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The role of Hercynian granites in the deformation and metamorphism of Brioverian and Palaeozoic rocks of Central Brittany

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SUMMARY: The late Proterozoic rocks of Central Brittany, represented essentially by Upper Brioverian sediments, are considered to be a late to post-tectonic molasse to the Cadomian chain. The poly-orogenic character (Cadomian and Hercynian) of the deformation structures affecting these rocks is noted from the Baie de Douarnenez to the Rennes region. However, the main syn-metamorphic deformation event is clearly of Hercynian age. Furthermore, we show that this event and the associated metamorphism are directly related to the emplacement of the Hercynian leucogranites. The syntectonic nature of the leucogranites, with respect to the deformation of their envelope, is therefore affirmed and the concept of a 'Brioverian basement', in the mechanical sense of the term and contrasted with a 'Palaeozoic cover', must be abandoned.

The greater part of Central Brittany (Fig. 1) comprises a group of sedimentary rocks, discordantly overlain by rocks of Lower Palaeozoic age (Bolelli 1944; Chauvel & Philipott 1960; Le Corre & Chauvel 1970), which Barrois (1895, 1899) named the Brioverian. The Brioverian, which has long been the subject of lively debate, especially with regard to its age and the existence of a Lower Palaeozoic unconformity, is now considered to represent a type Upper Proterozoic stratigraphic sequence (Cogné 1962, 1972).

From the structural point of view, the diverse hypotheses postulated for Central Brittany would appear to be closely tied to each worker's interpretation of the relationship of the Palaeozoic rocks to those of the Brioverian. Barrois, having rejected an unconformable relationship, considered all the deformation

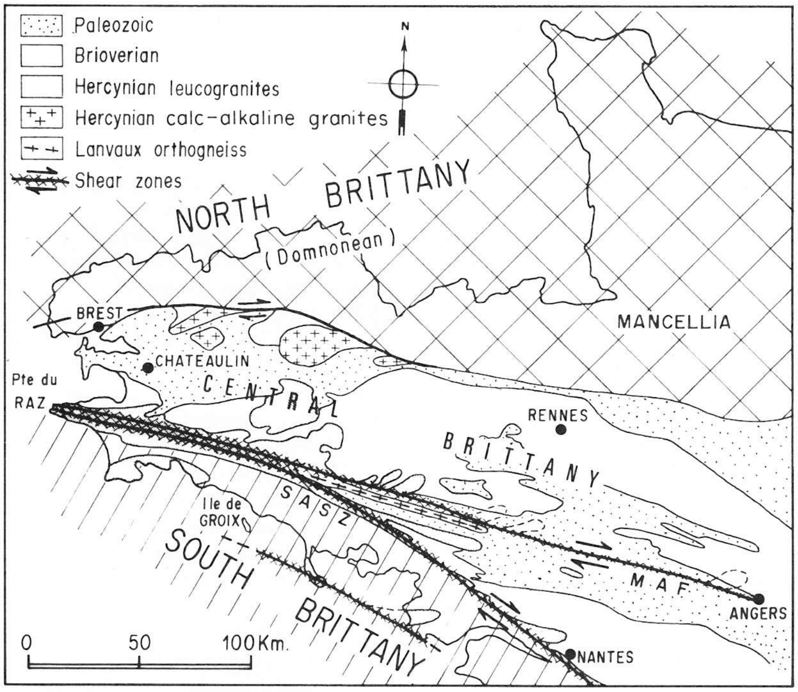

FIG. 1. Generalized map to locate Central Brittany in the context of Massif Armoricain (MAF: Malestroit–Angers fault; SASZ: South Armorican Shear Zone).

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of the Brioverian to be of Hercynian age. This led him to illustrate (Barrois & Pruvost 1929) the folds in the Brioverian as being concordant with those in the overlying Palaeozoic rocks. Pruvost (1959) finally accepted the existence of an unconformity at the base of the Palaeozoic succession in Central Brittany. Furthermore, he proposed that a deformation event which pre-dated the Arenig transgression was no more than a late, mild echo (the 'Vendian' phase) of the important Precambrian folding known to have occurred in Normandy. Later, when firm proof of the widespread nature of the unconformity had accumulated, the major part of the deformation of the Central Brittany Brioverian was attributed to the Precambrian Cadomian orogeny (Cogné 1962, 1972).

