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Shear zones in the granodioritic massifs of the Central Pyrenees and the behaviour of these massifs during the Alpine orogenesis

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THE PALAEOZOIC formations of the Pyrenees were intruded by a series of granitic plutons during the Hercynian orogenesis. These granitic massifs have behaved in an interesting manner during the Alpine orogenesis.

The Bassiés granite (Pyrénées Ariégeoises) (Fig. 1) intruded argillaceous pre-Silurian formations. Its general shape is elliptical with map axial ratio of 2:1 and its long axis is oblique to the regional trend. Its north and south boundaries are the North-Pyrenean fault in the north and the Mérens fault in the south. These two large longitudinal faults extend for several kilometres and are marked by wide vertical zones of mylonite (about several hundred metres thick in some areas). They are cut by a set of transverse faults with mylonite zones (between 1 and 15 m thick) extending regionally and with a general NW–SE trend and steep dip. The faults affect not only the pluton but also the gneiss massifs like Aston and Hospitalet and neighbouring Mesozoic terrains such as the basin of Tarascon. The transverse faults become parallel to the longitudinal faults around them.

Away from the pluton, the main orientation of the principal Hercynian foliation is N 110° and vertical. Close to the massif, especially in the NW and SE borders, this orientation varies. These variations are related to zones of folding which are limited by the transverse mylonites. The same geometrical disposition can be seen in the Mesozoic Tarascon basin (Fig. 1).

Study of the large longitudinal fault mylonites (North-Pyrenean fault and particularly the Mérens fault) indicates: (i) a polyphase deformation (numerous examples of refolded folds) with strongly deformed and mylonitized rocks with regions of weaker deformation and mylonitization and occasional lenticular undeformed zones; and (ii) two types of mylonite assemblages: a quartz, biotite, muscovite, albite, microcline assemblage associated with a tectonic layering (layers of dominantly quartz alternating with dominantly phyllitic layers and feldspathic layers), this assemblage is of relatively high temperature; and a muscovite, siderite, sphene, epidote low temperature assemblage. The age of these faults has been the object of many discussions (Destombes & Raguin 1955, Autran & Guitard 1957, de Sitter & Zwart 1959, Raguin 1964, 1977, Zwart 1965, Arthaud *et al.* 1975, Aparicio *et al.* 1975, Soula 1979). They are thought to have formed during the third Hercynian deformation with a sinistral sense of horizontal shearing (Aparicio *et al.* 1975, Soula 1979) because of the geometric and genetic relationships between the faults and the third Hercynian folds and the similarities between the high temperature assemblage contemporaneous with the faulting and the metamorphic assemblage of the third Hercynian deformation. The faults were reactivated with the same shear sense during the Alpine orogenesis. The Alpine displacement along the Mérens fault, for example, was accompanied by the development of the low temperature assemblage and its slip can be calculated from the relative displacement of the late Hercynian metamorphic isograds around the Aston-Hospitalet massif (see the map of Zwart 1972).

The transverse fault mylonites cut the same formations as those affected by the longitudinal faults, but show a more homogeneous deformation and a low temperature mineral assemblage. Since the faults continue into Mesozoic formations and only show a low temperature assemblage, and are often geometrically related to folds of the Tarascon basin, we think that these transverse faults formed during the Alpine orogenesis.

All the minor structures suggest that the Bassiés massif is a competent yet deformable body within a more ductile matrix of surrounding Palaeozoic formations and that the whole was affected by a sinistral regional Alpine shearing. It is interesting to see the geometrical analogy between the regional structure and the structures developed in one of Ghosh & Ramberg's (1976, fig. 25) experiments. The regional shearing generated a rotation movement of the competent pluton producing disturbances localized near the massif (varying orientation of the Hercynian schistosity considered as a marker line) and with development of Alpine folds. Refolding of Hercynian folds with favourable orientations occurs in the area between the Bassiés massif and the Aston massif. The evolution of the major folds leads to the relatively late development of transverse faults and mylonites. The evidence of the genetic relationships between Alpine folds and mylonites appears in the Tarascon basin. It accounts for the fact that the regional sinistral shearing leads to transcurrent faulting in the same direction along the longitudinal faults but with a right hand displacement along the transverse faults.

