the Ebro block in the south, the basins encroach more and more on these blocks during the long history and the folding phases follow them faithfully step for step in the same direction.

The last phase of the whole sequence is the morphogenetic phase which occurred probably quite at the end of the Miocene or in the Pliocene. Two Miocene or younger aplanation surfaces or peneplains have been preserved admirably in the central zone of the Pyrenees, only slightly remodeled by later glaciations. The principal surface is found in the central zone a little above 2000 m altitude and gradually drops to both sides thus forming a very broad and shallow arch. A higher surface at roughly 2400 m alt. is less well preserved. The base of this arch is not quite horizontal, the whole orogene has been tilted as a block with a north dipping slope, with the result that the southern marginal trough, the Tremp basin, is at a much higher altitude than its northern equivalent which is completely buried beneath younger sediments. Therefore we find the original post-Eocene folding phase conglomerates outcropping high above the river beds in the south and mostly deeply buried in the north. The age of the morphogenetic uplift has been revealed to us by a small outcrop of sediment, filling up an ancient gorge in the granite and Paleozoic rock of the central zone, containing at its bottom conglomerates and at its top some lignites (see 9th day). The pollen of the latter give its age roughly as Pontian (Jelgersma, 1957).

STRATIGRAPHY

The details of the stratigraphy of the Paleozoic of the Central Pyrenees is very insufficiently known because fossil evidence is almost completely absent exept in the Silurian black shales.

There is a lower, neritic Cambro-Ordovician series below the Silurian and a shale-limestone sequence of the Devonian above it, topped by the Lower Carboniferous.

THE CAMBRO-ORDOVICIAN

The Cambro-Ordovician consists of a monotonous series of slates, sandy slates, quartzites and microconglomerates of unknown thickness certainly exceeding 2000 m and probably less than 5000 m. One gets the impression that a shaly habitus prevails in the west and south and a psammite character in north and east. Most probably the deepest exposed rock is the limestone and black ferruginous slate outcropping in an antiform near Lladorre in the Cardós river, which could perhaps be identified as the "série de Canaveilles" of Cavet, 1951. If older sediments are present their original character is masked because they are replaced by micaschists and augengneisses. Above it occurs a finely stratified series of thin slate and sandsone alternation of "schistes rubanés" character, overlain at its turn by a thick slate-sandy slate-quartzite-microconglomerate sequence. It is only at the top that better recognizable horizons occur, coarse conglomerates, massive dolomite, limestone and thin slightly calcareous fossiliferous slates. The latter have given a Caradoc fauna (Roussel, 1904, Dalloni, 1930, Cavet 1958) and represents the oldest fossiliferous horizon in the Pyrenees. Whether Cambrium is represented by some part of the lower series (série de Canaveilles for instance, as has been suggested by Cavet, or below a certain conglomerate as suggested by Destombes, 1953) remains a matter of conjecture. Even Pre-Cambriam might be present in the lower part of the section.

The development of the top part of the Cambro-Ordovician is very irregular. The thick massive dolomite-limestone series of Trimouns (Zwart 1954) and that of Bentaillou are not in the same position in relation to the Silurian for instance, the first being almost right below it, the second being separated from it by a few hundred meters of sediments carrying a thin stratified calcareous layer (probably an equivalent of the Caradoc fossiliferous horizon) and a thick conglomerate. The Bentaillou limestone can be followed eastwards to the north flank of the Auzat granite, but the conglomerate above it disappears in that direction. The limestone can most probably be correlated with the thick dolomite round the Marimaña granite, where it carries at its base a typical alternation of limestone and quartzite called "sandwich limestone". Sometimes it is a typical crinoid limestone. In the western portion of our map this limestone horizon has disappeared, but a $\pm$ 20 m thick limestone occurs again at the base of the Silurian in the Bosost dome. It links up roughly with the Bentaillou limestone by its occurences north of the Barrados valley and in the Liat region. As all these limestones are apt to be mineralized, talc in Trimouns, lead-zinc ores in Bentaillou, Liat and Bosost, it has been referred to as the "metalliferous limestone" (Mussy, 1869—70). The extension of this limestone/dolomite facies has been given by Zandvliet, 1960 (fig. 1).

Coarse conglomerates occur both above and below it in the Bentaillou region and even as far south as Llavorsi one can observe two conglomerate horizons with a calcareous layer with slates and sandstones between them. The pebbles consist almost exclusively of quartzite or quartz and are not particularly well rounded. The matrix may be either sandy or shaly. Sometimes the pebbles are tectonically flattened, sometimes they have preserved their original shape, but the matrix has been intensively folded and flattened. Near the village of Tor, near the Andorra border, they are clearly of a fluviatile origin with sand lenses on the lee side of a big pebble and sandy clay around it. Their rather monomict character and their fluviatile origin suggest that all the pebbles are directly derived from the Cambro-Ordovician itself. On top of the massive limestone occur occasionally limestone breccias in a shaly matrix. The facies of the whole sequence is neritic and certainly not a flysch facies.

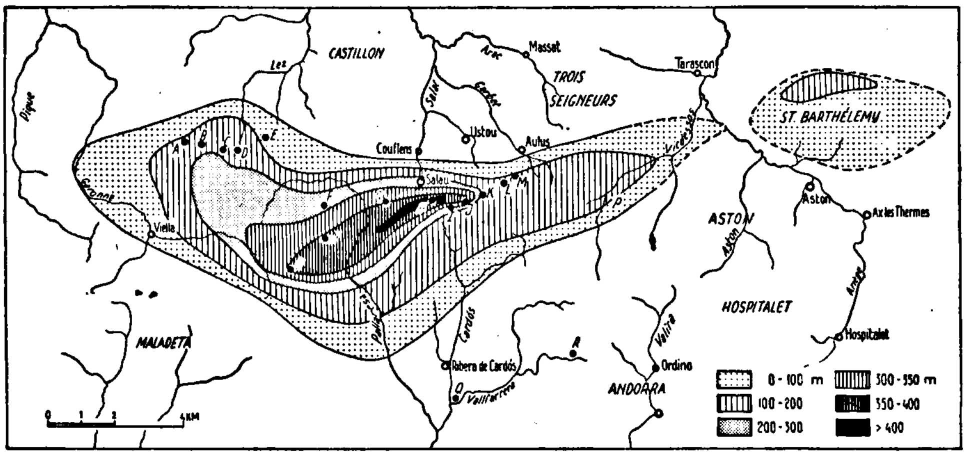


Fig. 1. Isopach map of the Upper Ordovician massive limestone-dolomite. After Zandvliet, 1960.

THE SILURIAN

The Silurian is represented by its well known black shale facies characterized by graptolites and occasional beds of Orthoceras bearing black limestone. It is a typical euxenic facies with pyrite and a certain carbon content, very high alumina, low silica and relatively high iron content. As the iron occurs as an easily soluble sulfide, the rock always give rise to ferruginous springs.

The graptolites, mainly Monograptus, have shown that the Silurian is complete except perhaps the extreme lower and upper members, but as no single top to bottom section has been analysed and this rock is always extremely tectonized the evidence is rather incomplete.

Rather frequently, and in particular in the north, the black shales carry black limestone beds with orthoceras and a few brachiopods. Very rarely a sandstone occurs within the black slates.

As the top of the Ordovician has a rather variable composition it would not be impossible that there exists a slight disconformity at the basis of the Silurian

The top of the Silurian has been chosen arbitrarily where the black slates are covered either by limestone or by calcareous slates. In the south the top is formed by an alternation of black slates and thin limestones intercalations. As long as fossil evidence is lacking we are here at a loss where to draw a reasonable limit between the Devonian and the Silurian.

In the region of Plà de Beret, between the Upper Pallaresa and Iñola rivers, the typical black slates are missing altogether. Most probably this is due, however, to fault movements and squeezing along the top of the Ordovician and not to facies change.

The thickness is difficult to evaluate because the black slates are invariably strongly tectonized, sometimes squeezed in thin strips, sometimes accumulated in thick masses. Nevertheless it seems to be thicker in the north, perhaps 200 m, than in the centre where 50 m would be perhaps a better guess.

THE DEVONIAN

The Devonian shows a very variable facies, as well in a north-south direction as east-west, parallel to the mountain chain, but the variation is most pronounced in a N-S cross section. We find in the Valle de Aran, the central portion of the axial zone, a completely different development as compared with the northern and southern sections which, at least for the upper part, are rather similar. The main diference lies in the development of the Upper Devonian, which in the north and south is characterized by a griotte facies sometimes of great thickness, which is completely missing in the centre. In the centre a curious quartzitic and grauwacke turbidite facies, which is unknown in the border regions, has developed above a limestone-shale alternation. This turbidite sequence is overlain by a fine grained green slate which could perhaps be correlated with similar slates on top of the griotte occurring in the NW. In the SW region, between the Esera and Ribagorzana rivers an alternation of quartzites and dolomites occurs below the griotte separated from it by a slate horizon. Dating by fossils of the whole sequence in only possible in the extreme north, in the Arize massif principally, and possibly also on the southern border. The griottes often carry goniatites but seldom well enough preserved for determination. Recently conodonts have given better results (Ziegler 1959).

The thickness of the Devonian is also very variable. In the Salat area it has been valued at 1400 m, but further west only at 300—400 m and in the Arize massif at 360—540 m. In the Llavorsi syncline it is only 330 m thick and in the Valle de Arán several ridges and basins have been distinguished with greatly varying thicknesses (Kleinsmiede, 1960).

There can be no doubt that after the very regular sedimentation of the Silurian, the Devonian represents a period of much greater unrest.

The top of the Devonian seems to be locally a period of emergence. In the north, in the Arize massif and elsewhere coarse monomict limestone conglomerates have been found and there the upper limestones often show a karstic surface erosion (Ovtracht, 1956). Moreover the boundary with the Carboniferous is variable. In the central syncline of the axial zone the Carboniferous rests probably on the basal limestones. In other sections, however, there is an unbroken sequence from Devonian to Carboniferous (Ziegler, 1959).

CARBONIFEROUS

The *Carboniferous* rocks have to be subdivided in a pre-Hercynian-folding sequence and a post-Hercynian sequence.

The pre-Hercynian Carboniferous

Since Ziegler, 1959, has shown with conodonts, and Durand Delga, 1958 with tentaculites, that at least in some sections the Tournaisian is not missing, as had been assumed until then, the evidence of the field geologist both in the Montagne Noir and in the Pyrenees, who often have found evidence of a gradual transition from Devonian to Carboniferous, stands on much firmer ground.

The Carboniferous both in the south and in the north starts with a chert horizon, carrying phosphate nodules. The chert is followed by shales and sandstones, which in the north carry occasionally a goniatite fauna of Upper Visean age. In the south these shales are characterized by single corals. Both the shales and sandstones are often micaceous.

Often the cherts are missing and are replaced by pebble beds or conglomerates in which well rounded quartz pebbles and angular chert pebbles dominate, and which carry occasionally gneissic or other crystalline rock pebbles (Bellver district). These conglomeratic beds occur in the Jueu syncline, in the north west of our map and in the southern zone. Sometimes both the chert containing conglomerates or breccias are present in one section (Salat valley). Thin limestones occur occasionally in the shale-sandstone sequence.

A different facies is developed in the central syncline of the Upper Esera and Jueu valleys, where we find black micaceous sandstones and shales with plant fragments, sometimes of large dimension. This flora has been regarded as Lower Westphalian by Zeiller (Roussel 1904).

The post-Hercynian Carboniferous

In the northern border zone of the Pyrenees it are the red Permo-Triassic rocks which cover unconformably the Hercynian folded Paleozoic, but in the southern border zone there occur Upper-Carboniferous and perhaps Permian rocks between the Permo-Triassic and the Hercynian folded sequence.

In one outcrop near Aguiró a coal seam is known, situated between two coarse conglomerates, which has delivered an Upper Westphalian flora (Dalloni, 1930). The upper conglomerate is followed by the volcanic sequence, mostly tufs, which is common all along the southern border of the Pyrenees, and which carries coal seams with a Stephanian flora. The same formation has also been reported from Mouthoumet.

In one outcrop, opposits Arcalis in the Pallaresa valley, black carbonaceous shales have given a flora containing Walchia's and which is regarded as Permian (Dalloni, 1930).

The Stephanian is overlain everywhere by the Permo-Triassic, sometimes with a slight unconformity.

The Stephanian volcanic formation shows abundant evidence of volcanic activity in the neighbourhood, bombs and lapilli for instance and has accordingly a laterally strongly varying development. Towards the top it carries fresh water cherts, conglomerates, sandstone beds, black shale beds and coal seams and at the base we find sometimes coarse conglomerates as at Aguiró or shally weathered surface deposits of the older rocks, cracks in the Devonian limestones filled up with pebbles and similar rock types.

THE PERMO-TRIASSIC

The Permo-Triassic is developed in its classical continental facies of red cross-bedded sandstones, quartz-pebble conglomerates, breccias and red mudstone.

The Triassic follows with the typical muschelkalk, gray dolomite and cavernous dolomite (anhydrite dolomite, cargneules) and the Keuper gypsiferous marls, pure gypsum, salt, black shale, carrying small and large bodies of basic rocks (ophites) and folded slabs of muschelkalk.

THE POST-TRIAS FORMATIONS

Little attention has been paid by us to the Mesozoic younger than Trias and to the Tertiary, except where their occurence threw special light on the structural development. We refer the reader to Casteras, 1933 for the northern border zone and to Misch, 1934, for the southern border.

The most conspicious member is without doubt the thick Urgonian limestone which forms a very pronounced chain of hilltops along the North-Pyrenean fault zone. In the south each of the north-south running rivers has cut a deep canyon in these thick and strongly folded limestones. The maximum development of this Lower Cretaceous sequence (Urgonian limestone and Aptian shales in the north) is restricted to narrow zones flanking the axial zone in the north and the Nogueras zone in the south.

In the northern zone the Cenomanian is unconformable on this Lower Cretaceous and its coastal facies line coïncides roughly with the North-Pyrenean fault zone. This coastal facies is characterized by coarse conglomerates, arkoses with a calcareous matrix, big slided blocks of older rocks (granites and Devonian limestone) and similar phenomena of Wild-Flysch character. In the south such unconformity is unknown.

During the Senonian and Eocene the depositional basin shifted further outwards.

The next folding phase was late Eocene. It put a stop to the sedimentation in the southern marginal through and originated the enormous accumulation of conglomerate mostly of oligocene age in the southern border of the Pyrenees, which can be studied particularly well near the little town of Pobla de Segur. They were deposited there on a strongly dissected landscape of Lower Cretaceous rocks.

The next Tertiary formation met with in the axial zone of the Central Pyrenees is a small outcrop of Upper Miocene lignite, clays, sandstone and coarse pebble beds preserved in a filled up canyon on the crest between the Arties and Aguamoix rivers in the Valle de Aran. The top of this formation is covered by some 40 m of moraine which forms part of the general glacial cover of the ± 2000 m aplanation surface. This latter surface ranging from 1850—2350 m altitude is well developed both on the French (platform of Aston) and Spanish side (Coma Romadera) of the central Pyrenees. As the above mentioned canyon probably dates form the first morphogenic uplift of this aplanation surface, this uplift apparently did not start before the end of middle Miocene. Remnants of a higher and older surface at 2400—2600 m altitude have been preserved in some places on the spanish side (Montareno, for instance) (Zandvliet, 1960).

The present topography of the Pyrenees is largely pre-glacial, and the glaciations modified the relief only very slightly. Most glacial cirques are remarkably shallow and morainic material does not descend far in the valleys.

STRUCTURE

The Central Pyrenean area represented on the accompanying 1: 200.000 map (Plate I) and sections (Plate II), contains principally the axial zone and the adjoining north and south Pyrenean internal zones. Of the northern internal zone it are mainly the satellite massifs of St. Barthélemy, Arize, Trois Seigneurs and Castillon which are included. The southern internal zone has been called the Nogueras zone by Misch. The axial zone is separated by the north Pyrenean fault zone, running over Aston, Vicdessos, Aulus, Bordes and St. Béat, from the satellite massifs. In the south its border is marked by an almost straight line of Permo-Triassic crossing the Segre, Pallaresa, Ribagorzana and Esera rivers, south of which we find the narrow Nogueras zone consisting of Upper Paleozoic masses surrounded by Triassic.

The structural history of this map section can be divided in three main episodes, the Hercynian orogenesis, the morphogenetic uplift and the Alpine orogenesis.