Henceforth, in terms of Hercynian events, the Brioverian was generally considered to form a relatively rigid basement to a Palaeozoic cover sequence. Some minor Hercynian reworking was proposed, either locally in the vicinity of the unconformity '*accordance tectonique*', Kerforne (1919), Milon (1928); '*discordance tectonisée*', Bolelli (1951), Chauvel & Philippot (1957), or within the Brioverian by tightening of Cadomian folds (Klein 1957), or within the Brioverian by tightening of Cadomian folds (Klein 1957) and/or slip along pre-existing planar structures (Bradshaw *et al.* 1967). The notion of a major Hercynian deformation event within the Brioverian, with folding and cleavage formation superposed upon older Cadomain structures, was initially proposed for the Crozon Peninsula (Finistére) by Le Corre & Chauvel (1970). This idea was later taken up and developed for the Baie de Douarnenez (Darboux 1974; Darboux *et al.* 1975) and the Rennes (Le Corre 1977) and Gourin (Hanmer 1978) areas.

In this paper, we present recently acquired data and show that the major tectonic and metamorphic evolution of the Brioverian of Central Brittany is of Hercynian age and is closely related to the emplacement of Carboniferous granites.

Geological situation of Central Brittany

Central Brittany is bounded to the N by the Mancellian and Domnonean domains (Cogné 1971) (see Fig. 1), which are composed essentially of Precambrian granitic and metamorphic rocks and which remained relatively rigid during the Hercynian events. The southern limit is formed by the South Armorican Shear Zone and the Malestroit–Angers fault zone (Fig. 1). Defined thus, Central Brittany is mainly composed of unmetamorphosed to epimetamorphic sediments of Brioverian and Palaeozoic age, cut locally by intrusive Hercynian granites. The Palaeozoic sequence, unconformably overlying the Brioverian, generally commences with Lower Ordovician formations at the base (red beds or Armorican quartzite) and passes more or less continuously up into Carboniferous sediments at the top. The Brioverian sequence (cf. Darboux 1974; Le Corre 1977) in the main comprises clastic land-derived sediments (conglomerates, often immature sandstones, well-laminated siltstones) with rare calcareous mud horizons. Given the somewhat piecemeal nature of the available detailed information and despite attempts to prove the contrary (cf. Pruvost 1959), it would appear both difficult and premature to define valid stratigraphic divisions within this sequence. The Brioverian of Central Brittany seems to correspond, on the whole, to sedimentation accompanying the rapid denudation and levelling of nearby continental highlands since it frequently contains rock fragments (e.g. black cherts and mica schists) apparently derived from an older Brioverian sequence identified in N Brittany. In essence, the Brioverian of Central Brittany is a coherent unit corresponding to the upper part of a more complete Brioverian succession, the lower part of which constituted a chain of Cadomian highlands.

The Brioverian and Palaeozoic sediments of Central Brittany are intruded by Hercynian granites (cf. Cogné 1971; Vidal 1976) which are more voluminous at outcrop as one passes westwards. These granites correspond in part to a belt of biotite-muscovite leucogranites, which outcrop along the entire length of the South Armorican Shear Zone, and in part to a suite of calc-alkaline granites and granodiorites of irregular distribution but which are especially common in the NW of the region (Fig. 1). Whereas the leucogranites are spatially associated with a ductile shear zone, the calc-alkaline granites and granodiorites are aligned along a high level fault system which passes N and E of Brest (Fig. 1). The latter granitoid rocks are probably coeval with the leucogranites but may represent higher level instrusions.

