

A NEW INTERPRETATION OF THE STRUCTURAL AND METAMORPHIC HISTORY OF THE WESTERN ASTON MASSIF (CENTRAL PYRENEES, FRANCE)¹

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ABSTRACT

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Detailed structural analysis has yielded new data on the structural and metamorphic evolution of the western Aston Massif and on the nature of the transition zone between the supra- and infrastructure in the central Pyrenees. The low-grade suprastructure is characterized by a steep axial-plane cleavage, whereas a flat-lying schistosity predominates in the high-grade infrastructure. Structural cross sections through the transition zone indicate that the steep cleavage is a first (F_1) structure which becomes progressively deformed towards the higher grade rocks by second and third generations of structures (F_2 and F_3). The third deformation in particular is characterized by a flat-lying axial-plane schistosity.

Two dome-shaped metamorphic isograd patterns occur in the area. These isograd patterns match with a structural dome which largely results from F_2 deformation. Third generation flat-lying structures, while being moderately developed in the transition zone, predominate in the central part of the dome, suggesting thermally induced vertical shortening. Two younger generations of broadly post-metamorphic steep folds (F_4 and F_5) only slightly affected the major structure.

The relationship of deformation and metamorphism is different for the two metamorphic thermal highs. In areas where these two thermal highs intersect, two phases of metamorphic mineral growth can be demonstrated, indicating the complex nature of the Pyrenean metamorphism in such localities.

INTRODUCTION

The central or axial zone of the Pyrenees is made up of sedimentary and igneous rocks of Palaeozoic age which, except for a number of late Variscan bodies of granodiorite, have been deformed and metamorphosed during the Variscan orogeny (Fig. 1). Towards the north and south, narrow zones of Mesozoic rocks show the influence of deformation and local metamorphism of Alpine age. Within the axial zone, these Alpine imprints are possibly reflected by a late generation of folds and shear zones developed in the vicinity of Alpine folds.

In the fifties and early sixties ALLAART (1954), LAPRÉ (1965), VERSPIJCK (1965) and ZWART (1965) studied the metamorphic pattern of the Aston massif. In the Cambro-Ordovician rocks

they recognized a progressive metamorphic sequence including a muscovite zone, a muscovite-biotite zone, a staurolite-andalusite-cordierite zone and a cordierite-sillimanite zone. This sequence culminates in the partial melting of pelitic rocks and represents a succession in space as well as in time (see also ZWART, 1979). In addition, LAPRÉ (1965), ZWART (1965) and OELE (1966) demonstrated the multiple character of the Variscan deformation and recognized four generations of folds. The first phase, referred to as the main phase, was considered to be responsible for a steep slaty cleavage in the low grade rocks and a shallowly dipping schistosity in higher grade rocks. The second phase with N-S fold axes and gently-dipping axial planes was found mainly in the western part of the Aston metamorphics. The third phase, developed in low as well as in higher grade rocks, included a conjugate set with steep NW-SE and NE-SW striking axial-plane crenulation foliations. The fourth phase, with E-W striking steep axial planes and equally marked by a crenulation cleavage, showed the same areal distribution as the third phase. The peak of the metamorphism was considered to have occurred during the third and between the third and fourth phase.

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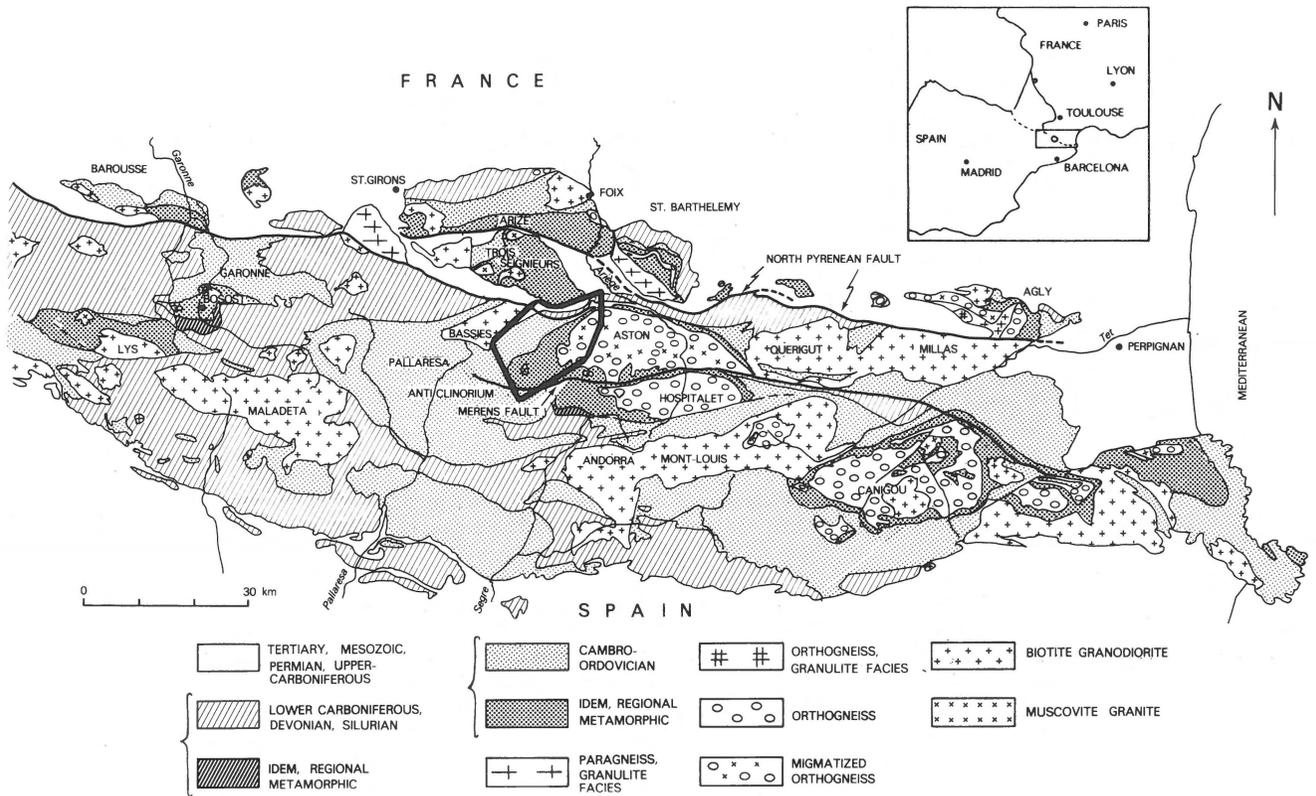


Fig. 1
Map of the Variscan Pyrenees, showing location of the area studied.

Within the axial zone a twofold division can be made on the basis of structural style and metamorphic grade. Following WEGMANN'S (1935) definitions, ZWART (1962) thus recognized a low-grade *suprastructure* characterized by steep folds and steep axial-plane foliations, regionally overlying an upper-greenschist to amphibolite facies metamorphic *infrastructure* in which the dominant foliations are subhorizontal and in which multiple folding points to a structural history of greater complexity than in the low-grade rocks.

