PERGAMON

Journal of Structural Geology 23 (2001) 1597–1614

JOURNAL OF STRUCTURAL GEOLOGY

www.elsevier.com/locate/jstrugeo

The Ancenis Terrane: an exotic duplex in the Hercynian belt of Armorica, western France

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Received 19 November 1999; revised 3 January 2001; accepted 8 January 2001

Abstract

The Ancenis Terrane, bordering the Loire, France, consists of Precambrian Brioverian basement and three Paleozoic sedimentary sequences: marine Ordovician to Devonian shelf sediments; Lower Carboniferous synorogenic intermontane sediments (the 'Culm'); and coal-bearing Namurian deposits. The terrane is completely bound by faults, and its geology is in marked contrast with that of its neighbours. New data and observations along the terrane's southern boundary show that the Ordovician–Devonian sequence occupies a transpressional shear zone, and can be described as a tectonic mélange. The Culm outcrop, previously interpreted as a sinistral pull-apart structure, is reinterpreted as a Lower Carboniferous dextral pull-apart, and it is shown that Carboniferous transpression and thrusting remodelled the pull-apart basin into its present 'mica-fish' shape. With its remarkable concentric structure, and within a plate tectonic setting of mega dextral displacements along the northern boundary of Gondwana, the Ancenis Terrane can be interpreted as an exotic duplex.

1. Introduction

The Ancenis region (Fig. 1) sits within the dextral South Armorican Shear Zone and the Hercynian Orogen. The region exposes low-grade Precambrian Brioverian meta-sediments, marine Ordovician to Devonian shelf sediments, non-marine Lower Carboniferous 'Culm', and Namurian coal-bearing deposits. Several small plutons of the post-tectonic Mésanger Granite (unknown age) intrude the Culm (Cavet et al., 1978). The overall structure of the region has been described as a syncline (Cavet et al., 1978; Diot and Blaise, 1978), and as an asymmetric half graben (Dubreuil, 1980), with the Culm filling a sinistral pull-apart basin (Diot, 1980), and the Namurian filling a series of narrow basins along the Nort-sur-Erdre Fault (Diot and Blaise, 1978).

Diot and Blaise (1978) proposed that the sinistral pull-apart structure was initiated in the Lower Paleozoic, the site of a discrete, tectonically controlled, sedimentary basin from the Ordovician through the Devonian. However, a discrete basin for this period is not supported by Robardet et al. (1994) who note that the Ancenis sequence is part of the greater north Gondwana marine shelf succession that extended over much of northern Africa, Iberia, and western and southern France. They state (p. 4): "All the north Gondwanan regions maintained strong sedimentary and faunal affinities throughout the Paleozoic period". The Ancenis succession has coarse sands and red beds at the base of the Ordovician sequence, glaciomarine dropstone deposits in the Ashgillian, a condensed and euxinic Silurian sedimentary sequence, and Devonian limestones, in common with many other north Gondwanan regions, but it lacks the thick Ordovician 'Grès Armoricain'. At that time, the Ancenis region was in an outershelf position, and in common with Montagne Noire, its fauna maintained an easy relationship with Bohemia (Cavet and Pillet, 1964; Henry, 1989).

Despite the similarities between Ancenis and many other areas in the wider region, explaining the plate tectonic setting of Ancenis, and its context in Armorica, is beset with problems, as outlined by Shelley and Bossière (1999, 2000). First, there is the general problem that the innershelf successions of northern Brittany are now further away from the main Gondwana landmass than outershelf successions such as Ancenis and Montagne Noire. Second, throughout south Armorica and the Massif Central there are large areas of lower-middle Paleozoic oceanic volcanics, ophiolites, volcanic arcs, and high pressure metamorphics

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0191-8141/01/$ - see front matter
PII: S0191-8141(01)00014-1