Deformation structures in both the Brioverian and Palaeozoic rocks follow a roughly E–W trend. The main structure comprises a set of upright horizontal folds with an associated axial-planar cleavage. In detail, the cleavage strikes more or less E–W in the eastern sector, turning to ENE in the W (Fig. 2). A subhorizontal mineral alignment lineation is generally developed parallel to the fold axes. Measurement of conglomerate pebbles in the Brioverian (Le Théoff 1977) and of deformed fossils and sedimentary features in the Palaeozoic rocks (Le Corre 1968, 1969*a*, 1978*b*) show this to be an extension lineation. A crenulation of variable intensity whose axes are always parallel to this extension lineation is often seen to deform the cleavage. While the extension lineation is always subhorizontal, the intersection lineation of bedding on cleavage surfaces within Brioverian sediments is dispersed along an E–W great circle (Fig. 3). Such a dispersal is not found in the Palaeozoic rocks. This suggests the existence of pre-cleavage folding of the

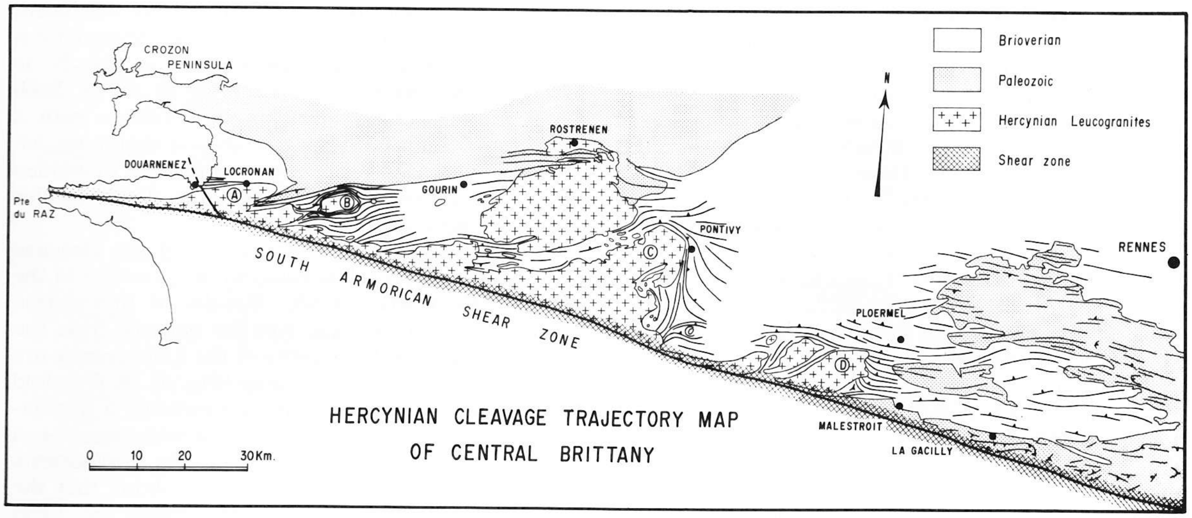

FIG. 2. Cleavage trajectory map (Hercynian regional cleavage) in the Brioverian and Palaeozoic rocks of Central Brittany. Ticks indicate dip of cleavage planes of <60°. Relationship of cleavage trajectories to Hercynian granites lying along the South Armorican Shear Zone and interpretation are discussed in the text. A: Locronan massif; B: Le Merdy massif; C: Pontivy massif; D: Lizio (= Guehenno = La Villeder) massif.

Brioverian bedding surfaces which was not accompanied by cleavage formation (Le Corre 1977). Indeed, such folds are visible in the northern Baie de Douarnenez (Darboux *et al.* 1975).

Age of the cleavage-associated deformation in the Brioverian

Since the cleavage in the Palaeozoic rocks affects sediments as young as Carboniferous in age, it can be attributed to a Hercynian deformation event. However, the age of the cleavage in the Brioverian can be examined using several lines of evidence.