A major structural problem in the geology of the central Pyrenees is the relationship between the supra- and infra-structure (ZWART, 1962, 1979), LAPRÉ (1965), ZWART (1965) and OELE (1966) argued that supra- and infra-structure developed simultaneously during the first (main) phase of deformation. However, problems with this interpretation were already expressed by ZWART (1979, p. 38, and 1981). SEURET & PROUST (1968) and MATTE (1969) claim that the oldest folds are recumbent and that they are overprinted by younger structures with steep axial planes. There is ample evidence to the contrary, however (ZWART, 1979, and this paper).

Detailed mapping and structural analysis have yielded new data on the geometry of the western part of the Aston massif and on the nature of the steeply and gently dipping axial-plane foliations and their transition. The data lead us to propose a new interpretation of the structural evolution and its relation to the regional metamorphism.

LITHOLOGY

The lithology of the area is briefly summarized below. For a more elaborate description of the various rock types the reader is referred to LAPRÉ (1965), VERSPIJCK (1965) and ZWART (1965, 1979).

A major part of the area (Fig. 2) is made up of a monotonous sequence of metamorphosed psammitic and pelitic rocks of Cambro-Ordovician age (CAVET, 1957; ZWART, 1965; HARTEVELT, 1970). Locally, and mostly in rocks of low metamorphic grade, primary sedimentary features including graded bedding and cross-lamination provide criteria for the determination of the facing direction. A reconstruction of the stratigraphy on the basis of these criteria indicates in sections from north to south that gradually deeper portions of the Cambro-Ordovician sequence are exposed towards the higher grade rocks. The lower part of this sequence contains more psammitic rocks than the upper part. The upper part is generally pelitic but contains layers of coarse sandstone and fine-grained conglomerate with quartz pebbles up to about 1 cm. Individual beds of these conglomerates can be mapped over a distance of more than one kilometre, but eventually they wedge out. Some of these layers cut across metamorphic isograds. The upper part of the sequence contains few layers of strongly folded limestone and marble. The thickness of the Cambro-Ordovician sequence in the area investigated is at least five kilometres.

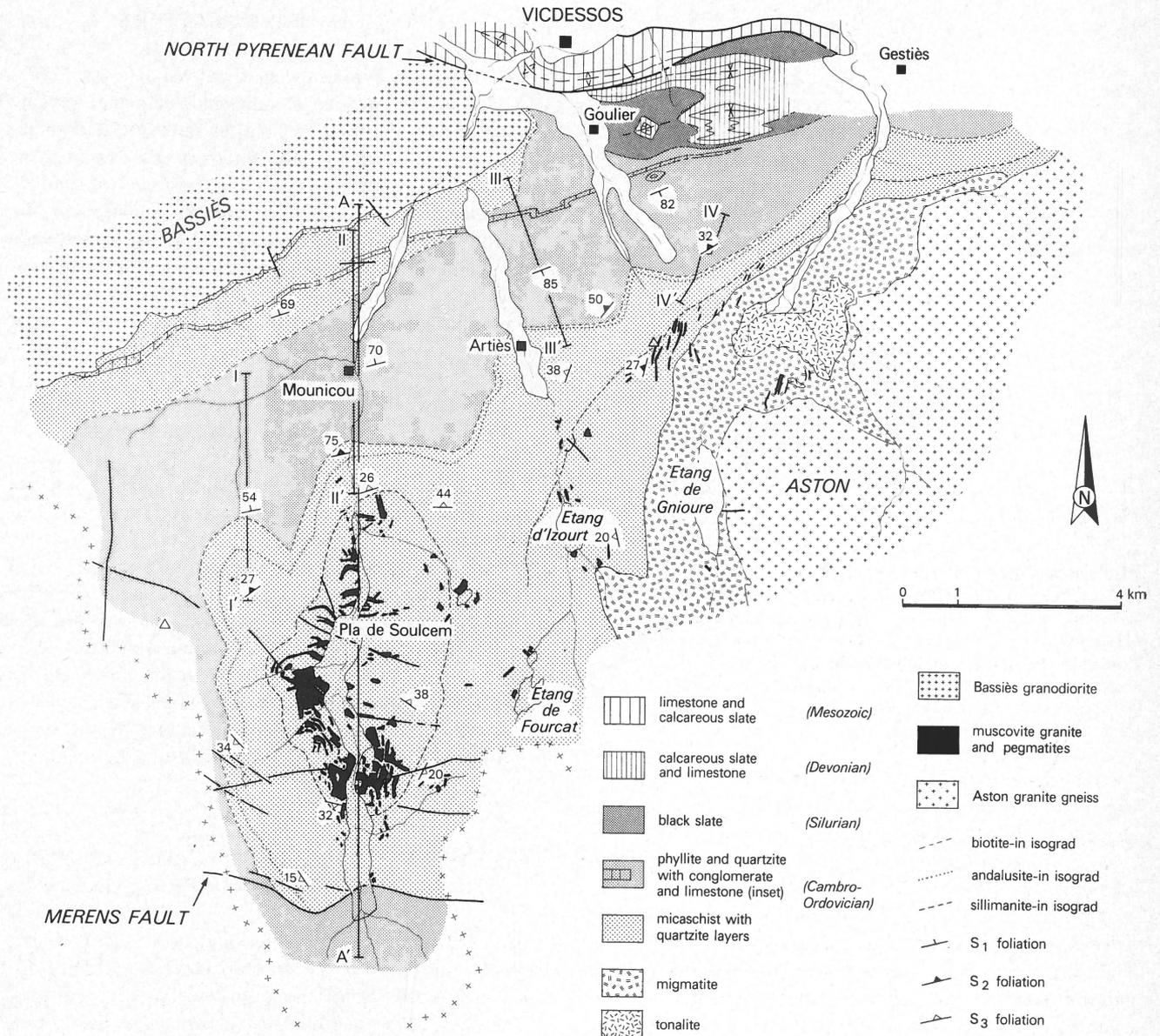


Fig. 2 Geological map of the W Aston massif.

Dark-coloured slates of Silurian age conformably overlie the Cambro-Ordovician rocks. They form a layer of a few hundreds of metres thickness, overlain by up to 800 metres of Devonian slates and limestones.

The Variscan metamorphism has affected this Palaeozoic sequence and transformed the Cambro-Ordovician rocks into muscovite-chlorite schist, biotite-muscovite schist, and into andalusite ± staurolite ± cordierite ± sillimanite bearing biotite-muscovite schist. Migmatites mark the highest metamorphic grade reached in the area. Irregular bodies of tonalite in the migmatites are considered as the autochthonous or parautochthonous products of anatexis.

