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The South Armorican Shear Zone

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Abstract—The main lithological features and structural relations of the South Armorican Shear Zone (S.A.S.Z.) are described and the evolution of physical conditions during deformation is outlined. Age constraints on the timing of shearing deformation are discussed and an attempt is made to place the S.A.S.Z. in its regional geodynamic context.

INTRODUCTION

Most of the structural evolution of the Armorican massif has taken place during the Cadomian (late Proterozoic) and Hercynian orogenies. Cadomian events are particularly important in the northern part of the massif and may be related to plate tectonic processes as proposed by Lefort (1975) and Auvray (1979). The southern part of the massif also provides evidence for the operation of plate tectonic processes and various models for paired metamorphic belts during pre-Hercynian and Hercynian times have gained support (Nicolas 1972, Carpenter & Civetta 1976, Hanmer 1976, Cogné 1977, Peucat *et al.* 1978).

Later, during Hercynian and late Hercynian times (Arthaud & Matte 1975, 1977) the whole of the Armorican massif seems to have undergone deformation related to a major continental collision (Cogné 1977) and there is a characteristic development of ductile shear zones (e.g. the North Armorican and South Armorican Shear Zones) (Fig. 1).

The North Armorican Shear Zone (N.A.S.Z.)

The N.A.S.Z. is an important shear zone recognised by Chauris (1969) as passing through the Molène – Moncontour lineament. This lineament (Fig. 1) separates the North Armorican domain, characterised principally by Cadomian magmatism, metamorphism and deformation, from a Central Armorican domain where Cadomian effects are weak. Dextral movement across this lineament appears to be in the range of 20 km at the present level of outcrop, although important lateral displacement may have preceded the intrusion of the Hercynian granite markers (Watt & Williams 1979).

The South Armorican Shear Zone (S.A.S.Z.)

The S.A.S.Z., as defined by Cogné (1960) corresponds not only to the main E–W and NW–SE trending branches of mylonite in South Brittany – Vendée but also to the deformed zone between the two main branches. This study presents the main petrographic and structural features of the S.A.S.Z. and aims to characterise the development of shearing phenomena in the region.

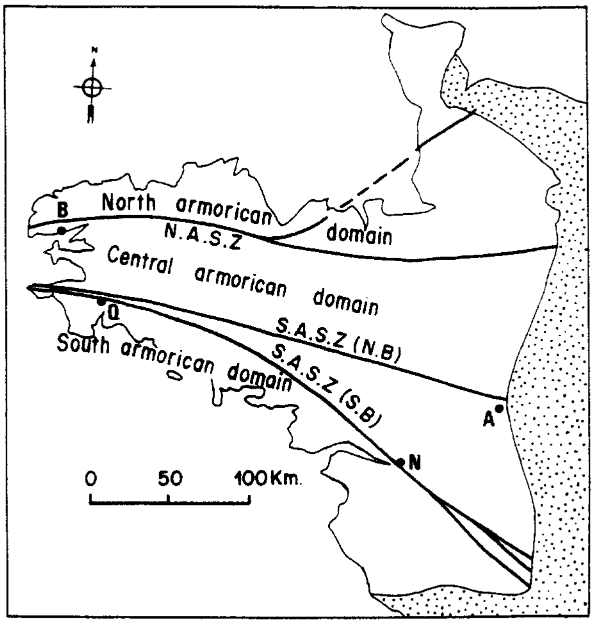

Fig. 1. Sketch map to show location of main shear zones within the Armorican massif. Major domains of the massif also indicated. (N.A.S.Z.) North Armorican Shear Zone, (S.A.S.Z.) South Armorican Shear Zone with (NB), northern and (SB) southern branches. A: Angers, B: Brest, N: Nantes, Q: Quimpes.

GEOLOGICAL SETTING OF THE S.A.S.Z.

The S.A.S.Z. lies between two domains within the Armorican massif which have suffered contrasting metamorphic and structural histories (Fig. 1). To the North, the Central Armorican domain is made up of a late Proterozoic (Brioverian sedimentary succession) (Le Corre 1977) and its Palaeozoic cover. Both these units were deformed and metamorphosed (Hanmer *et al.* in preparation) during the emplacement of 330 My two-mica granites (Vidal 1973).