A detailed study of the unconformity indicates the existence of a pre-Palaeozoic folding event. Furthermore, comparison of structures on either side of the unconformity (Le Corre & Chauvel 1970; Darboux *et al.* 1975; Le Corre 1977) shows that certain folds in the Brioverian in the immediate vicinity of the contact represent minor folds on the limbs of major structures affecting the adjacent Palaeozoic rocks and therefore cannot be of Cadomian age. In the eastern sector, conglomerates at the base of the Palaeozoic pile ('Poudingue de Montfort') contain pebbles of Brioverian material. Some facies are exclusively comprised of pebbles of Brioverian siltstone in a coarse, silty matrix. The Hercynian cleavage of the matrix continues into the previously uncleaved pebbles irrespective of pebble orientation (Le Corre 1977). This suggests that any deformation in the Brioverian, prior to the main cleavage-forming event, occurred above the cleavage front. Comparison of finite strain across the unconformity (Le Théoff 1977; Le Corre 1978*b*) shows that the finite strain ellipsoids are similarly oriented in the Brioverian and Palaeozoic rocks, particularly with respect to the horizontal principal extension direction.

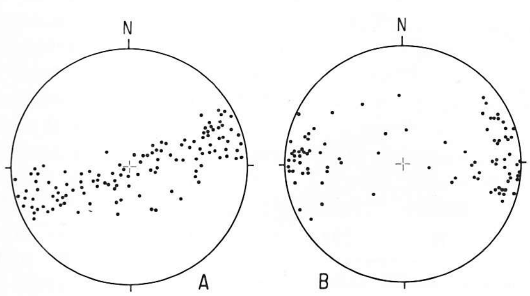

FIG. 3. Sterogram plots of bedding/cleavage intersection in the Brioverian. A: Baie de Douarnenez (after Darboux 1974); B: the Rennes area (after Le Corre 1977).

Other evidence is presented in the form of a cleavage map (Fig. 2). From the map it will be seen that, in the vicinity of the Brioverian–Palaeozoic contact, the cleavage in the Brioverian continues without deflection into that of the Palaeozoic rocks. In the eastern sector, this cleavage is clearly seen to be axial planar to the major, mapping-scale synclines within which the Palaeozoic sediments are preserved. In the vicinity of the unconformity, therefore, the foregoing evidence suggests that the cleavage associated deformation in the Brioverian and Palaeozoic rocks is one and the same and of Hercynian age. To the SW, however, in the absence of Palaeozoic sediments we turn to other evidence. Here, the generally ENE-oriented cleavage more or less contours the Hercynian granites (Le Merdy, Pontivy, Lizio) but locally is truncated by them (Rostrenen) (Hanmer & Vigneresse, pers. comm.; Berthé, pers. comm.). In terms of relative timing of granite emplacement and envelope deformation, this relationship is equivocal. However, in the Brioverian rocks about the Le Merdy, Pontivy and Lizio granites the cleavage (schistosity) is arranged in triangular patterns or cleavage triple points (C.T.P.). Recent work by Brun and collaborators (Ledru & Brun 1977; Brun *et al.* 1976; Brun & Pons 1979; Brun, pers. comm.) shows that C.T.P.'s result from the interference of two strain fields; a local radial shortening component in the immediate vicinity of the intruding and expanding granite, producing cleavage elements parallel to the granite boundary, and a regional shortening component, here N–S, which produces the cleavage elements at a tangent to the granite outline. It is emphasized that this analysis concerns a unique cleavage-forming event resulting in a single cleavage. From Fig. 2, therefore, the cleavage in the south-western Brioverian formed synchronously with the emplacement of the late Hercynian granites.

Furthermore, cleavage dip varies systematically. While to the W it remains more or less vertical, in the eastern sector the cleavage is vertical to the N and becomes progressively more shallow and northward dipping as one passes southwards. Associated folds pass from upright and symmetrical in the N to asymmetrical and southward-verging in the S. Such variation in cleavage attitude is compatible with a syntectonic, radially-expanding granite diapir model. One may reasonably suspect the presence of hidden Hercynian granite bodies at shallow depth in this south-eastern region.