Massive granitic gneisses of the Aston Massif overlie the Cambro-Ordovician rocks in the eastern part of the area

studied (Figs. 1, 2). Intense deformation and partial melting of these gneisses indicate that they suffered the same orogenic history as the metapelitic sequence. Radiometric Rb/Sr whole rock age determinations of the granitic gneisses by JÄGER & ZWART (1968) indicate an Ordovician age of emplacement. It should be noted, however, that GUITARD (1970) reports a Cambrian age of 535 Ma of similar orthogneisses in the Canigou-Carança massif in the eastern part of the axial zone (see also VITRAC-MICHARD & ALLÈGRE, 1975). ZWART (1981) interpreted the Aston granitic gneiss as a deformed laccolith-shaped intrusion in the Cambro-Ordovician sequence. According to GUITARD (1963) and AUTRAN ET AL. (1966) the Canigou gneisses represent a late Precambrian basement on which the Cambro-Ordovician sediments have been deposited unconformably.

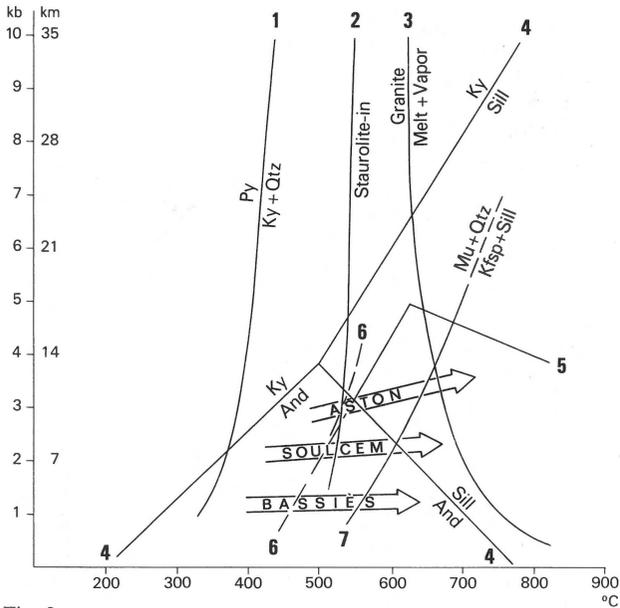


Fig. 3

PT diagram showing inferred metamorphic evolution for the Aston and Soulcem thermal highs; 1 – according to Haas (1971); 2 – according to Winkler (1979); 3 – melting curve for granite at $p_{tot} = PH_2O$ according to Luth et al. (1964); 4 – Al-silicates according to Holdaway (1971); 5 – estimated Cordierite stability in natural pelites according to Richardson (1970); 6 – Chlorite + Andalusite + O = Mg – Cordierite + H_2O (Schreyer & Seifert, 1976); 7 – according to Evans (1965).

Irregular patches and veins of pegmatite and muscovite-granite occur within the amphibolite facies rocks. It has been suggested that they represent parautochthonous intrusives derived from partial melting of the pre-Variscan granitic rocks (ZWART, 1979, 1981).

In a late stage of the Variscan orogeny the Bassiès granodiorite intruded the Palaeozoic sequence (Figs. 1, 2). The mineral zonation which developed in the contact aureole indicates intrusion into relatively shallow levels of the crust (see also Fig. 3). To the north, the Bassiès granodiorite and the Palaeozoic metasediments are cut off by the North Pyrenean fault which separates these rocks from multiple folded limestones and calcareous slates of Cretaceous age.

THE METAMORPHIC PATTERN

The 1:50 000 scale geological map, sheet Aston (ZWART, 1965) shows a single progressive metamorphic sequence ranging from low-grade phyllites to migmatites and associated tonalitic rocks underneath the granitic gneiss of the Aston massif. The present study has revealed the existence of another thermal high centered around Pla de Soulcem in the Mounicou valley (Fig. 2). This thermal high is characterized by the abundant occurrence of muscovite granites and pegmatites. Migmatites, however, are rare in this locality. The metamorphic aureole surrounding the Bassiès-Auzat granodiorite represents a third thermal high, but in contrast to the two others it is a typical contact metamorphic aureole.

In the area where the mineral zone boundaries related to the Aston and Soulcem thermal highs intersect, progressive mineral reactions as well as the relationship between deformation and metamorphism suggest that the Pla de Soulcem thermal high is younger than the Aston thermal high. This point will be further discussed below.

The mineral zone boundaries surrounding the Aston massif, Pla de Soulcem, and Bassiès-Auzat granodiorite allow tentative conclusions with regard to PT-path topologies. The PT-trajectories shown in Fig. 3 are primarily based on the disappearance of muscovite + quartz near the andalusite-out boundary in the Soulcem area, and the stable coexistence of the two minerals beyond the sillimanite-in boundary up to the level of incipient migmatization in the Aston thermal high.

STRUCTURAL ANALYSIS IN CROSS SECTIONS THROUGH THE METAMORPHIC ZONES

Published data from LAPRÉ (1965) and OELE (1966) indicate that the western part of the Aston massif has the shape of a half-dome, cut off towards the south by the Mérens fault (Fig. 2). The shape of this half-dome is determined by the attitude of the principal foliation planes which curve around from an E-W to a N-S strike in the Mounicou and Artiès valleys, where foliations dip to the west. Superimposed on this half-

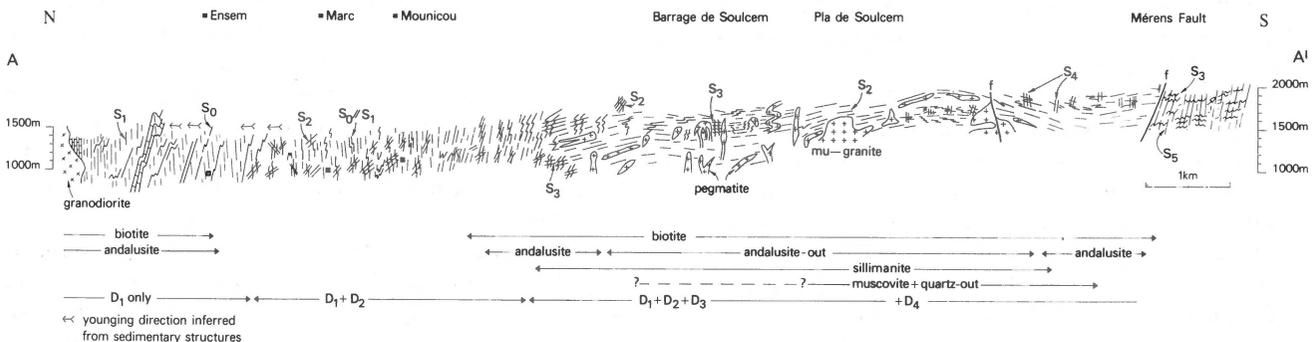


Fig. 4

Structural cross section across the Pla de Soulcem thermal high. For location see Fig. 2.