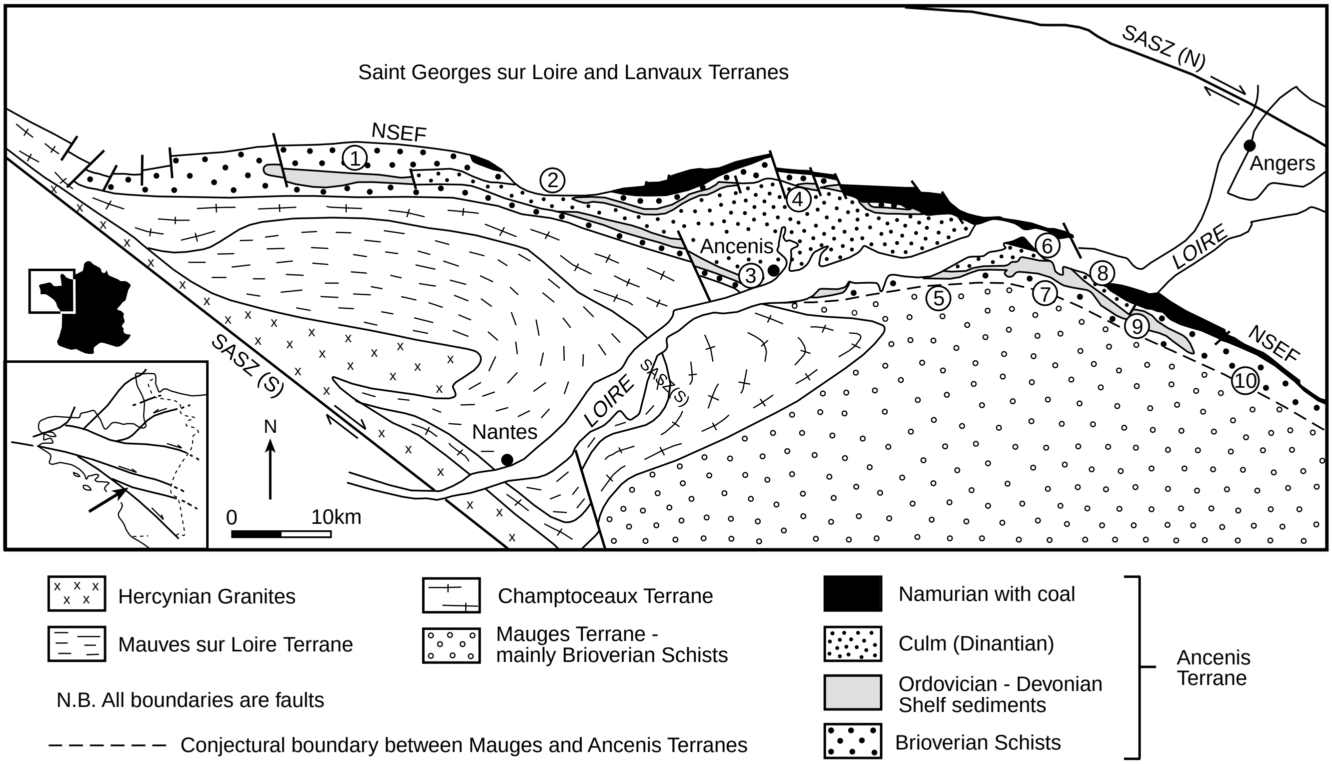


Fig. 1. Geological map of the Ancenis Terrane and surrounding areas. SASZ (N) and SASZ (S) are the northern and southern branches of the South Armorican Shear Zone. NSEF is the Nort-sur-Erdre Fault. Boundaries within the Ancenis Terrane are taken mainly from Diot and Blaise (1978). Other boundaries are generalised from the 1:50,000 geological maps of France. Terrane terminology is from Shelley and Bossière (2000). Numbers 1–10 indicate some localities mentioned in the text: 1, Blain; 2, Nort-sur-Erdre; 3, Pierre-Meslière; 4, La Roche Blanche; 5, St Laurent du Mottay; 6, Chateaupanne; 7, Moulin de Chateaupanne; 8, Chalonnes-sur-Loire; 9, Chaudefonds-sur-Layon; 10, Le Champ-sur-Layon.

(Bernard-Griffiths et al., 1986; Girardeau et al., 1986; Ledru et al., 1986; Ballèvre et al., 1987; Guiraud et al., 1987; Bodinier et al., 1988; Dubuisson et al., 1989; Barrientos, 1992); the famous Ile de Groix eclogites and blueschists represent subduction of some of these oceanic sediments and volcanics to depths greater than 70 km, followed by exhumation, all or mostly within the Devonian (Peucat, 1986; Shelley and Bossière, 1999; Bosse et al., 2000). All this indicates substantial tectonism and volcanism, which has been linked to the lower-middle Paleozoic opening and closing of a South Armorican Ocean (Cogné, 1977; Dubuisson et al., 1989). However, the Ancenis region sits right in the heart of south Armorica, and contains a stable platform sequence of sediments of the same age as these tectonic and volcanic events (Robardet et al., 1994). In other words, the Ancenis region and much of south Armorica are incompatible. Third, on a larger scale it is problematic that none of the shelf successions adjacent to south Armorica and the Massif Central in central and north Brittany, Aquitaine and the Montagne Noire are interrupted by significant tectonism from the lower Ordovician through the Devonian (Robardet et al., 1994).

We have undertaken new field studies at Ancenis because it is a key region, which, on a small scale, encapsulates the larger scale issues. The purpose of this paper is to record our observations and to present a new interpretation of the Ancenis structure and its tectonic setting.

By way of introduction, it should be noted that exposures in the area are poor, generally. The northern rim and western parts of the Ancenis Terrane are particularly lacking in exposure. Relatively fresh rocks are never far below the surface, however, and one can be reasonably sure that the main boundaries on the 1:50,000 geological maps are accurate, based on longstanding knowledge of material exposed from time to time in ditches dug for water mains, and the like.

2. Faults of the Ancenis and adjacent areas

2.1. Terrane boundaries

Gondwanan France is characterised by fault-bounded areas, as recognised for example by Rolet (1994), amongst others. Most recently the fault-bounded areas have been discussed by Shelley and Bossière (2000) in terms of a tectonostratigraphic terrane model. Fig. 1 shows some of the terranes within the south Armorican region. The Nort-sur-Erdre Fault (NSEF) bounds the Ancenis Terrane on its north side against the St Georges-sur-Loire Terrane. To the south of Ancenis are the Mauges, Champtoceaux and Mauves-sur-Loire Terranes, all of which are truncated by the southern branch of the South Armorican Shear Zone (SASZ-S) and the associated syntectonic granites. Running more or less parallel to the NSEF, and forming the northern boundary of the Lanvaux Terrane (which itself is faulted against the St Georges-sur-Loire Terrane), is the northern branch of the South Armorican Shear Zone (SASZ-N). The disparate nature of these terranes is well established (Rolet, 1994): for example, the St Georges-sur-Loire Terrane contains low grade metamorphosed Silurian N-type and E-type MORB oceanic volcanics, as well as some IAT and BAB (Ganne and Bossière, 1999, pers. commun.), and has been compared with volcanics offshore in Baie d'Audierne, near Brest, by Lefort (1989); the Champtoceaux Terrane consists of thinned continental crust and plutonic rocks metamorphosed in the Devonian at very high pressures, and compared with the Malpica Tuy unit of NW Spain by Ballèvre et al. (1994); and the Mauges Terrane exposes Cambrian acidic volcanics and volcanogenic sediments resting on Precambrian Brioverian schists (Cavet et al., 1966). None of these Paleozoic volcanic and metamorphic events are represented in the Ancenis region. Conversely, none of those other terranes expose the Paleozoic sedimentary sequences found at Ancenis. The *prima facie* case for major displacements along the terrane boundaries described below is compelling.

The NSEF, which forms the northern boundary of the Ancenis Terrane, is notable for the Namurian coal basins that developed along it, and Lorenz and Lorenz (1983) noted that it continued to be active in the Mesozoic, having an important control on sedimentation in the Paris Basin. The fault is not generally exposed, and ideas on its orientation and the displacement across it vary more according to the regional interpretation of the geology than on direct observation. Thus, the idea that the Ancenis Paleozoic rocks were deposited in a sinistral pull-apart basin requires it to be a sinistral fault. Barbaroux and Cavet (1983) described it as vertical but Marchand et al. (1988) noted, in the west of the region, that it dips to the north, representing thrusting from the north and dextral shearing. The description in Rolet et al. (1994) is quite ambivalent: sinistral in their fig. 17, but dextral in fig. 19. Most workers regard the fault as dextral during the Namurian, but observations of Marchand et al. (1988), and the way the fault curves and cuts across geological boundaries near the town of Nort-sur-Erdre (Barbaroux and Cavet, 1983), suggest an important late thrusting component. Diot and Blaise (1978) record the fault as a combination of thrusting from the north and dextral shearing post Namurian.