To the South of the S.A.S.Z. lies the South Brittany metamorphic complex, composed mainly of granites and medium to high grade schists and gneisses. The structural and metamorphic evolution of the South Brittany metamorphic complex is essentially pre-Hercynian, probably related to the development of a paired metamorphic belt between 430 and 380 My ago (Peucat *et al.* 1978). All the granites and variously metamorphosed rocks of the South Brittany metamorphic complex,

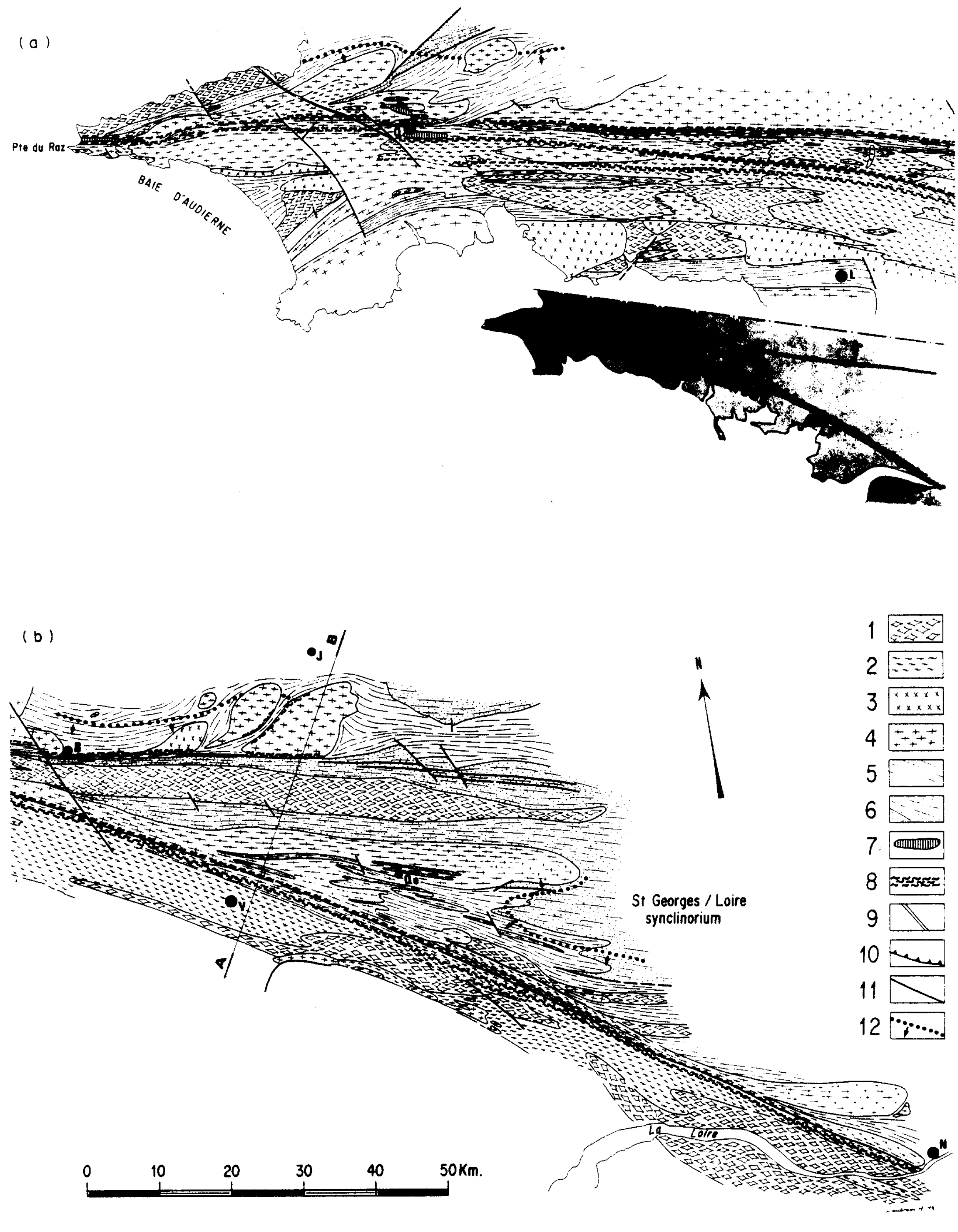

Fig. 2. Geological sketch map of the South Armorican Shear Zone (1) Pre-Hercynian orthogneisses (480–430 My). (2) 'Anatectic' granites and migmatitic gneisses (430–380 My). (3) Hercynian biotite granites (? 340 My). (4) Hercynian two-mica granites (330–300 My) (leucogranites). (5) Late Proterozoic (Brioverian) metasediments. (6) Lower - Mid Palaeozoic metasediments. (7) Stephanian sediments. (8) Main zone of mylonites and cataclasites. (9) Dolerite dyke (~ 190 My). (10) Northward dipping mylonite zone. (11) Faults. (12) Biotite-in isograd. B: Baud, J: Josselin, L: Lorient, N: Nantes, Q: Quimper, Qe: Questembert, V: Vannes.

as well as parts of the Central Armorican domain, are involved in the succession of events related to the development of the S.A.S.Z.

TIME RELATIONS AND GEOMETRICAL DESCRIPTION OF DEFORMATION IN THE S.A.S.Z.

Northern branch of the S.A.S.Z.

First of all, it should be noted that the two main branches of the S.A.S.Z. become difficult to distinguish from each other as one proceeds westwards from Quimper (Fig. 2). The northern branch of the S.A.S.Z. is sublinear and extends for about 300 km along a bearing N 100°E from the Point du Raz to near Angers. In its western part, the northern branch is relatively easy to trace (W of Josselin) and mainly cuts across the Hercynian two-mica granites. The shear zone itself is 300–400 m wide and made up of mylonites and ultramylonites. Mylonitic schistosity is vertical or steeply dipping to the N and the stretching lineation is sub-horizontal. Both mesoscopic and microscopic structures remain unchanged throughout the length of the shear zone and provide evidence for dextral shearing (Berthé *et al.* 1979). Cataclastic effects become more marked towards the western part of the zone.