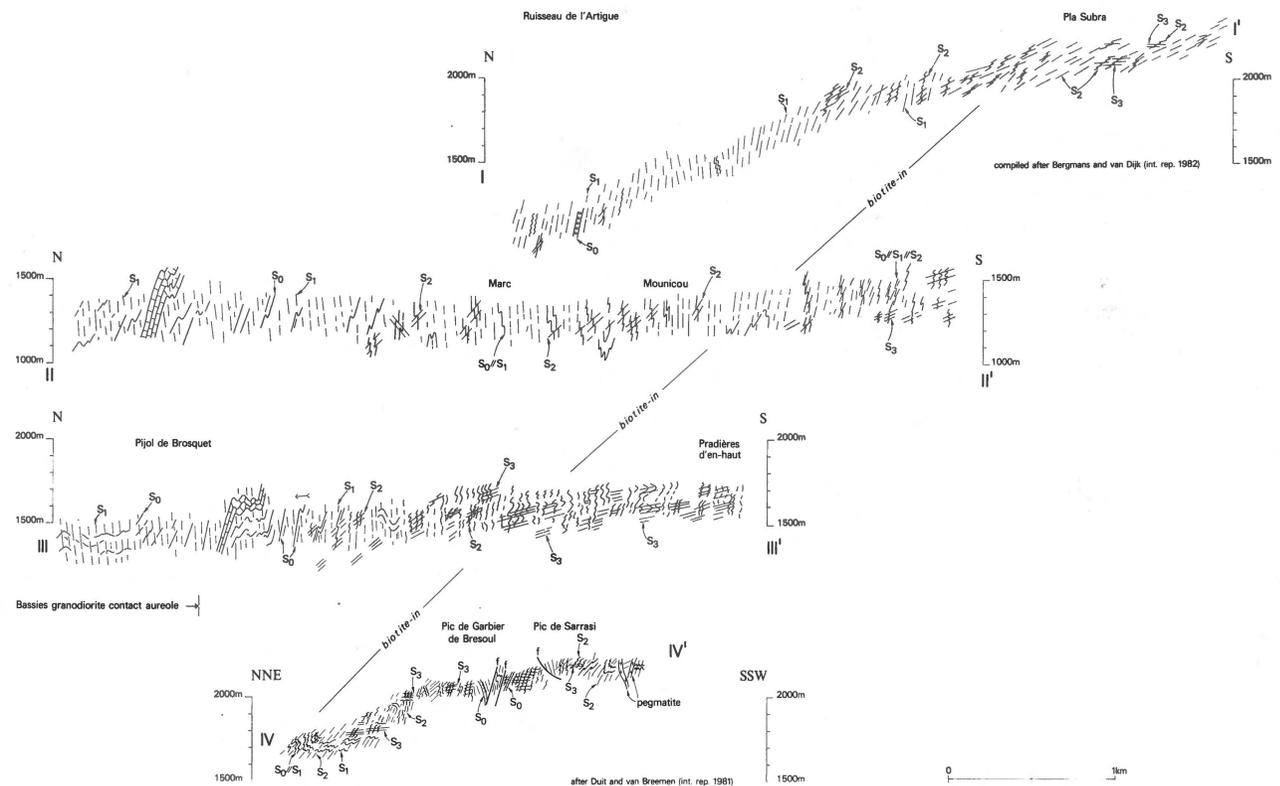


Fig. 5
Structural cross sections across the transition of the low-grade suprastructure and the amphibolite facies infrastructure. Location of sections is indicated on Fig. 2.

dome is a minor dome structure around Pla de Soulcem. The dome structures remarkably match the metamorphic pattern (Fig. 2).

In cross sections across the transition between the supra- and infra-structure (Fig. 4, 5) it appears that the structure becomes progressively more complicated with increasing metamorphic grade, and towards the structural domes. The principal foliation in the higher grade rocks is a combination of F_2 and F_3 structures, and not an F_1 structure as argued by LAPRE (1965) and OELE (1966).

Four structural cross sections are discussed below. The orientation data from these sections are presented in Fig. 6.

The cross section in the Mounicou Valley across the Pla de Soulcem thermal high (section AA', Figs. 2, 4, see also Fig. 5, section II) shows a single major fold generation (F_1) with a steep axial-plane cleavage developed in the low-grade metapelites. Folds of the bedding are generally tight and occur in dimensions of a few centimetres to hundreds of metres. Generally the folds are asymmetric with a long northern and a short southern limb. Way-up criteria indicate that the sequence is younging in a northerly direction. On a large scale the folds are considered as being parasitic to the Pallaresa anticlinorium (ZWART, 1979). In pelitic layers the folds possess a well-developed axial-plane slaty cleavage which, due to the tightness of the folds, is almost parallel to bedding. In more quartzitic beds, a spaced cleavage is more

inclined to bedding due to cleavage refraction. Frequently, a crenulation cleavage with steeply plunging fold axes deforms the slaty cleavage but is not associated with folds larger than decimetre size. They represent a late generation of structures, tentatively correlated with F_4 in the high-grade rocks.

A few hundred metres outside the biotite-in isograd a second generation of folds gradually becomes important. Concomitantly the fold style changes from open to tight and isoclinal, accompanied by the development of a pervasive axial-plane foliation (S_2) which dips steeply to the north. Earlier structures are commonly transposed parallel to S_2 , and only careful observation allows recognition of the transition from dominant F_1 structures to dominant F_2 structures (Fig. 4; see also Fig. 5, section II). Further towards the higher grade rocks the S_2 transposition foliation is folded in turn by another set of folds (F_3) with a gently north-dipping axial-plane foliation, S_3 . Complete transposition of the earlier foliation into the plane of S_3 occurs locally. This is obviously related to the composition of the rocks in that earlier foliations in quartzitic rocks have commonly been preserved, whereas in micaceous layers these foliations may be completely obliterated (see also Fig. 7d below). Mesoscopic F_3 folds are not present in every locality and are apparently developed in domains. The S_3 schistosity is by no means penetrative throughout the high-grade part of the section. In places the prominent flat-lying foliation can be shown to be an S_2 transposition foliation, rotated into a horizontal attitude as