The southwestern boundary of the terrane is against the Champtoceaux high-grade meta-plutonic terrane. Variously this fault has been described as a northwards dipping reverse thrust (Marchand, 1981; Barbaroux and Cavet, 1983) or a normal detachment fault (Ballèvre, 1992; Ballèvre and Marchand, 1996; Ballèvre et al., 1999) with the relatively unmetamorphosed Ancenis Paleozoic rocks sliding to the north off the exhumed high pressure complex of Champtoceaux which, according to this model, were thrust from the north. The problem, again, is that the fault is seldom exposed, and the interpretations of it are based on interpretations of gross geological relationships rather than direct evidence. The detachment fault, for example, is placed by Ballèvre (1992) and Ballèvre and Marchand (1996) between the Champtoceaux complex and the Brioverian Schists, but the concept of its movement history depends not on evidence from the fault itself but on the interpretation of Diot (1980) and Dubreuil (1986), that the rocks above that boundary, and below the southern boundary of the Culm outcrop, are olistostromal, and related to gravity sliding off the detachment.

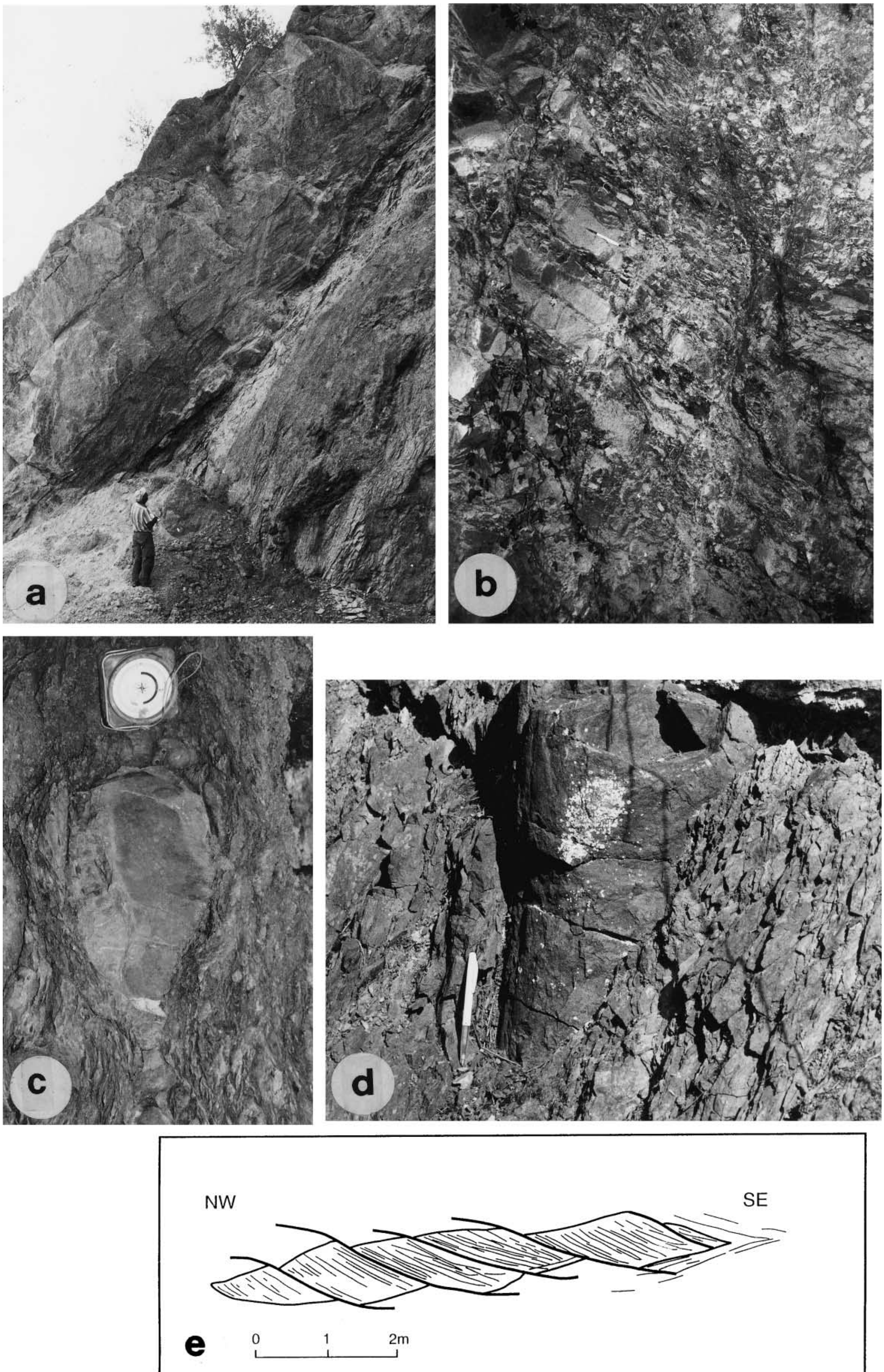
The southeastern boundary of the Ancenis Terrane, within the basement Brioverian, corresponds to the important tectonic boundary, shown on the 1:50,000 Sheet 484, Thouarcé map (Blaise et al., 1985), which separates an area to the north with vertical fold axes from an area to the south with horizontal axes (Diot and Blaise, 1978). The boundary runs parallel to and approximately 3 km distance from the NSEF, through Le Champ-sur-Layon, on the south side of the eastern tail of the terrane. This boundary also separates the contrasting Lower Paleozoic successions of the Mauges (Cavet et al., 1966) and Ancenis Terranes.

The southern and northern boundaries of the terrane merge in the west (Marchand et al., 1988), so that where the terranes curve in towards the SASZ-S, the Ancenis Terrane wedges out and the St Georges-sur-Loire and Champtoceaux Terranes are in direct contact with each other. They also probably merge in the east, under the Mesozoic cover of the Paris Basin. In essence, the terrane has the shape of an augen with long tails.