Fortunately the Hercynian and Alpine deformations can be separated rather well. The axial zone has suffered no Alpine deformation except along narrow zones on its southern and northern boundary and along fault lines in the axial zone. Neither have the northern Paleozoic satellite massifs been strongly deformed in Alpine time. The Nogueras zone on the contrary has been deformed in the Tertiary. The whole mountain chain is concerned in the morphogenetic upheaval, independent of its previous structural history. Nevertheless in detail it is often difficult to assign a certain structural feature to one of the major orogeneses, in particular in the northern and southern internal zones.

In a former paper, de Sitter 1956, we have called attention to the symmetry of the Pyrenean orogene, its centripetal development and its intercontinental character. The orogene is situated between two cratonic blocks, the Aquitanian block in the north and the Ebro block in the south. Its development as a distinct structural unit dates with certainty from the beginning of the Devonian, as is true for all European Hercynian orogenes. Since then it has developed outwards further and further, encroaching on the continental regions to the north and south, towards its present stage with marginal troughs in the south (Cuenca de Tremp) and in the north. The Hercynian and Alpine structures are not independent, they form here one unit. Nevertheless the Tertiary structures are not quite parallel to the Hercynian ones. The North-Pyrenean fault between Vicdessos and Castillon cuts obliquely through the E-W Hercynian folds of the Salat basin.

The Hercynian structure as a whole has a distinct cleavage type of folding, strongest in the centre and showing transitions to the concentric type both towards the north (Arize massif, Estours) and the south (lower Ribagorzana-Baliera rivers). This fact gives a strong support to the thesis that the present Pyrenean chain is also the Hercynian chain and did not extend much further north and south.

The cleavage and axial plane dip variation is not quite so symmetrical. It is true that it is vertical in the Salat, slightly north dipping in the Valle de Aran and Upper Pallaresa and Cardos rivers, but further south this dip decreases regularly and becomes very flat indeed downstream of Llavorsi and elsewhere near the southern border of the axial zone. Towards the north, however, flattening of the axial plane cleavage with southern dip is not so pronounced, although in the Arize massif and in the Estours region of the axial zone the axial planes do dip towards the south, but some structures in the Lez river dip northwards.

The intensity of the stress cleavage in general is less in the Carboniferous than in the Cambro-Ordovician, and its greatest development is neither quite central, it is outside the metamorphic regions, higher in the south than in the north.

Another asymmetry of the orogene is demonstrated by the regional metamorphism, which in the Central Pyrenees is distinctly restricted to a northern zone and is particularly strong in the satellite massifs of the northern internal zone. Whether the distribution of the intrusive masses in general has a tectonical background or not is difficult to ascertain, more in detail there certainly are significant coïncidences between structural lines and the arrangement of plutons.

A look at the map shows that there is one central anticlinorium containing the Aston massif in the east and the Lys-Caillouas massif in the west. It is flanked in the south by a narrow syncline, the Llavorsi syncline in the east and centre, the Jueu syncline in the west.

The central anticline has in its centre the outcrop of the "série de Canaveilles" near Lladore which continues eastward in the Hospitalet massif. South of this massif we find the Tor-Ordino syncline in Andorra and north of it an important thrustfault, the Merens faultzone, dying out westward.

North of the Aston dome, and north of the north-Pyrenean fault the four satellite massifs of Castillon, Arize, Trois Seigneurs and St. Barthélemy, once certainly forming a single unit, one dome, with a strongly developed regional metamorphism. They were separated from one another and probably from the Aston massif also in a late Hercynian phase, a separation which was accentuated by the Cretaceous phase of faulting along the North Pyrenean faultzone.

A smaller Cambro-Ordovician dome on both sides of the Garonne river has been called the Bosost dome, a structure with a regional metamorphic centre round this town.

Between and round these three main units, the central anticlinorium, the satellite massifs dome and the Bosost dome, we find the Devonian in strongly compressed form, mostly as vertical or north dipping isoclinal folds. There is a pronounced difference in style of folding between that of the Cambro-Ordovician and that of the Devonian. The Devonian (with Carboniferous) has been sheared off its Cambro-Ordovician basement along the incompetent Silurian slates and forms isoclinal folds of some hundred meters width, whereas its basement shows besides some larger folds numerous small and micro folds. The top of the Ordovician is generally a gently curved dome surface in strong contrast with the isoclinal folds of the Devonian bedding planes. There can be no doubt that it is the extremely incompetent character of the Silurian which caused this strong disharmonic folding. This strong disharmony is less well developed on the southern border of the axial zone, where the top slates of the Ordovician sometimes are included in the Devonian folds (Schulman, 1959 and morning 2nd day, fig. 7).

The axial plane of the long syncline of Llavorsi has a distinct northern dip of some 70—60°. On the map it looks a simple isoclinal syncline but in good outcrops, in the northern Devonian flank for instance, one can see that many small parallel folds accompany the major structure as large sized parasitic folds. Approaching the Maladeta massif both flanks become more complicated and show several secundary folds of Silurian and Devonian. The same is true at its eastern end in and near Andorra, where a whole set of secondary folds, even with thrusts, are exposed. There even the upper Ordovician slates take part in this small scale folding of the Devonian.

South of Llavorsi we find another large anticlinorium of Cambro-Ordovician rocks, reaching from Seo de Urgel to the Noguera de Tor, where it plunges down below the Devonian. In this structure the disharmonic folding along the Silurian slates is beautifully exposed in the Tor valley (Fig. 14). South of this anticlinorium in the Pallaresa, Flamisell and Mañanet valleys, the Devonian shows horizontal recumbent folds with Silurian in the cores of the anticlines and sometimes Lower-Carboniferous in its synclines. It has been proposed that these folds are due to gliding tectonics, the Devonian mantle of the anticlinorium gliding down, sheared off from the apex. Two facts contradict this hypothesis. First of all that the Devonian is still present on the apex in the Monseny ridge (NE of Capdella) and occurs there also in recumbent folds. Secondly the cleavage planes in the Cambro-Ordovician basement flatten also to an almost horizontal position near Rialp and thus are roughly parallel to the axial planes of the Devonian folds further south.

Further west in the Ribagorzana, Balliera and Esera valleys the fold axial planes are steeper, but always dipping north.

REGIONAL METAMORPHISM AND INTRUSIVE ROCKS

The regional metamorphism in the Central Pyrenees is restricted to the northern half of the Mountain chain. South of the Llavorsi syncline no regionally metamorphosed rocks occur. Generally the metamorphism has attacked only the Cambro-Ordovician, but occasionally Silurian and Lower Devonian participated in this process. The regional metamorphic rocks occur either as large monoclines in the north Pyrenean massifs, or broad anticlines in the axial zone.

The regional metamorphism can, on one hand be subdivided in several succeeding phases, and on the other hand in areas with different rocktypes. Thus it appears that space as well as time are concerned in the study of these rocks. This is the main reason that no two metamorphic areas are exactly similar, although the Aston-Hospitalet anticline resembles in several respects the Canigou massif, and the Agly finds its counterpart more or less in the Barthélemy massif.

Firstly the differences in space will be treated, and then the chronological succession of the metamorphism, although both subjects cannot be treated entirely separated.

One of the most striking features of the north Pyrenean massifs and the gneiss anticlines of the axial zone are the different types of gneiss occurring in both regions. The most characteristic rock type of the north Pyrenean massifs is a linear garnet-augengneiss, of which one of the most important features is the direction of lineation N-S, in contrast with the E-W strike of the Hercynian belt of the Pyrenees.

Garnet-augengneisses have been found in the Agly massif (lineation N 30 E), in the Barthélemy and Arize massifs, (lineation N-S), as relics in the Trois Seigneurs massif, and finally almost the whole of the Castillon massif is made up of these rocks (lineation also N-S). The mineralogical composition of these gneisses with quartz, plagioclase, potassium feldspar, biotite, garnet, cordierite and absence of muscovite, is typical for katazonal conditions, and in fact these are the only really katazonal rocks of the Pyrenees. The rather dry metamorphism is typical of metamorphism close to the granulite facies, and the presence of hypersthene is not uncommon. Real granulites have been described by Guitard from the Agly massif. The only hydrous minerals are biotite and hornblende.

In the garnet-augengneiss numerous layers and lenses of amphibolites, calc-silicate rocks and marbles occur, testifying, together with the presence of aluminium-excess minerals as garnet and cordierite, to the sedimentary origin of these gneisses.

In the Barthélemy, Arize and Castillon massifs these gneisses are the deepest exposed rocks, and in the first two areas a thick succession of other rocktypes succeeds these gneisses towards the top.

In the Agly massif the garnet-gneisses are almost immediately overlain by mica-schists, which in their turn grade into phyllites.

In the Barthélemy massif the garnet-gneisses can be subdivided in several units, based on different relations between crystallization and deformation. Towards the top they change into non-linear migmatites, without garnet, but with muscovite and much fibrolite. The migmatites are covered by a layer of leucocratic gneiss, which in its turn is overlain by mica-schists. Both contacts of the leucocratic gneiss are sharp. The mica-schists change gradually into phyllites, which are overlain by the Silurian black slates. A similar kind of succession exists in the Arize and Trois Seigneurs massifs, although there the amount of exposed garnet-gneiss is small. In the Castillon massif, the original cover of the garnet-gneiss has disappeared and the whole massif is made of the same kind of gneiss.

The most difficult problem in the north Pyrenean massifs is the explanation of the N-S lineations in the garnet-gneisses, which seems to fit badly in the regional picture. A solution originally proposed by the junior author that they represent an older basement, does not seem warranted, in view of the situation in the Agly massif, and the gradual transitions of garnet-gneiss to overlying migmatites. An absolute age determination may settle the issue.

The migmatites of the north Pyrenean massifs are feldspathized mica-schists, and occur also in the gneiss areas of the axial zone. At many places the typical banded migmatites are, due to continued recrystallization, converted into quartz-dioritic rocks, often with cordierite and sillimanite. Especially in the Trois Seigneurs massif this process was important, and there it was accompanied by strong mobilization and rheomorphism resulting in complete disorientation and flowing around of inclusions of amphibolite, calc-silicate rocks and marbles, which originally formed continuous stratigraphic horizons. The same process has taken place in the Barthélemy massif, but on a smaller scale.

The metamorphic front, in this case the biotite isograd, shows a variable position with regard to the Silurian. In the eastern part of the Barthélemy massif biotite-schists reach as high as the Silurian, and the thickness of these schists amounts to only a few hundred metres. Towards the west the isograd sinks off, together with an increased thickness of the mica-schists. This trend can be followed in the Arize massif, where several thousands of metres of phyllites, covering a thick series of mica-schists, lie below the Silurian black slates.

The regional metamorphic anticlines of the axial zone are characterized by the absence of garnet-augengneisses, and instead leucocratic augengneisses form the core of these anticlines. These augengneisses differ in several respects from the garnet-augengneisses. The lineations, due to elongation of minerals, are E-W and parallel to the trend of the fold axes of the low grade Paleozoic. The mineralogical composition is different, garnet is absent, and biotite and muscovite are present besides both feldspars and quartz. The contact with overlying and intercalated mica-schists is always sharp, and the absence of any typical sedimentary relict as amphibolites, marbles or quartzites in the gneisses renders a determination of the original, premetamorphic rocks difficult. There is choice out of three different possibilities,

(1) they are pre- or syntectonically intruded granites,
(2) they are isochemically metamorphosed sediments, for example arkoses,
(3) they are metasomatic pelites or semipelites.

It is up till now, not possible to make a definite choice between the three possibilities. There are arguments pro and con all three of them. For an igneous origin pleads the homogeneity of the gneisses and their sharp contacts with the enclosing rocks. This does not explain, however, why the augen-gneisses are always bound to a certain degree of metamorphism, unless it should be a synkinematic contact metamorphism, making mica-schists as contact rocks. This, at least, could explain, why such a gneissified granite does not occur in lower grade rocks, but it does not clarify the question why such a granite is always restricted to Cambro-Ordovician rocks, and never has reached Devonian or Carboniferous rocks, which both have been intruded by the late tectonic instrusive biotite-granodiorites. Furthermore it does not explain the metamorphism in the satellite massifs, in which such gneisses hardly occur.

An isochemically metamorphosed arkose series, as advocated by Guitard (1958) is not supported by field evidence, as complete absence of any such sediment outside the metamorphic areas and the lack of transitions between augengneiss and micaschists, which would be expected when a pelite-arkose series would be metamorphosed, since there is little reason to assume that only the pure end-members, pelite, or arkose existed and no intermediate sediment, yielding for example a gneiss with aluminium silicates. Such gneisses, however, do not exist. For these reasons I am in favour of a metasomatic origin for the augengneisses, the original rocks being normal, pelitic or semipelitic Cambro-Ordovician rocks. This is especially supported by the situation in the Hospitalet massif, where the upper boundary of the gneiss is oblique with regard to the stratigraphic limits. A sedimentary origin of these augengneisses is further supported by zircon studies, recently carried out by G. W. Verspyck.

In any metamorphic region of the Pyrenees the gneisses or migmatites are overlain by a series of mica-schists, in which at least three metamorphic zones can be distinguished: a low grade chlorite zone with sericite-chlorite-phyllites, a medium grade biotite zone with biotite-muscovite-schists, and a higher grade andalusite-zone, containing biotite, muscovite, andalusite, staurolite and cordierite, the three aluminium-silicates usually occurring in a stable assemblage. Sillimanite or fibrolite occurs as a fourth aluminium silicate, but it is always associated with granitization, and is largely a metasomatic mineral, usually replacing biotite. It is not indicative for katazonal circumstances, and is in most rocks of the Pyrenees a mesozonal mineral. Somewhere in or below the andalusite zone gneisses, migmatites or granites appear for the first time.

With regard to the historical development of the metamorphism, it can be stated that there is a close correlation between different kinds of deformation and the nature of metamorphism. Roughly speaking there is a decline of the size and intensity of folding, accompanied by a decreasing orientation of minerals, ending up in unoriented post-kinematic crystallization.

We distinguish an early synkinematic phase, characterized by formation of schistosity and strongly oriented crystallization, a late-kinematic phase, with cross-folds in NW-SE and NE-SW direction, with weak orientation of new minerals, and a post-kinematic phase, not accompanied by movements in the metamorphic regions. There are several, probably more or less local complications to this scheme; for example an isoclinal folding phase with N-S axes, earlier than the crossfolding has been rather important in the Bosost dome.

During the early synkinematic phase linear mica-schists and augengneisses have been produced in which all minerals are elongated or oriented in E-W direction. The schistosity is plane in outcrops and has usually low dips. There is no doubt that this phase of metamorphism is contemporaneous with the cleavage folding in the low grade Paleozoic sediments. All large structures, as the Cambro-Ordovician dome of the Pallaresa, the Llavorsi-syncline and the Aston-Hospitalet gneiss anticline date from this folding period. In slates and mica-schists a new deformation, the cross-folding has made small folds, not usually exceeding a size of a few metres, and is often accompanied by a fracture cleavage which in slates is always post-crystalline. In mica-schists mica's may grow in the fracture cleavage and thus produce a coarse second schistosity, which as a rule can immediately be identified under the microscope. Minerals like andalusite and cordierite grow usually unoriented, and only occasionally in the foldaxes of the cross folds. The direction of cross folding is mostly NW-SE, but a second set at right angles to the first one, occurs also at some places.

In gneisses and migmatites this phase takes a quite different aspect. The folds become much more disharmonic and their direction less regular. The style of deformation is very plastic. This mobilization is in the field, without exception accompanied by the occurrence of smaller or larger granitic patches. Under the microscope it appears that all these rocks have been subjected to a recrystallization, completely obliterating the earlier augengneiss-texture, even in those rocks, which in the field are still augengneiss. Field evidence leaves little doubt that these granite patches are made by recrystallization of the original gneiss, probably without much introduction of new material, except water. Therefore granitization and mobilization are closely linked, and apparently are interrelated. The conclusion that granitization and plastic deformation in the gneisses are contemporaneous with cross folding in slates and schists is warranted by the distribution in the field; strong cross folding in schists near granitized gneisses; weak or no cross folding in not recrystallized augengneisses. Further evidence is furnished by pegmatite sills, genetically belonging to the metamorphism, which are cross folded together with enclosing schists. In general granitization has continued in post-kinematic time, resulting in unoriented, crosscutting granites and pegmatites, showing no structural influence on adjacent rocks or inclusions. The occurrence of fibrolite in some of the granites and pegmatites and in the surrounding schists, is related to the granitization, and is to my opinion the result of aluminium metasomatism, originating from the schists which have been granitized.

The whole of the Aston massif has been subjected to this mobilization and granitization, and in any respect they resemble Sederholm's classical migmatite areas. The eastern part of the Hospitalet massif has been preserved in its early synkinematic state, and a comparison between the gneisses of both areas is extremely useful.