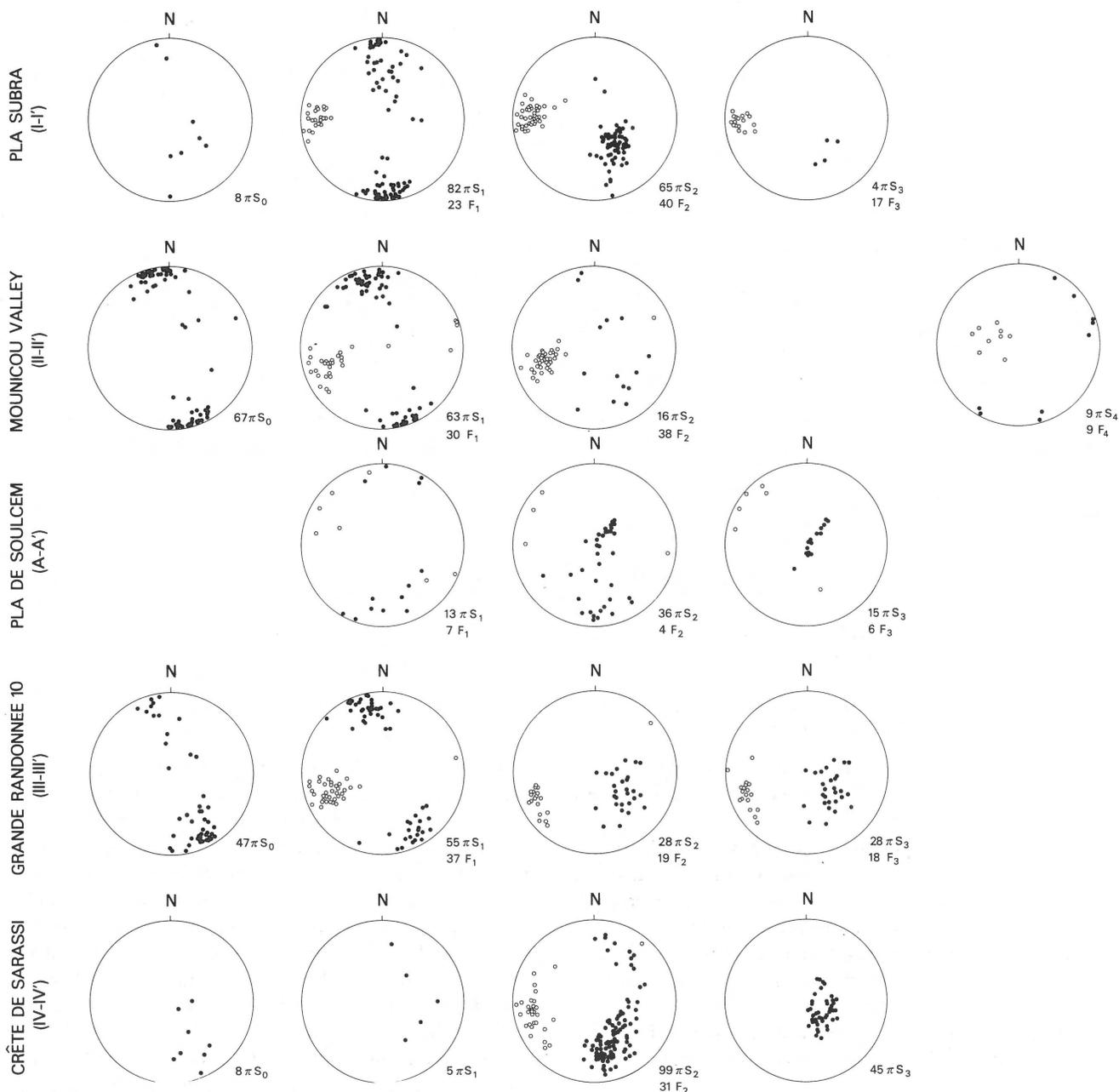


Fig. 6
Orientation data from the cross sections studied.

a result of non-penetrative F₃ deformation. As a consequence, detailed analysis of overprinting relations is needed to distinguish between domains characterized by flat-lying S₂ foliations and domains of flat-lying S₃ foliations.

Near the core of the Pla de Soulcem thermal high irregular masses of muscovite-granite and masses and veins of pegmatite transect the F₂ structures (LAPRÉ, 1965). The pegmatite veins in particular are folded by F₃, commonly with a steeply dipping enveloping surface. The bodies of muscovite granite are observed to cut the S₃ foliation indicating that their intrusion proceeded after the development of the F₃ folds.

A structural development similar to that in the Mounicou valley has been observed in three other cross sections (Fig. 5), one in the Western part of the area into the Soulcem thermal high (section I) and two across the northwestern part of the Aston thermal high (sections III and IV).

Cross section I (Fig. 5) shows a clear overprinting of the regionally steep S₁ cleavage by second generation crenulation cleavages with a moderate dip to the NW. Beyond the biotite-in isograd towards the south a flat-lying S₃ foliation is observed to be superimposed on the S₁ and S₂ cleavages.

Cross section II (Fig. 5) into the Aston thermal high shows major F₁ folds with a steep, locally incipient S₁ cleavage (Fig.

7a) which towards the south becomes gradually overprinted by metre-scale folds (F_2) with a north-dipping S_2 crenulation cleavage (Fig. 7b). These folds show a rather irregular distribution. Locally they are tight and have a transposition foliation parallel to their axial planes. In other outcrops, however, no axial-plane structures are observed. Further south, up to metre-scale recumbent folds (F_3), locally with a

pervasive transposition foliation (S_3), are prominent. Unfortunately, overprinting relationships between F_1 , F_2 and F_3 structures on outcrop scale are scarce. A comparison with the section of Fig. 4 (section II in Fig. 5) suggests correlation of the recumbent structures with the F_3 generation folds encountered near Mounicou. Outside the area of the cross section, near Étang d'Izourt, the prominent foliation shows gentle

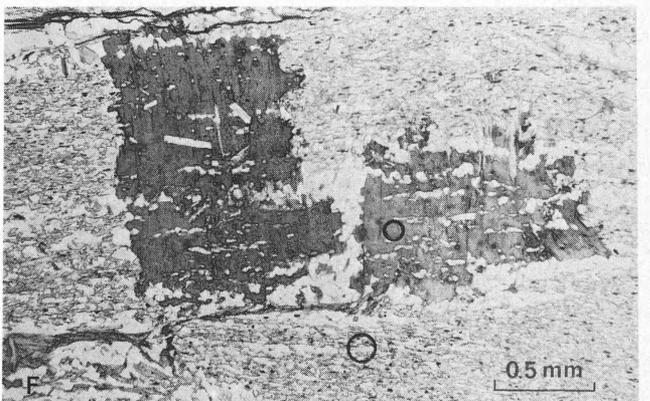
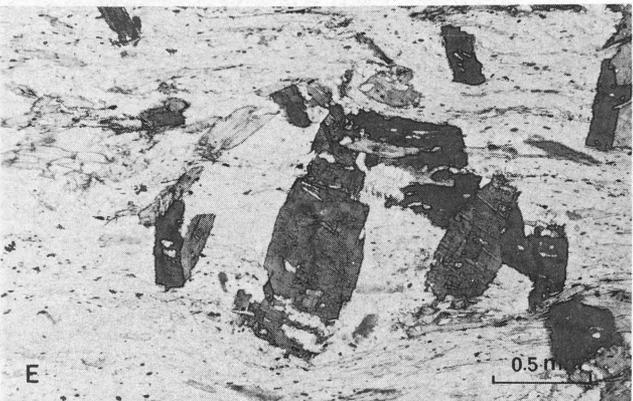
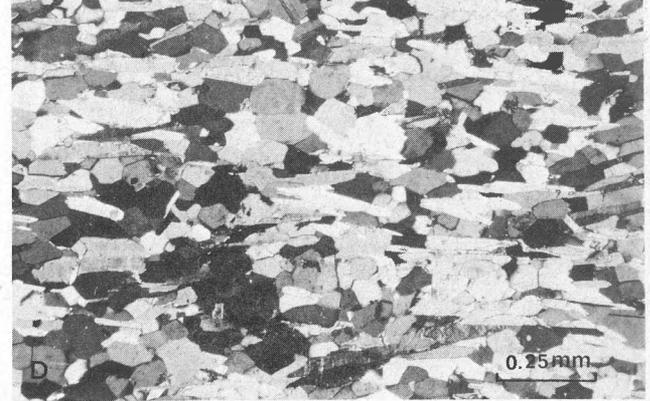
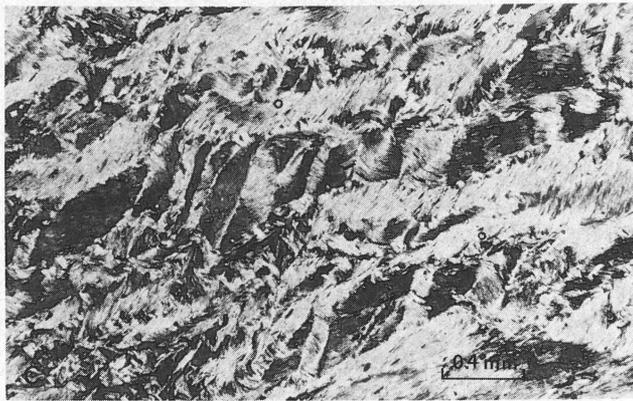
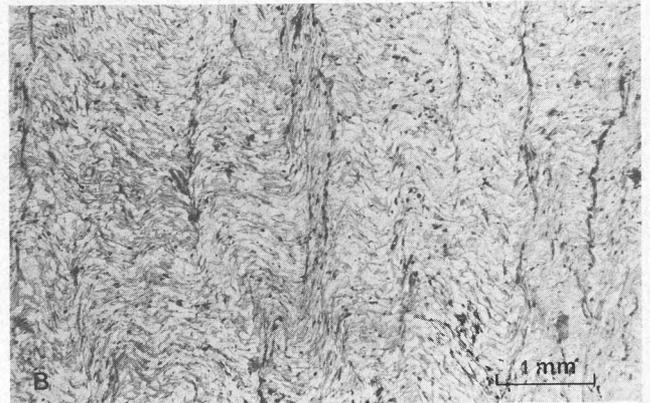
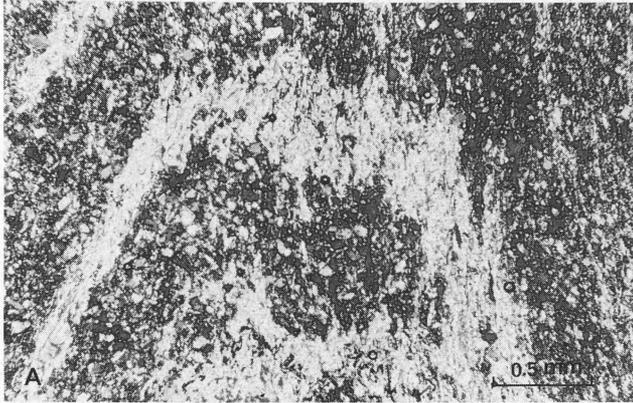


