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MINOR STRUCTURES IN THE UPPER VICDESSOS VALLEY (ASTON MASSIF, FRANCE)

BY

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ABSTRACT

Several folded structures are described from an area in the western part of the Aston massif. The examples discussed date mainly from the first, the third and the fourth phase of deformation.

1. INTRODUCTION

During the summers of 1958—1960 I mapped the western part of the Aston massif as a contribution to sheet 6, Aston, of a series of maps published by the Department of Geology of Leiden University. The emphasis was laid on a detailed structural analysis of the area, especially since at the beginning of my work little was known about the various folding phases in the Central Pyrenees. The area I mapped consists of the valleys of Mounicou (= upper Vicdessos) and Pla Subra and it is to the west bounded by the Spanish frontier ridge. Moreover some work was done in the Arinsal valley in Andorra and the Farrera valley in Spain.

The area is well exposed, mainly due to the strong relief varying from 400—3100 m. The main valleys run north-south and the ridges in between have steep slopes. The Aston-Hospitalet massif is a large gneiss anticline, cut in two by the Mérens fault. The western part of the Aston massif consists of phyllites and mica-schists; south of the Mérens fault phyllites only, forming the western part of the Hospitalet massif are exposed. Besides studying the minor and microstructures much attention was paid to the transition of low angle schistosity in the metamorphics to the steep cleavage in phyllites.

My work was supervised by Dr. H. J. Zwart with whom I had many discussions in the field as well as in the laboratory.[1] For one fieldseason I received financial aid from the "Molengraaff-fonds" for which I am very grateful.

2. MORPHOLOGY

The physiographic features of the area are for a large part due to erosion by glaciers. The Mounicou valley is mainly shaped by glacial action. The long and broad flat parts ("Pla") are followed by rock bars where the river cascades downwards. Altogether four of such flat glacial basins occur upstreams from Marc in this typical stepped valley. Glacial cirques occur in the main valley and many of its tributaries often contain small lakes. The western slopes of the Mounicou and the Subra valleys are very rugged and steep and at most places inaccessible, whereas the eastern slopes are much more gentle. Further glacial features are roches moutonnées, rock glaciers, small moraines and polished and striated rock surfaces.

[1] After Mr Lapré left Leiden University, some new results about the various structures in neighbouring areas were obtained. In editing his MSc thesis some of the interpretations are adapted to these newer data.

At a few places remnants of an older erosion surface occur, for example at the top of the Montcalm peak (3077 m), but due to strong erosion much of this ancient peneplain has disappeared in my area.

3. STRATIGRAPHY

The rocks in the mapped area consist entirely of Cambro-Ordovician sediments in which any stratigraphic subdivision is hard to make. To the north dated Silurian has been described by Allaart (1953) and all rocks in my area occur stratigraphically below this formation and are combined as Cambro-Ordovician. Near the top, close to the Silurian one or two limestone bands have been found near the Auzat granodiorite. Stratigraphically deeper a number of discontinuous microconglomerate layers occur in the phyllites and micaschists. Still farther south a number of small outcrops of limestone or marble have been mapped. They constitute a stratigraphic horizon somewhere in the Cambro-Ordovician.

A few outcrops of limestones and marbles have been found in the micaschists near Pla Subra and the Port de Roumazet. The limestones of Pla Subra can be divided into two types:

1. 1 to 2 metres thick limestones layers in which rounded pieces of calcsilicate rocks occur, which due to the weathering are very conspicuous. The matrix shows flow structures. In the larger pieces sedimentary banding is still visible (fig. 1). The schistosity is parallel to the limestone-micaschist contact.

2. 10 tot 50 cm thick limesilicate layers in the andalusite schists. Hornblende garven occur in these calcsilicate rocks.

Near the Port de Roumazet limestones with a thickness of one to four metres have been found in which one to ten cm thick quartzitic and epidote bearing calc-silicates occur. In the limestones, crystals of muscovite up to 1 cm occur. It is not

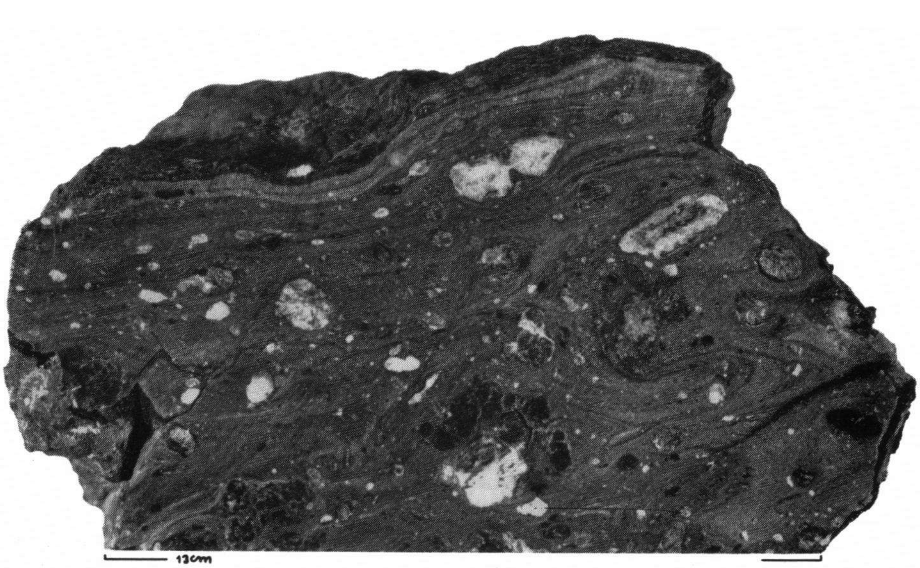


Fig. 1 Folded marble with pieces of limesilicate rocks

certain whether or not these limestones and marbles represent one stratigraphic horizon. Furthermore some thick quartzites occur, but they cannot be followed over any appreciable distance. Presumably the oldest sediments occur immediately north of the Mérens fault, although it is difficult to check this statement. For further details about the stratigraphy I refer to the publications of Zwart and Verspyck.

4. PETROGRAPHY

In the northern part of the area the rocks are epizonal phyllites with some interbedded quartzites and microconglomerates. The phyllites are characterized by shining s-surfaces which often are crenulated. Macroscopically no minerals could be recognized, but under the microscope it appeared that sericite is the main mineral in the phyllites. Besides, more or less quartz is present and further some chlorite, ore and a few other accessories.

About one kilometer south of the village of Mounicou the phyllites grade into biotite-schists which carry locally a large amount of porphyroblasts of andalusite, cordierite and sometimes staurolite. Biotite also may occur as porphyroblasts. The epi-mesozonal boundary swings to the south, west of the Mounicou valley and lies a few hundred metres below the high ridge which forms the frontier with Spain, until it is cut off by the Mérens fault. All along this line the phyllites grade immediately into andalusite-schists without intervening biotite-schists. The andalusite and cordierite porphyroblasts are very large, especially in the Subra valley where they reach lengths of several decimetres. Usually they are randomly oriented in the schistosity plane.

In the Mounicou valley at low altitude many small stocks, dykes and sills of muscovite-granite and pegmatite occur in the micaschists. These granitic rocks are usually unoriented. Locally the country rock contains macroscopically visible sillimanite. In some of these rocks garnet occurs in fairly large quantities. It is often found near or in calcsilicate rocks.

5. THE SUCCESSION OF THE STRUCTURES

In the mapped area folds with different orientations have been found. It could be shown that the formation of these folds occurred in several successive phases of deformation, each determined by the shapes of the folds and the orientation of axial plane and fold axis.