Although during the early synkinematic phase the Pyrenees can be divided in two zones, a northern one, later forming the satellite massifs, and a southern one, the future axial zone, respectively characterized by garnet-augengneisses and leucocratic augen-gneisses, this difference holds no longer good for late- and post-kinematic time, because the same kinds of migmatite, accompanied by mobilization, occur in both zones.

The biotite-granodiorites of the Central Pyrenees are all of the diapiric intrusive type. The date of their emplacement can be established with regard to the different folding phases, and with the aid of porphyroblasts in the contact rocks. It appeared that rocks with late E-W folds of cleavage have been hornfelsized, clearly indicating a later age for the contact metamorphism. Relations of andalusite porphyroblasts with the surrounding slate in contact metamorphic aureoles, also indicate a post-kinematic origin. The same conclusion had already been reached by the occurrence of the granodiorites in regional metamorphic terrain, as for example in the Trois Seigneurs massif. There mica-schists with a late static phase of muscovitization have clearly been remetamorphosed near the contact of the granodiorite, thus testifying to an age later than the last phase of the regional metamorphism.

As a rule the biotite-granodiorites occur outside regional metamorphic areas, and intruded all Paleozoic strata up to the Carboniferous. The smaller stocks show a certain structural influence on their host rocks, refolding them around different axes. Much new light on this problem has been thrown by J. Brindley, who mapped the Marimaña and Tredos stock in great detail. The larger bodies, like the Maladeta and Auzat batholiths, are, on the map, clearly discordant, and their structural influence on the adjacent sediments is far less than could be expected by their enormous volume. It is suggested that these large bodies rose to higher levels along vertical faults, uplifting the covering sediments, which have been eroded away.

THE EXCURSION

The excursion started from the southern border of the axial zone and went north by way of Seo de Urgel, passed through Andorra and descended the Ariége river, then went west to the Garonne river and crossed the axial zone again going

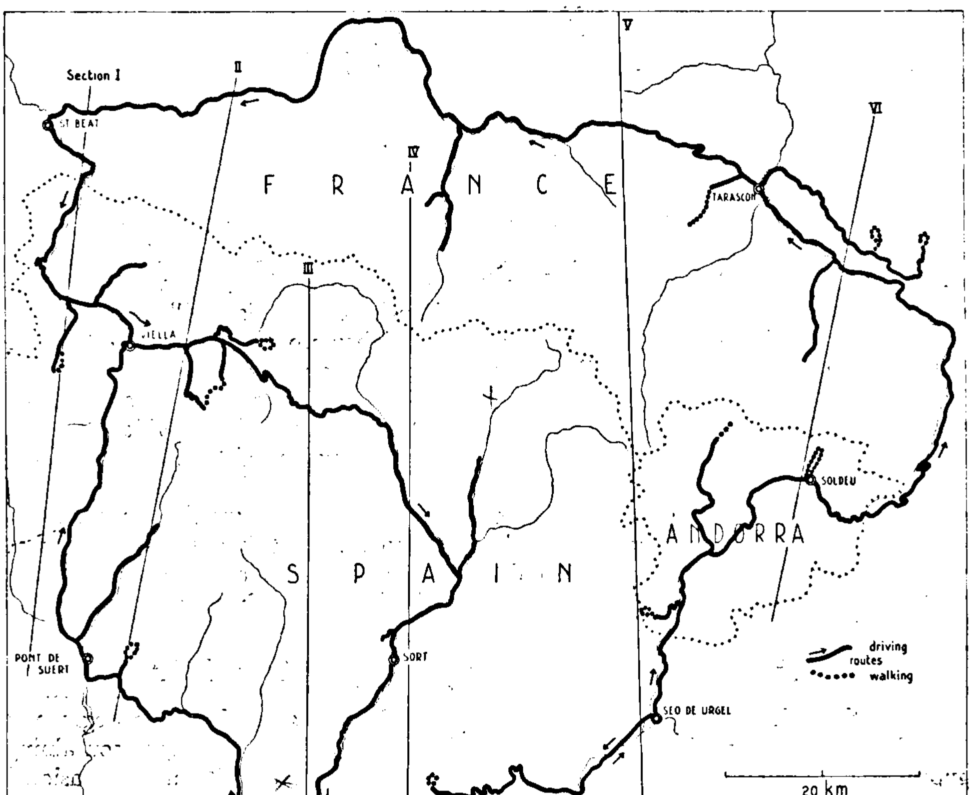


Fig. 2. Excursion route.

south by way of the Pallaresa river. The Nogueras zone and the unconformable cover of Stephanian, Trias and Tertiary were studied the first day south of Seo de Urgel and the last days between Pobla de Segur and Pont de Suert (fig. 2).

Program

1st day —	From Seo de Urgél to Tahús-Castells and back		
2nd day —	morning —	Rio Fontanedo	
	afternoon —	El Serrat (Andorra)	
3rd day —	morning —	Val d'Inclés	
	afternoon —	Hospitalet - Ax les Thermes - Tarascon	
4th day —	morning —	Basal gneisses of the St. Barthélemy massif	
5th day —	Aston valley		
6th day —	1st party —	Trois Seigneurs massif	- St. Béat
	2nd party —	Estours, Salat valley	- St. Béat
7th day —	Col de Menté - Viella		
8th day —	morning —	Jueu valley	
	afternoon —	folded pegmatites of Rio Barrados	
9th day —	Moncasau —	Aguamoix	
10th day —	morning —	Marimaña granite (Prof. Brindley)	
	afternoon —	Salardu - Sort	
11th day —	morning —	Sort-Lladorre	
	afternoon —	Sort-Pobla de Segur-Pont de Suert	
12th day —	morning —	Stephanian and Triassic of Malpas	
	afternoon —	Rio de Tor section	

1st day. From Seo de Urgél to Tahús-Castells

Leaving Seo de Urgel, quite near the town, the road passes between two hills, both consisting of Ordovician schists. Against these hills a coarse fluviatile conglomerate-sandstone series has been deposited, which occupies a small basin west of the Segre river. Its age is supposed to be Pontian-Plaisantian (Chevalier, 1909; Boissevain 1934), the same age as the basins higher up the Segre river in the Bellver region. The formation lies unconformbly on and against the schists and is certainly not separated from it by faults as Boissevain suggests. The road follows the river and runs on quaternary alluvium. A little beyond the village of Pla de San Tirs the road cuts into the red sandstone and mudstone of the Trias, which show here a regular dip of some 40° south. On the other side of the river, to the west below the Trias, one can see the remnants of a small excavation for a coal seam of the Stephanian, which is exploited east of this village 500 m high in the mountains. The flora of Pla de San Tirs, collected on both sides of the Segre valley contains several Pecopteridae and gives a Stephanian age (Dalloni, 1930, p. 97—100).

The Trias of Hostalets shows a succession of red quartz conglomerate at the base, followed by thick red mudstones and red fine grained crossbedded sandstone. We take the bridge across the river, and the road leading to Novés de Segre and pass first through these beds and then enter into the gypsiferous Keuper containing gypsum, gypsiferous marbles with some limestone and dolomite and occasional cellular dolomites.

A little further upstreams near the village of Belpuy we pass again through the red beds of the Triassic and then into the Devonian limestones. The contact Trias-Devonian is not a normal contact, but a fault.

South of the Rio de la Guardia we see the imposing 300 m high and steep northern front of the Sierra de Prada, consisting of Mesozoic limestones with dark Dogger dolomite at its base and Triassic in the valley and thick massive

Urgonian limestone forming most of the steep wall. This abrupt boundary between the Paleozoic rocks with or without a Trias cover and the Mesozoic limestones is typical for the whole southern border of the Central Pyrenees. The south-Pyrenean north-south rivers cut deep canyons through this Mesozoic limestone zone, "defilados", and the excellent exposures on the canyon walls show that the iimestones are often folded almost isoclinally in vertical folds. This boundary between Mesozoic and Paleozoic is in principal a steep flexure or fault, and the deep erosion along that line as in the Guardia river, which we are following now, is often due to the presence of soft gypsum along the fault line.

The road exposures are in rather massive gray limestones of the lower half

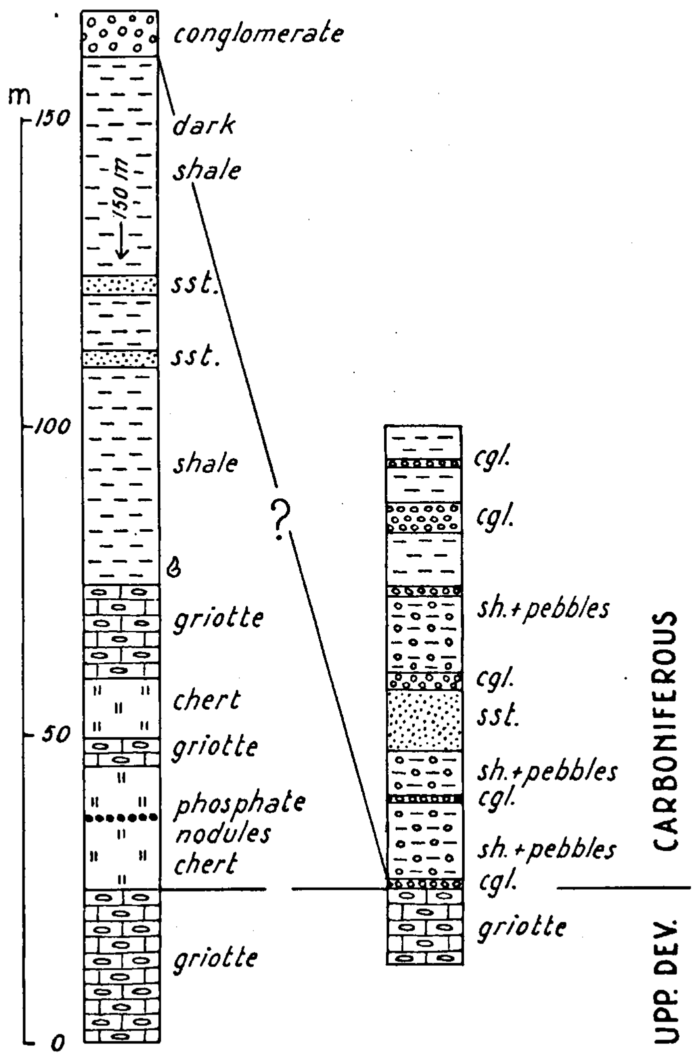


Fig. 3. Two sections of Upper Devonian-Carboniferous, both in Nogueras zone north of Rio de la Guardia valley. To the left complete section, right lower part Carboniferous missing. After Mellema.

of the Devonian section, with occasionally an outcrop of black Silurian slates. Where the road turns north following the Arroyo de Castellas, it soon enters a canyon with on both sides red and white Upper Devonian griotte limestones. When the road starts to climb up the mountain with hairpin curves it has entered already in Carboniferous shales.

The first stop on the second southern hairpin gives us a good exposure of the contact Carboniferous/Devonian. The gray and white Devonian griotte limestone is followed by a quartz-chert conglomerate, where the pebbles are floating in a shale matrix without touching each other. The conglomerate contains occasional gneiss pebbles (fig. 3).

Higher up beyond the village of Espahent the road enters the Trias cover, but the contact Trias-Devonian is nowhere well exposed. From a dominant point, just below the Trias a quarry in beautiful red "griotte" limestone with many goniatites, one has a good view to the east on the opposite canyon wall of the San Quirico Mountain. The structure, which dips steeply northwards and is thought to be Hercynian, consists of a repetition, by thrusting, of the same upper sheet of red and white griotte with in the core probably some fold repetition. The northern slope is roughly the Carboniferous-Devonian contact of the south flank of an E-W syncline.

The Trias wedge has a N-S trend and its western boundary is a thrust as can be seen in a road exposure. This N-S strike is evidently an Tertiary feature.

Some 3 km beyond the Trias-Devonian fault contact we find again a very good road exposure of the Devonian-Carboniferous contact. The gray griotte limestone contains near its top several chert layers. Then shales alternate with thin sandstones until the first conglomerate is found some 200 m above this contact (fig. 4). It is supposed that the series below the conglomerate and above the Devonian in this section is missing in the first section and contains the Lower Carboniferous.

The village of La Guardia is situated on an isolated Mesozoic limestone rock of about 1 km diameter surrounded on all sides by gypsiferous Triassic with small ophite bodies. A walk to the north along the ridge brings us to point where we have a good view westwards, on a cross section of the most southern longitudinal structure of the Nogueras zone, an overthrusted anticline in the Devonian, very well exposed in the small Arroyo west of La Guardia. The thrust movement is northwards and is of Tertiary age, because on the ridge we find an exposure of the same thrustplane showing a block of Dogger dolomite involved in the thrusting (fig. 4).

From La Guardia the road descends a little into the broad valley between La Guardia and Tahus, forming the watershed between the Segre and the Pallaresa river. This gentle hilly country presents a strong contrast with the deep canyon we have just left and represents a remnant of an older erosion cycle preserved at this altitude of 1400—1500 m.

Along the road to Tahus a road exposure shows the oligocene conglomerate unconformably on Cretaceous limestone, which we will see on a much grander scale on the 11th day.

When the road turns north to the village of Castells it cuts the gypsum of the Trias again and enters the Carboniferous and the Devonian griotte. Walking upstreams one passes through an excellent section of the Devonian and into the Silurian, which is very fossiliferous with graptolites, orthoceras and brachiopods. Its top shows an alternation of black shale and limestone, further down we are in the typical black staining shales of the Silurian.

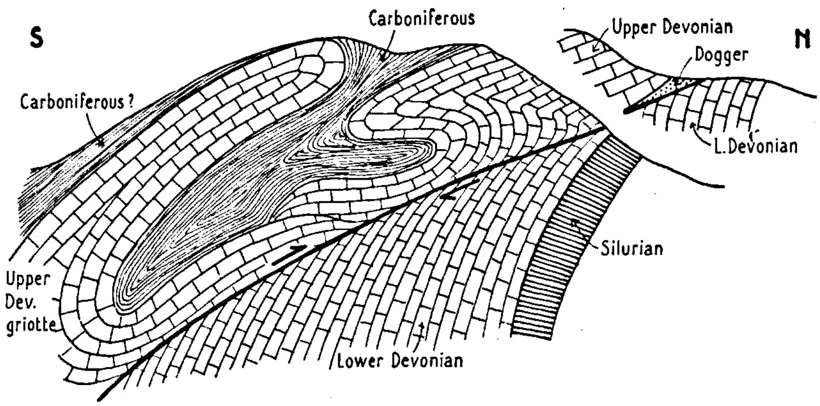


Fig. 4. Tertiary thrusting in Nogueras zone west of Guardia.
After Mellema.

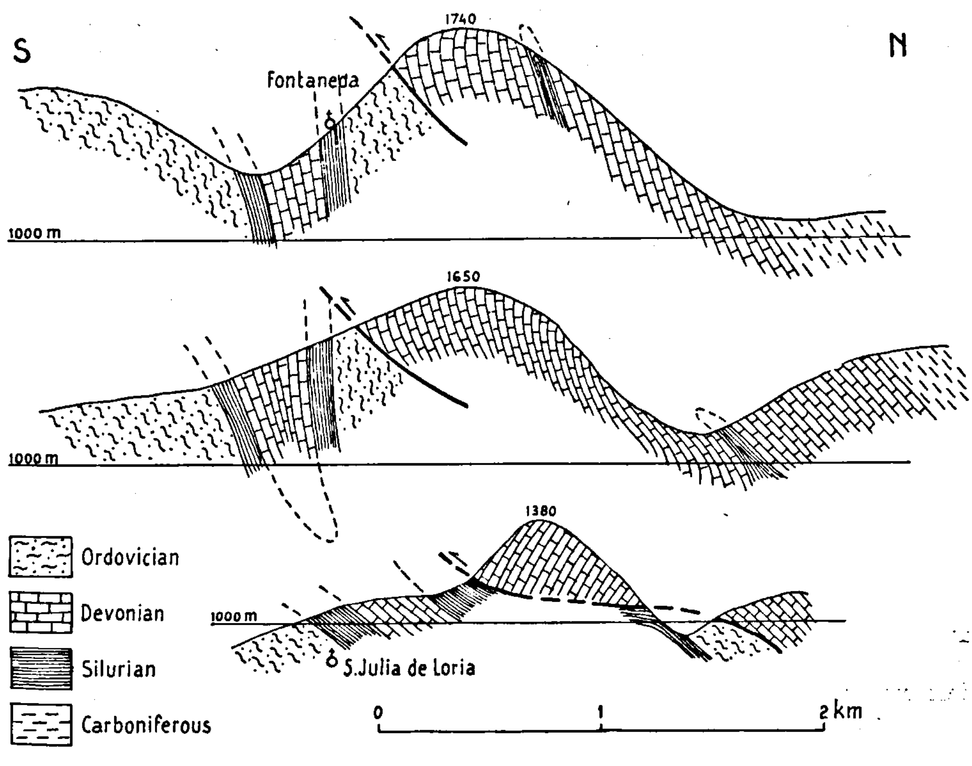


Fig. 5. Folding and thrusting in Llavorsi syncline in Andorra, Rio Fontenado.
After Dessauvagie.