Fig. 7
Microstructures in the W Aston massif (I).

A. F_1 fold with incipient cleavage from section III. B. S_2 crenulation foliation from section III. C. F_3 crenulations superimposed on F_2 microfolds in section IV. D. Aspect of S_3 schistosity near Pla de Soulcem, section AA'. E. Post- S_2 porphyroblasts of biotite from section III. F. Post- S_1 porphyroblasts of biotite included in andalusite, section III.

dips to the west. The S_2 and S_3 foliations strike NS in that area, which contributes to the geometry of the half-dome parallel to the pattern of the metamorphic isograds.

Cross section IV into the Aston thermal high (Fig. 5) shows many overprinting relationships of F_1 and F_2 as well as F_2 and F_3 structures on both outcrop and microscopic scales (Fig. 7c)

which correlate well with the structures described above from the other cross sections.

Small-scale folds and crenulations associated with NW-SE trending large-scale open and very open folds with steep axial planes affect the S_3 foliation in the Pla de Soulcem area (Fig.

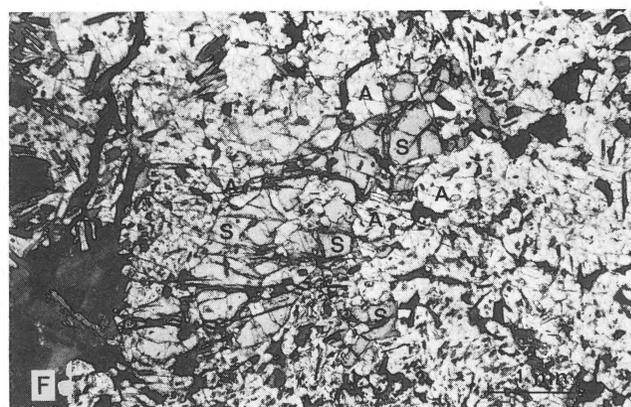
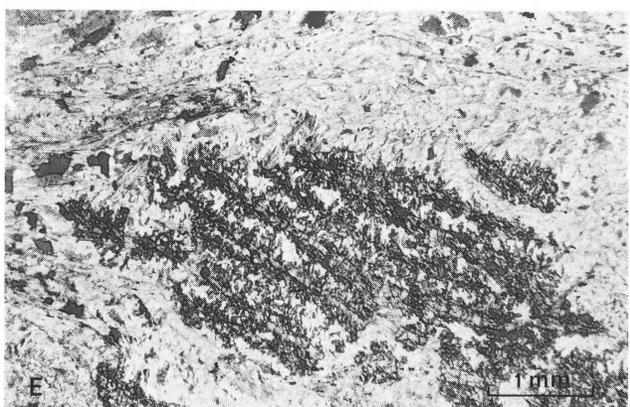
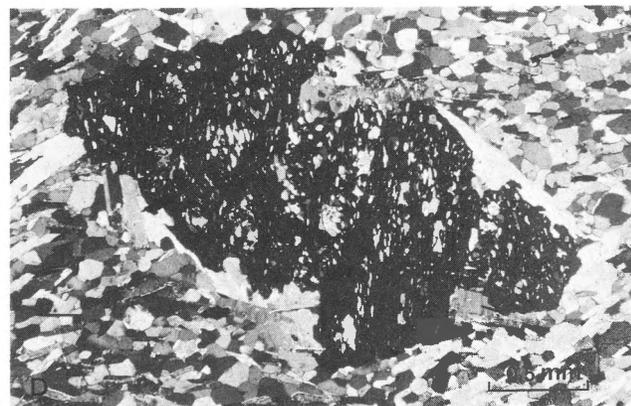
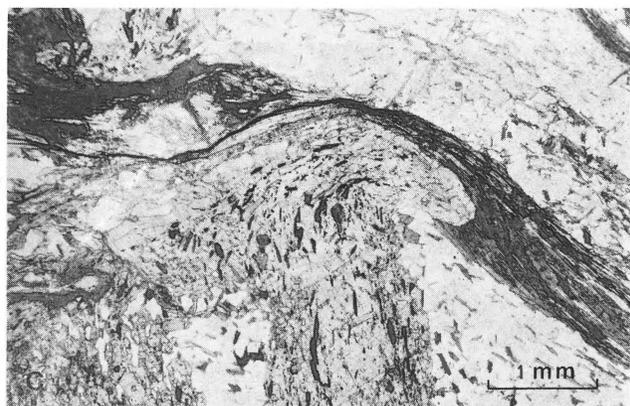
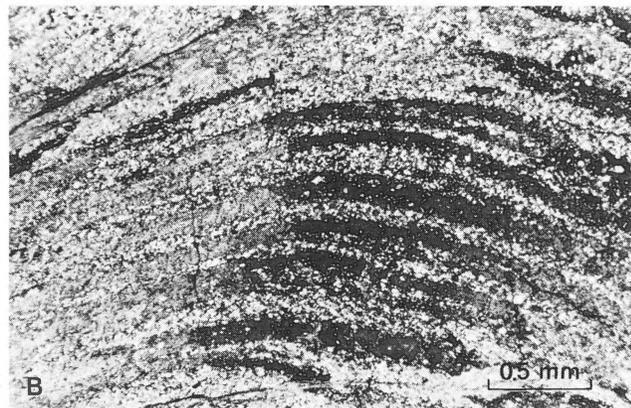
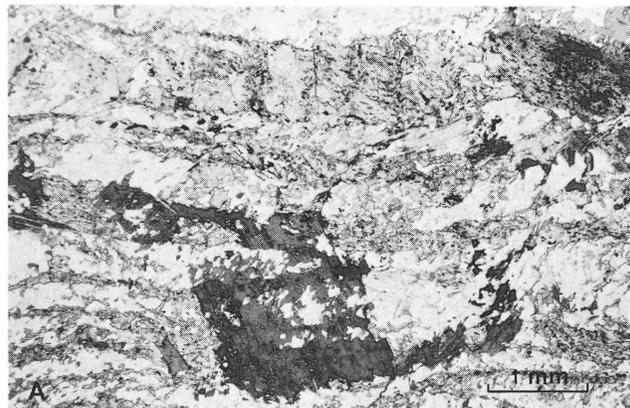