2.2. Faults within the Ancenis Terrane

Almost all major boundaries within the Ancenis Terrane, shown in Fig. 1, are faults (Cavet et al., 1971, 1978; Dubreuil, 1986; Lardeux and Cavet, 1994). The faulting is exemplified by the discontinuous nature of the units shown on the map (Fig. 1).

Just two localities, Moulin de Chateaupanne and La Guinière, are described by Blaise et al. (1970) and Diot (1980) as exhibiting depositional contacts of Ordovician sediments on the underlying Precambrian schists. Re-examination of the Moulin de Chateaupanne locality shows that the contact is not actually exposed, and that an exposed surface at the top of the basement looks like a clean fault surface, dipping 45° to the north, discordant with the stratification of the overlying Ordovician, which dips gently to the north. The exposures at La Guinière provide, therefore, a rare example of an unfaulted contact between the formations shown on the map (Fig. 1), but even this contact is within fault-bound blocks.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3. A major transpressional shear zone along the southern margin of the terrane

The 1:50,000 geological maps of the region (Cavet et al., 1970, 1978; Barbaroux and Cavet, 1983; Blaise et al., 1985; Marchand et al., 1988) show the Ordovician to Devonian succession as a number of disparate lenses of material, lacking continuity of succession. Apparent reversals of stratigraphic succession are indicated along the southern boundary of the terrane where fossiliferous cherts (phtanites) of Silurian age crop out to the north of Devonian limestone (Cavet et al., 1978). Numerous local formation names are symptomatic of the lack of stratigraphic continuity. The disparate relationships were explained by Diot (1980) and Dubreuil (1980, 1986) in terms of an olistostrome.

In this paper we present data which indicate a tectonic rather than sedimentary origin. Key observations are:

1. In widely separated lenses of material, lacking penetrative deformation, bedding almost uniformly dips to the north.
2. Boundaries of lenses are tectonic with slickensides, slickenfibres, and polished surfaces on planes discordant to bedding.
3. The matrix to the lenses is penetratively deformed and foliated, often markedly so. Foliation and stretching lineations are most commonly vertical.

Several of the better exposed locations illustrate these observations well, and are described below.

3.1. Chateaupanne Limestone

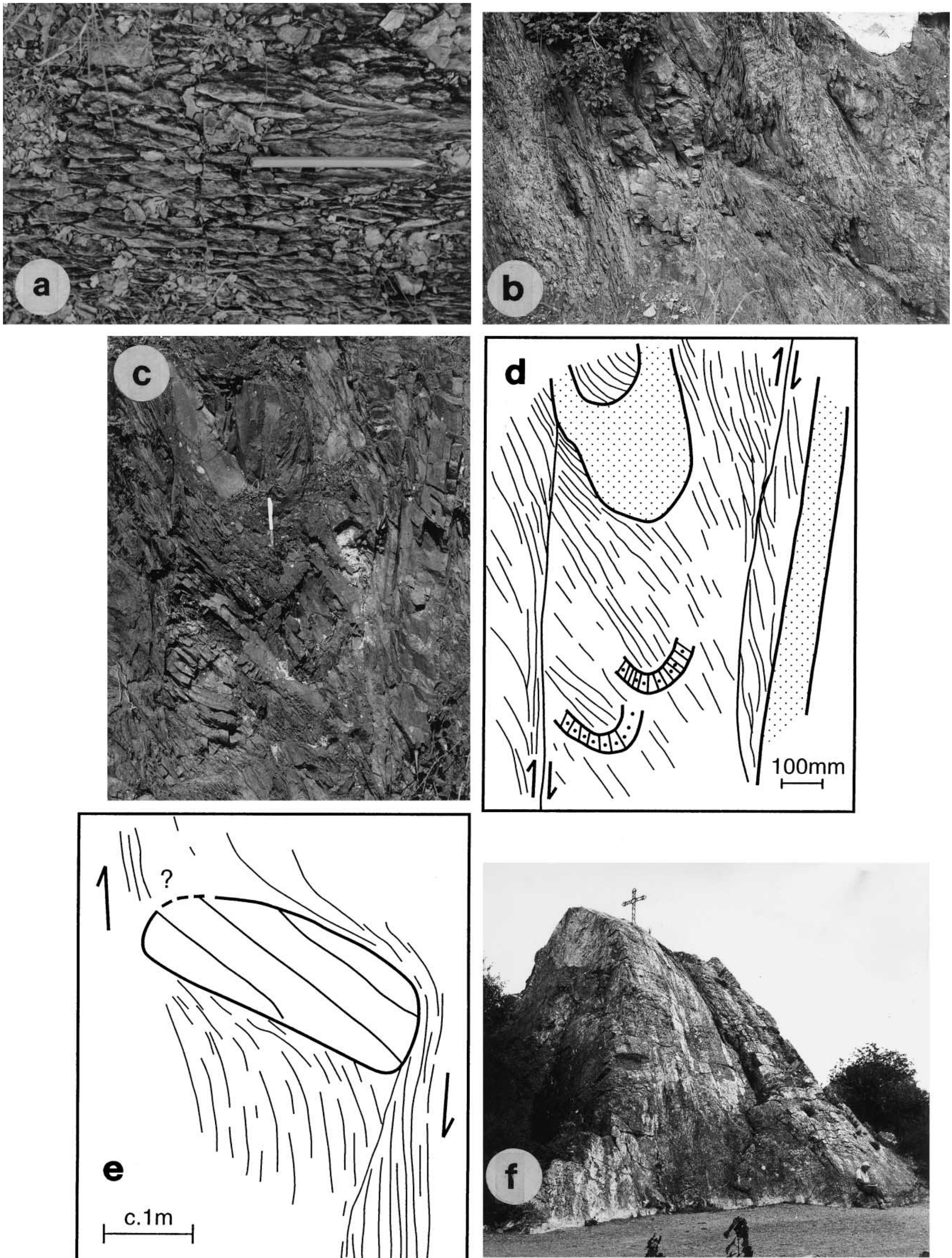
At Chateaupanne, 27 km east of Ancenis on the south side of the Loire (Fig. 1), Givetian limestone (Dubreuil and Vachard, 1979) is exposed in a large quarry and mapped as a huge block 2 km long (E–W), and up to 300 m in width (N–S). The quarry has worked vertically through 120 m of limestone, and drilling has proved another 30 m, below which is mudstone. On a high ledge at the western end of the quarry, volcanogenic sandstones and mudstones lie on top of the limestone, probably conformably. On the southern side of the quarry, limestone is interbedded with mudstone, dipping moderately or steeply north. But, in general, limestone bedding is discordant to the shape of the quarried limestone block. Thus, on the north side, towards the top, the overlying sandstones and mudstones are visibly downfaulted on a subvertical plane. An abandoned quarry, immediately to the northeast of the present workings, is made of massive limestone along its southern face, but the northern face is made entirely of the volcanogenic sandstones and siltstones which dip moderately to the north and which were downthrown on vertical faults. On the southern side of the main quarry, bedding planes are tectonically disturbed (Fig. 2a), and there are marked discordances due to faulting on sub-vertical planes. Cavet et al. (1971, p. 203) report Ordovician graptolites in mudstones immediately south of the limestone, and we interpret this in terms of downthrow of the Devonian to the north.