Towards the east (E of Josselin), the Northern branch of the S.A.S.Z. is more difficult to pick out. Instead, a zone of faulted and abnormal contacts can be observed within the Palaeozoic stratigraphic succession (Berthé in preparation). Groups of conjugate folds within formations of contrasting lithology also demonstrate the operation of an important dextral shear component (Berthé & Brun 1980).

Southern branch of the S.A.S.Z.

In this branch there are two main types of structure within the shear zone, that is vertical and allow dipping schistosities. The most important mylonite and ultramylonite zone with vertical schistosity is found near the southern limit of the southern branch of the S.A.S.Z. This major vertical shear zone is contained within 380 My - anatectic granites and Hercynian two-mica granites and is usually several hundred metres wide. Vertical shear zones can also be found further away from the major zone to the N, but they are thinner and more difficult to pick out. Schistosity strike within the shear zone turns gradually from N 100°E near Quimper to N 130°E in the region of Nantes. The mesoscopic and microscopic structures of this branch of the S.A.S.Z. also indicate an important dextral shear, according to Berthé *et al.* (1979). As observed in the northern branch, cataclasis becomes more intense towards the west and involves already mylonitised material.

A northward dipping, discontinuous mylonite zone can be observed from just west of Quimper to east of Vannes. The strike of schistosity within this zone is parallel or slightly discordant to that observed in the nearly vertical shear zones already described, and schistosity planes dip 20–40° to the NNE. Wherever the sheared material is granitic, a dextral shear component can be easily demonstrated (Berthé *et al.* 1979). North of Vannes, the shear zone is mainly composed of ultramylonitised quartzitic phyllites. Typical phyllonites (Fig. 3), corresponding to the descriptions of Higgins (1971) and Sibson (1977), are also observed with cross cutting deformed veins of two-mica and muscovite granite. All the ultramylonites of this zone show abundant non-cylindrical folds (Fig. 4) (Bell 1978, Quinquis *et al.* 1978); some of which resemble sheath-like structures. The axes of these sheath-like folds are generally parallel to a sub-horizontal lineation aligned N 90–100°E (Fig. 5). Orthogneiss lithologies within the shear zone show asymmetric pressure shadows around feldspar grains which indicate a dextral shear component.