Fig. 8

Microstructures in the W Aston massif (II)

A. Post- S_2 porphyroblasts of biotite included in andalusite (Etang de Fourcat). B. Post- S_2 porphyroblast of cordierite bent by F_3 . (Note undulose extinction indicating bending of the crystal. Cordierite schist from section IV). C. Porphyroblast of andalusite with pre- S_3 core and syn-post S_3 rim (section AA', near Pla de Soulcem). D. Pre- S_3 porphyroblast of staurolite (turned into extinction) showing internal fabric representing S_2 crenulation cleavage (section AA', near Pla de Soulcem). E. Same phenomenon in staurolite from section I. F. Corroded relics of staurolite (S) in Andalusite (A) near Etang de Fourcat.

4). These folds represent a fourth generation of folds (F_4).

South of the Mérens Fault in the same valley (Fig. 4), E-W trending chevron folds with steep axial planes (S_5) can be shown to be superimposed on four earlier generations of folds. The interlimb angle of these F_5 folds decreases away from the fault, which suggests a genetic relationship with the fault. They possibly represent an Alpine overprint (McCAIG, 1983, pers. comm.)

RELATIONSHIPS BETWEEN DEFORMATION AND METAMORPHISM

A relative timing has been established of the metamorphic mineral growth and of the development of the deformational structure. In addition to previous studies (ZWART, 1965; 1979; LARRÉ, 1965) we investigated the relationships between inclusion patterns in metamorphic minerals and external fabric, in outcrops along the cross sections described above.

In the low-grade pelites with an S_1 foliation only, chlorite occurs in lensoid stacks with their long dimensions parallel to the S_1 cleavage, indicating that the F_1 structures developed under low-greenschist facies conditions.

Beyond the biotite-in isograd biotite occurs in porphyroblasts of up to a few millimetres in size. The S_1 foliation in the matrix is often observed to be continuous with inclusion trails in the porphyroblasts, indicating post- F_1 growth. In rocks with F_2 structures the biotites are often deformed by F_2 crenulations, and the S_2 differentiated crenulation cleavage is bent around these biotites (Fig. 7e). However, in many other rocks the S_2 foliation is continuous with the internal fabric in the biotite which indicates that porphyroblastesis occurred post- F_2 .

The biotite microstructures are often preserved within andalusite porphyroblasts (Figs. 7f, 8a). Andalusite occurs in crystals ranging from a few centimetres up to a few decimetres in size. They show at least two types of inclusion patterns: one which delineates an S_2 crenulation foliation, and the other, straight and continuous, with a strongly flattened external S_2 fabric. Both types of microstructure indicate post- S_2 growth of andalusite. In the rocks in the Aston thermal high the S_3 crenulations and S_3 cleavages bend around the andalusite porphyroblasts, indicating that andalusite developed before F_3 folding. However, in the Pla de Soulcem thermal high two phases of andalusite porphyroblastesis can be demonstrated. This is particularly well illustrated in a number of outcrops in which pre- F_3 andalusite with inclusion trails representing S_2 is rimmed by younger, post- F_3 andalusite (Fig. 8c).

Like andalusite, staurolite is commonly observed to have inclusion patterns representing an S_2 crenulation cleavage (Fig. 8d, e). The S_3 foliation generally bends around these porphyroblasts and in many thin sections the S_2 foliation, while being represented by straight and undeformed relics in the staurolite grains is crenulated and folded by F_3 in the surrounding matrix. These microstructures indicate that staurolite developed predominantly between F_2 and F_3 .

Cordierite, like andalusite and staurolite, often contains inclusion trails delineating relics of a differentiated S_2 crenulation cleavage. Fig. 8b shows a cordierite crystal with an S_2 internal fabric that is folded by younger (F_3) deformation. The undulose extinction of the cordierite porphyroblast indicates that in this case the crystal lattice was folded whereby the inclusion pattern deformed passively. Outside the porphyroblasts the S_2 foliation is commonly crenulated by F_3 . It is therefore concluded that cordierite developed between F_2 and F_3 . In the Soulcem section, cordierite locally replaces post- F_3 andalusite rims such as those shown in Fig. 8c, which indicates post- F_3 growth of cordierite in that area.

Sillimanite mostly occurs as fibrolite and is difficult to relate to foliation development. The mineral is observed to form in progressive mineral reactions corroding biotite as well as andalusite. A broadly post-andalusite, hence a post- F_2 to syn- and post- F_3 age can be concluded.

Other progressive mineral transformations occur, in particular from staurolite to andalusite (Fig. 8f), and from staurolite to colourless mica (see shimmer aggregates, rims of colourless mica surrounding staurolite in Fig. 8d). Pseudomorphs of colourless mica after staurolite occur frequently in the central part of the Pla de Soulcem thermal high. Like in other areas in the Pyrenees (ZWART, 1979), they invariably occur near and in the sillimanite zone. The S_3 foliation is commonly warped around these pseudomorphs and the constituting micas do not show evidence of deformation and recrystallization related to F_3 . Therefore, they are considered to represent a post- F_3 prograde metamorphic reaction. A similar progression has been described by GUIDOTTI (1968) from pelitic schists in Maine, U.S.A.