Besides its orientation, the nature of the cleavage also shows a direct relationship to the presence of the granites (Le Corre 1978*b*). Results of thin-section determination of cleavage type for material from the Ploërmel region in the vicinity of the Lizio granite are presented in the form of a map (Fig. 4). A four-fold classification of cleavage type representing a qualitative increase in deformation intensity has been adopted (see Le Corre 1978*b*, 1979). Fig. 4 indicates a N–S gradient and, more particularly, shows that the cleavage intensity contours wrap around the Lizio granite. The syntectonic emplacement of the granites, therefore, has not only introduced a mechanical anomaly into the regional picture, as shown by the cleavage map, but also a thermal anomaly which facilitated the cleavage-associated deformation processes. The leucogranites themselves carry a variably-developed foliation and lineation subparallel to the regional

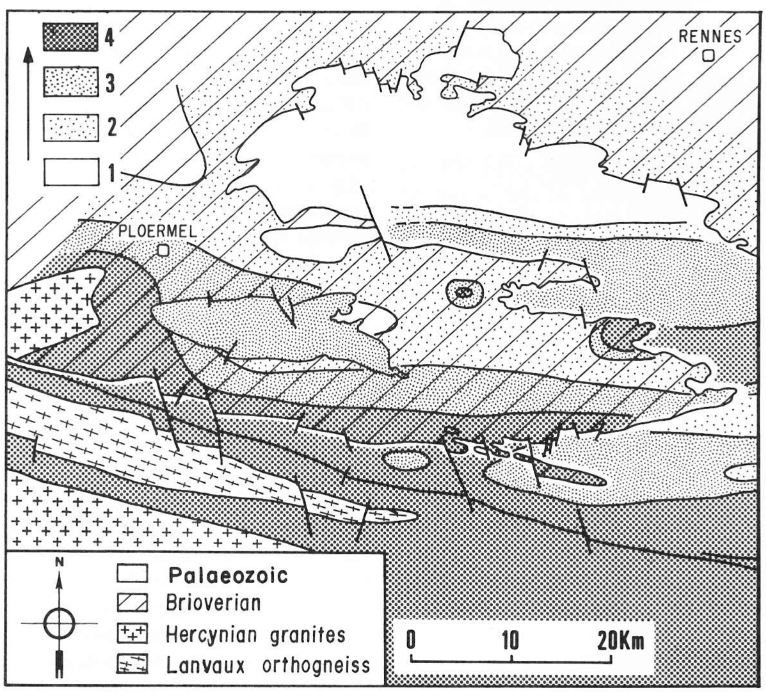

FIG. 4. Map of cleavage-types in Brioverian pelitic rocks and Palaeozoic rocks (Schistes d'Angers) of the Rennes area. 1: Fracture cleavage; 2: initiation of cleavage associated recrystallization; 3: slaty cleavage with residual microlithons; 4: penetrative slaty cleavage. Note the clear passage from 1 to 4 as one approaches the Lizio granite massif (Ploermel area) and the Malestroit–Angers fault (MAF).