The same evolution can be inferred from the map relationships in the Marimana massif and its country rocks (Hartevelt 1971, fig. 2), and particularly from the distribution of the Devonian limestones in the northeastern and southwestern parts of the pluton. The rota-

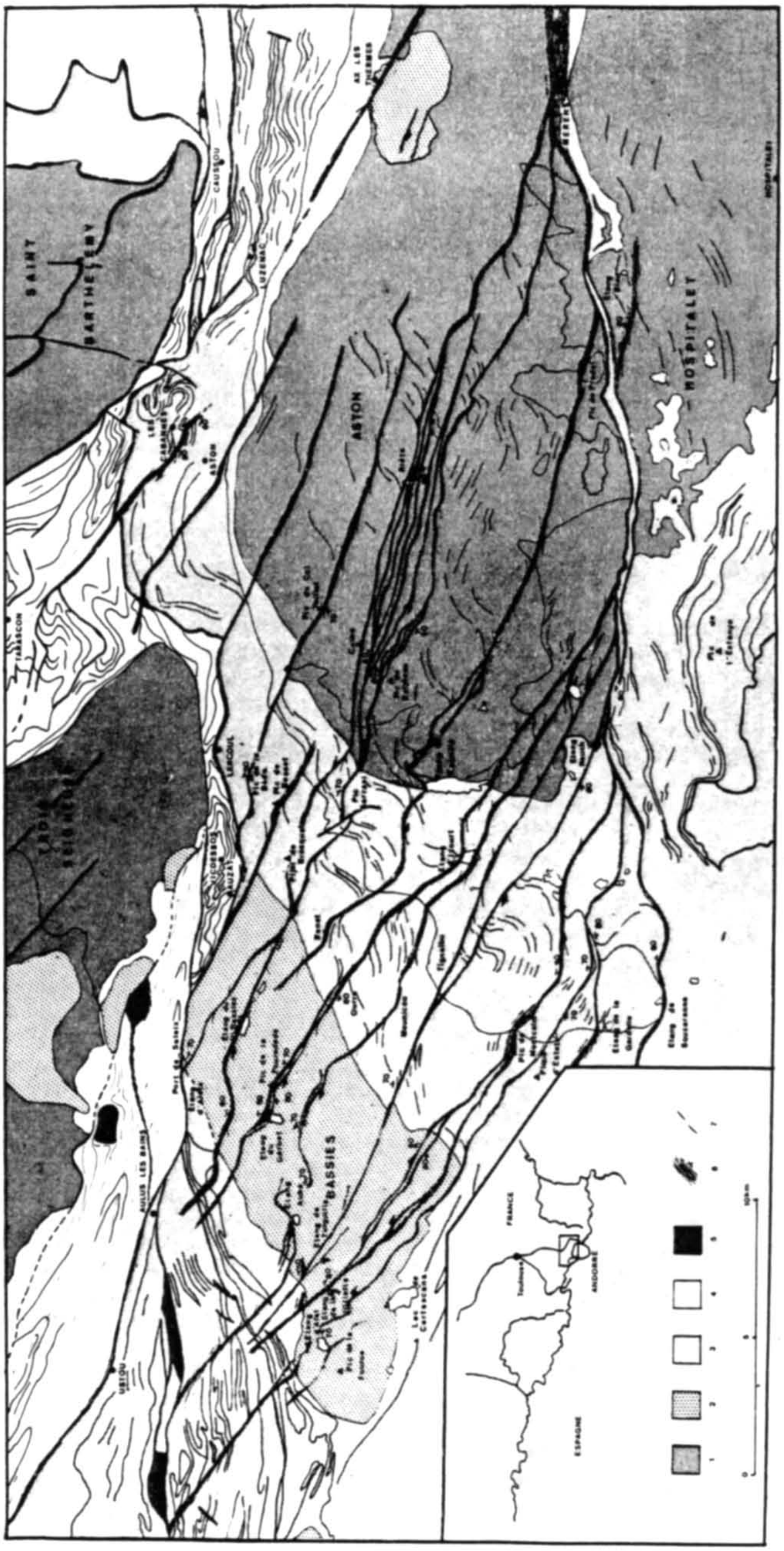

Fig. 1. Longitudinal and transverse faults in Ariege country: 1: gneiss; 2: granitic rock; 3: Paleozoic formations; 4: Mesozoic formations; 5: lherzolite, ophite; 6: mylonite zones; 7: schistosity plane.