The described relationships of metamorphic mineral growth with the development of deformational structures are summarized in Fig. 9. These relationships indicate that the Pla de Soulcem thermal high reached its climax of regional

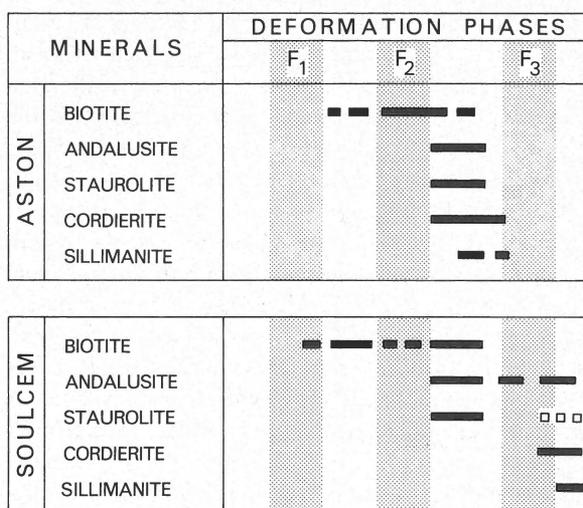


Fig. 9
Timing of porphyroblastesis relative to the development of the deformational structures, for the Aston thermal high, and the Pla de Soulcem thermal high.

metamorphism in a relatively late stage of the deformation history. The progressive mineral transformations suggest that during the development of this thermal high earlier Aston isograds became gradually overtaken by rising isotherms of the Pla de Soulcem thermal high, modifying previous staurolite-andalusite-biotite assemblages to produce rims of andalusite and rims of white mica around staurolite relics, as well as rims of young andalusite and/or cordierite and sillimanite around older andalusite.

The contact metamorphic minerals biotite, andalusite and cordierite that are related to the Bassies granodiorite postdate the F_1 structures (ZWART, 1979). A later (most probably F_4) deformation has affected these rocks and postdates the porphyroblastesis of these minerals. Due to the position of the granodiorite in the F_1 structural domain there are no data available to elucidate the time relationship of the contact metamorphic minerals with respect to F_2 and F_3 .

DISCUSSION

The data lead to the following conclusions with regard to the geometry of the structures and the distribution of regional metamorphism in the Western Aston Massif.

There is a relationship between the occurrence of particular fold-generations and the isograd pattern. F_2 and F_3 structures are confined to the higher grade areas, with F_2 structures predominantly along the outer margins of the thermal (and structural) domes and F_3 structures in the central parts (Figs. 4, 5). They are related to the development of the structural dome around the Aston thermal high, delineated by the change of the S_2 (and S_3) strike observed both in the Artières valley as well as west of the area (LAPRÉ, 1965; OELE, 1966). Our observations in the transition zone between the high- and low-grade area (infra- and suprastructure) suggest that F_3 involved vertical shortening, causing local folding of earlier foliations around the thermal high, as well as intense flattening and development of a flat-lying schistosity in the high grade rocks above the thermal high. It is evident that the development of this structure involved multiple deformation during Pyrenean-type LP-HT metamorphism.

At Pla de Soulcem a smaller dome-shaped structure is superimposed on the major half dome around the Aston-gneiss (Fig. 2). Granite and pegmatite intruded after F_2 and during and after F_3 at Pla de Soulcem as witnessed by the cross-cutting contacts with F_2 and F_3 foliations. This suggests a causal relationship between granite emplacement and dome formation, like in other areas where intruding granite plutons are known to have developed deformation aureoles (BRUN & PONS, 1981; RAMSAY, 1981; HOLDER, 1979; 1981). A similar explanation for the development of the Aston structural dome is less straightforward in view of the pre-Variscan emplacement age of the Aston granite-gneiss and its Variscan deformation and metamorphism. The gneiss will have played a major role in localizing deformational and metamorphic

patterns in the area. At least one Variscan foliation cuts across the contact between granite-gneiss and underlying migmatites. Later greenschist facies mylonite-zones which locally developed along the contact are therefore not considered of major importance with respect to early Variscan history. They may well be of Alpine age.

The following sequence of events can be inferred from the data presented in this paper.

The first deformational episode on a regional scale, F_1 , is held responsible for the development of the Pallaresa anticlinorium, which gently plunges to the west, and shows a steeply dipping E-W striking axial-plane cleavage, also in the area which now shows gently dipping foliations. The Aston granite gneiss is located in the core of this structure (Fig. 1). It is unknown whether any fabric was produced in this granite during F_1 . Metamorphic grade in this stage reached low greenschist facies in the metapelites.

During a second deformation episode a structural dome started to develop around the Aston granitic gneiss. Tight F_2 folds developed with moderately to steeply dipping axial planes and trends varying from ENE-WSW in the NE part of the area to NNE-SSW in the area west of the granitic gneiss. Metamorphic grade increased to lower amphibolite facies during F_2 .

In the high-grade area within the dome vertical shortening occurred during a third deformation episode, accentuating the dome structure. Metamorphic grade increased to upper amphibolite facies producing migmatites near the Aston granitic gneiss. Pegmatites and muscovite-granites intruded in particular near Pla de Soulcem where a small dome structure is superimposed on the larger half dome developed during F_2 .

Small-scale folds and crenulations with NW-SE (F_4) and E-W (F_5) steep axial planes postdate the peak of the Variscan metamorphism. F_4 folds deform the S_2 and S_3 foliations in large scale gentle folds (Fig. 4) accentuating the dome-shape in the Soulcem area. The F_5 structures related to the Mérens Fault seem to have had little effect on the overall structure, and may well be of alpine age (McCAIG, 1983, pers. comm.)

Earlier structural studies differ on various points from the present interpretation of the structural history of this area. The principle difference with earlier interpretations by ZWART (1965), LAPRÉ (1965) and OELE (1966) is the recognition in this study of the flat-lying structures as younger structures, superimposed on a steep early foliation. SOULA (1982) explained similar structures which he described as being produced during one single deformation episode (D_2 , which can be correlated with $F_1 + F_2$ in this paper) as a result of large scale diapiric updoming of both the granite gneiss masses as well as the granodiorite bodies during a period of N-S compression. A correlation of SOULA's results with the earlier studies by ZWART (1965), LAPRÉ (1965) and OELE (1966) and with the present study is summarized in Table I.

Table 1

ZWART (1965)		THIS PAPER		SOULA (1982)
LAPRÉ (1965)				
OELE (1966)				
-		-		D ₁
F ₁	—	F ₁]]	D ₂
F ₂	—	F ₂		D ₄
F ₃	—	F ₃]]	D ₃
F ₄	—	F ₄		
		F ₅		

Correlation of the present results with previous studies.

Current studies of the structural and metamorphic evolution in the Hospitalet massif, the Bosost area and the Lys-Caillaouas massif yield preliminary results which indicate a structural and metamorphic history reminiscent of that in the Aston massif.

In our opinion we have touched here upon a fundamental problem in structural geology. Many high-grade areas show shallowly dipping foliations irrespective of the presence of nappe structures and it becomes increasingly evident that such areas have undergone multiple deformation. However, it is only rarely possible to unravel the structural evolution in its progression from very low to high metamorphic grades and in this sense the relationships in the Pyrenees seem to be unique.

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