2nd day. Morning: Rio Fontaneda

The main road northwards towards Andorra stays in the Ordovician schists nearly until the frontier. A road exposure near km 8 gives a good example of the thick conglomerate near the top of the Ordovician. Near the village of Santa Julia one can cross the river and follow a small road up the mountains. Along this road there are good exposures of the Silurian and Devonian, further on the road follows the southern slope of the Rio Fontaneda and enters the Ordovician shales. On the opposite slope one gets an admirable view of two narrow bands of black Silurian slates with between them a band of Devonian limestone and on top Ordovician shales. The band of Devonian is the core of an isoclinal syncline, plunging towards the east.

On top of the Ordovician the Devonian is again exposed, apparently thrusted over the Ordovician (fig. 5). Near the frontier ridge the road crosses the Devonian syncline and in some exposures one can see the strongly developed cleavage planes crossing the faintly preserved bedding.

From the frontier ridge a very good view westwards shows the complicated structure of the southern flank of the Llavorsi syncline consisting of several synclines with Devonian cores alternating with anticlines with Silurian cores, apparently sheared of from their Ordovician substratum.

2nd day. Afternoon: El Serrat

From Santa Julia the excursion drove to the city of Andorra, passing the Andorra granodiorite, and then in the direction of El Serrat in the Valira del Norte. First we passed the northern limb of the Llavorsi syncline, then the Cambro-Ordovician anticline near la Massana, and the Devonian of the Tor syncline near Ordino. Before reaching El Serrat we passed a very large outcrop of Silurian schists. El Serrat is situated on the Cambro-Ordovician meta-sediments which form the cover of the Hospitalet gneiss anticline. The limestone of the Canaveilles series crosses the river a few hundred metres south of El Serrat. The Silurian somewhat further south lies here in abnormal tectonic position.

Both structurally and petrographically the El Serrat-schists show a complex history, which in principle is twofold. The first phase of folding was cleavage folding with east-west direction. The grade of metamorphism was low; producing phyllites or muscovite-schists. The second folding phase was of different character, predominantly concentric and with fold axes in NW-SE direction. Between both folding periods the grade of metamorphism rose to that of the andalusite zone, resulting in the growth of coarse unoriented crystals of biotite, andalusite, staurolite and cordierite, lying in a matrix of muscovite-schists. Microscopic evidence confirms the later age of the second folding with regard to the andalusite zone metamorphism. In all cases staurolite, andalusite and cordierite contain rows of inclusions which are not folded. This indicates that first the schistosity must have been produced, then the crystals were formed, inheriting the undeformed schistosity and finally the schists were folded in NW-SE direction, producing microfolds in the schist matrix. In many cases the crystals of andalusite and cordierite were folded and deformed also. The stout staurolite crystals usually are undeformed.

Upstreams from El Serrat we had ample opportunity to study these rocks. Beautifully folded andalusite was found and abundant staurolite often with penetration twins.

On the way back the excursion made a stop south of El Serrat to collect some samples of the Silurian, which shows the same kind of metamorphism and tectonic evolution as the El-Serrat schists. In a crumpled matrix of fine grained carbonaceous sericite-schists, andalusite porphyroblasts are at random distributed. The inherited plane internal schistosity of the andalusite is explained by growth after the first cleavage folding, and before the microfolding of the schists matrix.

The excursion then drove back to Andorra and from there to Soldeu. One stop was made near Encamp to examine the Cambro-Ordovician phyllites with three lineations; the first is the E-W cleavage-bedding intersection, the second parallel to the crossfolding in El Serrat and the third again with E-W direction.

The last stop was made near Canillo where a cleavage fold in Devonian limestone is exposed. It shows well developed parasitic folds of thin quartzitic layers.

The excursion reached Soldeu at darkness, where the night was spent.

3rd day. Morning: Val d'Incles

From the junction of the Andorra highway and the road in the Incles valley the excursion climbed up the EW slope of this valley.

The first outcrop we visited, was a strongly folded quartzite, under- and overlain by mica-schists. The quartzite is distinctly linear, the lineations being parallel to the fold axes and the general strike in this region, that is E-W. Very few indications were seen of the NW-SE crossfolding. Further to the north andalusite-schists are well exposed. In these rocks two different structures can be discerned. The oldest one is an andalusite-mica-schist, with mica-crystals elongated in E-W direction and parallel to the fold axes. Andalusite and cordierite with their longest axis in the direction of the E-W lineation. Staurolite occurs as stout prisms, often with penetration twins. These schists are affected by the crossfolding in NW-SE direction, consisting of microfolding of the S-plane. A second generation andalusite has grown in these fold axes, resulting in mica-schists in which both directions are equaly well visible. The intensity of the crossfolding and accompanying metamorphism is in Incles much less than in El Serrat. Another difference is that the Incles-schists were synkinematically already andalusite-schists, in contrast with the synkinematic phyllites of El Serrat.

Besides the NW—SE crossfolding, another direction, NE—SW, is present in these micaschist. This direction is well developed in the mica-schists W of Port de Fontargente, where both directions alternate in different localities. Rarely the two crossfoldings occur in one rock. They are both characterized by the same microfolds of the s-plane and oriented andalusites. Together with the original E—W lineation it is a symmetrical set, suggesting that the stress field was still oriented in N—S direction, during the crossfolding. For some unknown reason the NW—SE direction predominates, not only in the Incles valley but but over a large part of the metamorphic zone of the Pyrenees.

Continuing northward the excursion arrived in the gneisses which underlie the andalusite-schists. The boundary between both rocktypes is sharp, although some micaschist-slivers occur in the gneiss close to the contact. The gneisses near the contact are fine grained, but soon become more coarse grained towards the centre. The gneisses are homogeneous biotite-muscovite augengneisses with a distinct E—W lineation and schistosity, both structural elements are parallel to those of the overlying mica-schists. Signs of crossfolding do not occur in the gneisses, but this is possibly due to the greater competency of the gneiss. The gneisses are quite homogeneous and there are no crosscutting elements.

3rd day, afternoon, Hospitalet-Ax les Thermes-Tarascon

After lunch the excursion drove on to the Port d'Envalira and then to Hospitalet. Before Hospitalet we passed the Soldeu-Lanoux fault which separates the Cambro-Ordovicien phyllites in the south from the gneisses of the Hospitalet massif in the north. Near Hospitalet a stop was made to examine the gneisses of the Hospitalet massif showing here the incipient stages of granitization, which are absent in the Incles valley but which become more pronounced in easterly direction.

The next stop was made near Mérens to examine the Mérens fault zone. The Mérens faut is a very long E—W-running reversed fault, which can be continued all the way from the Pic de Montcalm to the Mediterranean. The northern block is upthrown as most E—W faults do in the Pyrenees. The gneisses of this block are over a thickness of several hundreds of metres mylonitized; the mylonites being sheared to augengneisses with steep lineations in the sense of the main movements. Folds do occur in the mylonites, and are strictly parallel to the lineations.

Between Mérens and Port Banyells a second fault accompanies that of Mérens. This so-called fault of Pinet runs on a distance of 100—400 m to the south parallel to the Mérens fault.

The metamorphics of the Hospitalet massif are exposed south of the Pinet fault, and between the two faults a sedimentary series outcrops, which probably represent the "Canaveilles" series. The continuation of this zone to the west and east suggests that this sedimentary zone belongs to the cover of the Hospitalet massif, which by the movements along the Mérens fault is thrust over the gneisses of this massif.

The last stop was made near the funiculaire of le Saquet, between Mérens and Ax-les-Thermes, where granitized and mobilized augen-gneisses could be studied. The augen-gneiss of the Aston massif are in principle similar to those of the Hospitalet massif, but they have undergone a longer lasting metamorphism. This has lead to the formation of unoriented granitic rocks at the expense of the augen-gneisses. This granitization takes place on a small scale, resulting in the occurrence of small irregular granite patches in the gneiss, as well as on a large scale, resulting in the formation of mappable granite bodies, as for example near Ax-les-Thermes. This granitization is always accompanied by more or less irregular folding of the schistosity of the gneiss and locally of strong mobilization which explains occurrence of disoriented gneiss relics in the granite. Of this process a good example could be seen in one of the erratic blocks in the Ariége river.

After this outcrop the excursion drove to Tarascon, first to Ax through the Aston gneisses, than from Ax to Sinsat through the sedimentary cover of the Aston massif, and from there to Tarascon through the Mesozoic Tarascon basin.

4th day morning: Basal gneisses of the St. Barthélemy massif

From Tarascon we drove to Appy, the starting point of our walk on the southern slope of the St. Barthélemy massif. The first outcrop visited at 1500 m altitude consists of folded garnet-augengneisses, the main object of this morning's excursion. The rocks of this outcrop are strongly linear and schistose gneisses, with s-planes dipping 20—40° N, and lineations in N—S direction. The mineralogical composition is quartz, potash feldspar, sodic plagioclase, biotite and garnet.

They are often banded, dark biotite-rich bands alternating with more leucocratic bands. Intercalation with amphibolites and calc-silicate rocks are quite frequent. On the visited locality the gneisses are folded, the fold-axes being parallel to the lineations. Further it became clear that there must have been an eastward movement of the upper limbs with regard to the lower, often accompanied by shearplanes or small thrusts. The axial planes of the folds and the shearplanes are parallel to the general dip of the schistosity in the area, Microscopic examination reveals that these gneisses show a strong post-crystalline deformation.

The garnet-gneisses are part of a considerable series of various gneisses and migmatites. The whole succession from the lowest exposed part to the non-metamorphic cover reads as follows:

top
- phyllites, mica-schists — metamorphic Cambro-Ordovicien
- migmatites (sillimanite-gneiss and quartz-diorite)
- granitic biotite-muscovite-gneiss
- linear garnet augen-gneiss
- schistose garnet-gneiss
- granite and gneissose granite

bottom

Our first explanation of the formation of this complicated gneiss succession was the supposition that the three lower members, clearly belonging together, represent an older basement, eroded and covered by the Cambro-Ordovician sediments, which on their turn were migmatized during the hercynian orogeny (Zwart, 1954). The main reasons for this supposition were the differences in mineraligocal composition, — no muscovite in the basal series, no garnet in the migmatites — the difference in structure, linear augengneisses in the basal gneisses, schistose gneisses above. Further it seems difficult to explain why the lineations in the basal gneisses run N—S, in contrast with the general E—W strike of the Paleozoic of the Pyrenees. Nevertheless we abandoned this point of view and now consider it possible that the whole gneiss series is a conformable sequence. This is mainly based on the fact that the transition garnet augengneiss to overlying migmatites is not sharp, as formerly stated, but gradual both in mineralogical and micro-structural sense. Moreover similar garnet-gneisses occur also in the Castillon and Agly massif, and in the latter area in a different stratigraphic position, immediately below the mica-schists. For a more detailed description see Zwart, 1959.

On the way back to Appy an outcrop of the schistose gneisses was examined, which shows a different style of folding. In this outcrop of garnet-gneiss the schistosity is folded in a rather irregular way, often disharmonious and with fold-axes not parallel to the N—S lineations. Moreover small granitic patches are visible in this gneiss, clearly indicating recrystallization after the phase which made the augengneisses. In all respects this folding is similar to the mobilized augengneiss of the Ariége valley which were visited the day before.

Immediately above Appy a zone of metamorphosed marbles and calc-silicates is exposed, with minerals as calcic plagioclase, diopside, hypersthene, phlogopite, forsterite, spinel, grossularite, scapolite and large titanite crystals. These marbles which run as a discontinuous zone in the southern part of the St. Barthélemy massif, are most likely a stratigraphic horizon.

4th day afternoon: Talc quarry of Trimouns

At one o'clock we arrived at Bestiac, where a bus of the Talc Company of Luzenac was already waiting, to bring us to the quarry. An excellent lunch was offered by the Company, after which a visit to the quarry was made.

The strongly tectonized talc, underlying Ordovician dolomite, is worked and sorted by hand. Several grades ranging in colour from white to gray and green, were seen. A few pegmatite dykes of rounded shape, bordered by a layer of ± 10 cm thickness of pure clinochlore were examined. At one place in the quarry steatite is exposed, which is not so strongly sheared. In this steatite a typical layering due to presence of graphite was observed, resembling in every respect a similar stratification in the overlying dolomite. Together with the frequently observed transitions between dolomite and talc-schist, this leads to the conclusion that the talc is a metasomatic dolomite. Its formation is contemporaneous with the migmatization of the metasediments which lie stratigraphically below the talc. The occurrence of pegmatites in the talc with reaction borders of clinochlore and the absence of pegmatites higher in the series, clearly links the formation of the talc with the migmatization. Except introduction of silica, aluminium was introduced, resulting in the formation of clinochlore which is always present in the talc-schists in smaller or larger percentages. It is probable that the dolomite is a metasomatic limestone, the magnesium also originating from the underlying migmatites. The grade of metamorphism of the talc schists is medium, since biotite-schist occur immediately under and even in the talc schists.

It seems probably that the enormous talc accumulation of Trimouns is in part tectonic. For more details see Zwart 1954 and de Sitter & Zwart 1959.

5th day: Aston Valley

From Tarascon the excursion drove to Les Cabannes and from there up the Aston valley to the dam near Riète. The general situation of the Aston massif was explained. From north to south the following succession occurs in the Aston valley.

Devonian:	limestones and slates
Silurian:	black slates
Cambro-Ordovician:	phyllites
	(andalusite)-mica-schists
	granitized augengneisses
	granitized flasergneisses
	migmatites
	Mérens fault

This succession represents also a stratigraphic sequence and the migmatites are without doubt the deepest exposed rocks of the Aston massif. Besides a vertical relation between augen- and flasergneiss, the augengneisses overlying the flasergneisses, there is a lateral change from flasergneiss to augengneiss in an eastward direction with the result that finally the augengneisses overlie immediately the migmatites. Towards the west the flasergneisses become very thick. To my opinion the augengneisses of the Aston massif are in principle comparable to the augengneisses of the Hospitalet massif and are synkinematically metamorphosed rocks. The transition to flasergneiss is always gradual and takes place by the disappearance of feldspar eyes and of lineations, resulting in a schistose gneiss. For this reason, I suppose that the feldspatization of the flasergneiss occurred somewhat later than in the augengneisses, towards the end of the main phase of deformation. Both, augen- and flasergneisses have subsequently locally been granitized, which process was accompanied by mobilization and rheomorphism.

After this introduction we had the pleasure to hear a very interesting exposure of the views of Prof. Raguin, based on his own mapping experience of this region:

"Bien que le levé géologique détaillé, que Mr Raguin poursuit dans le massif, en collaboration avec Mr Destombes, ne soit pas achevé, certains rsultats généraux ont pu être dégagés. Les nombreuses failles subverticales dont il vient d'être question et qui datent, pour la plupart, des dernières phases tectoniques rigides, probablement tertiaires, sont une caractéristique importante de la structure régionale. Les photos aériennes confirment leur importance dans tout le massif de l'Aston; la plupart se suivent sur plusieurs kilométres. Contre elles, les couches de gneiss sont souvent redressées, et laminées verticalement sur plusieurs dizaines de mètres d'épaisseur. Si l'on fait abstraction de cette tectonique rigide, on constate que le pendage des assises de gneiss est généralement faible, inférieur à 45° et très souvent subhorizontal (sauf aux bordures nord et sud du massif). Ainsi le massif apparaît dans son ensemble comme un vaste dôme très plat. Cette circonstance rend possible l'établissement d'une stratigraphie dans les formations gneissiques. Certains résultats en cours d'étude, et destinés à une publication prochaine à la Société Géologique de France, permettront quelques précisions sur l'âge de cer terrains. Il est déjà permis de penser que la "Serie de Canaveilles" des Pyrénées-Orientales (P. Cavet, G. Guitard 1958), attribuée au Cambrien probable, constitue une partie importante des formations qui ont cristallisé à l'état de flasergneiss et de gneiss oeillé."

The excursion then walked along the track in the western branch of the Aston valley. Near the dam the augengneisses, locally with granitic patches could be studied. Some folding of the s-planes, representing the incipient mobilization was seen here. Further beautiful mylonites, due to later faulting are excellently exposed along the path. A great number of such faults, mainly in N—S or E—W direction occurs in the Aston massif, but the displacement along the faults is usually minor. Further up the valley near the small pass, where the track goes down, mobilized and granitized flasergneisses are exposed. Here a discussion on the merits of the explanation as given by Dr Zwart took place.