A distinction has to be made between the lowgrade phyllites in the northern part of the area and south of the Mérens fault, where a steep to vertical cleavage plane is the most pronounced structure, and the mesozonal regional metamorphic rocks, with essentially flat lying to horizontal cleavage or schistosity. In both cases the cleavage or schistosity is due to a mineral orientation and is parallel to the axial planes of minor folds.

This s-plane is everywhere in the area the oldest recognizable fabric element, and although the orientation is different in rocks with a different grade of metamorphism, there are good reason to assume that both structures are of the same age. The foldaxis trends E-W in both cases.

In the metamorphics of the SW part of the area folds with N-S axes and a flat lying axial plane have been found. Under the microscope it becomes clear that these folds are later, as the folded surface is the s_1-plane. These s_2 folds are, however, quite rare in the area. Quite frequently the s_1 or s_2 surface is folded with steep axial planes and fold axes with different directions. Hence they must the younger than the second phase, but is it difficult to determine the relative ages of these later phases, because due to their similar shape the deformation planes are still planar.

Elsewhere in the Central Pyrenees the age relationships between these folding phases have been determined and it appeared that folds with NW-SE trending axes belong to a third and folds with E-W axes to the fourth phase of deformation (see table I) and these results are used in this paper (Zwart 1963, Boschma 1961).

TABLE I

Deformation phase	1	2	3	4
Axial plane	suprastructure s_1 E-W steep infrastructure s_1 flat horizontal	s_2 flat horizontal	s_3 NW-SE steep	s_4 E-W steep
Fold axis	E-W	N-S (NNW-SSE)	vertical to NW-SE	E-W

6. THE MAIN PHASE DEFORMATION; AXIAL PLANE S_1 FOLDAXIS B_1

6.1 *Phyllites*

This deformation is the first penetrative and also the most important one in this part of the Central Pyrenees.

Discussing this phase we shall start in the northern part of the mapped region. This part consists of phyllites with subvertical s_1 cleavage planes. To determine the character and amount of deformation measurements were made in the microconglomerates which occur in the northern part of the region. The measurements were made near Etang Sourd. It appeared that the pebbles are deformed to approximately three- axial ellipsoids. Most of the extension took place along the a-axis. This a-axis is the vertical in the cleavage plane and stands about perpendicular to the cleavage-bedding intersections. It is important to note that in the lower parts of the suprastructure a great difference between the elongation in the a- and the b-directions still exists.

In the riverbed of the Artigue near the village of this name occur some interesting main phase structures. Fig. 2 shows us a banded quartzite in which the sedimentary bedding and the cleavage plane make a small angle. The bedding is isoclinally folded, but in the picture the shape of the fold is exaggerated, as it is cut obliquely.

Fig. 3 is a fold cut perpendicular to the fold axis. The rock consists of a banded quartz-phyllite in which a small angle between the sedimentary bedding and cleavage exists. This results in the feature that the fold crosses the phyllitic layer.

Fig. 4 shows a characteristic picture of the main phase folding in a banded quartzite. The angle between ss and s_1 is about 30°. The sedimentary layering is easily recognizable, despite the strong cleavage.

Near Marc on the N-slope of the Artigue valley a large accordeon fold has been found and is pictured in fig. 5. This fold is defined by a quartzite band interbedded