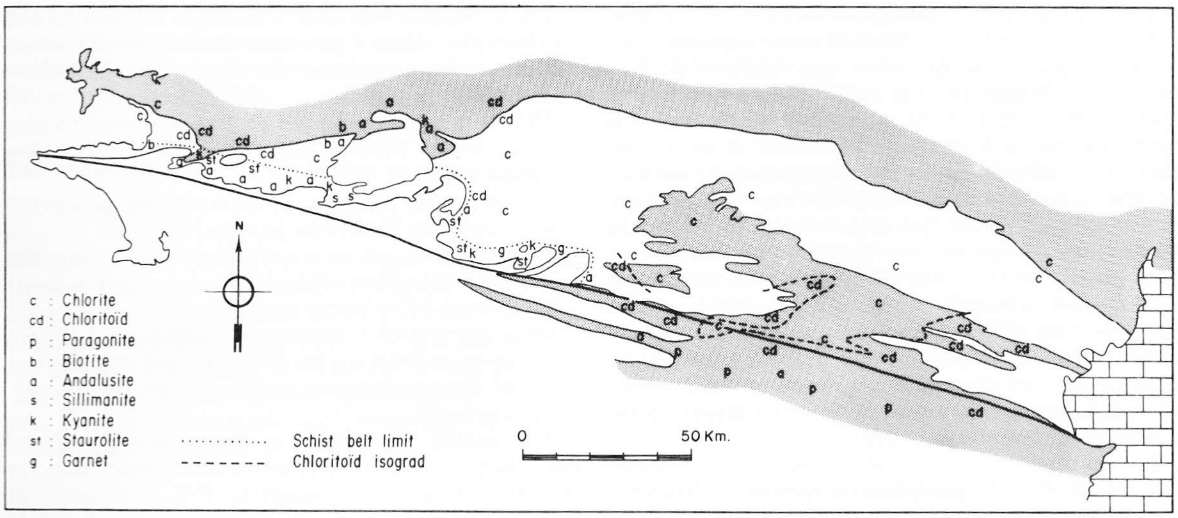

FIG. 5. Distribution of metamorphic index phases in the Brioverian (white) and Palaeozoic (stippled) metasediments of Central Brittany. The area is limited to the E by Mesozoic limestones. Discussed and interpreted in the text.

orientation of cleavage and mineral lineation in the country rocks. This structure is, however, best developed adjacent to the S Armorican Shear Zone where it passes into mylonites (e.g. Cogné 1957). Within the main body of the Le Merdy, Pontivy and Lizio granites, however, a mineral alignment fabric is only mildly developed and may indeed be absent, even at the contacts with the envelope rocks.

The metamorphism in Central Brittany

Metamorphically (Figs 5 and 6), Central Brittany has long been considered in terms of two domains: a south-western zone of micaschists and a larger zone of slaty to uncleaved rocks which, until relatively recently, were not considered to have undergone metamorphism (e.g. Barrois 1934; Cogné 1957). Since the recognition of the widespread occurrence of chloritoid in the latter domain (Barrois 1884; Boudier & Nicolas 1969; Le Corre 1969*b*), metamorphism in the Central Brittany sediments has been the subject of a number of field and laboratory studies (Barrois 1934; Bradshaw *et al.* 1967; Chauvel 1971, 1973; Darboux *et al.* 1975; Hameurt 1961; Hanmer 1977; Hanmer & Vigneresse 1980; Le Corre 1969*a*, 1975, 1978*a*, *b*; Le Corre & Le Théoff 1977; Plaine 1976; Quété 1975; Sagon 1965).

The slate-grade rocks, irrespective of age, in the eastern and north-western parts of the region, are characterized by a monotonous chlorite-muscovite-albite assemblage. In addition, chloritoid is locally abundant in rocks of suitable bulk chemical composition in the N of the region, but more especially along the length of the southern limit. Stilpnomelane occurs in restricted outcrops of sub-ore to ore grade iron-rich beds of Lower Ordovician age. To the W of Malestroit these southerly, chloritoid-bearing assemblages pass progressively southwards into a belt of micaschists, developed along the northern flank of the Raz–Malestroit granites. The width of the schist belt is highly variable, extending up to 10 km from the mapped granite contact between Locronan and Le Faouet, compared to half a kilometre or so in the vicinity of Pontivy. Within the schist belt, a metamorphic zonation of successive mineral assemblages is developed parallel to the limits of granite outcrop, in general passing from distal biotite assemblages to

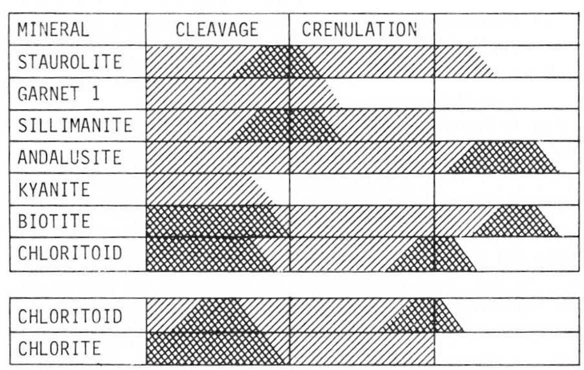

FIG. 6. Schematized deformation metamorphic mineral growth relationships in the Central Brittany Brioverian and Palaeozoic metasediments in the schist belt (upper) and in the eastern sector (lower).