Mr Guitard defended his opinion, derived from his extensive experience in the eastern Pyrenees, that the augen- and flasergneisses represent a particular stratigraphic horizon (Guitard, 1958).

Prof. de Sitter argued that apparenlty the succession of vertical cleavage and schistosity in the phyllites on top, overlying sub-horizontal and folded schistosity in the micaschists, which in their turn overlie strongly linear augengneisses, represents also a tectonical succession more or less independent of the original nature of the rocks.

The excursion then went back to the cars. Here a discussion was carried on, about the nature of the quartz-pebble gneisses, which according to Raguin, 1955, are the equivalent of the quartz-conglomerates of Marc in the low grade Cambro-Ordovician. Zwart explained his views, dividing his discussion in two parts, firstly why according to him these peculiar rocks are no ancient conglomerates and secondly how these rocks could be formed in a different way.

One of the main objections to Raguin's views refer to his sections, in which the Cambro-Ordovician conglomerates near Marc (Allaart, 1954) in the Cambro-

Ordovician are connected with the Peyregrand gneiss with quartz-sillimanite nodules. In evey section the replacement of the conglomerates by gneiss necessarily occurs in the air, whereas nowhere this transition can be studied on the ground. The contact between gneisses and micaschists or migmatites is sharp. Furthermore the conglomerates of Marc are a closely packed aggregate of small (± 1 cm) quartz pebbles, whilst the gneiss shows only sparsely distributed quartz nodules, which moreover are distinctly larger than the pebbles of the conglomerates of Marc. The quartz-nodules are always intergrown with fibrolite, a mineral not present in the conglomerates. Moreover the quartz nodule rocks show a granitic texture which is much less oriented than the host rock, the Peyregrand gneiss. This suggests a relatively late formation contrasted with ancient conglomerates. On several places we observed that the quartz pebble gneiss, which usually lies as layers in the Peyregrand gneiss, is in the direction of the strike cut off, or replaced by normal gneiss, without any tectonic contact being involved. Finally an oblique crosscutting vein of quartz-nodule gneiss, branching off a layer of this gneiss, has been found. All these observations are not in favour of Raguin's hypothesis.

As far as the origin of these quartz nodules is concerned, I can remark that the origin of the quartz cannot be separated from the formation of fibrolite, with which it is without exception intergrown. At many places in the flasergneiss more or less crosscutting, irregular movement zones occur, which have a lining of quartz-fibrolite. To my opinion these zones must be considered as a sort of stylolite, where part of the material has been dissolved, in this case the alkalis, leaving silica and aluminium behind, resulting in the formation of quartz and fibrolite. There can be no doubt, that these movement zones are later than the flasergneiss, and consequently the quartz-sillimanite linings also must be later. The quartz on these linings is striped, undoubtedly due to movement. The relation with the quartz nodule rocks is that in both the same minerals occur, quartz and fibrolite and that they usually occur together. Moreover transitions between both rocks have been found and it is suggested that recrystallization of the quartz-fibrolite zones brings about the concentration of quartz and fibrolite in nodules.

Raguin defended his point of view as follows:

Les gneiss de Peyregrand forment un niveau stratigraphique bien défini, au *sommet* des gneiss de l'Aston, particulièrement dans la partie occidentale du massif. Vers leur base on rencontre en général un faciès plus fin et plus leucocrate, contenant des lits réguliers à petits ovoïdes de quartz bien distincts de la mésostase. Ceux-ci ont la forme de petits galets, soit étirés avec une linéation prononcée dans certains bancs, soit systématiquement applatis dans d'autres bancs. De telles particularités sont usuelles dans les galets de poudingues métamorphisés. La fidélité stratigraphique de cette formation est pour Mr Raguin un argument essentiel en faveur de son origine détritique. Il regrette que le temps dont on dispose ne permette pas aux membres de l'excursion de voir quelques coupes de la base des gneiss de Peyregrand.

De Sitter remarks:
that although the nodular gneiss with its relatively very sparse nodules does not look very similar to a conglomerate bed, still Zwarts arguments as to the different aspects of the quartz nodules in the gneiss and the Marc conglomerate are not very convincing. These Ordovician conglomerats vary laterally enormously, they range from microconglomerates to boulderbeds, they are sometimes close packed and sometimes consist of scarce pebbles in a stratified sand-shale alter-

nation, they are apt to wedge out from a 100 m thickness to zero within a few hundred meters.

After lunch the excursion made one stop, halfway down the valley, to examine the granitized augengneisses. Here beautiful pegmatites in dykes and irregular patches are exposed.

Furthermore all transitions between finegrained muscovite granite and coarse pegmatite are exposed, indicating that both rocks are closely related.

6th day, 1st party. Trois Seigneurs massif — St Béat

Half of the excursion visited Etang d'Artax in the Trois Seigneurs massif. By car we drove to Gourbit and from there followed the footpath to the lake.

Several outcrops of quartzdiorite with inclusions of marbles, calc-silicates, quartzites and amphibolites were visited. The quartz-diorite is a more or less homogenous sillimanite-cordierite-muscovite-biotite rock, which was formed by feldspathization of mica-schists. Usually this transformation goes first to a magmatitic sillimanite-gneiss which by continuing recrystallization changes into an unoriented quartz-dioritic rock. Many relics of sillimanite-gneisses were observed in the quartzdiorites. This process of feldspathization was accompanied by strong rheomorphism, which has lead to complete disorientation of inclusions, which are very numerous in this area. These are relics of old sedimentary bands, which resisted to the process of granitization and now occur as marbles, quartzites and calc-silicates. It was observed that the biggest inclusions often have an E—W strike, parallel to the general trend of the Pyrenees, but the lineations are often very steep, suggesting that rotation has taken place.

One of the characteristic features of these quartzdiorites is that although there is a great deal of movement, the body as a whole has remained in place and did not rise as a migmatite dome.

Near étang d'Artax chlorite-albite rocks were seen. These rocks are the result of strong sodium introduction under epizonal circumstances, producing rocks consisting almost entirely of chlorite and albite. The megascopic appearance of the rocks, quartz-diorites with pegmatites and inclusions, is preserved during this process, but the microscopic structures have changed completely.

In the afternoon we drove over Massat; St. Girons to Portet, where a ophite body of cretaceous age is exposed. A stop was made to collect some samples. The last stop of the day was made at the lherzolite of Moncaup.

2nd party. Estours and Salat valley — St. Béat

The road from Tarascon to Massat takes us up to the Col de Port passing through Mesozoic rocks of the Tarascon basin, and beyond Saurat into the metamorphic rocks of the Arize massif. From the Col de Port one has a magnificient view on the great blocks of Mesozoic limestones of the Tarascon basin and its continuation in the North-Pyrenean faultzone between the Barthélemy massif and the axial zone. It is in this basin that Casteras (1933) demonstrated the unconformity between the Cenomanian and the Lower-Cretaceous. Towards the west the silhouet of the Monvalier is conspicuous on the skyline. Descending the valley towards Massat the road stays roughly on the branch of the north-Pyrenean fault between the Arize and Trois Seigneurs massifs. Beyond Massat the road enters into the intrusive granite of Lacourt belonging to the Arize massif.

Arriving in the Salat valley we turn upstream to the south, cross first the Oust basin and then the Lower Cretaceous band lying between the Trois Seigneurs massif and the axial zone. The Urgonian limestone and the Albian schists have both acquired a metamorphic habit during the Cretaceous, pre-Cenomanian folding. This metamorphic phase is characterized by scapolitization and marmorization of the limestones and is accompanied by intrusions of basic rocks varying from gabbro to peridotite composition (Zwart 1954, Ravier 1959), which are restricted to the north-Pyrenean faultzone. The basic intrusives have all the characteristics of an initial magmatic phase of geosynclinal facies, but as their intrusion is distinctly posterior to the Lower Cretaceous it can not be related to the basin forming of this external zone, but certainly is related to the faulting; it is typical of a fundamental faultzone (de Sitter, 1956).

Turning to the right at the village of Couflens de Betmajou we ascend the valley of Estours (Wissink, 1956), where road outcrops show us again the Devonian/Carboniferous boundary with abundant cherts with occasional phosphate nodules followed by shales of the Carboniferous. In one outcrop the latter show a remarkable wavy surface, which suggests large ripple marks, but is most probably of tectonic origin because its shape is exactly repeated in successive layers.

The visit to the large white-green patched griotte quarry of Estours is very interesting. The original layering of the rock is preserved by the alternation of green, greenish and white bands. The cleavage is admirably expressed by the orientation of the broken fragments of the white pure-limestone layers. The stretching of the rock is demonstrated by the roughly ESE long rods of these white limestone fragments, and the folding can be inferred from the bedding, which shows many flat gentle folds in a NE direction in the quarry but turns steep at the entrance. The cleavage and rodding is independent of this folding, because the rodding-lineation and the cleavage planes are not parallel to the fold axes and are themselves unfolded. Apparently we are here in the presence of a pre-cleavage folding stage. Similar features have been encountered elsewhere also, for instance in the southernmost griotte outcrop of the Ribagorzana river, and in the Carboniferous south of Col de Mente.

Returning to Couflens de Betmajou, and then driving upstream along the Salat river one passes first through a Carboniferous syncline, then through the Upper Devonian and Lower Devonian, finally entering the Silurian of the Couflens anticline. This anticline is also a faultzone characterized by large ophite bodies further east. These ophite intrusions are here as well as elsewhere of Cretaceous age, although here completely surrounded by Paleozoic rocks. This is proven by a small block of Urgonian limestone preserved in the faultzone a little east and some 500 m above the Salat river valley. The faultzone branches off the main North-Pyrenean branch near the village of Aulus.

The party returned and drove to St. Girons and then along the road of the river Bouigane to the Garonne valley. The road runs often along branches of the North-Pyrenean fault and gives the opportunity to see some of the diorite-peridotite sequence of the accompanying intrusive rocks. Arriving in the Garonne valley the party drove to St. Béat for the night. This village lies in a narrow gorge, cutting through Urgonian limestone, brecciated and marmorized, belonging to the North-Pyrenean faultzone.

7th day. Col de Mente and along the Garonne river to Viella

A small road leads from St. Béat up to the Col de Mente. The first outcrop along the road near this village shows the brecciated character of the marmorized Urgonian limestone, the second, a little further one, an ophite intrusion of very basic character. The Col de Menté itself is heavily wooded and shows only numerous ophite blocks.

Going up southwards one stays in the woods with occasional blocks of red Triassic rocks. On top of the Tuc d'Itang one sees the red rocks overlying unconformably the Carboniferous slates. From the top of this mountain one has a beautiful view westwards on the North-Pyrenean faultzone and northwestwards on the section of Pic du Gars with Mesozoic overlying Devonian-Silurian-metamorphic rocks of the Barousse satellite massif.

Walking along the ridge towards the west we enter the Carboniferous shales, which contain here a few very remarkable sandstone layers. These latter partly consist of a typical arkose with white feldspar crystals in a finer matrix and with scarce well rounded pebbles. In other outcrops the rock shows strong synsedimentary disturbances with light coloured arkose and pebble units in black shale, typical gliding structures. One could call the rock a slide-conglomerate or slide-arkose.

Another pecularity of these arkose beds is that the strike is almost N—S and therefore demonstrate also a pre-main folding fold structure.

Our walk takes us, further down, several times across the Carboniferous-Devonian boundary with Devonian griottes, green Upper-Devonian slates and black Carboniferous slates and cherts. Near Argut we enter into the black Silurian slates.

In the afternoon we drove the Garonne river upstreams, passings the frontier at the Puente del Rey, where the valley narrows.

A few kilometers beyond Lez a very good outcrop just beside the road of alternating sandstone and slate bands in the Cambro-Ordovician, show an interesting type of folding. The principal small folds appear to belong to the first E—W folding. Parallel to their axial plane runs a quartz vein which shows its own peculiar folding, oblique to the first folds. In some of the slates a faint trace of fracture cleavage is visible, running roughly parallel to the axial plane of the folds of the quartz vein.

We pass the village of Bosost, and have a look at the pegmatite exposure one kilometer upstreams of this village opposite the hydroelectric plant.

Here as in all other regional metamorphic areas of the Pyrenees the zonal sequence of the metamorphism is: chlorite zone, biotite zone, andalusite zone. Somewhere in the andalusite zone starts a pegmatite and granite bearing zone and no pegmatite ever comes higher in the succession, neither here, nor in the Aston dome or in any of the other metamorphic areas. The outcrop in question consists of fine-grained muscovite-granite with irregular patches of coarse grained pegmatite, consisting of big (10—20 cm) microcline crystals, often graphically intergrown with quartz, surrounded by a rim of radially intergrown coarse biotite and plagioclase crystals. In the microcline occurs plumose mica, an intergrowth of quartz and muscovite, which replaced the microcline. Besides these minerals, garnet, tourmaline and beryl are present.

Further on, the road crosses the river and a road outcrop just after this bridge shows horizontal schistosity in micaschists. The micaschists are distinctly linear due to the occurrence of elongated micas. The s-planes are folded along axes which make an angle with the mineral lineation. This folding is later than the first phase during which the schistosity and lineations were produced.

Somewhat further on, highly metamorphic Upper-Ordovician limestone crops out along the road.

Before we reach the bridge leading to Las Bordas there is an outcrop of folds in somewhat marmorized Devonian limestone with an E—W trend.

The party drove on to Viella for dinner and the night.

8th day. Morning. Jueu valley.

The Jueu river from Las Bordas upstreams to a little above the large source of the Guëlls de Jueu (= eye of Jupiter) cuts first through the complicated isoclinal folds of the Devonian, then it crosses the central anticline which runs from the Lys-Caillouas region in the west to the Marimaña dome and beyond that to the Aston dome in the East, and finally arrives in the Carboniferous of the core of the Jueu syncline.

Driving up from Viella and passing the village of Las Bordas the first good outcrop shows us the graded sandstone of the Las Bordas sandstone group. The Devonian of the Valle de Arán consists from top to bottom of:

Viella slates, green slates and green arkostic sandstone
Las Bordas sandstone, graded and increasing in thickness and slate content from west to east
Escaleta slates and limestone
Basal limestone
Silurian blacks slates.

As none of these groups yielded any fossils we only know their relative position in the Devonian (Fig. 6).

Some of these quartizitic sandstones of Las Bordas are very well graded and a careful survey of the ridge above the road outcrops revealed six well exposed hinges, partly synclines, partly anticlines. The total thickness can therefore not be measured but is not thought to be here much more than 50 m. Some of the sandstones have developed beautiful mullions parallel to the fold axis, plunging eastwards.

Driving up we cross, beyond the Ermita de l'Artiga de Lin, the central anticline with Cambro-Ordovician slates in the core and Silurian black slates in both flanks. Where the road starts its hairpins, we find the first outcrops of the Devonian basal limestone of the south flank of the Jueu syncline and descending the path leading to the big source of the Guëlls de Jueu and the construction works of capturing its water, we cross a faultzone between these limestones and the black Carboniferous slates and sandstones. As the Carboniferous of the Plan d'Etang, containing plant remains (Lepidodendron, Sigillaria), lies always directly on the basal limestone of the Devonian we suppose that the higher levels of the Devonian have been eroded before its deposition, but every time we do find a contact between the two formations it has proven to be a fault contact. We hope that the Upper Esera will give us more definite information.

The Guëlls originate in a morainic cover on the slope consisting exclusively of blocks of Carboniferous rocks apparently overlying an outcrop of Devonian limestone. The sink holes which collect the water are situated in the same Devonian limestone cropping out along the border of the Maladeta massif in the Upper Esera region and has to pass beneath a much higher ridge formed by Carboniferous rocks belonging to the syncline in order to reach the source area (Fig. 7).