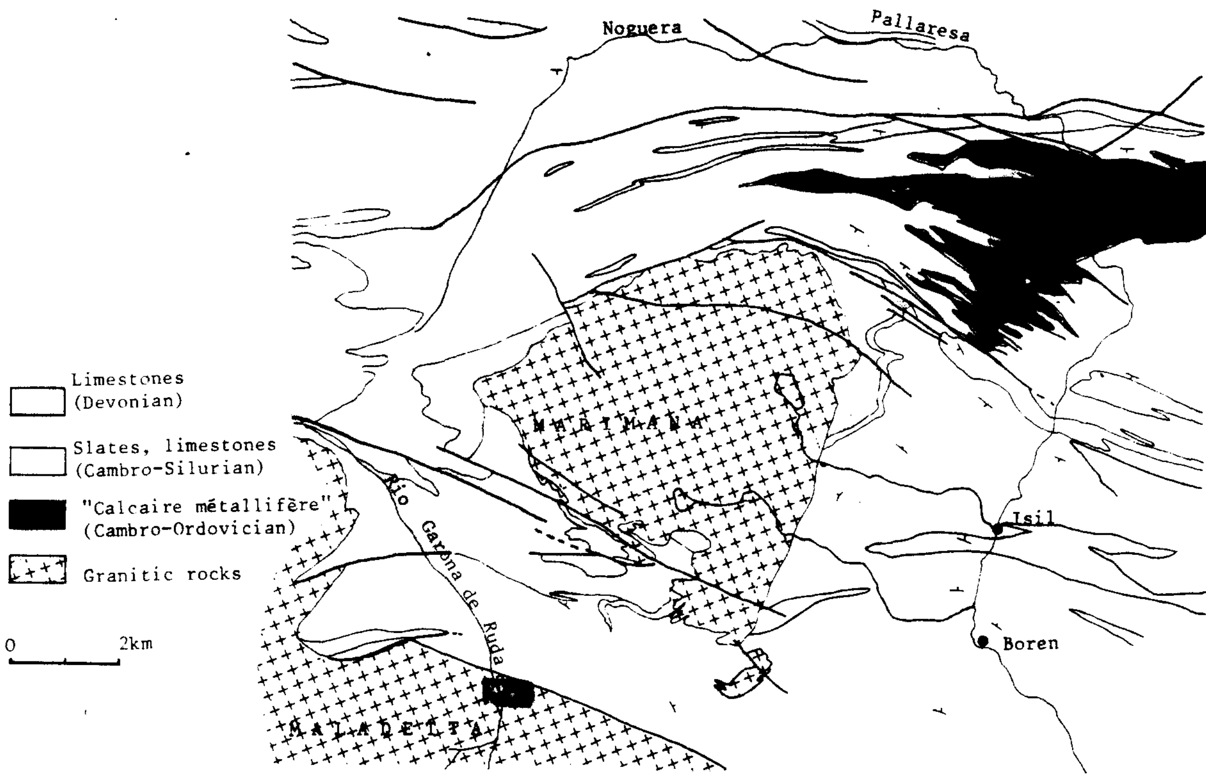

Fig. 2. Marimana massif (Hartevelt 1971).