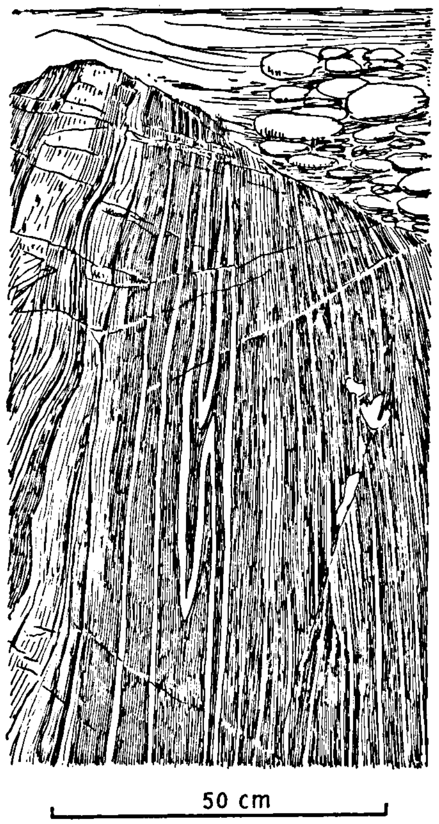


Fig. 2 Isoclinal s_1 folds in Artigue river

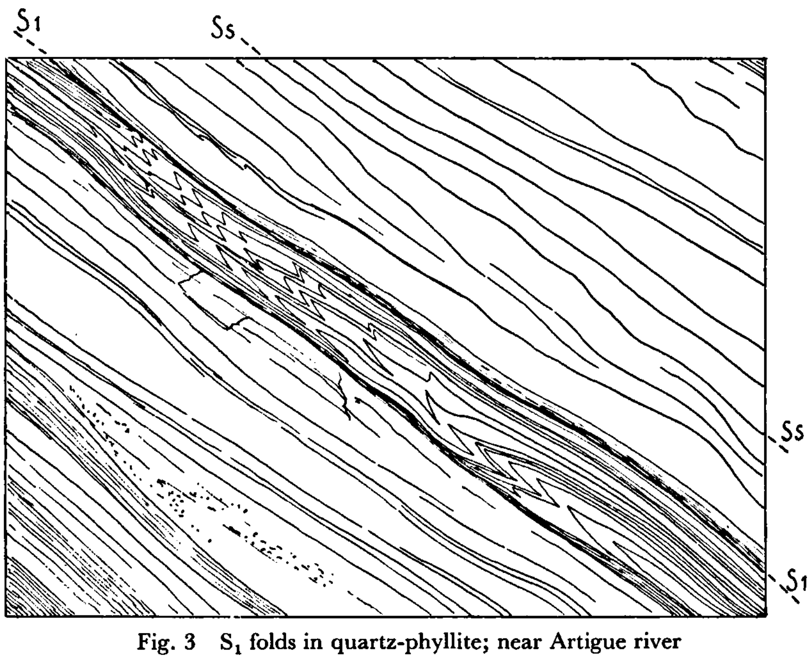


Fig. 3 S_1 folds in quartz-phyllite; near Artigue river

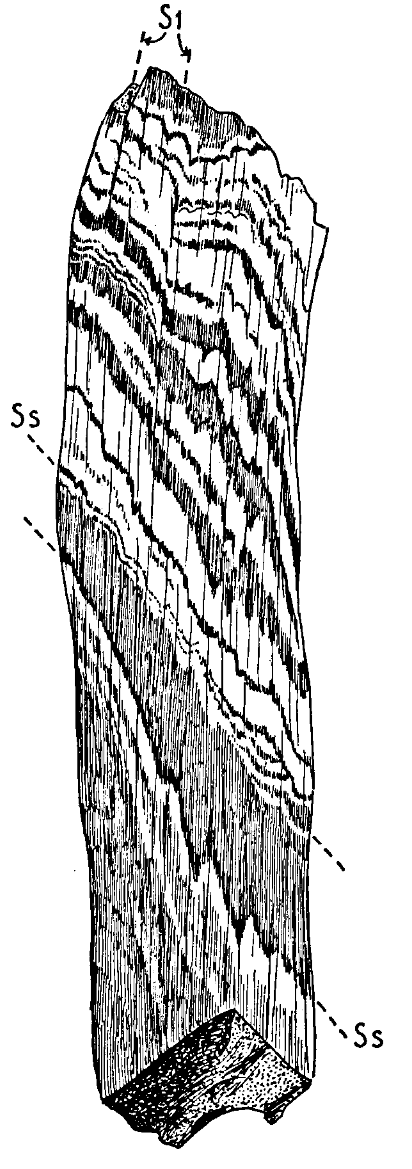


Fig. 4 Bedding with crosscutting cleavage, s_1

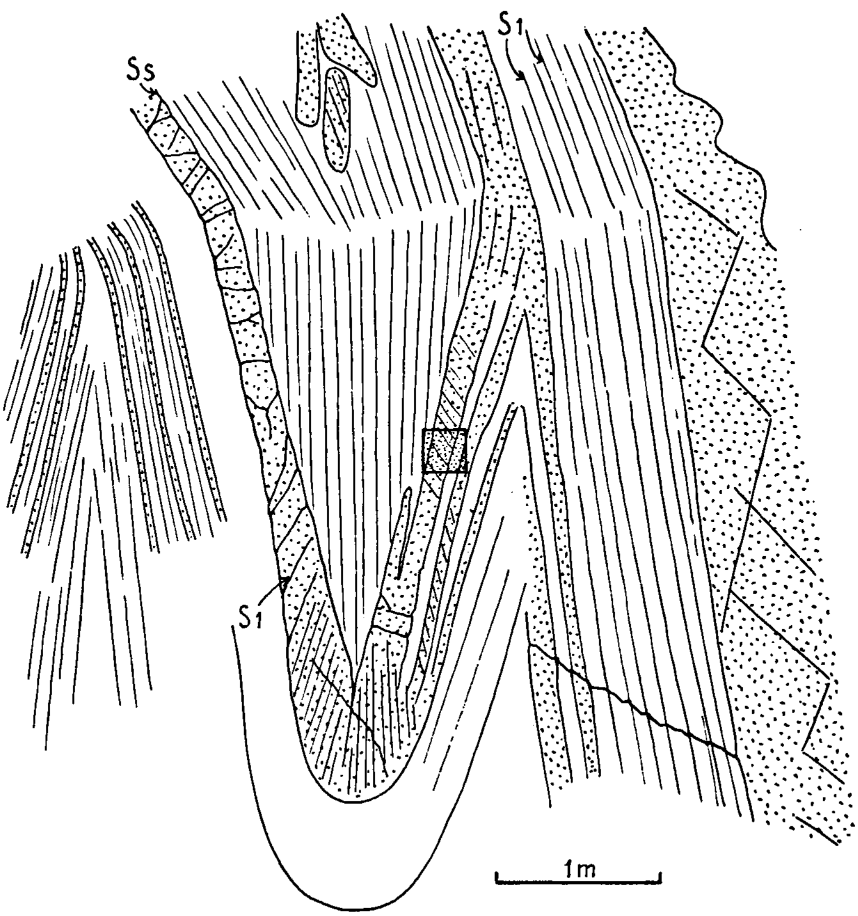


Fig. 5 Main phase fold near Marc

with pelitic material. A fracture cleavage is well developed in the quartzite and shows a marked fanning in the fold hinges. A detail of this fold is given in fig. 6. The place of the sample is indicated by a little dotted square on fig. 5 and shows us a tectonic banding produced by the main phase deformation in the quartzitic band. This tectonic banding is due to concentration of micaceous material on the fracture cleavage planes. This concentration might be formed from pelitic material from the quartzite itself or from pelitic material from the surrounding schists. In the last case the pelitic material penetrates the quartzitic layer along the cleavage surfaces. Both mechanisms may have interacted, for instance quartz may dissolve along shearzones and leave a mica-rich band, but on the other hand the wedge shape of the banding near the boundary of the layer may be an indication, that there pelitic material from the surrounding schists was introduced.

Fig. 6 Fracture cleavage in quartzitic layer in phyllite; detail of fig. 5 (1 ×)

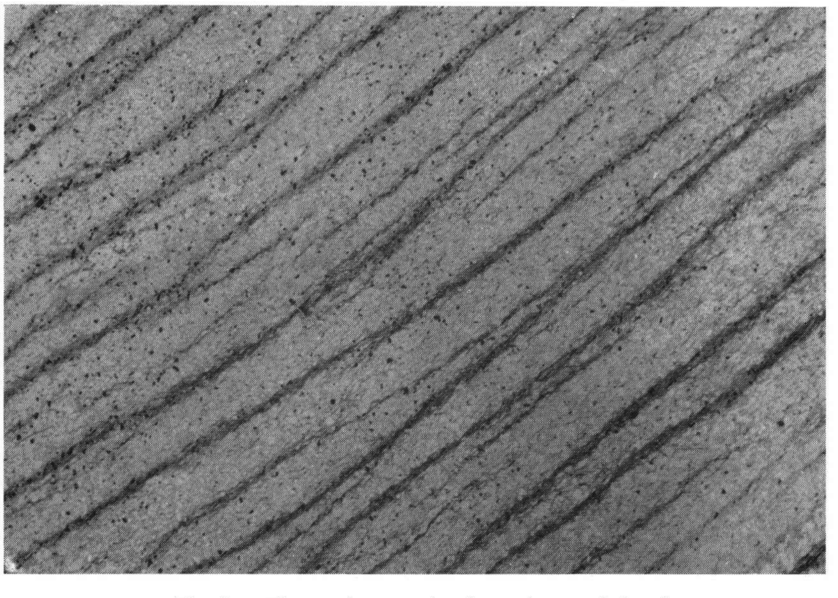


Fig 6a Photomicrograph of specimen of fig. 6

6.2 *Micaschists*

In this region the sub-horizontal schistosity plane is well developed. Due to deformation and metamorphism the sedimentary structures disappear although in a few outcrops some sedimentary banding is still evident. Fig. 7 is a good example of this. We see a typical main phase fold; the sedimentary banding is marked by the folded quartzite layers. The cleavage is badly developed in these layers and in the fold hinges. In the pelitic part the axial plane cleavage is well developed.

In the quartzites often a small angle between cleavage and sedimentary banding

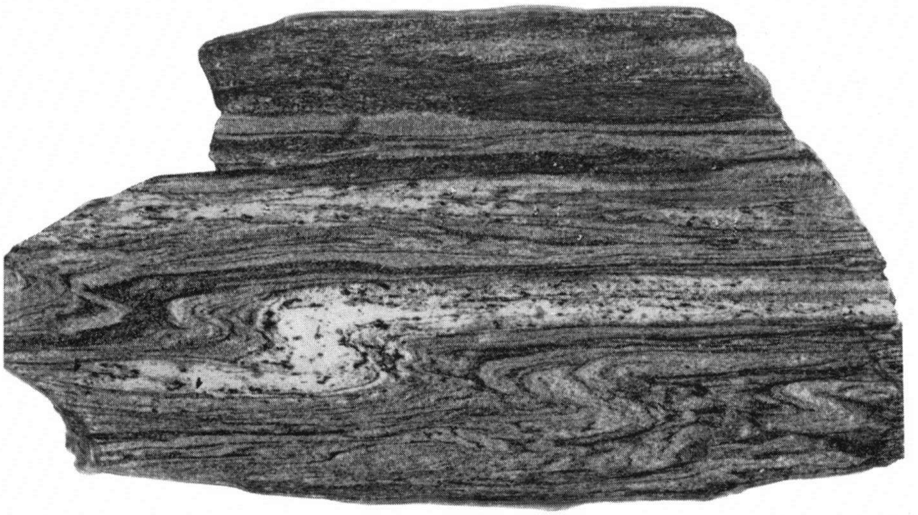


Fig. 7 Folded bedding with axial plane schistosity s_1 in micaschist. (1 ×)

exists. The result is that lense structures are formed as shown in fig. 8. In the larger quartz lenses the angle between sedimentary bedding and cleavage is easily visible.