andalusite-staurolite bearing ones closer to the granites. The order of appearance of index minerals is not constant throughout the schist belt (Hanmer & Vigneresse 1980) and this may reflect lateral variation of PTX conditions (e.g. of fO_2; Ganguly 1968; Richardson 1968; Grieve & Fawcett 1974; James *et al.* 1976). Locally, andalusite is absent in the immediate vicinity of the granites where sillimanite is the Al_2SiO_5 polymorph. Of prime importance are the scattered occurrences of kyanite in pegmatitic and quartz segregations within the schist belt between Locronan and La Villeder (Barrois 1934; Cogné 1957, 1971; Barrière *et al.* 1973). Almandine garnet and cordierite are largely absent; garnet only occurs in pelitic rocks in the vicinity of the Guehenno massif and in calcareous quartzites adjacent to the Rostrenen granite (Barrois 1884; Pruvost *et al.* 1945).

From microtextural and field observation the relationship of metamorphic mineral growth to deformation structures (schistosity and crenulation) have been deduced and are given in Fig. 6 (Hanmer 1979; Hanmer & Vigneresse 1980). Briefly, an andalusite-kyanite-sillimanite-staurolite-biotite assemblage accompanied cleavage formation adjacent to the leucogranite outcrop (see also Fig. 5). Andalusite-sillimanite-staurolite-biotite assemblages continued to grow during the crenulation formation. Post-crenulation, an andalusite-biotite assemblage formed at the expense of staurolite within the staurolite-bearing schists, implying a sharp decrease in metamorphic pressure at roughly constant temperature (e.g. Winkler 1976, fig. 14-1).

The mica-schist belt attenuates at the mapping scale to the E of Malestroit. Even the southern part of this eastern sector is dominated by the chlorite-muscovite-albite ± chloritoid assemblage (Le Corre 1969*b*, 1975, 1978*a*). A rough metamorphic zonation generally parallel to the direction of the Malestroit–Angers fault zone is marked by (Fig. 5):

(a) Southward increase in the amount of chlorite, and
(b) confinement of paragonite and chloritoid to the S of the sector.

Furthermore, regional studies of crystallinity index (Weaver 1960) recently undertaken throughout the area (Le Corre 1975; Le Corre & Le Théoff 1977; Quété 1975; Plaine 1976) indicate a clear increase in the degree of metamorphic crystallization of illite-phengite-muscovite-type phyllosilicates in the Ordovician pelites (see also Sagon & Dunoyer de Segonzac 1972 for the SE flank of the Chateaulin syncline). Le Corre (1975, 1978*a*,*b*) demonstrated that the crystallinity index contours are parallel to the chloritoid isograd. Moreover, the local ENE-oriented La Gacilly bulge in the chloritoid isograd is reflected by the crystallinity index contours. This metamorphic anomaly coincides with a gravity low taken to represnt a buried ENE-oriented granite lobe.

From microtextural observations the relationships of metamorphic mineral growth to the deformation structures have been deduced (Le Corre 1969*b*, 1978*b*; Quété 1975) (Fig. 6).

The metamorphism in the eastern and western sectors of Central Brittany therefore show the following common features:

(a) southward increase in metamorphic grade towards the Hercynian granite belt;
(b) conformity of metamorphic zonation with the outcrop pattern of the Hercynian granites, irrespective of sediment age;
(c) a metamorphic maximum, syntectonic with respect to deformation (cleavage and crenulation) of the envelope sediments, irrespective of sediment age.

The spatial association at the mapping scale of syn-schistosity andalusite-sillimanite-kyanite (e.g. in the Le Faouet area) suggests P-T conditions of metamorphism corresponding to the Al_2SiO_5 triple point (Hanmer & Vigneresse 1980) (Fig. 5). Reactions resulting in staurolite assemblages in the presence of quartz-muscovite suggest temperatures of approximately 550°C (e.g. Ghent 1974; Winkler 1976; Holdaway 1978). If these mineralogical data can be taken into account to determine P-T conditions, the metamorphic maximum in the western schist belt would correspond to 550–600°C at 5–6 kb (P_{H_2O}) (Richardson *et al.* 1969; Winkler 1976). The mineral assemblages to the E are not sensitive indicators and conditions there are difficult to deduce.