If the Chateaupanne block were a huge olistolith one would expect the host sediment to have been greatly disturbed during deposition. Only tectonic disruptions are seen, however, and evidence of faulting and tectonic shearing is everywhere. Within the massive limestone block itself, most shearing is along vertical lines on very diversely oriented faults planes. Although both the southern and northern margins exhibit evidence for vertical faults with downthrow to the north, there is also widespread evidence of horizontal movement, particularly outside the confines of the limestone block itself, and slickenfibres indicate dextral shearing. Some faulting appears to have been quite superficial, with brecciation and pug formation, and it is noteworthy that the sediments in the main quarry, despite their age and tectonic setting, are not cleaved or penetratively deformed.

3.2. North of Chateaupanne Quarry

Immediately north of the abandoned part of Chateaupanne Quarry, there is a narrow cleft that gave access from the north. The cleft runs for approximately 70 m across a shear zone, and exposes a sharp transition from the relatively unsheared sand/siltstones of the quarry to a mélange of thoroughly sheared material. At the quarry face, the bedded sand/siltstones dip moderately to the north, and are cut by discrete subvertical faults. For the first 5 m into the cleft, the bedded succession is cut by several subvertical (dip 85°N) shear zones, which anastomose along the bedding planes (Fig. 2b). The sense of shear is down to the north. Dips to the north are maintained up to about 20 m into the cleft. The next 50 m is highly sheared and contains lozenge-shaped blocks, decimeter to several metres in size, with diversely oriented bedding, and shearing on vertical planes trending E–W to WNW–ESE. As already noted by Diot (1980), some of the shearing is up from the south, the opposite of that seen at the southern end of the

Fig. 2. (a) Shearing more or less parallel to bedding, seen clearly in the reentrant that runs up to the right from the man. View to east in southeast corner, upper level of Chateaupanne Quarry. (b) Subvertical shear planes that cut across and anastomose along beds that dip north (to the right). Near southern entrance to the cleft north of the abandoned Chateaupanne Quarry. View is approximately 1.3 m across. (c) Boudinaged competent block set in highly sheared matrix near northern entrance to the cleft north of the abandoned Chateaupanne Quarry. Shear planes are subvertical. Compass for scale. Reproduced with permission from Diot (1980, Plate 4, fig. 4). (d) Sandstone layer in sheared vertical slaty matrix with vertical fold axis (ca. parallel to biro that is ca. 140 mm long). The fold is sheared off on the left side, suggesting dextral shear. (e) Dextral shears at Site des Malpaves affecting a tectonically shaped lens of sandstone within the dominantly sinistrally sheared SE part of the exposure.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cleft and in the main quarry; and Diot (1980, fig. 66) recorded subvertical striations associated with these reverse movements. Diot (1980) interpreted the sheared sandstone blocks as slump-balls in an olistostrome. As Hsu (1968) pointed out, however, sandstone fragments around which shaly material flows are typical of a tectonic mélange, not an olistostrome (where the relationship is typically the opposite), and at Chateaupanne, the rhomboidal shapes, and the smooth, slicked surfaces are clearly tectonic in origin (Fig. 2c). If some blocks did originate as olistoliths they have at least been severely tectonically modified. Diot (1980, fig. 66) recorded a strong horizontal alignment of boudins and sheared blocks, which reflects the intersection of anastomosing shear surfaces with subvertical movement directions rather than horizontal stretching. Because of the sheer sides of the cleft, it is impossible to see the shear surfaces in plan view.

3.3. Exposures along the road 1 km WNW of Chalonnes-sur-Loire

The rocks are slaty, and sandstones are severely boudinaged, folded and sheared. The cleavage and bedding are subvertical and strike NW–SE. A sandstone layer folded about a vertical axis is shown in Fig. 2d; slaty cleavage is along the axial plane of the fold. The folded sandstone is sharply truncated on the north side, suggesting dextral shearing along the cleavage plane. A stretching lineation in the cleavage is horizontal, but some of the boudinage in this exposure suggests vertical extension too. In addition, there are shears running NNE–SSW, dipping moderately southeastwards, along which the movement is dextral.

3.4. Site des Malpaves (12–15th century cemetery), Chalonnes-sur-Loire

This remarkable rock platform on the south bank of the Loire contains empty graves, dug into the rock, and is approximately 120 m long and up to 30 m wide. It displays shearing along both horizontal and vertical lines, and a particularly good plan view of the shear zone. The foliation runs NW–SE and dips steeply northeast. Blocks of sandstone are boudinaged and have subvertical boundaries parallel to foliation, often discordant to bedding which dips more gently to the north.

The subvertical foliation is cut by discrete shears, separated by the order of 1 m, and they anastomose and sometimes cut already existing boudins or tectonically shaped lenses of sandstone (Fig. 2e). The blocks are clearly discontinuous along both the vertical and horizontal directions. Along the vertical line, shearing is mainly down to the north; along the horizontal line, shearing is both dextral (on planes trending between NW–SE and NNE–SSW) and sinistral (on planes trending between NW–SE and E–W). Sinistral shears dominate in the SE part of the outcrop, dextral shears in the NW part. These two parts are separated by a central zone of dextral faulting and shearing. The surfaces within the shear zones and on the blocks are often very polished, and the cleavage anastomoses to form lozenge or almond-shaped bodies on a small scale (Fig. 3a).