The total thickness of the north dipping shear zone is unknown, but probably exceeds 200 m. Vertical cataclastic shear zones are seen to cut across the northward dipping ultramylonites, and strike in the direction N 110–120°E.

Poor and discontinuous exposure throughout the region make a detailed examination of field relations between vertical shear zones and north dipping ultramylonite units very difficult. Some general points, however, can be made: there is no observed transition

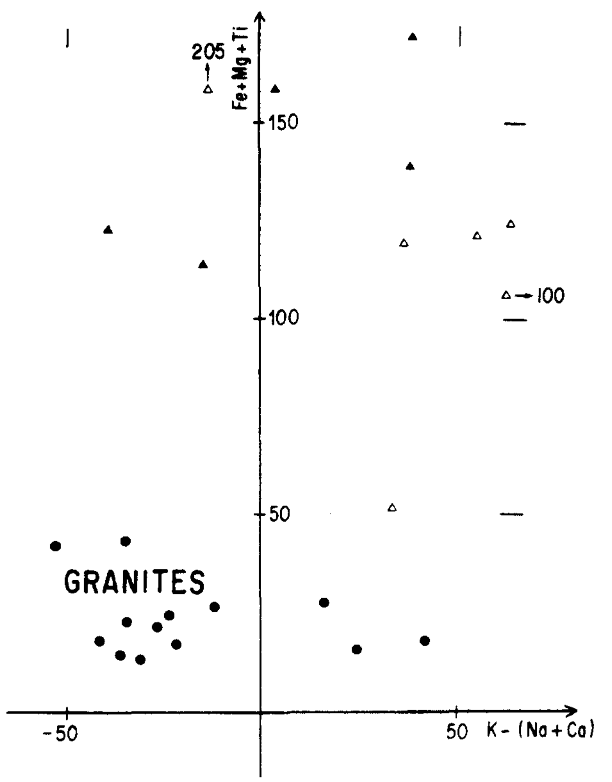

Fig. 3. Major element discriminant function diagram of De la Roche (1964) showing distribution of plutonic rock types. Two-mica granites and the mylonitic rocks derived from them (filled circles) are grouped together near the compositional field for 'granites'. Quartzitic phyllites and phyllonites (filled triangles), as well as phyllonitic micaschists (empty triangles), are discriminated from the granites and show a wide dispersal across the diagram.