Conclusions

The evidence presented above is based on various geological criteria: classical petrographical and structural observation, finite strain analysis, examination of the geometrical and developmental characteristics of the regional cleavage and the detailed study of metamorphic mineral assemblages. This coherent body of evidence unequivocally solves the question of the age of the main deformation and metamorphism in the Brioverian rocks of Central Brittany. Furthermore, it provides us with a reasonably detailed model to account for the relationships between deformation, metamorphism and granite emplacement in this part of the Hercynian chain.

The age of the deformation

All the evidence indicates that the main cleavage-associated deformation in the Brioverian of Central Brittany is attributable to the Hercynian orogeny. This main deformation is superposed upon a relatively mild folding event of pre-Ordovician age, generally unaccompanied by cleavage formation and attributable to the end of the Cadomain orogeny. The Upper Proterozoic sediments of Central Brittany form part of a late Brioverian sequence which represents the erosion of the Cadomian mountain chain itself. This molasse was only affected by late orogenic events prior to the Ordovician transgression.

The tectonic role of the Hercynian granites

The disposition of the cleavage traces and the existence of cleavage triple points clearly demonstrate the mechanical role played by the diapiric ascent of the granites during the regional shortening. Moreover, the cleavage intensity contours imply the existence of a strain gradient, thus indicating the thermal influence of the granites during the development of the regional cleavage. The emplacement of the Hercynian granites was therfore syn-tectonic with respect to the main deformation in Central Brittany.

Metamorphic relationships

The very clear spatial association of the Hercynian granites with the highest grade of metamorphism, the EW increase in maximum metamorphic grade with increasing excavation of the granite belt and the conformity of the metamorphic isograds and crystallinity index contours to the granite outcrop pattern together suggest that a regional, low temperature–intermediate pressure metamorphism, affecting both Brioverian and Paleozoic sediments, was perturbed to the S by the emplacement of hot granites.

Geodynamic consequences

The heat exchange between the granites and the envelope rocks caused a sharp southward temperature gradient and an intermediate temperature–intermediate pressure metamorphism in the more southerly rocks. This conclusion is in marked contrast to the generally-accepted notion of previous authors that the metamorphic regime in Central Brittany is characterized by low pressures. This last point obviously poses a difficult regional problem since the proposed metamorphic pressures attained in the western sector (5–6 Kb) require an overburden approaching 20 km in thickness. However, at most, one can only conceive of a Palaeozoic sedimentary pile some 5000 m thick in Central Brittany. Can one therefore propose that a thick nappe, now entirely eroded, overlay the now visible Palaeozoic rocks during Herycynian times ? Could such a thickened overburden itself have provoked the thermal anomaly which resulted in the Hercynian plutonism ? The answers to these questions are perhaps related to a model of northward obduction in S Brittany as inferred from the geology of the Ile de Groix blueschists (Quinquis 1979). However, it is clear that such a model is based on the significance of mineralogical assemblages in terms of P-T conditions and perhaps this is also a problem.

Finally, despite the existence of a major stratigraphic unconformity between Brioverian and Palaeozoic rocks, Central Brittany is seen to be an essentially Hercynian domain. It follows that, in this region, the notion of a rigid 'Precambrian basement' to a Palaeozoic cover sequence must be abandoned. The Brioverian and Palaeozoic rocks have reacted as a relatively homogeneous unit during the Hercynian compression, contemporaneous with the ascent of the granites. The strictly syn-tectonic nature of the plutonism does not appear to be an isolated case in the Hercynian chain. Indeed, the same type of relationship between main regional deformation and granite emplacement can be demonstrated in other areas, for example in northern Normandy (Ledru & Brun 1977), and the northwestern part of the Sierra Morena (Brun & Pons 1979).

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