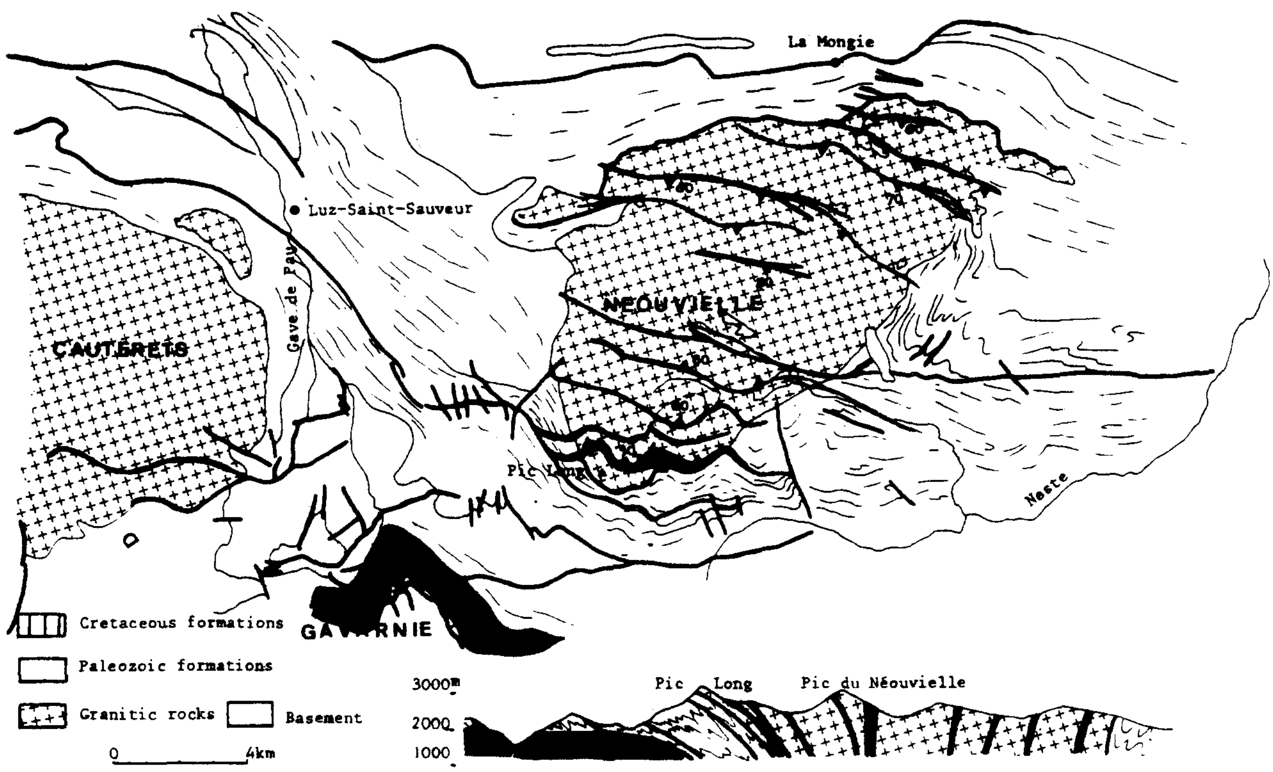

Fig. 3. Neouvielle massif.

tion here is greater than that in the Bassiés massif, because the axial ratio of the massif is near 1:1. Analogous geometry indicates sinistral shearing for the small Salau massif (between the Bassiés and the Marimaña massifs) which is intruded into limestone formations.

In the Néouvielle massif (Fig. 3) in the West of the chain, the overall geometrical lay-out is very similar to the massifs described above. In particular the massif is subdivided by a family of fan shaped mylonitized zones. The mylonites have a northern dip in the south, a southern dip in the north and are vertical in a central