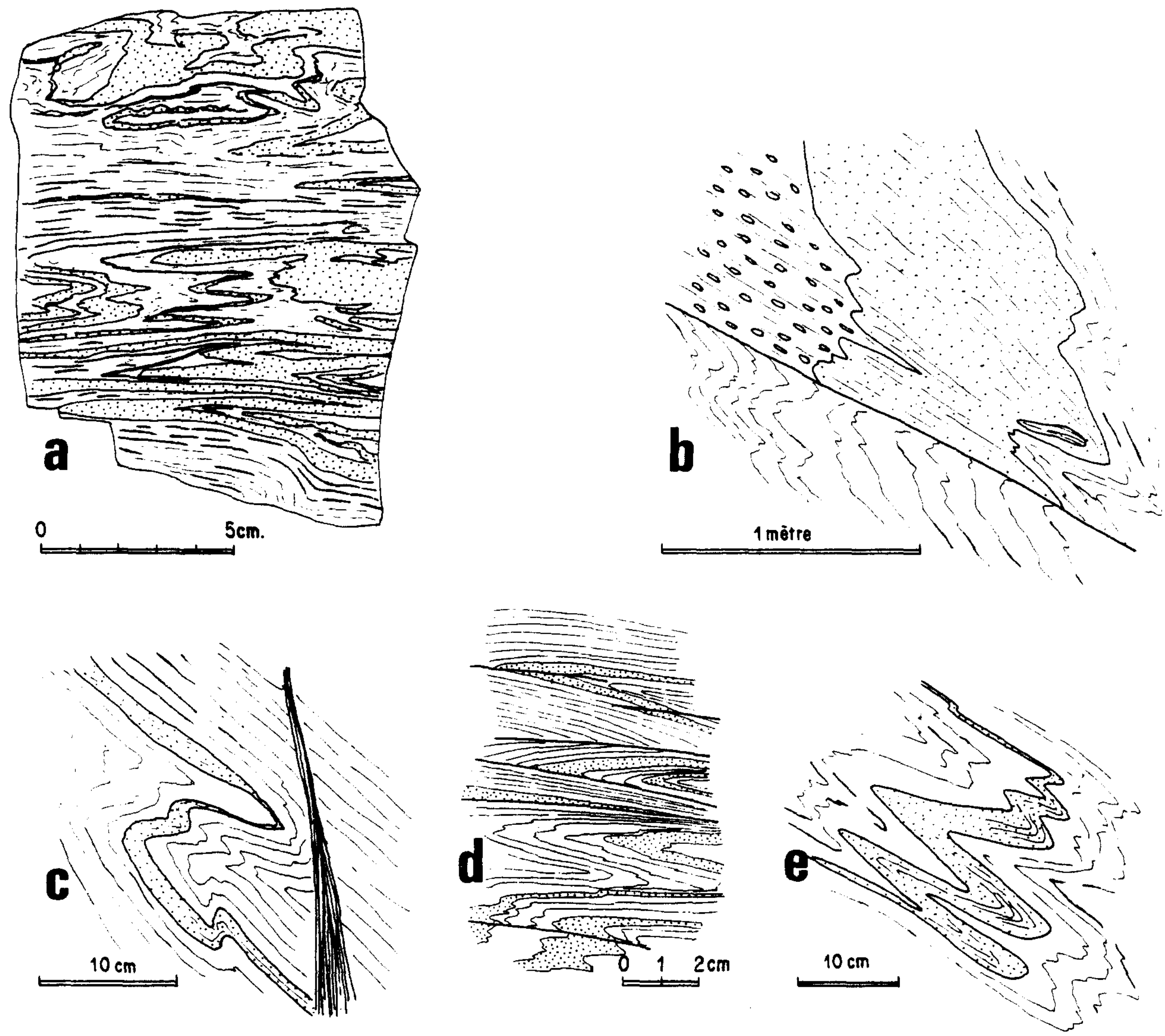

Fig. 4. Fold styles of non-cylindrical folds in quartzitic phyllites and phyllonites N of Vannes. Stippling indicates either leucocratic material (a, d) or granitic veins (b, c, e).

along strike between vertical and sub-horizontal shear zones; and neither is there any observed down-dip transition between the two different types of shear zone. As indicated in Fig. 6, the northward dipping shear zone is apparently trapped between vertical zones to the north and south; and as previously mentioned, vertical cataclastic shear zones are seen to cross-cut the northward dipping ultramylonite unit.

Although the existence of mylonite zones with vertical schistosity is easily explained by a transcurrent shear zone model, the significance of the northward dipping mylonite unit is more difficult to interpret. Three possible interpretations are discussed here. (1) The northward dipping mylonite unit may result from the southward tilting of an initially vertical shear zone. Such a process, if it took place at the same time as shearing, would be inconsistent with a transcurrent fault mechanism. Furthermore, the juxtaposition and mutual geometrical relationships between the different mylonite units appear to rule out a block tilting hypothesis. (2) Although the shearing deformation is mostly concentrated into vertical zones, there may have been

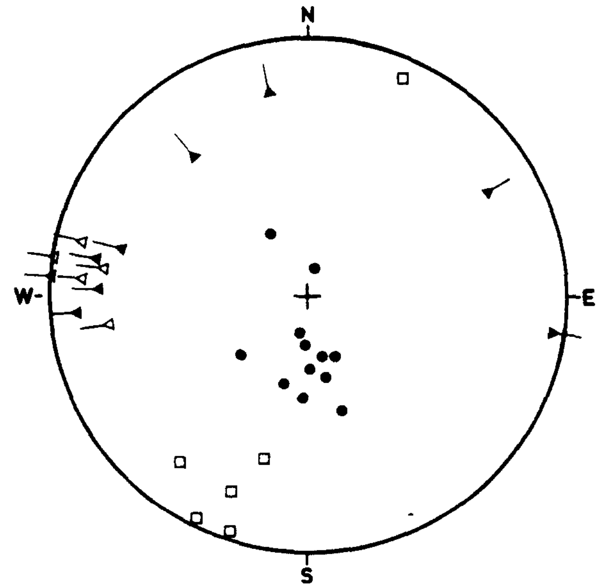

Fig. 5. Stereographic projection (southern hemisphere) of structural data for quartzitic phyllites and phyllonites as in Fig. 4. Filled circles: π poles to mylonitic foliation surfaces. Filled triangles: fold axes. Empty triangles: stretching lineations. Empty squares: π poles to cataclastic planar surfaces.