3.5. North of Chaudefonds-sur-Layon

The shear zone is well exposed along the road to Ardenay, between 250 and 500 m north of Chaudefonds-sur-Layon, and exhibits the typical lozenge-shaped blocks (Fig. 3b). Again, a combination of horizontal and vertical movement is represented. Boudinaged sandstone layers and disrupted quartz veins indicate vertical extension, and shearing up from the south. Folds of sandstone plunge steeply to the west, and in combination with the shears seen on adjacent horizontal surfaces, indicate dextral movement along subhorizontal lines. Slickenfibres, likewise, indicate shearing along subvertical and subhorizontal (plunge to E) lines.

Where folds are seen, foliation is usually more or less parallel to axial planes with typical refraction of cleavage in the sandstone. There is much shearing along the slaty cleavage, however, with the consequence that sandy fold hinges may lack limbs, sandstone layers lack continuity (Fig. 3c and d), and cleavage in one place (Fig. 3c and d) is oblique to the sandstone on one limb of a fold in a way that indicates a complex strain history.

3.6. The limestone blocks of Chaudefonds

An example of a supposed olistolith of limestone is described by Diot (1980) just 250 m NW of Chaudefonds, on the NW side of Le Layon, in the back yard of a residence (Fig. 3e). The block is 3–4 m long and ca. 1 m thick, and its shape is dominated by shear surfaces, which dip gently north. Within the block are probable bedding surfaces,

Fig. 3. (a) Lozenge-shaped structures in pelitic material, Site des Malpaves, due to anastomosing shear surfaces subparallel to the overall foliation which trends NW–SE. Plan view. (b) Lozenge-shaped sandstone blocks in shear zone. View is to the W, in a road cutting, and measures approximately 3.5 m across, N of Chaudefonds-sur-Layon. (c) Complex fold and fold-cleavage relationships, and fold hinge detachment, N of Chaudefonds-sur-Layon. The accompanying drawing, (d), clarifies relationships. Sandstone is stippled, and three-fold hinges are observed (the fold axes plunge steeply west). The lower two are detached from any continuous layer, and show refraction of cleavage. The larger body of folded sandstone is cut across by the foliation in an unorthodox way, clearly seen on the left and inside the fold. Curved foliation surfaces indicate shearing up to the south. View is to the west. (e) Sketch, looking west, of a limestone block set in sheared slaty rock near Chaudefonds-sur-Layon. The limestone exhibits a planar structure (probably solution altered bedding) that dips more steeply to the north than the lower surface which is marked by veins. The foliation of the slaty sheared matrix is perturbed by the block in the manner shown, suggesting shearing up to the south. (f) View of Pierre-Meslière looking from the west. The trace of bedding can be seen dipping moderately to the NE, and the main curved surface exposed is tectonic showing vertical slickensides. Note man for scale at right.