Driving up the road beyond the Guëlls to the glacial basin of the Upper

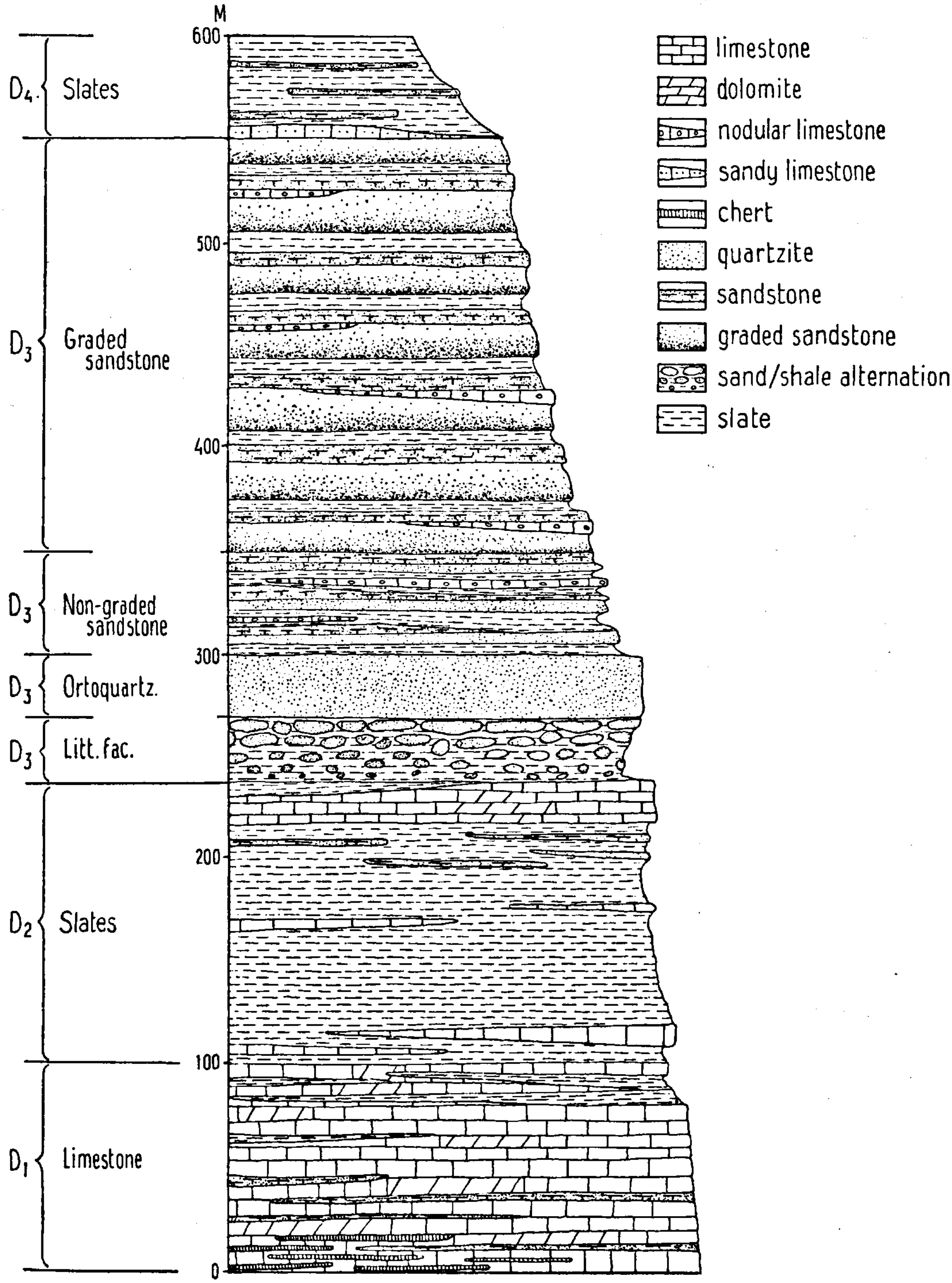


Fig. 6. Devonian of Valle de Arán. After Kleinsmiede, 1960.

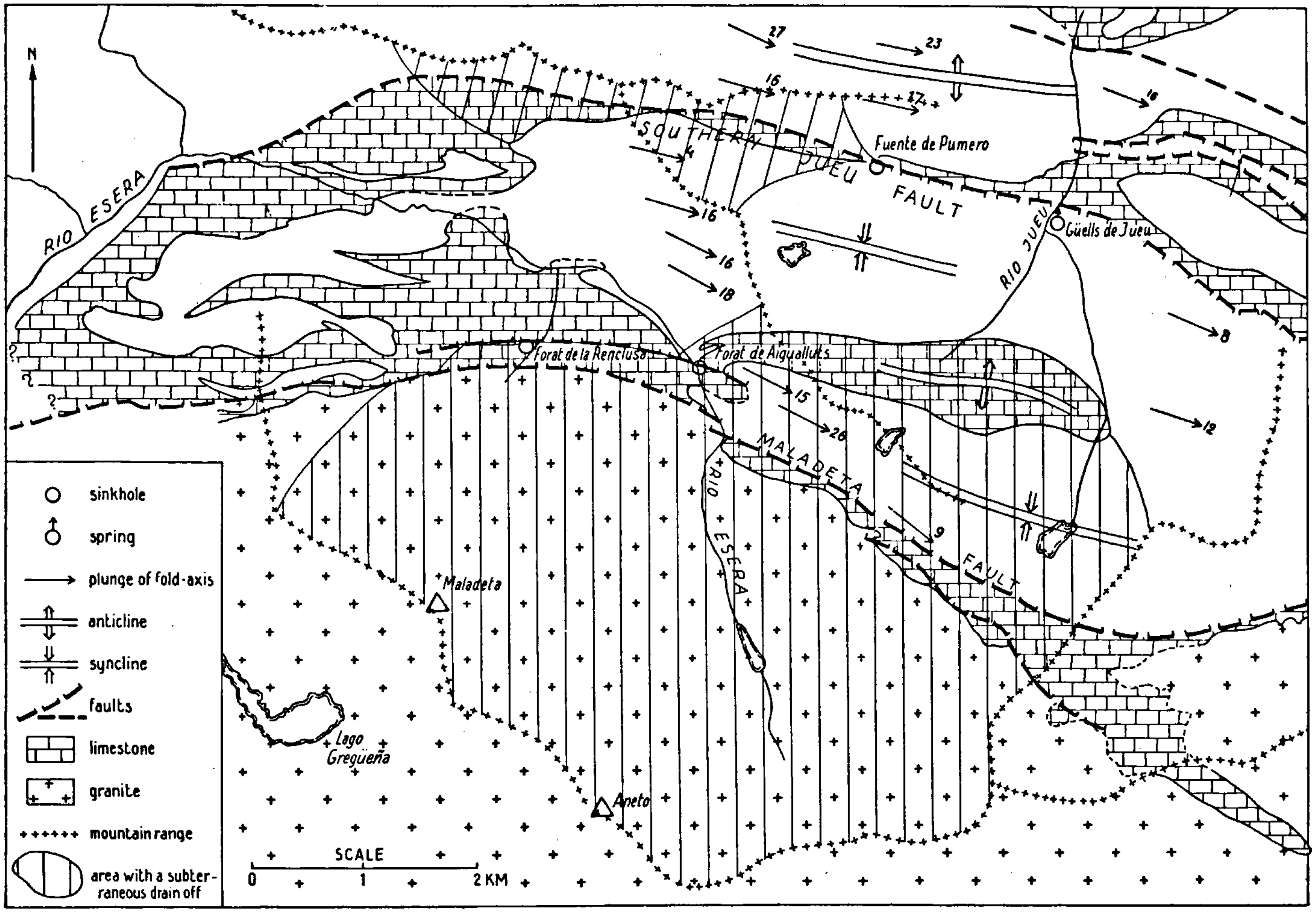


Fig. 7. Hydrogeological basin of the Jueu river with sink holes and sources. After Kleinsmiede, 1960.

Jueu river one can admire the concentric folds of Carboniferous syncline, the steep southern flank of the secondary Devonian anticline of the Artiga basin and study the Carboniferous rocks in the blocks that lie around here. Many of those consist of the quartzite conglomerate which is typical of the lower part of the Carboniferous and very similar to that which we saw on the first day on the southern border in the Nogueras zone.

8th day, afternoon: Barrados valley pegmatito

From Las Bordas the excursion drove up the Barrados valley, first passing the folded Devonian and a thick Silurian section, and then the Bosost fault. North of this fault the metamorphic Cambro-Ordovician is exposed, consisting of andalusite-mica-schists with small pegmatites and granite bodies. The main object of this afternoon's excursion was a conformable pegmatite, folded together with the enclosing mica-schists (fig. 8) (Zwart, 1958). The pegmatite consists

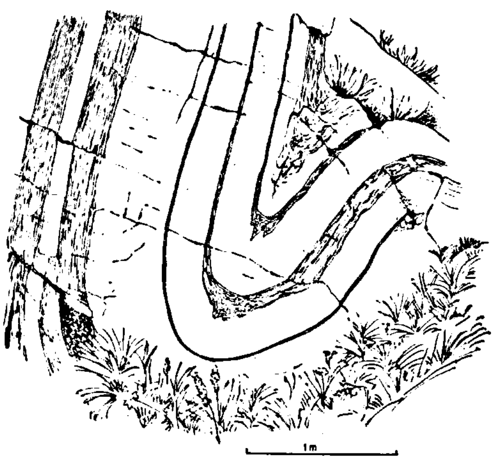


Fig. 8. Folded pegmatite in micaschists, Barrados valley. After Zwart, 1960.

of several parallel veins and sills, ranging in thickness between more than one metre to less than one cm. The thickness of the individual pegmatites remains constant throughout the outcrop. The mica-schists between the pegmatites also vary in thickness and in one pegmatite occurs a thin screen of less than $1/2$ cm thickness. The pegmatite is cordierite bearing, and contains further quartz, sodic plagioclase, muscovite and tourmaline. The mica-schist consists of quartz, sodic plagioclase, muscovite, biotite, cordierite and andalusite. Near the contact with the pegmatite there is an enrichment of tourmaline in the schists. In the schists of the same fold occurs a strongly boudinaged calc-silicate rock, apparently representing a sedimentary horizon.

The folds of the pegmatite are clearly of concentric type; part of the schists show the same type of folds, but in the strongly bent hinges the schists are crumpled and show an axial plane fracture cleavage, moreover there is a flattening of the schists in the flanks and a thickening in the hinges.

The pegmatites have an unoriented texture, although muscovite crystals perpendicular to the walls are quite common. In the hinges the minerals like plagioclase and muscovite are often folded or broken, indicating postcrystalline deformation. Very typical are, however, the fan-shaped muscovite crystals, suggesting that folding and formation of the muscovite were contemporaneous.

The described features can be explained with the following development:

1) shear folding, formation of mica-schist with plane, undeformed schistosity, boudinage of the calc-silicate rock, no pegmatite
2) beginning of the formation of the pegmatite, either by intrusion or by replacement
3) folding of the schistosity, accompanied by further crystallization of the pegmatite.

The Barrados pegmatite is one of the clearest examples of contemporaneity of a second folding phase (folding of a pre-existing schistosity) and emplacement of granites and pegmatites, which belong to the regional metamorphism.

9th day. Moncasau-Aguamoix

The car took us from Viella to Arties and then upstreams the Arties valley to Moncasau, the last stretch with the funicular. The horizontal path along the slope at 1965 m alt. gives us a good section of the granite of the Maladeta and the hornfelses of its thermal aureole. There is one particular interesting outcrop of mylonitised granite of a greenish colour by the chloritization of its mica and felspar. This narrow zone was crossed inside the mountain by one of the watertunnels bringing the water of the Colomés basin to the hydroelectric plant of Arties and caused grave difficulties in the construction. This E—W faultzone has been found also at the opposite side of the valley and further east. There is a good evidence that at least some of its movement is Tertiary because the only outcrop of Triassic in the whole axial zone besides that on its border zones, is situated quite near this fault. Its preservation is certainly due to this young movement, but the original fault may be older. The path, we follow, brings us to the Pruedo platform belonging to the 2000 m aplanation surface, covered with a thick morainic blanket, and turning east we find this Triassic outcropping over a small distance. It consists of the usual reddish micaceous shale and sandstone.

The platform itself is part of the 2000 m aplanation surface, the best preserved surface of the Pyrenees, the same level as the Aston platform we saw on the fourth day looking from the St. Barthélemy massif southwards.

Descending towards the Aguamoix valley a few hundreds meters north of the Triassic outcrop we find below the 40—50 m thick morainic blanket, the top sediments of a remarkable section of an Upper Miocene deposit preserved in a filled up E—W running canyon between the Aguamoix and Arties valleys.

The top sediments consist of hard clays and thin lignites, perfectly horizontal. The lignites contain pollen which allowed to fix their age as probable Upper Miocene. (Jelgersma, 1957). Downwards the section becomes sandier and coarser and the bottom half consists mostly of a stratified conglomerate with rounded pebbles, many derived from the Triassic, but otherwise from all kinds of the surrounding Paleozoic rocks. The bottom of the canyon lies at ± 1800 alt. on granite some 200 m above the valley floor of the Aguamoix river (fig. 9).

Apparently this Miocene deposit has been preserved because the present N—S valley left it intact. Apparently this E—W valley has been eroded just after the morphogenetic uplift of the 2000 m surface and thus dates this move-

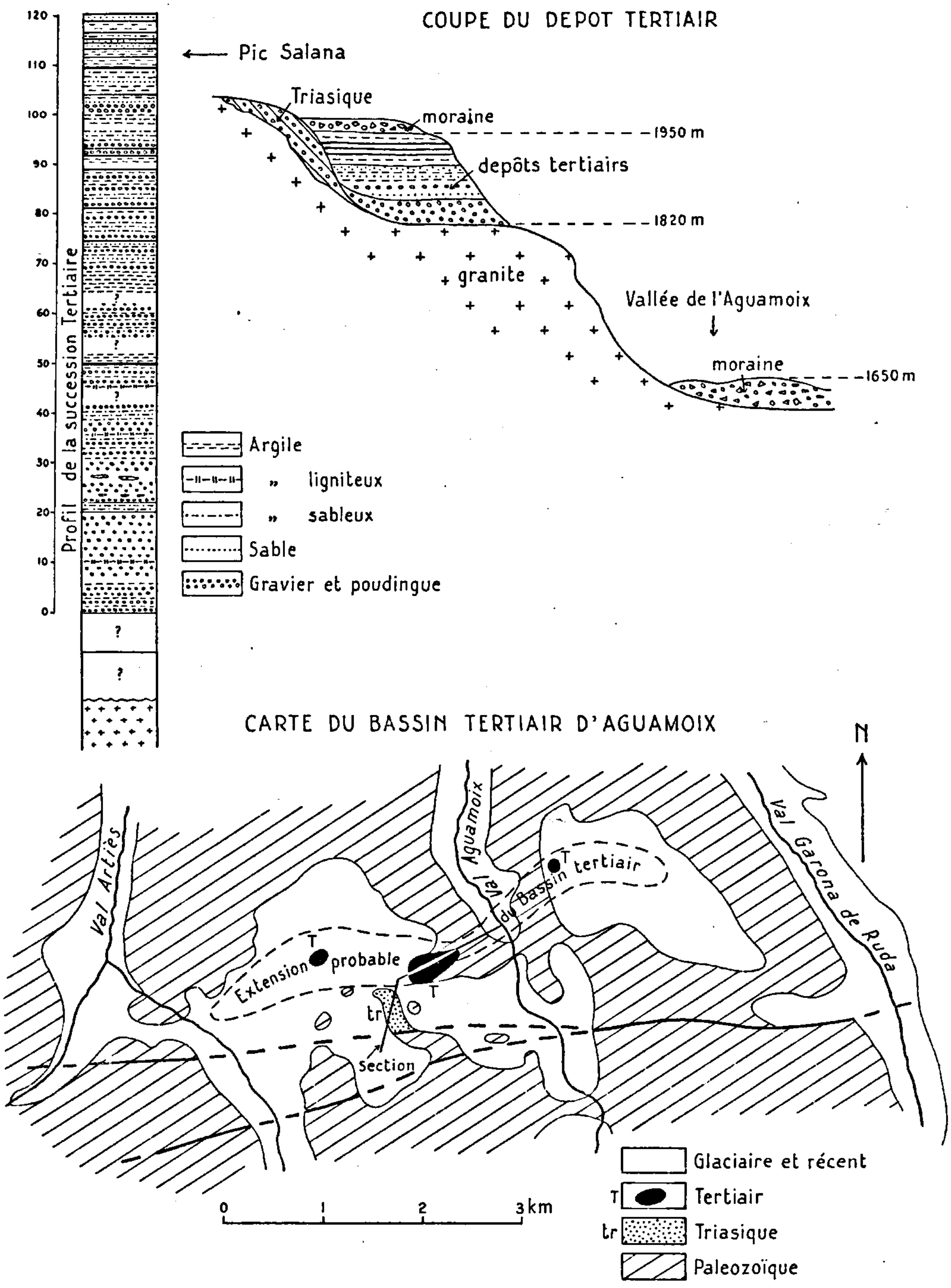


Fig. 9. Upper Miocene deposit of Aguamoix. After de Sitter.

ment as Upper-Miocene. There is one higher and older surface between 2400–2600 m alt., much less well preserved.