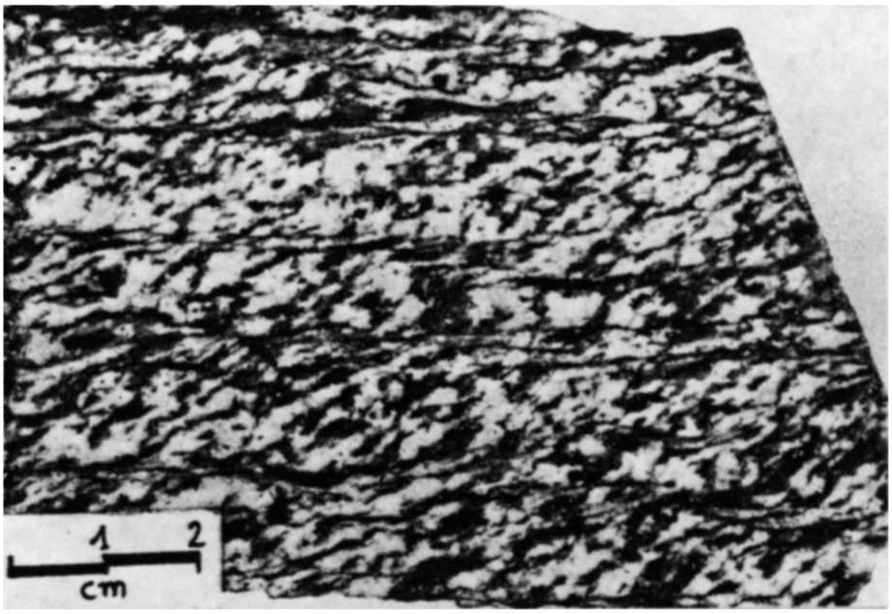

Fig. 7. Photo of polished slab of deformed Questembert granite showing closely associated development of C and S planes (see also Berthé *et al.* 1979).

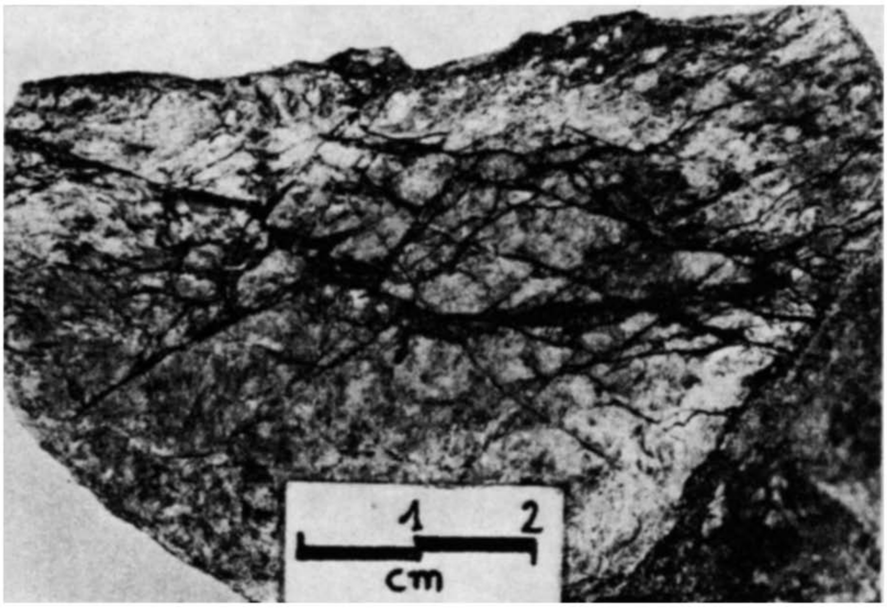

Fig. 8. Photo of brecciated rock sample showing clasts of mylonitic material – a possible pseudo tachylite?