Main phase folds are rarely found in the schists, due to the isoclinal character of the folds and the flattening of the schists. A careful search, however, always yields a few of such folds. Fig. 9 shows us a main phase fold in an andalusite-micaschist, the folded surface being a quartzitic layer. The isoclinal character and the flattened limbs are typical properties of these folds.

In general the following properties of the main phase folds in this area can be ascertained: in the schists isoclinal folding with sharp hinges, well developed schistosity parallel to the axial planes of folds. In the quartzites isoclinal and concentric folding with sharp and round hinges; schistosity is locally developed and fans about the axial planes of the observed folds.

Fig. 10 is a picture of a pegmatite with a folded structure. The axial planes of the folds are parallel to the schistosity of the surrounding andalusite-bearing micaschists and they represent a kind of parasitic folds. Obviously the pegmatite was already present before important flattening of the schists took place. Possibly the flattening occurred during the main phase and then the pegmatite should have been emplaced before or early in this phase. Another possibility is that the schists have

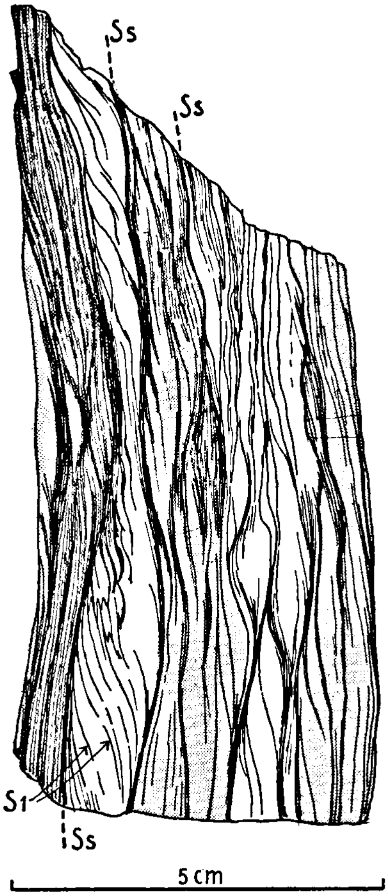
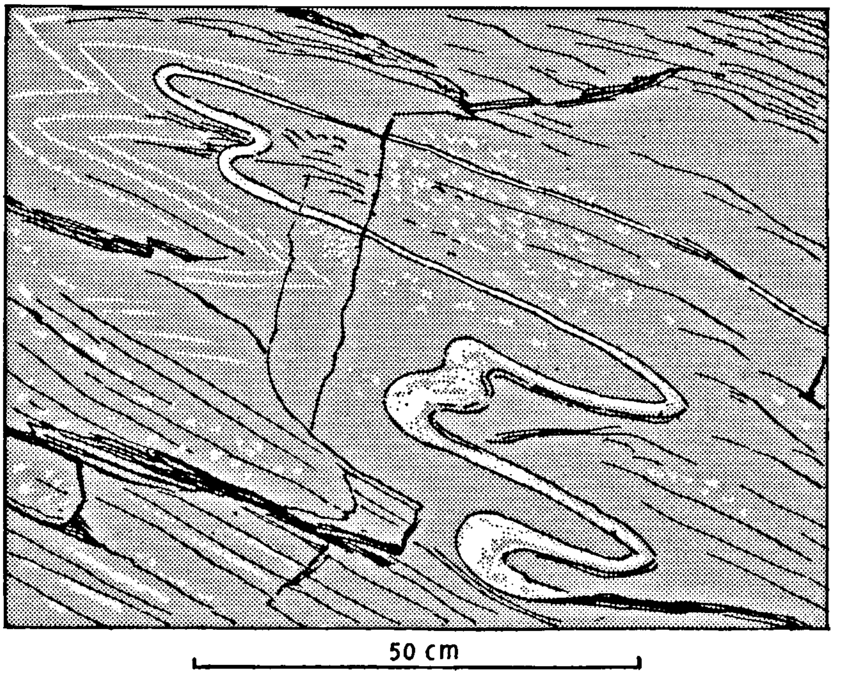


Fig. 8 Lense structure in micaschist due to small angle between ss and s_1

Fig. 9 Isoclinal folds of bedding in micaschist



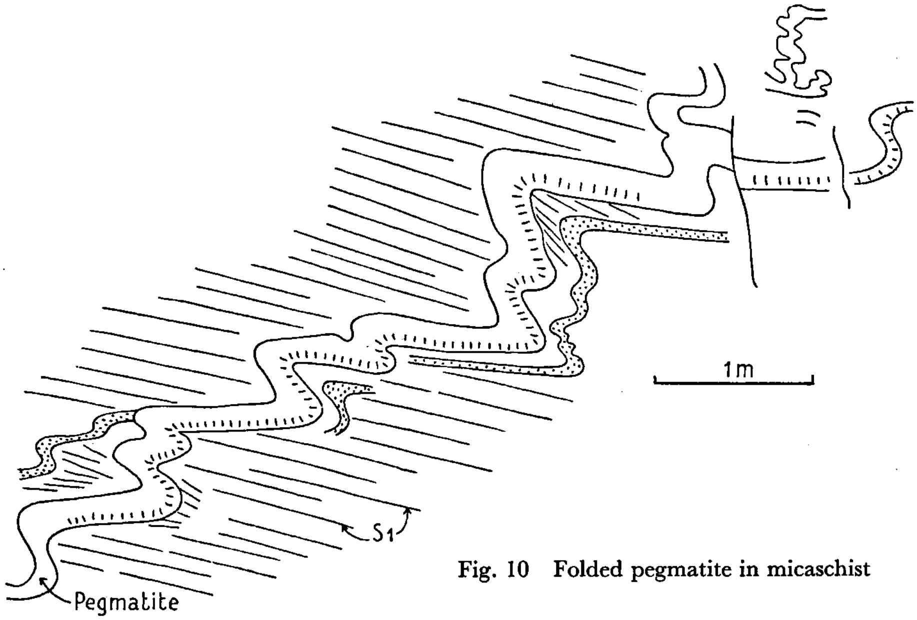


Fig. 10 Folded pegmatite in micaschist

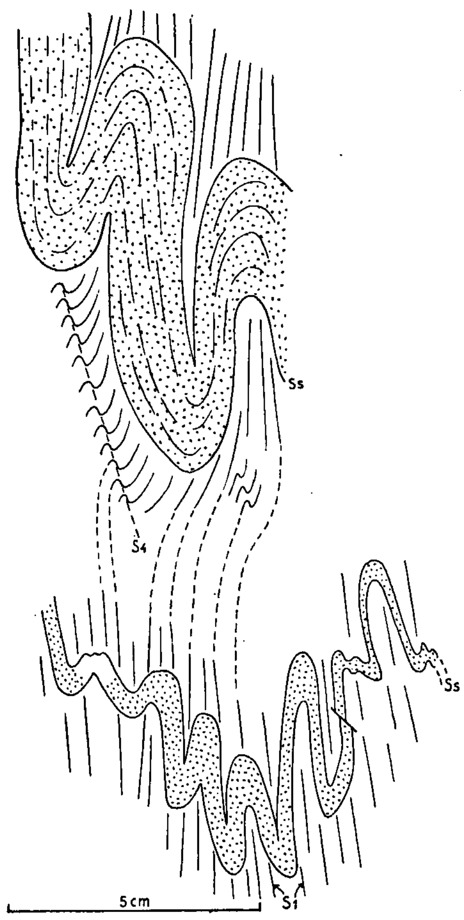


Fig. 11 Main phase folds in phyllite, south of Mérens fault.

undergone renewed flattening during the second phase and in that case the pegmatite could be younger than the first, and older than the second phase.