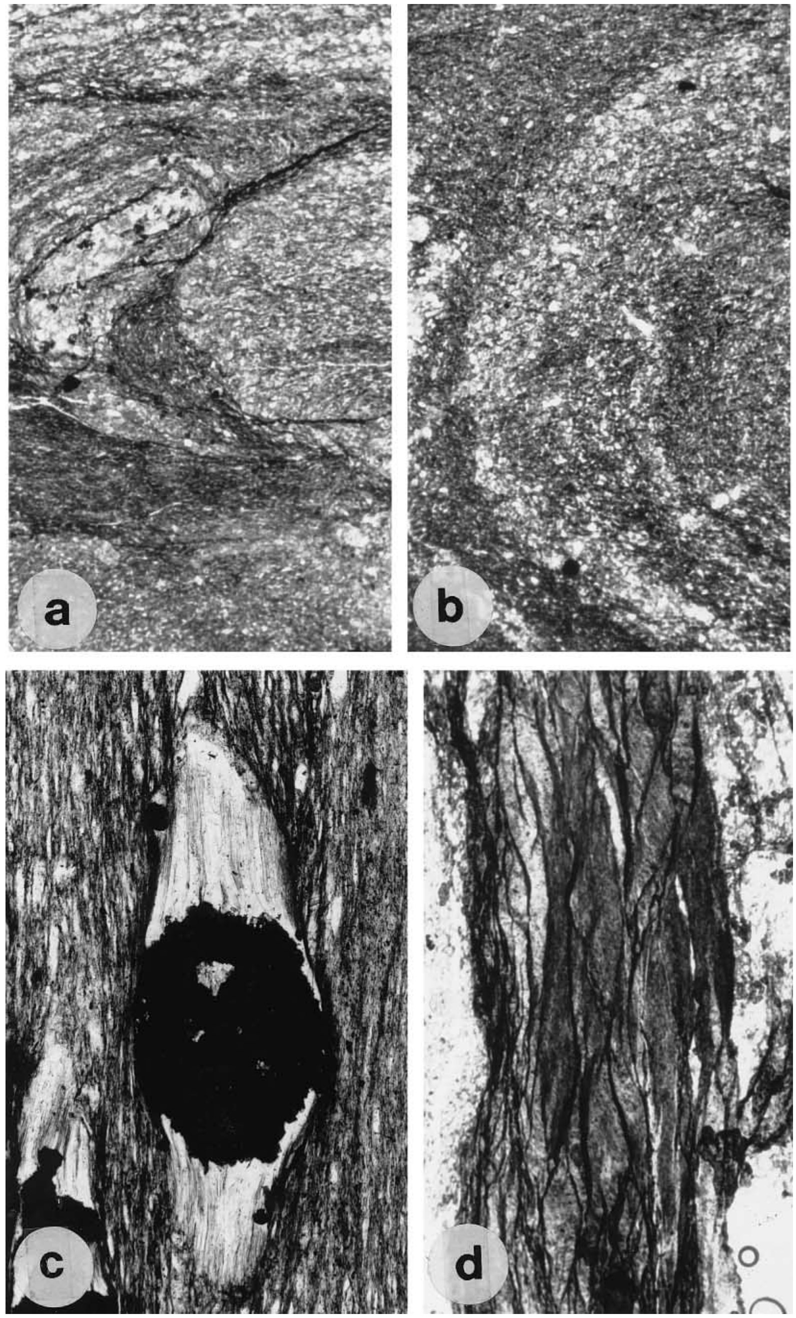

Fig. 4. (a) Complexly folded and sheared phyllite 200 m east of Pierre-Meslière. View in thin section is looking along the vertical fold axis. View measures 4.1 × 2.4 mm. (b) Folded bedding, the nose of a tight fold in phyllite 200 m east of Pierre-Meslière. View in thin section is looking along the vertical fold axis. View measures 4.1 × 2.4 mm. (c) Pressure shadow of sheet silicates, showing vertical stretching in phyllite from near Pierre-Meslière. Same specimen as (a) and (b), but in side view. View measures 1.0 × 0.6 mm. (d) Severely sheared sheet-silicate rich layers in Brioverian schists 200 m inside the dextral Hercynian shear zone 1 km NW of Le Champ-sur-Layon (Fig. 1) in the eastern tail of the terrane. Shear planes are vertical and run WNW–ESE. View measures 4.1 × 2.3 mm.

modified by solution, which dip moderately to the north, oblique to the block itself. The matrix to the block is the same as the pervasively sheared slaty material described immediately above, and the cleavage anastomoses around the limestone, but with an asymmetry that suggests shearing up from the south (Fig. 3e). All the boundaries of the limestone block are highly sheared, and the matrix planes discordant to the limestone are shear planes, not bedding. Therefore, it is not possible to say with any certainty that this is an olistolith dropped into soft sediment, but one can certainly say it is a block in a shear zone.

According to the map of Diot (1980), numerous other small lenses of limestone occur nearby, and 250 and 500 m to the WNW of Chaudefonds are 100-m-sized limestone blocks. Similar blocks occur throughout the Ancenis region, and although exposures in the area are generally very poor, the limestones often stand out as small knolls and have been worked for lime. Where margins of the blocks are visible, as at Chateaupanne and the block at Chaudefonds, they are seen to be tectonic, and Dubreuil (1986), for example, noted that a limestone lens near Pierre-Meslière is both affected and wrapped around by a strongly developed schistosity. The lenticular shapes are typical of tectonic modification, and the blocks are set in a highly sheared matrix.

3.7. Pierre-Meslière

Pierre-Meslière (Fig. 1), 4 km WSW of Ancenis, is the site of a great upstanding lensoidal quartzite block (Fig. 3f) set in phyllites derived from well-laminated silts. The block has been quarried for a long time, so that menhirs nearby were made from it by Neolithic man. The quartzite extends WNW–ESE for at least 250 m, parallel to the terrane's southern margin, as a vertical sheet several metres thick. Another satellite block outcrops 100 m to the NW of the main sheet. Bedding dips moderately north, discordant to the overall shape of the quartzite sheet, which is entirely bound by tectonic contacts, marked by polished and slicked steep to subvertical surfaces, and with shearing along steep lines (Fig. 3f).

The phyllite host to the quartzite is more metamorphosed than the slaty rocks of Chalonnes and Chaudefonds, and is in marked contrast to the unmetamorphosed rocks of Chateaupanne and the undeformed sandstones rich in lithics and feldspar that litter the vineyards a few metres south of the quartzite (these sandstones, unfortunately, are not clearly exposed). The phyllitic cleavage is steeply dipping and axially planar to folds with down dip axes (plunging NNE), as described by Diot (1980) from the motorway cutting at La Rillouse, 3.5 km WNW of Pierre-Meslière. We have observed the same structures (Fig. 4a and b) in drains immediately northeast of Pierre-Meslière, and stretching parallel to the vertical fold axes is shown by simple pressure shadows (Fig. 4c). At La Rillouse, Diot (1980) noted folds verging to the west, and interpretated this in terms of sinistral shearing, but our observations immediately north of Pierre-Meslière itself show that a combination of both dextral and sinistral horizontal shearing is present. Shearing is, however, along both the vertical and horizontal directions. As at Chateaupanne, some of the shearing northeast of Pierre-Meslière seems to have been quite superficial, with vertical zones of brecciation and pug formation.

In the far west of the Ancenis Terrane, south of Blain (Fig. 1), the Chapelle St Roch is built on a 90 m long lensoidal block of quartzite, similar to that at Pierre-Meslière. Otherwise, in this part of the terrane, exposures are virtually non-existent. On the 1:50,000 map it is noted that the rocks near Blain are similar to those of Pierre-Meslière.

3.8. Southeast of the Culm outcrop

The Ordovician to Devonian rocks form a lensoid body less than half a kilometre wide, running west for nearly 4 km from Le Mesnil-en-Vallée, on the southern side of the Loire. An outcrop along the road to St Laurent du Mottay (Fig. 1) exposes pelites sheared along subvertical surfaces into lozenge-shaped bodies. The foliation is approximately E–W. There is the usual problem of lack of exposure in this area, but the lensoidal and discontinuous nature of the Ordovician–Devonian sequence, as shown on the 1:50,000 maps, indicates its general faulted and sheared nature.

3.9. Interpretation as a tectonic mélange and transpressional shear zone

We suggest the observations above are inconsistent with an olistostromal origin for the Ancenis complex of Ordovician–Devonian sediments. The consistent northerly dip of bedding in tectonically bound lenses cannot be reconciled with tumbling of blocks expected in an olistostrome. It is consistent, however, with inhomogeneous shear and deformation partitioning where competent blocks retain their original orientation whilst strain is taken up by the more ductile matrix, a mechanism described by Ramsay (1962) and Bell (1985).

We suggest, therefore, that the Ordovician–Devonian marine succession comprises a tectonic mélange, and the orientation of structures indicates a transpressional shear zone. The geometry of transpressional shear zones has been described by Dewey et al. (1998) and Fossen and Tikoff (1998). In general, for reasons such as those outlined by Molnar (1992), an oblique convergence may be partitioned into separate transcurrent faults and thrusts, and/or into a ductile zone of strain with extension along both vertical and horizontal lines, often partitioned locally along discrete shears (Tikoff and Greene, 1997). Unless the direction of convergence makes a very acute angle with the shear zone ($<20°$), the overall direction of extension in a ductile shear zone will be vertical, not horizontal (Tikoff and Greene 1997; Dewey et al., 1998).