In the afternoon the excursion visited the valley of Gessa and studied there the beautiful exposed isoclinal folds of the Devonian limestones and slates accompanied by small thrusts giving the whole structure an imbricated nature (fig. 10). The black slates below the deepest exposed limestone failed again to

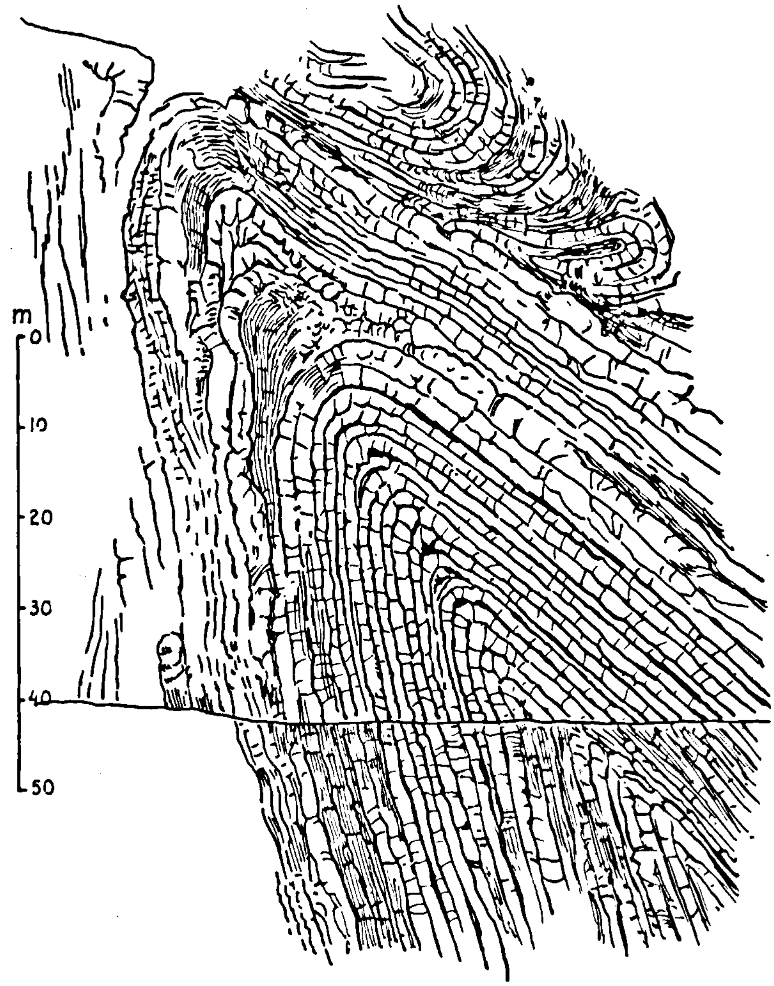


Fig. 10. Narrow fold in Devonian of the Gessa valley, Valle de Arán.
After de Sitter.

give us any fossils. They look almost like Silurian slates but have never given any fossil evidence, and might well be Devonian.

10th day. Morning: Marimaña granodiorite (by Prof. Brindley)

We drove by car up to the Pla de Béret which forms the watershed of one of the branches of the Garona river and the Pallaresa. From here a general view of the granodiorite body, located at the north-western termination of the main Lower Palaeozoic massif of the Pyrenean axial zone, is obtained. Along its steep northern contact upright, tightly packed, isoclines in the Ordovician limestones can be pointed out. In the region between the Rio Malo and Rio Ruda these incline gently off the plunge of the Lower Palaeozoic massif, and further to the south-west interfering structures from the steep south-western flank of the latter feature are developed.

A traverse on foot across the Ordovician contact rocks showed spotted slates, andalusite hornfelses, and metamorphic limestones of the aureole. From the high spur overlooking the gorge of the Rio Malo a striking view of the gently inclined, discordant, western termination of the granodiorite was obtained. Here the lower members of the ordovician succession — psammitic-pelitic groups and the "Sandwich" limestone — are truncated by the plutonic boundary, which at the site visited lies against the main Ordovician limestone. They persist, however, in a zone of rafts, virtually undisturbed, within the normal granite. Granitic dykes extend into the country rocks at the main contact, and were observed at one point to end abruptly against the massive limestone after traversing the bedded hornfelses — a consequence, apparently, of the more plastic behaviour of the limestone in contrast to the rocks beneath. It seems as if the plutonic body arose, at this point, essentially by dilation and disarticulation of its surrounding.

During the descent by car from the Pla de Béret we had a good view of the Salardu stock — a small granodiorite body, bluntly lenticular in outline, which displays vertical walls without indication of the presence of a roof. It shows clear evidence of a displacement, laterally, of the isoclinally folded Devonian rocks examined on the previous day at Gessa. The eastern portion of this body is concealed by surface deposits of the Iñola valley, but on the west an elaborate fingering contact shows local development of a hornblende-bearing facies against limestone groups in the surroundings.

Near the Bonaigua Pass the Tredos granite was viewed from the opposite side of the Rudi Valley. It is a steep-walled body, truncated by the 2000 m aplanation surface and is a more or less circular in plan, smoothly enveloped by the Ordovician and Devonian limestones.

10th day. Afternoon, drive from Salardu to Sort

Driving up to the Puerto de Bonaïgua the road stays mostly in the Upper Ordovician marbles. Just beyond the pass large blocks of the Upper Ordovician conglomerate lie around. The pebbles consist exclusively of quartzite or quartz and the matrix has often a finely stratified sandy constitution, and has been strongly folded. Some of the flatter pebbles are conform to these folds, but most of them show little flattening. A bit further down a good road outcrop shows the quartzite grits of the Upper Ordovician.

The road follows the Bonaigua stream, to the south we see the Maladeta granite massif and to the north the Marimaña granite is hidden from our view by Cambro-Ordovician rocks. The road reaches the Pallaresa valley in the village of Esterri de Aneu and follows this river downstreams. We make one other stop to study a secondary knicking of Ordovician slates in an outcrop on the east side of the valley near the village of Bogari. The knicking planes dipping southwards are very numerous and only a few centimeters apart. A very few of a conjugate set of knickzones can be observed.

Driving downstream one enters the north flank of the Llavorsi syncline where the Espot river joins the Pallaresa. The black Silurian slates contain graptolites here. They are followed by Devonian limestone, strongly cleaved and further down by Carboniferous slates. On the opposite side of the valley, the eastern slope, some recumbent folds can be detected in the Devonian when the light is favourable, which it was not when the excursion passed. These folds emphasize again the fact that everywhere in the Central Pyrenees the structure is much more complicated than a simple mapping can reveal, every time an exceptional good outcrop is available new secondary features show up.

The southern flank of the Llavorsi syncline is not so well exposed and the road downstream soon enters the Cambro-Ordovician of the southern anticline.

11th day. Morning from Sort to Lladore

Driving up the Tabescan valley we started in the north and studied the outcrops along the road from north to south, each of them showing a particular type of cross cutting tectonization.

The first Cambro-Ordovician outcrop we visited was concerned with a rock type of a quick alternation of shale and sandlayers of millimeter or centimeter thickness, a "schist rubané", which allows a close analysis of the tectonization.

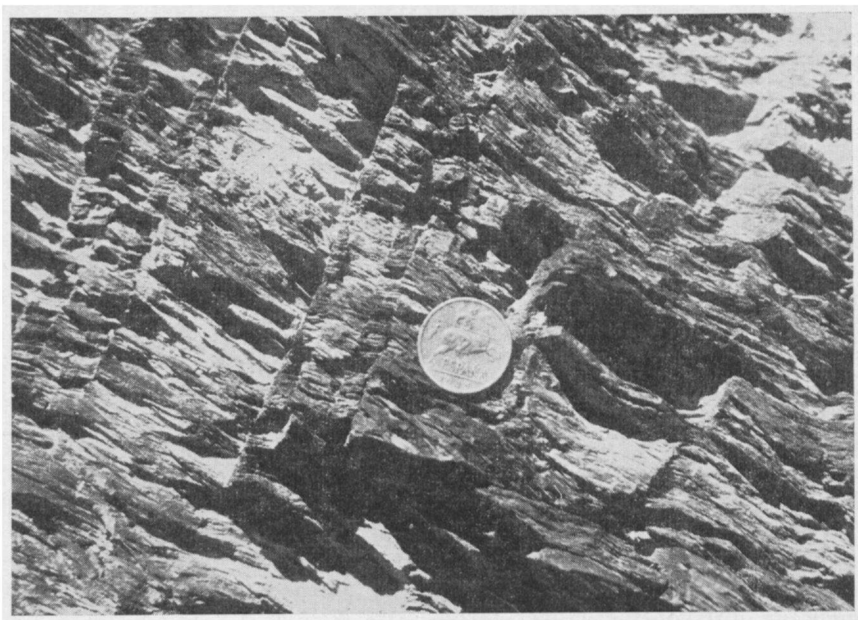


Fig. 11. Knicking in Ordovician slates near Llavorsi. After Zandvliet, 1960.

The outcrops show roughly vertical, steep, but not iosclinal folds of 10—20 cm width accompanied either by close cleavage in the slates or by a coarse fracture cleavage, both strictly parallel to the fold axial plane. A closer scrutiny reveals, however, that a much more intense isoclinal folding existed before, because we can see that the sandlayers show minor centimeter wide folds with pronounced thickening in the hinges and flattening in the flanks. It is quite clear that the vertical layer folds have folded a pre-existing schistosity plane with its own minor isoclinal folding.

The second outcrop, in the upper part of the Cambro-Ordovician showed very good exposed knicking planes. The schistosity plane dips northwards, the knicking zones southwards. The knicking, always between a pair of planes en-

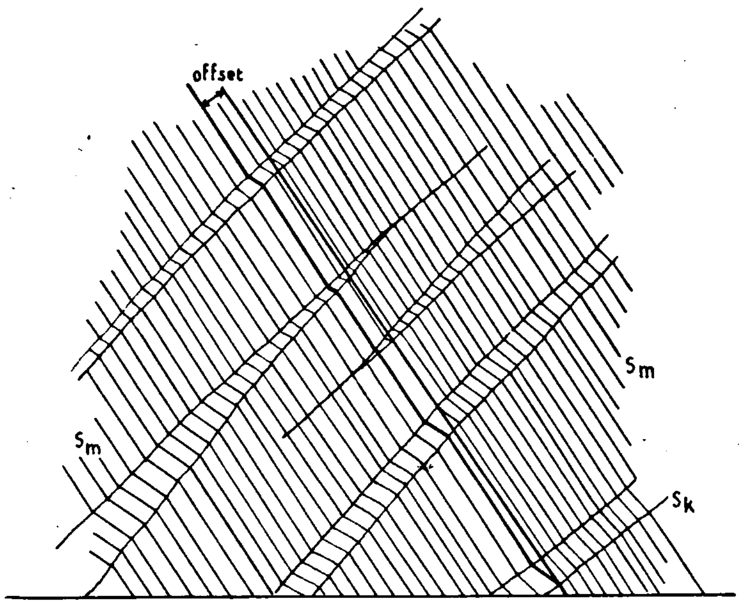


Fig. 12. Knicking in Ordovician slates near Llavorsi. After Zandvliet, 1960.

closing a knick zone 1—20 cm wide invariably shows a subsidence of the southern block and represents a dilatation in the horizontal sense (figs. 11 & 12). The knickzones go straight up the mountain flank.

Walking down along the river one passes through the Upper Ordovician with two conglomerate zones with a limestone in between and a few coarse gritty sandstone beds. We are here in the north flank of the Llavorsi syncline and going further south we soon pass through the Silurian slate belt which is not exposed in the valley because its outcrop is occupied by a large landslide consisting almost exclusively of debris of the black Silurian slates. The top of the Devonian consists of limestone and its first exposure shows a beautiful boudinaged massive limestone bed between a slate-limestone alternation, which curves round the boudins in a curious way (fig. 13) most probably also witnessing of a secondary folding phase.

The Carboniferous slates of the core of the syncline do not show here any particular disturbance of their regular cleavage, but higher up towards the village of Tirvia knicking has folded both the Devonian and the Carboniferous.

Driving down from Llavorsi to Sort through the Cambro-Ordovician of the southern anticline one can notice the gradual flattening of the cleavage, which first dips some 60° north but near their southern boundary only have a 10—20° northern dip. Just before the southern boundary of the Cambro-Ordovician the road crosses the Pallaresa river from its eastern to its western bank and the outcrop just south of the bridge shows a very complicated folding picture. Isoclinal folds of sandbanks of 20 cm thickness have a horizontal axial fold plane but perpendicular fold axes. Occasionally one sees elliptical isolated sandstone bodies in the shale or recumbent folds of sandstone with variable fold axes. This outcrop might represent a folded slumpbed as was suggested by Prof. Gill, and not a refolded schistosity.

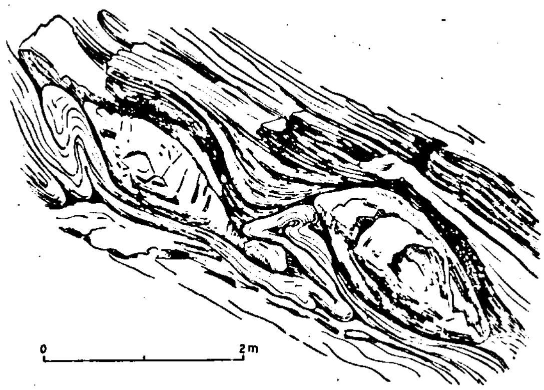


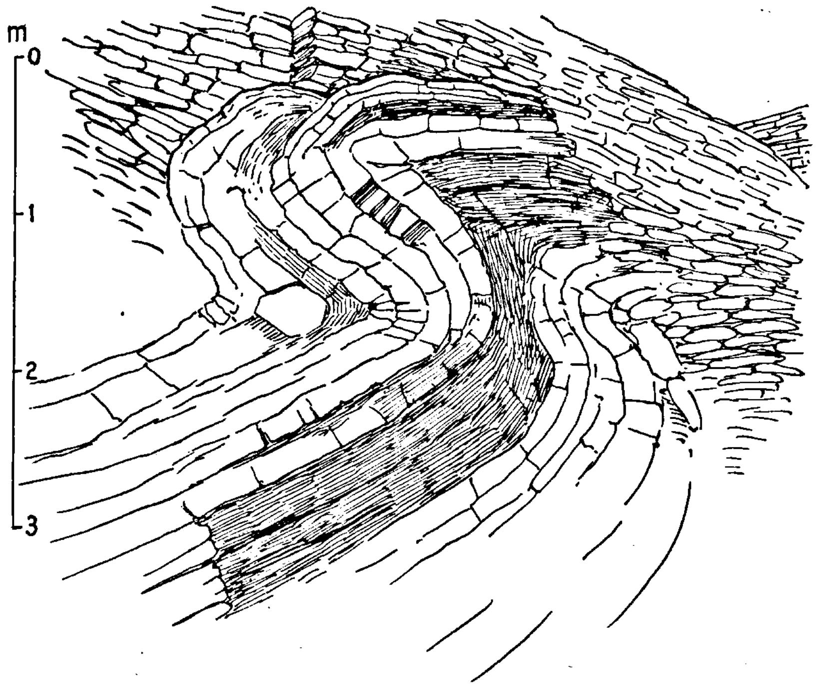
Fig. 13. Boudinaged Devonian limestone of Llavorsi syncline north flank. After de Sitter.

Between Rialp and Sort the excursion took the road branching off to Olp. In this village is exposed one of the best examples of the recumbent folds in the Silurian of the south flank of the southern anticline. The rock consists of black slate in thin layers between 10 cm thick bands of orthoceras limestones (figs. 14 & 15). These recumbent folds occur everywhere in this steep southern flank until on the top of the anticline in the Monseny region. Originally it was thought that they represent cascade folds gliding down from the top of the anticline, but the fact that they occur also on the top of the anticline and that the cleavage planes in the Cambro-Ordovician core are roughly parallel with the axial planes of these folds, makes this conclusion doubtful.

The flat axial planes and cleavage is not a result of later Alpine deformation because one can limit the action of this later deformation to a narrow zone varying from 100 m to one or two km breadth along the Permo-Triassic border of the axial zone. In this zone the recumbent folds or the flat cleavage are bent down again to a drooping sometimes vertical position.

Afternoon. Drive from Sort to Pobla de Segur and Pont de Suert

The village of Sort itself is situated in a narrow belt of Keuper gypsiferous rocks with ophiolite bodies trending N—S along the river valley flanked on the east bank by Cambro-Ordovician and on the west bank by Devonian recumbent folds. Descending the valley one can see that on the eastern bank the unconformable post orogenic Permo-Triassic cover lies on the Cambro-Ordovician in the Boca di Cantó, whereas on the right bank it lies on the Devonian folds. Evidently there was a N—S late Hercynian fault or fault-trough running roughly in the present river valley, which has been filled up with Keuper sediments.