All these structures mentioned above occur in the western part of the Aston massif. South of the Mérens fault structures occur, similar to those in the phyllites of the Aston massif.

The cleavage planes are subvertical; the fold axes trend E-W and have a gentle plunge. The metamorphic grade is low; all rocks are metamorphosed in the epizone.

In a few outcrops main phase folds have been found. Fig. 11 gives us an example of one of these folds, which also shows some fourth phase deformation.

On the map, plate 1, measurements of the main phase cleavage or schistosity planes are assembled. The dome-shape of the main phase structure is easily recognizable on this map, and also the flat position of the schistosity in the metamorphics and its steep attitude in the lowgrade sediments. Variations of this pattern are due to the later deformations.

7. THE SECOND DEFORMATION; FOLD AXIS B_2; AXIAL PLANE S_2

In the region around Etang de la Gardelle many folds with N-S axes and subhorizontal axial planes are found. The axial planes of these folds are parallel to the main phase schistosity planes; the axes are perpendicular to the main phase foldaxes. The deformation caused renewed flattening of the rocks. This deformation seems to be restricted to a small area lying near the western boundary of the micaschists. An example of this folding is given in fig. 16, which also contains folds due the third (NW-SE) and fourth (E-W) phase. In the last part of this article some more information about this deformation is found.

8. THE THIRD DEFORMATION; FOLD AXIS B_3 AXIAL PLANE S_3

The third deformation is the most important refolding in this part of the Central Pyrenees.

Fig. 12 is a part of a thin section, cut perpendicular to the third phase foldaxis. In this thin section ss and s_1 are parallel and s_3 makes an angle of 50° to the ss/s_1 surface. The third phase developed in this rock a crenulation cleavage which is visible on the schistosity plane as a "strong" lineation. This lineation dips in this example to the NW.

Fig. 13 is a photograph of a thin section from Carla. The sedimentary bedding and the main phase schistosity (ss and s_1) are subparallel. They are disturbed by an s_3 crenulation cleavage. The third deformation formed a new banding (right part of the photograph). This new s_3 banding is due to zones of shear (the dark flexure zones) and zones of sigmoidal folding.

In general we may conclude that lineations belonging to the third deformation phase occur in the whole area; in the phyllites a distinct new cleavage is developed; in the micaschists this surface is less well developed and here we recognize the third deformation by lineations and small folds of the mainphase schistosity plane.

The plunge of the folds is mainly determined by the strike and dip of the mainphase planes. On the map, plate 2, we assembled the measurements of these folds and it is clear that there is a large variation in the plunge. This is of course due to the dome shaped main phase structure.