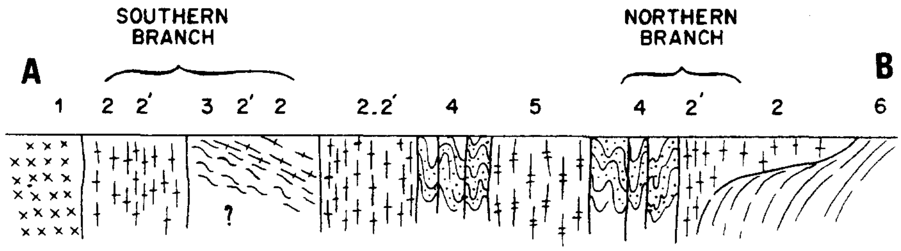

Fig. 6. Schematic cross-section along line A–B indicated in Fig. 2. (1) 'Anatectic' granites. (2) Hercynian two-mica granites. (2') Mylonitic and ultramylonitic granites. (3) Quartzitic phyllites and phyllonites. (4) Palaeozoic metasediments. (5) Pre-Hercynian Orthogneisses (Lanvaux). (6) Late Proterozoic (Brioverian) metasediments.

isolated belts where synchronous thrust tectonics were locally important. The absence of transition zones between vertical and northward dipping units would suggest that movement continued in the vertical shear zones after thrusting, thus isolating the northward dipping thrust unit from its root zone. (3) Dextral shear within the S.A.S.Z. may have initiated along an already established linear discontinuity of major importance [e.g. the thrust tectonic model of Jegouzo (1976) or a boundary between different plutonic domains].

This discontinuity, or zone of weakness between different crustal blocks, may have been the site of early thrust movements which were later overprinted by the development of vertical shear zones.

Belt of deformation between the two main branches of the S.A.S.Z. (intermediate zone)

This intermediate zone occupies a triangular area, essentially synclinal in structure, which closes to the west between the two main branches of the S.A.S.Z. It is made up of Late Proterozoic (Brioverian) and Lower-Middle Palaeozoic metasediments which are intruded by both pre-Hercynian (Lanvaux I, II and III orthogneisses of Vidal 1972) and Hercynian (e.g. Questembert two-mica granites, Vidal 1973) granitoids. All the rocks in this zone have suffered more or less intense shearing deformations consistent with a dextral shearing component. Intense deformation is particularly apparent in the Questembert granite (Fig. 7) and also in Lower Palaeozoic strata near the western end of the St Georges-sur-Loire synclinorium (Pivette 1978, Gapais 1979). In the latter case, shear movements can be shown to have been contemporaneous with the emplacement of Hercynian two-mica granites.

External zones

Two shear zones external to the S.A.S.Z. can be identified, one is situated within the granitic rocks of the Baie d'Audierne, the other is found between two-mica granites to the south of Josselin (Berthé in preparation). In these two cases, the shear zones strike N 50–60°E and the shearing component is *sinistral.* These external shear zones can be interpreted as being conjugate to the principal shearing direction in the S.A.S.Z.

TYPES AND DEVELOPMENT OF PHYSICAL CONDITIONS IN THE CRUST DURING SHEARING DEFORMATION

As described in the preceding sections, both cataclastic and mylonitic material can be found together, the former being generally formed at the expense of the latter. All types of mylonite are seen, from protomylonites to ultramylonites (blastomylonites and phyllonites are also observed). These rocks always show a well marked foliation and the minerals are generally deformed by plastic processes. However, it is not uncommon to find individual feldspar grains showing evidence for both rupturing deformation (disintegration with rotation and displacement of fragments) and plastic flow (deformation bands and microfolds, straining of twin lamellae). It remains impossible to establish a relative time-sequence for these different processes on the mineral scale.