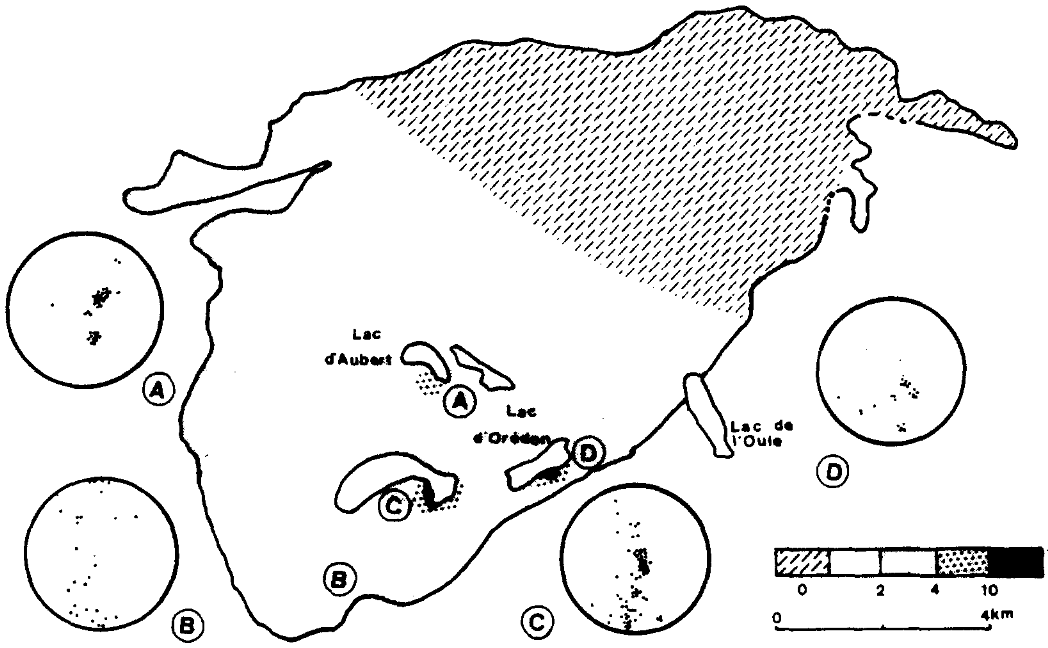

Fig. 4. Orientation and distribution density of shear zones in the Neouvielle massif. A: 45 measurements; B: 40 measurements; C: 80 measurements; D: 50 measurements.

part. They were active or were reactivated during the Alpine orogenesis. The mylonite zones cut diabase sills which have a post-Hercynian age and these sills cut the Gavarnie basement which has Hercynian structures unaffected by the Alpine deformation seen in the cover rocks.

The Néouvielle massif shows an important Alpine upwelling of the pluton and the development of late Alpine shear zones. The minimum value of the upwelling can be deduced from a cross section (Fig. 3). There is a difference of 2 km between the top of the Néouvielle massif and the top of the Gavarnie basement. These two areas were at the same altitude during the Middle Cretaceous, being cut by the same unconformity.

The latest shear zones are developed in the mylonites and in the granodioritic material. These are usually about 1 cm wide and a metre long. In the unmylonitized material, single and conjugate shear zones are seen. Their general orientation is E–W and horizontal. In the mylonite zones, the shear zones are very narrow and often only one of the conjugate planes is developed. Where the deformation is ductile, the shear zone displacement profiles can be either symmetrical or asymmetrical. The shear zones in the central area of the massif and the top of the Gavarnie basement. These two areas were at the same altitude during the Middle Cretaceous, being cut by the same unconformity.

The distribution density of the shear zones in the massif is heterogeneous (Fig. 4): shear zones are entirely absent in the northern part, relatively abundant in the central part and present in the southern border zone. Displacement measurements show a movement towards the south for those shear zones with a northern dip. On the conjugate zones, the measured displacements are systematically greater in the north dipping shear zones than in the south dipping zones.

The structural position of the Néouvielle massif is important, since the pluton is situated directly north of the large Gavarnie nappe (Lamouroux *et al.* in press). The upwelling of the massif created the slope necessary for the gravitational gliding of the overlying Mesozoic strata (Déramond 1979).

The three massifs (Bassiés, Marimana, Salau) are situated in a zone which is limited by great longitudinal faults, and the distinctive field relations of the massifs provide a key to the regional structure. They have been affected by a regional sinistral shearing which leads to rotation with development of new folds and/or refolding of Hercynian folds and to the formation of late mylonitic zones. This same evolution and behaviour has probably affected other massifs situated in the same geological context, for example, the Montlouis and Quérigut massifs. Both massifs show, on the map, an oblique orientation with respect to the general regional structure (orientation which is compatible with an Alpine sinistral shearing) and are affected by numerous mylonitic zones (for the Montlouis massif personal information by Autran; for the Quérigut massif see Leterrier 1972).

Other massifs (Néouvielle but also Cauterets, Lys or Maladetta) show, in addition, an important upwelling and the late development of shear zones. The position of these plutons, in the root zone of the large nappe structure of the Southern part of the Pyrenees, might explain their specific structures.

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