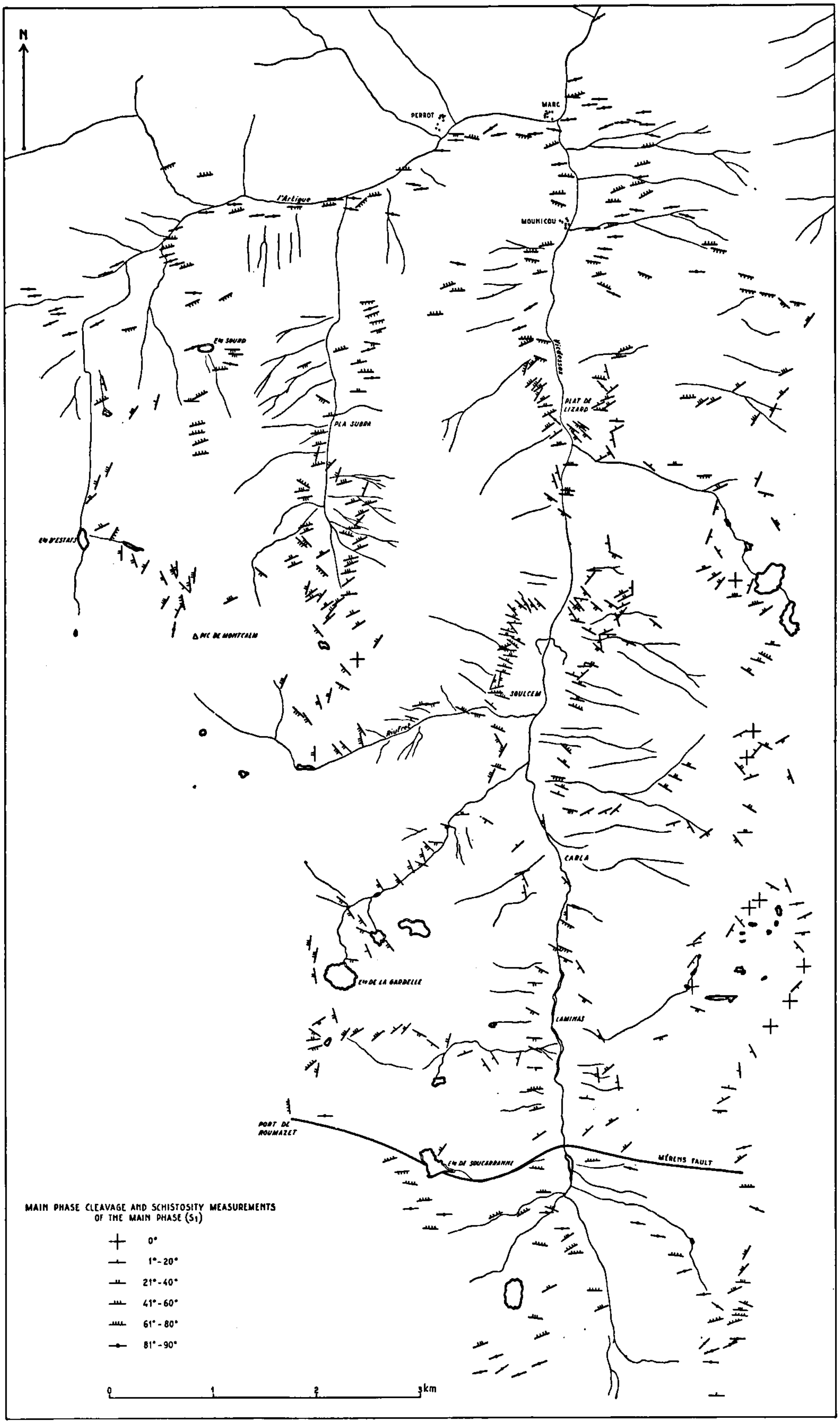


Plate 1 Cleavage and schistosity of first, main phase, s_1

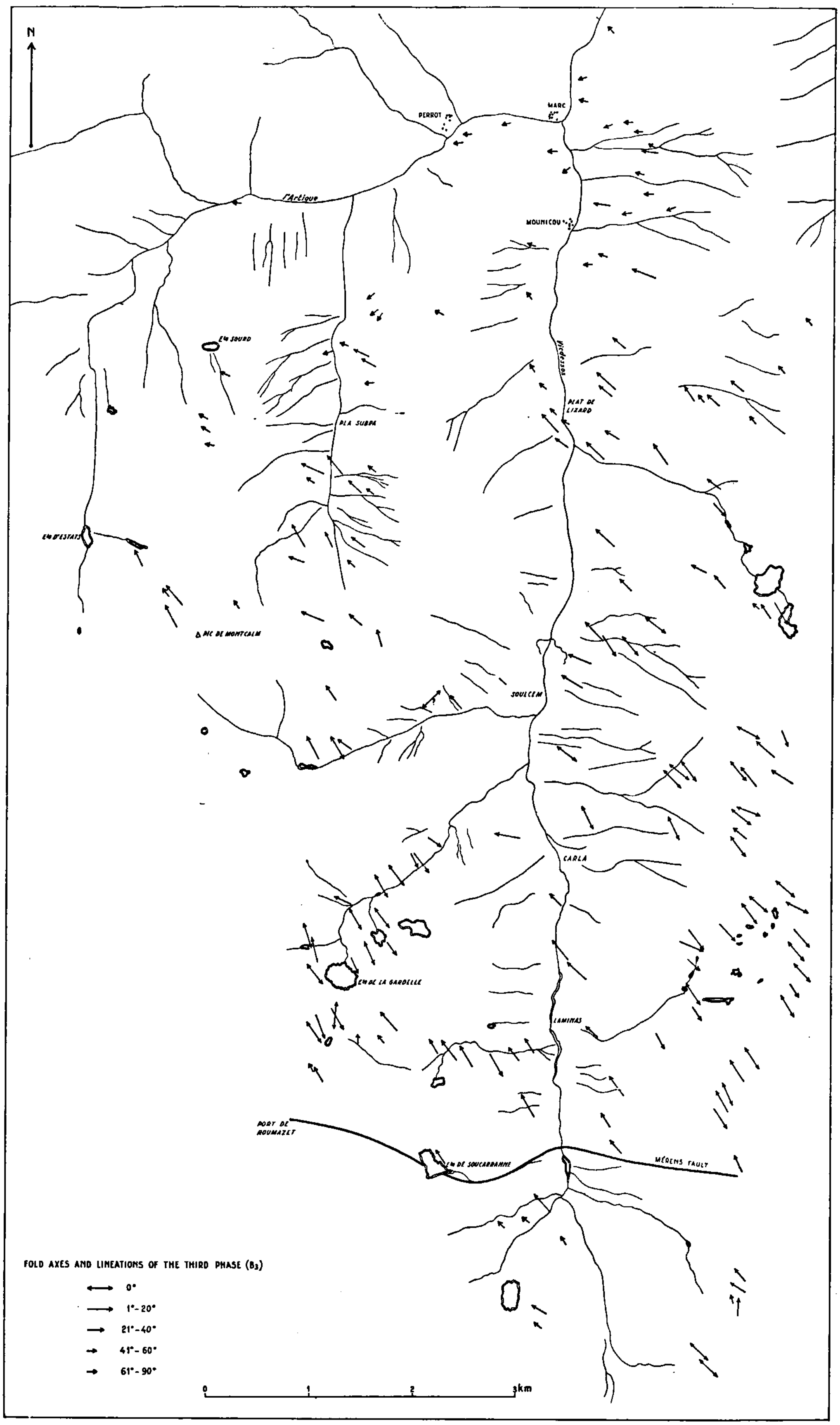


Plate 2 Foldaxes and lineations of third phase, B_3

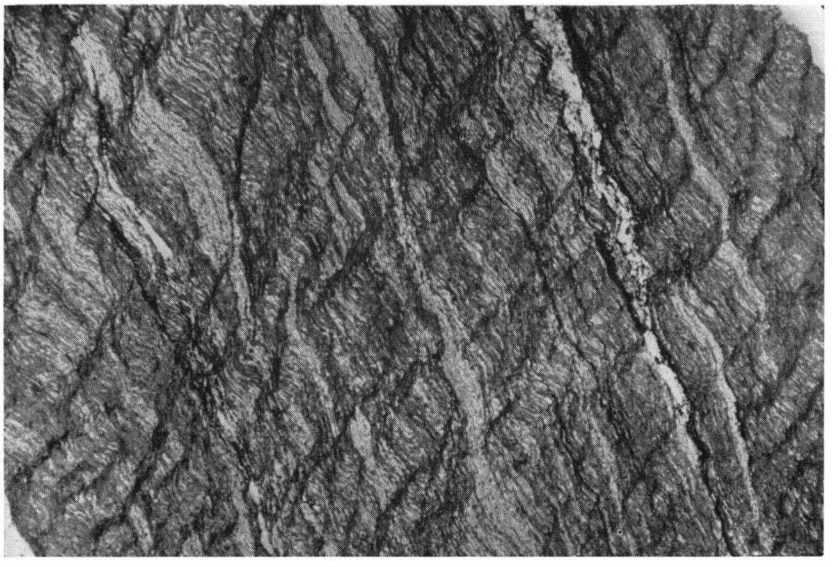


Fig. 12 Microfolds of third phase; folded surface is s_1

Fig. 13 Micaschist with tectonic banding due to third phase folding

9. THE FOURTH DEFORMATION; FOLD AXIS B_4; AXIL PLANE S_4

The axial plane of this deformation is subvertical and has an E-W strike. In this part of the Aston massif the fold axes plunge to the west.

Folds of the fourth deformation occur abundantly in the mapped area. Many of these folds are of the accordeon type, other have more rounded hinges. Their axial plane cleavage is visible in the field as a coarse jointing. For examples see below.

10. INTERFERENCE BETWEEN THE SUCCESSIVE FOLDS

Fig. 14 from a sample collected near Carla shows us the interference between the main, the third and the fourth phase of deformation. The sedimentary bedding is well visible on the s_3 plane. It is difficult to determine in this sample the age relationships of the third and fourth deformation because due to the similar shape of the folds both deformation planes are planar. Remarkable is that in this sample these folds are of the same kind.

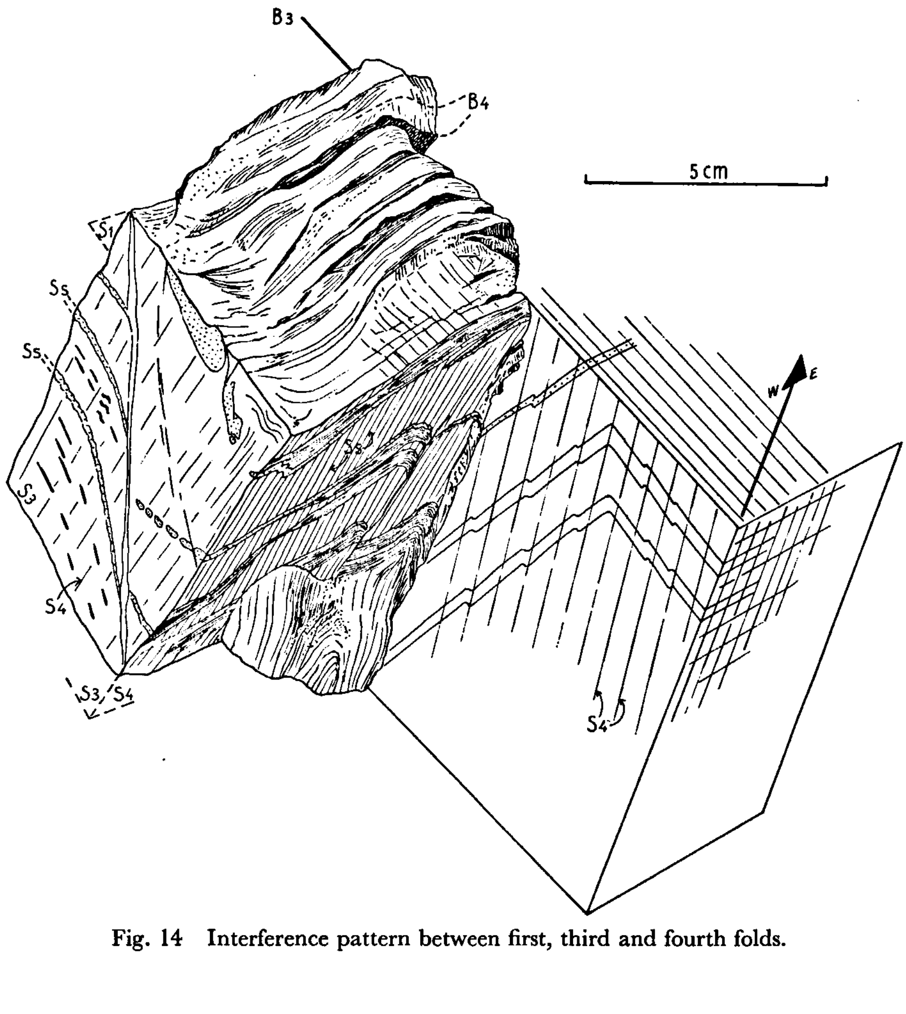


Fig. 14 Interference pattern between first, third and fourth folds.