When biotite is part of the original (pre-shearing) paragenesis, it is seen to remain stable and re-crystallise during deformation of the shear zone rocks. This is equally true of the hornblende found in some deformed quartz-diorites. Quartz and muscovite show plastic deformation in all rock types of mylonitic affinity. These observations on mineral stability enable us to estimate the metamorphic conditions during deformation as being low to medium grade ($> 400–450° < 600°C$, Winkler 1974) with an overburden of the order of 10 km (Sibson 1977).

Cataclastic rocks range in type from protocataclasites to ultracataclasites (Sibson 1977), but the mineral paragenesis of the matrix is difficult to determine on account of the very small grain size. Generally, the presence of quartz, muscovite and chlorite would indicate low grade metamorphism (Winkler 1974) associated with the cataclasis. In addition, there are various breccias, with angular blocks separated by a dark, usually re-crystallized matrix, which resemble pseudotachylites (Fig. 8) (Higgins 1971, Sibson 1977).

The development of mylonites on the one hand and cataclasites on the other would suggest initiation of the shear zone in relatively deep crustal conditions (Q.P. regime) followed by uplift and cataclasis (E.F. regime, Sibson 1977) as shearing phenomena continued at shallow levels.

CHRONOLOGY OF DEFORMATION IN THE S.A.S.Z.

A maximum age limit for the observed deformation is provided by the Rb–Sr isochron ages of 320–330 My obtained on two-mica granites cut by the S.A.S.Z. (Questembert, Vidal 1973; Pontivy, Mifdal 1979). This radiometric age corresponds to end-Dinantian to Namurian times on the Phanerozoic time scale (C.P.T.S. Supplement 1971) using 1.42 10^{-1} ^{1} an^{-1} as the Rb decay constant. The two-mica granites are cut by both the northward dipping mylonites and the vertical shear zones. Clasts of mylonitised granite have been observed in sediments of Stephanian age occurring in three small fault-bounded basins in S.W. Brittany (Cogné 1960). This observation serves as a minimum age limit for some of the shear movement on the western part of the S.A.S.Z. Other types of clast, including albite micaschists and meta-trondhjemite, have been recorded in these Stephanian arkoses and conglomerates, but it appears that deformation continued after uplift of the metamorphic basement and Hercynian granites since the Stephanian sediments are themselves sometimes strongly deformed along the shear zone. Finally, the different sectors of the S.A.S.Z. are cut by dextral wrench faults trending N 130–140°E which predate the beginning of the opening of the Atlantic Ocean (190 My ago, Lefort 1973).

GEODYNAMIC CONTEXT

Palaeomagnetic pole positions for the end-Devonian and early Carboniferous show the possibility of convergence and eventual collision between two supercontinental blocks — Gondwana to the south and Laurasia to the north (Scotese *et al.* 1979). Cogné (1977) has proposed the western European Hercynian fold belt is the result of continental collision and that leucogranitic plutons (two-mica granites in this text) were generated during an Himalayan-type orogeny (Andrieux *et al.* 1977) in the Armorican massif.

Considering only the southern part of the Armorican massif, it is immediately apparent that the trend of the high-temperature metamorphic belt is oblique to the dominant structural lineaments in the Central Brittany domain. The St. Georges-sur-Loire synclinorium, thought to be a zone of crustal thinning during the Lower Palaeozoic (Cogné 1977), is also seen to die out towards the west along the southern branch of the S.A.S.Z. The hypothesis of an early phase of thrust tectonics along the southern branch of the S.A.S.Z. (Jégouzo 1976) would seem to account for the present day obliquity of this branch in relation to the main S.A.S.Z.

CONCLUSIONS

1. The S.A.S.Z. is a major ductile shear zone within the West European Hercynian fold belt.

2. Most of the mylonitic and cataclastic rocks of the S.A.S.Z. were generated within a large-scale dextral shear zone and were derived from fairly homogeneous starting materials (e.g. two mica granites).

3. Cataclastic processes have affected already mylonitised rocks, especially towards the west of the S.A.S.Z.

4. The absence of recognizable external markers and the complexity of deformation within the shear zone prevents an estimate being made for the amount of dextral displacement across the S.A.S.Z.

5. The S.A.S.Z. is situated at the limit between crustal blocks which have suffered different tectono-metamorphic histories during pre-Hercynian times and which were finally brought together by oblique collision during the Hercynian orogeny.

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