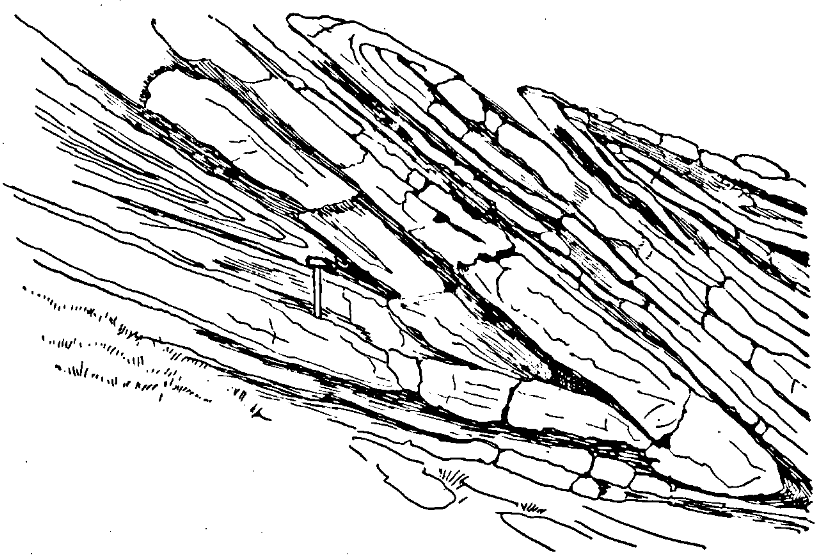


Fig. 14 & 15. Recumbent folds in top Silurian-base Devonian near Olp (Rialp) Pallaresa valley. After de Sitter.

Further downstream the road cuts through the red beds of the Permo-Triassic which is folded here together with its Devonian basement in a large anticlinal fold with a south dipping axial plane.

Opposite the village of Arcalis at km 101 there occurs an outcrop of black Carboniferous shales with abundant plant remains belonging to another anticlinal core beneath its Permo-Triassic cover. The flora of this outcrop with Walchia dates the rock as Permian according to Dalloni, 1930. The unconformity of the Permo-Triassic conglomerate is very well exposed and the discolouring of the black slates at the top to green and reddish colours witnesses of the weathering before the conglomerate deposition.

The Alpine refolding of the Devonian is well exposed where the Pallaresa river cuts through the Devonian griotte of the Coma di Tó, where one can see a large fold with an almost vertically plunging axis exposed on the eastern bank.

Looking back to the north from the village of Gerri del Sal situated in a Keuper zone south of the Coma di Tó zone, one can see the vertically standing red beds of the Permo Triassic against complicated folds of the Devonian. The gypsum layers of Gerri contain occasional salts beds which give rise to the very salty springs which are exploited in drying pans along the riverbed for salt production. One sees on both sides of the river chaotic structures of muschelkalk folds and ophiolite bodies in the Keuper gypsum.

After passing through another zone of red beds and Devonian griotte one enters the canyon cut out in the Urgonian limestone. The zone between this Urgonian limestone and the first Permo-Triassic cover of axial zone in the north has been called the Nogueras zone and represents the strongly folded, both by Alpine and Hercynian orogenesis, southern border zone, which the excursion also visited on its first day.

In the canyon one can see the strong almost isoclinal folds in the Urgonian partly covered by travertine and a bit further on, the first remnants of the discordant cover of Oligocene conglomerates. These post-tectonic conglomerates have been deposited on a strongly dissected landscape of Cretaceous limestone, and are found now as pockets at wildly different altitude levels. Somewhat further down the river the basis of the conglomerates is below the valley floor and both sides of the river are formed by steep conglomerate walls.

Approaching Pobla de Segur the basis of the conglomerates rises again above the valley floor level and when the road has passed through this village and turned to the west in the direction of Pont de Suert one has a wonderful view of the flat lying Oligocene conglomerates on the steeply folded Upper Cretaceous. These conglomerates sometimes are deposited directly on old screes with angular components of the Cretaceous rocks and consist near the contact only of Cretaceous boulders and pebbles. In the valley of the Flamisell where this conglomerate follows immediately on the Permo-Triassic, it consists only of Permo-Triassic rocks. Further away from the basis the association of the boulders and pebbles becomes more diversified.

12th day: Morning visit to Stephanian and Triassic of Malpas

A short drive brought us from Pont de Suert to the confluence of the Barranco de Viu and the Barranco de Peranera river. The first outcrops along the Peranera river shows the Keuper gypsum followed by a thick limestone member of the Triassic commonly called Muschelkalk. Upstreams of these the road and river cut through the red shale and sandstone of the Triassic and then into the Devonian, which is soon replaced again by Stephanian tufs on the left bank of the river. We drive further upstreams and see beyond the bifurcation of the road to Malpas village again muschelkalk outcrops which are again replaced by red Triassic rocks before arriving at loading station of the Malpas coalmine. This repetition of the sequence of Triassic-Stephanian-upper Paleozoic, often in upside down position is typical of the complicated tectonics of the narrow Nogueras zone. Further upstreams we enter again in the Stephanian. The colliery exploits a coal seam of Stephanian age. As the road stops at the coalmine the excursion proceeded on foot following the stream, a course which caused considerable discomfort due to the unusual high water level of the stream, particularly in the narrow gorge cut through andesitic lava. Beyond that the canyon widens somewhat and narrows again entering the Devonian belonging to the border of the axial zone. The horizontal structure of the Devonian can be seen a few hundred meters beyond the unconformable contact with the vertical Stephanian, and it looks as if in this intervening zone the Devonian has been considerably crushed. Going back to the Stephanian and crossing the stream on a very rickety foot bridge we find the path that leads upwards to the village of Erill-Castell. Along this path the volcanic rocks of the Stephanian are well exposed, tuffs, mostly unstratified often containing well preserved bombs and numerous lapilli sometimes stratified witness of the volcanic character of this formation and even of the close by position of a volcanic centre.

About half way up the hill, the unconformable contact with the Devonian is well exposed. The basal layer consists of red shale with numerous fragments of Devonian shale or badly rounded limestone pebbles deposited on weathered crevassed Devonian limestone and filling the crevasses. Elsewhere the base has been observed to be strongly conglomeratic and further east near the village of Aguiró a coal seam between two conglomerate layers has delivered an Upper Westphalian flora.

On the other side of the steep valley we are climbing up, the extremely irregular sedimentation, showing evidence of gliding in this volcanic core, is well exposed. The village of Erill-Castell is perched on the hard rock of an andesite lavastream which we passed already in the riverbed. Going south we pass upwards in the stratigraphic sequence of the Stephanian. The rocks become less exclusively volcanic, containing shales, some fresh water cherts, sandstones and the coal seam mentioned before, in a regularly bedded series. On the flank of the opposing hill the slight unconformity of the Triassic on the Stephanian is clearly visible.

In the last two days we saw thus three important unconformities: Stephanian on Devonian, Trias on Stephanian and Oligocene on Upper Cretaceous.

The footpath towards Malpas leads us through the red Triassic rocks, alternating shales and cross bedded sandstones with occasional development of cleavage in the shales or rather unstratified mudstone. The southern dip increases southward to almost vertical, until we suddenly arrive on a much flatter slope where the red Trias is also flat lying, but overturned as can be ascertained by the cross bedding. Beneath these red bed first the Muschelkalk and below that the gypsum is outcropping in a steep valley. An exploratory drillhole for coal, of which a gypsum core was found on the drill site, did not take into account the reversed position of the Triassic and instead of finding the supposed Stephanian coal below the Trias it entered into the gypsum of the Keuper, which anyhow is outcropping very near this location at the bottom of the steep valley.

The Muschelkalk is accompanied by a cavernous dolomite, originally an anhydrite-dolomite rock, typical for this facies of this formation.

Afternoon. Rio de Tor section

By driving upstream to the north from Pont de Suert, following the Rio Tor, we pass first through the Keuper mingled with Muschelkalk slabs and ophite bodies in a chaotic mixture and then through the steeply south dipping red Trias. Beyond the Trias we enter into the Lower Carboniferous slates which have not yet yielded us fossil evidence for its dating, although they contain some corals. These Carboniferous rocks certainly have been folded by the Hercynian folding and we call them Lower Carboniferous in analogy with the Visean of the North Pyrenean zone and in order to distinguish them from the post-Hercynian Upper carboniferous Stephanian. Near the village of Llesp we enter into the Upper Devonian griotte limestone, which is folded in a most complicated fold with two fold axes, one almost vertical, the other with an east—west strike. An outcrop in the Rio Ribagorzana in the same horizon, and better exposed, shows that a N—S striking fold is older than the E—W striking cleavage. Further on, the road crosses a thick griotte limestone section, and beyond that we get a view on a thick reddish coloured limestone bed rising up from the river valley along its eastern slope with a dip to the north. In this band, and also in a similar band on the western slope one can distinguish many secondary flat recumbent folds. They belong to a unit of Devonian limestone alternating with occasional quartzites below the griotte. This rock crops out also in a good

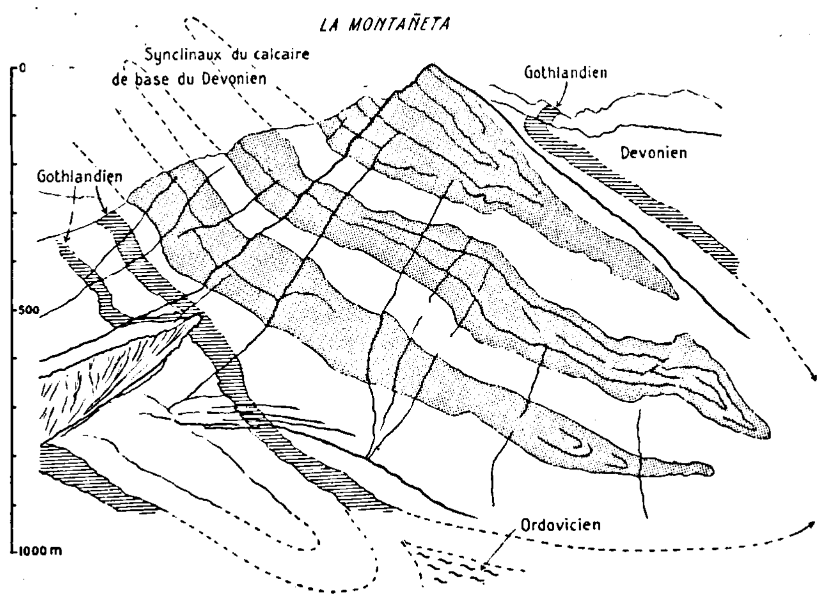


Fig. 16. Recumbent and pinced folds of basal Devonian and Silurian sheared off from the Ordovician Montañeta, Rio de Tor. After de Sitter.

road exposure forming an asymmetric anticline with a flat north dipping axial plane. There can be little doubt that many fold repetitions occur here probably very similar to the ones described further on, exposed in the flank of the Montañeta (fig. 16), but perhaps on a larger scale. Beyond the village of


SET OF N-S CROSS SECTIONS
CENTRAL PYRENEES
scale 1:100.000
by
L.U. de Sitter and H.J. Zwart
N
S
ST. BARTHÉLEMY MASSIF
ASTON MASSIF
HOSPITALET MASSIF
ANDORRA GRANITE
Série de Canaveilles
Merens fault
VI
ARIZE MASSIF
TROIS SEIGNEURS MASSIF
NORTH PYR. FAULT ZONE
AUZAT BATHOLITH
Série de Canaveilles
Seo de Urgel
Segre R.
V
Tor syncline
Llavorsi syncline
Couflens
Série de Can.
Ord
D
IV
NOGUERAS ZONE
MARIMAÑA BATHOLITH
syncline
Llavorsi
D
III
NORTH PYR. FAULT ZONE
Bentaillou
Garonne R.
Artiés
MALADETA BATHOLITH
SALARDÚ STOCK
ARTIÉS STOCK
Quartz veins
BARRUERA STOCK
dyke swarm
II
BOSOST DOME
D
I
Quarternary or recent
Mesozoic
Ophites of Triassic and Cretaceous age
Gypsum-salt
Red sst. cgl. claystone
Trias
Stephanian (volcanics)
Carboniferous with chert at the base
Griotte of Upper Devonian
Limestone
Slate
Sandstone
Devonian
Undifferentiated Devonian
Silurian
Lst. and cgl. in top of Ordovician
Non metamorphic Cambro-Ord. sericite schists, phyllites, quartzites, slates
Mica-schists
Migmatite-quartz-diorite series
Basal gneisses (garnet-augengneiss)
Augengneiss
Flasergneiss and granitic gneiss
Muscovite-granite
Granite or granodiorite intrusives

Barruero the road crosses the intrusive hornblende bearing granite of Barruero which is accompanied by a swarm of north dipping dykes parallel to the cleavage of the isoclinal folds. They show up very well on the western slope of the river as light coloured bands. The eastern slope, opposite the Barruero granite, consists of Cambro-Ordovician.

Beyond the village of Erillavall a road exposure gives another excellent demonstration of the cross folding phenomena, with fold axes almost perpendicular to one another. When the road has crossed to the eastern side of the river we get a good view of the steep eastern slope of the Montañeta mountain, in which three isoclinal synclines of the basal Devonian limestones are visible (fig. 16) flanked on both sides by narrow bands of Silurian which form isoclinal anticlinal cores. Although the structural details of this section have not yet been worked out, the reported complications warrant that the structure is very complicated with certainly two and probably three folding phases. One phase is anterior to the cleavage folding and as the cleavage plane has been folded also, there must be, locally at least, also a third post cleavage folding.

The party then returned to Pont de Suert, had its final dinner there and split up next day for its home journey in different directions.

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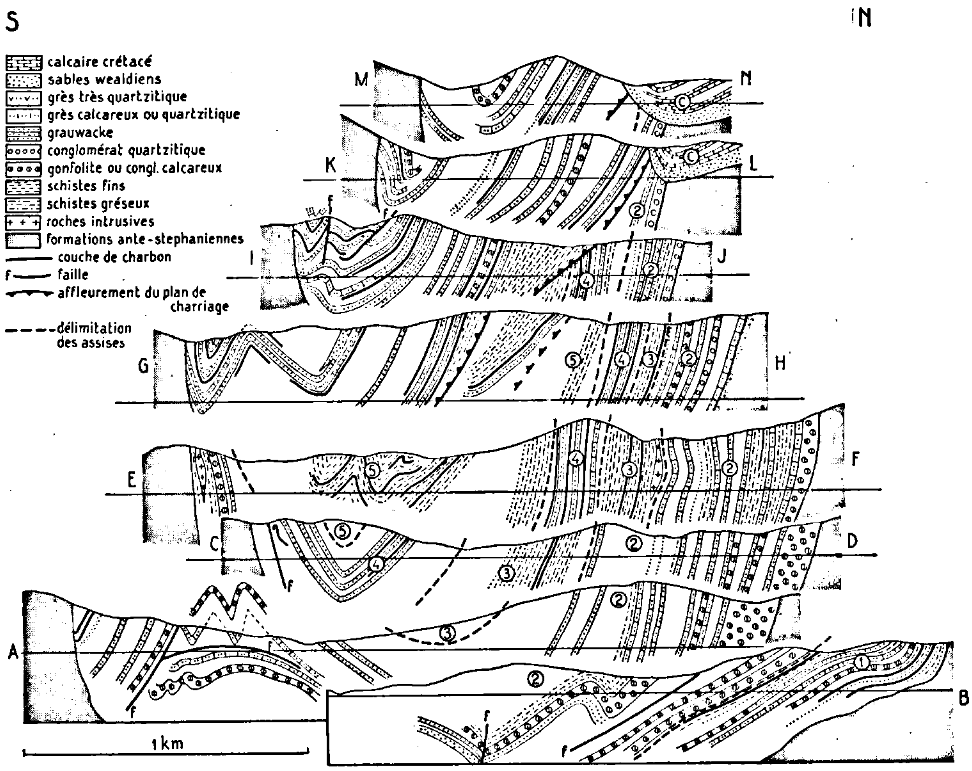
S
N
calcaire crétacé
sables wealdiens
grès très quartzitique
grès calcareux ou quartzitique
grauwacke
conglomérat quartzitique
gonfolite ou congl. calcareux
schistes fins
schistes gréseux
roches intrusives
formations ante-stephaniennes
couche de charbon
faille
affleurement du plan de charriage
délimitation des assises
1 km

Fig. 1