Fig. 15a + 15b represent a micaschist in which the sedimentary bedding (ss) makes a small angle with the mainphase schistosity (s_1). On s_1 a distinct lineation is visible belonging to the third deformation (B_3) which is folded by the fourth folds (B_4). We can recognize also the cleavage plane of the third deformation (s_3) and the poorly developed plane of the fourth deformation (s_4).

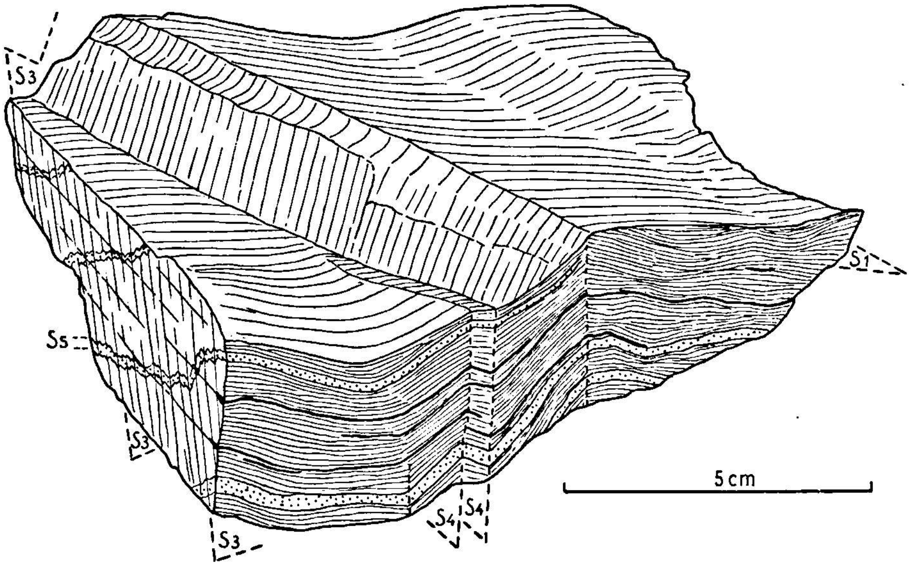


Fig. 15 A and B. Interference pattern between first, third and fourth folds.

Fig. 16 from a specimen collected near Etang de la Gardelle shows the results of the second, the third and the fourth deformation. The fold axis (B_2) and the axial plane (s_2 // s_1) of the second deformation are flat lying. When examining these folds under the microscope it becomes clear that they are s_2 folds because the folded banding is a s_1 banding and not the sedimentary bedding. The third deformation (B_3 and s_3) and the fourth deformation (B_4 and s_4) are easily recognizable.

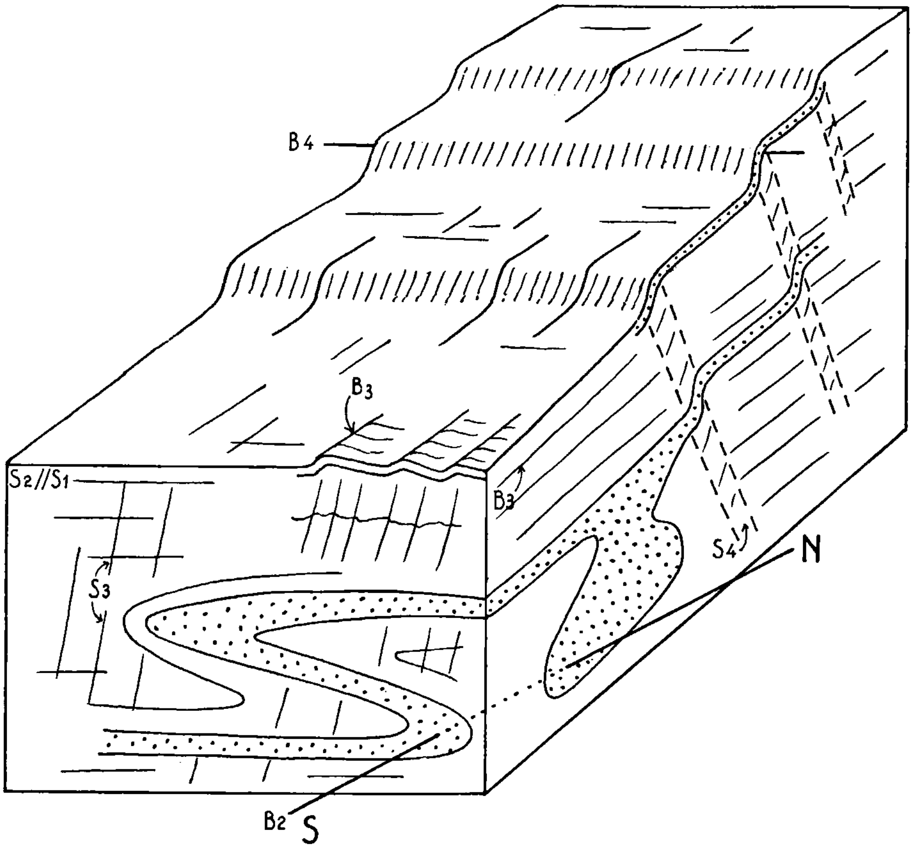


Fig. 16 Second, isoclinal fold with s_3 and s_4 folds and cleavage

11. RELATIONS BETWEEN DEFORMATION AND METAMORPHISM

Some relations between deformation and metamorphism are discussed in order to determine the relative ages of metamorphic and folding phases.

Fig. 17 shows us an example of a pegmatite in a micaschist (Mounicou valley). The folds are undisturbed main phase folds of which parts seem to be replaced by pegmatitic material. This replacement, a process related to the regional metamorphism, took place after the formation of the main phase folds.

In the exposures around the Pla Subra the following data can be obtained. In the micaschists two deformations occur: the main phase deformation that formed the schistosity planes of muscovite-schists and the third deformation that formed a

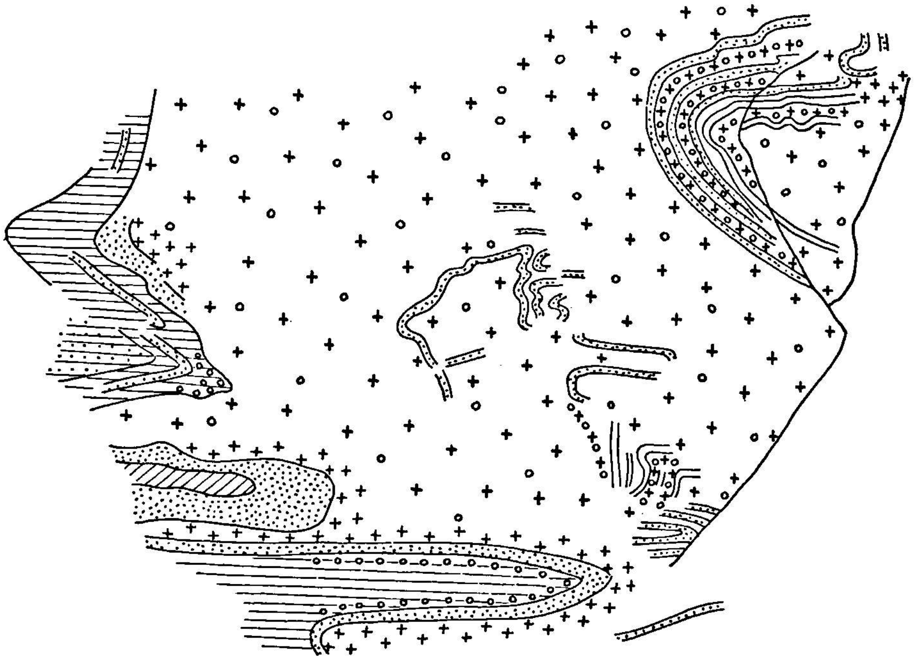


Fig. 17 Pegmatite, penetrating and replacing micaschist
Crosses = pegmatite; dots = quartzite; unbroken lines = micaschist;

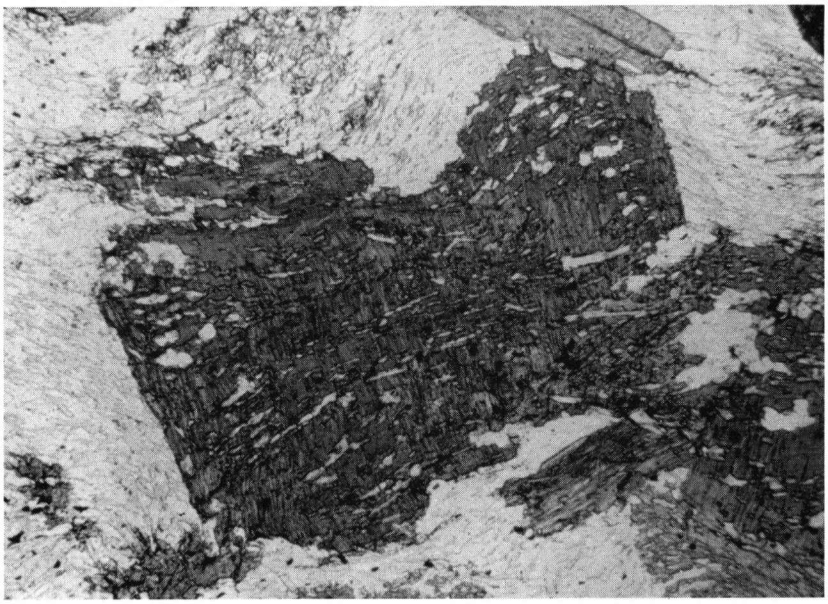


Fig. 18 Biotite crystal with incipient helicitic folds of third phase; Pla Subra

crenulation cleavage. The crenulation cleavage is well developed and is found in almost every outcrop. After the main phase andalusite, staurolite, cordierite and biotite porphyroblasts were formed. Many biotite porphyroblasts have grown through the crenulation cleavage without deforming it. Most of these porphyroblasts contain small quartz inclusions lying in rows. These quartz inclusions form the same type of micro folds as the surrounding schists. We concluded that the biotite was formed after the crenulation cleavage of the third deformation. In some biotite crystals, however, it is evident that they contain helicitic folds of the third phase, but they are also deformed by it and apparently folding continued after the formation of the crystals. These biotites were formed during the third deformation. The examination of the other porphyroblasts yielded the same results. Our conclusion is that the growth of the andalusite, staurolite, cordierite and biotite took place during and after the third deformation in the western part of the micaschist area; fig. 18 and fig. 19 are two examples of these schists.

Another relationship is shown in fig. 20, an andalusite bearing micaschist form the Riu Fret area. The folds in the quartz layers date from the main phase. The original ss (sedimentary bedding) can hardly be recognized due to the strong main phase deformation. The formation of the andalusite must be late kinematic with regard to the first phase. The rotation of the andalusite will be due to late movements on the schitosity plane, belonging to the main phase.

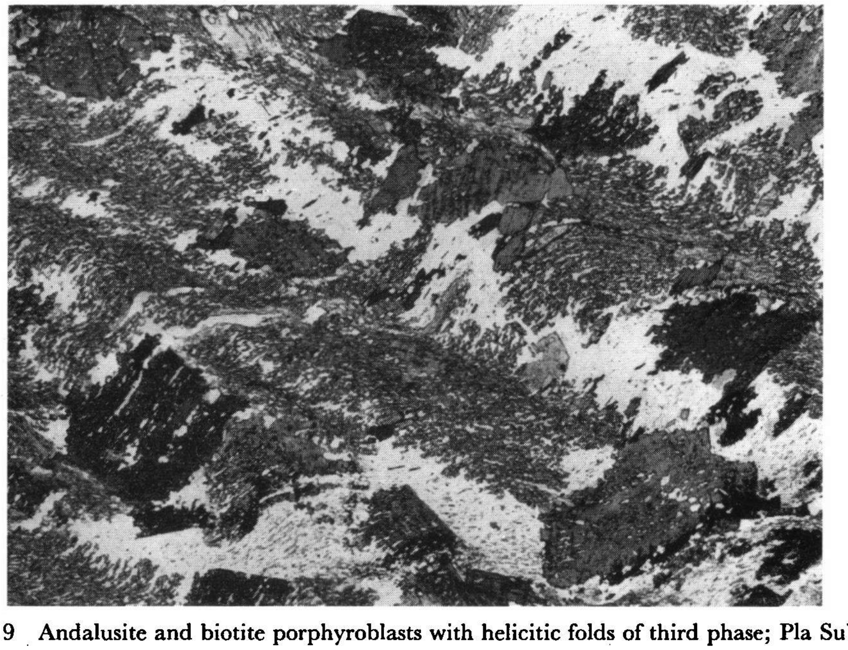


Fig. 19 Andalusite and biotite porphyroblasts with helicitic folds of third phase; Pla Subra.

Fig. 20 Andalusite (A) in schist from Riu Fret; andalusite rotated.

12. CONCLUSION

Deformation during the main phase is responsible for the shape of the metamorphic dome and the formation of isoclinal folds in the rocks. The orientation of the strain ellipsoid in this part of the Aston massif can be measured with the aid of the deformation of the conglomerates. According to these measurements near Etang Sourd the subvertical a-axis is the longest one and is ependicular to the W-plunging b-axis. The a-axis lies in the axial plane of the folds and is changing its position with that plane (cleavage or schistosity) to a subhorizontal position in the centre of the dome. Extension in a vertical direction with a horizontal schistosity is hard to understand. Moreover from several observations it could be concluded that the schistosity plane here is also a plane of flattening. The question arises which is the direction of elongation. Zwart supposes b-axis extension in the linear gneisses in the deeper parts of the dome. He also supposes a connection between the b-axis extension in the subhorizontal part of the dome and the N-S second deformation phase. This is based on the following suppositions. The b-axis extension diminishes going from infrastructure to the supra-structure thus both in vertical and in E-W direction. This may result in a secondary stressfield in the transitional zone. By this stressfield folds with N-S axes and subhorizontal axial planes could be formed. The fact that these folds are limited to the transitional zone strengthens this hypothesis. The same may apply to the third phase of deformation which is also caused by an E-W directed largest principal stress (Zwart 1963) although this phase is far more widespread than the second phase. Summarizing we might say that the b-axis extension in the infrastructure and in the transition zone changes into the subvertical a-axis extension in the supra-structure. The transition between the two types of major structures is gradual (Oele 1964). More information about this zone will be given elsewhere.

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