Shearing in the Ordovician–Devonian sediments of Ancenis has all the hallmarks of a transpressional shear zone: subvertical shear planes, often two lineations with extension along both the vertical and horizontal, and partitioning of the deformation in a very intimate way along anastomosing shear zones. The shear zone is 1–2 km wide.

The dominant sense of shear along the horizontal direction is not easily determined. The fundamental problem is lack of exposure, especially a lack of sections in plan view. We have observed only dextral slickenfibres on discrete fault surfaces, and within the ductile shear zone we have observed more dextral than sinistral shears. Where dextral and sinistral shears occur together, the dextral are usually more continuous. Nevertheless, we have observed a lot of sinistral shearing, and whilst antithetic sinistral shears,

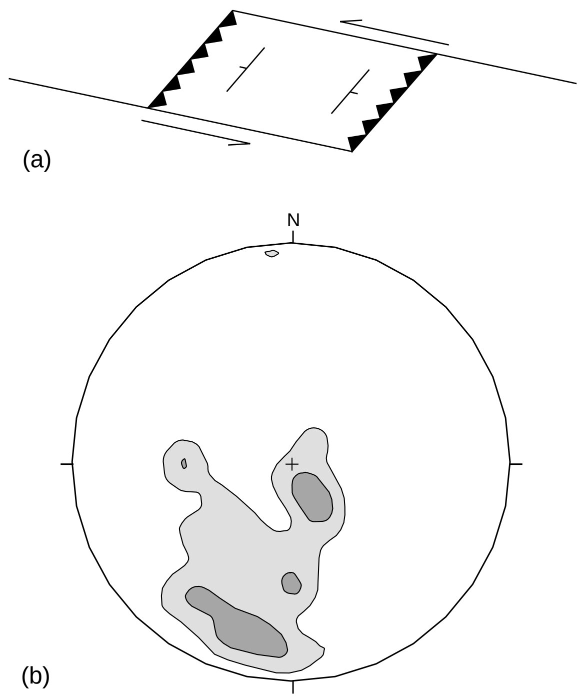

Fig. 5. (a) Diagrammatic sinistral pull-apart basin in the present orientation of the Ancenis Culm Basin. Toothed margins indicate possible normal faults, and the dip signs indicate the probable orientation of sediments in such a basin. (b) Lower hemisphere equal area contoured plot of poles to 87 bedding planes in the Culm of the Ancenis Basin. The data do not fit the model shown in (a). Contours at 2.2 and 5.0% per 1% area, maximum 7.7%. Data taken from the map of Diot (1980).

bookshelf sinistral shears, and sinistral shearing at the ends of boudins can be expected within a dextral shear zone, it may also be that the sinistral shearing is a response to horizontal stretching along the transpressional zone. Stretching along the horizontal direction parallel to the Armorican shears has been recorded in adjacent areas (e.g. Bouchez and Blaise, 1976; Dubreuil, 1987), and possible reasons are discussed by Dewey et al. (1998) and Fossen and Tikoff (1998). One reason could be that a transpressional arc is stretched as it is wrapped around a convex plate margin, or bent by an indentor, and this idea seems particularly appropriate for the Ancenis Terrane since it lies on the curved Ibero–Armorican arc, formed according to Matte and Ribeiro (1975) by the indentation of a rigid Iberian block, or according to Shelley and Bossière (2000) by wrapping of dextral shear zones around a convex plate margin. The paleomagnetic evidence is that the Armorican region was rotated 40–50° clockwise by the end of the Carboniferous (Perroud, 1986; Edel, 1987).

3.10. The transpression as it affected the Brioverian

As already noted, the southeastern boundary of the Ancenis Terrane corresponds to a marked change in Brioverian structure. In the Mauges Terrane to the south, the foliation is subhorizontal; in the Ancenis Terrane it is subvertical. Diot and Blaise (1978) showed that vertical foliation development was accompanied exclusively by dextral shearing, contemporaneous with movements on the NSEF. Samples we have collected exhibit extreme shearing (Fig. 4d). Subvertical foliation characterises the basement Precambrian throughout the entire Ancenis Terrane, and we suggest it represents Hercynian transpression.

Dextral shearing in the basement was preceded by sinistral shearing (Diot and Blaise, 1978), and the latter was the basis for their proposition that Paleozoic marine sediments and the Culm were deposited in sinistral pull-apart basins. Those movements, however, are not dated, and we suggest they may be Cadomian, given that sinistral shearing characterises that period of deformation (Balé and Brun, 1983; Strachan et al., 1996). It may be, therefore, that the Hercynian Ancenis Terrane boundaries are in part rejuvenated Cadomian lineaments.

4. The Culm and Namurian

In contrast to the pre-Carboniferous sediments and Brioverian basement, the Culm generally lacks penetrative deformation. We have plotted dips of bedding from the map of Diot (1980) and they are mainly to the north and northeast (Fig. 5). A thick sequence of conglomerates in the eastern part of the terrane (Poudingue d'Ingrandes) dips steeply to the northeast.

We observed one interesting exception to the usual north-northeast dip, in a road cutting on the northern side of the Culm exposures, exactly 1.25 km southeast of La Roche Blanche. Here, bedding strikes E–W, vertical, and atypically, a well-developed slaty cleavage dips moderately to the north. This observation is compatible with compression during the Hercynian Orogeny and thrusting from the north, but the asymmetric fold and cleavage development is very localised since other exposures near the north of the Culm outcrop display the normal northwards dip.

The Namurian deposits also dip towards the north, rotated into this orientation, according to Diot and Blaise (1978), by thrusting from the north and dextral shearing. According to our observations, the Namurian is less deformed than the Culm. The Namurian is cut by vertical faults in a quarry by the main road east of Chalonnes-sur-Loire at Chapelle Ste Barbe des Mines; the faults strike 030 and 080° and are marked by horizontal slickenlines.

5. A tectonic interpretation of the Ancenis region

At first glance, the almost concentric pattern of Brioverian schists, Ordovician to Devonian sediments, and Culm, suggests a syncline (Fig. 1), and it has been referred to as such (e.g. Cavet et al., 1978; Diot and Blaise, 1978).This interpretation was abandoned by Dubreuil (1980, 1986) and Lardeux and Cavet (1994), and the reasons are clear: the vast majority of sediments simply dip north,

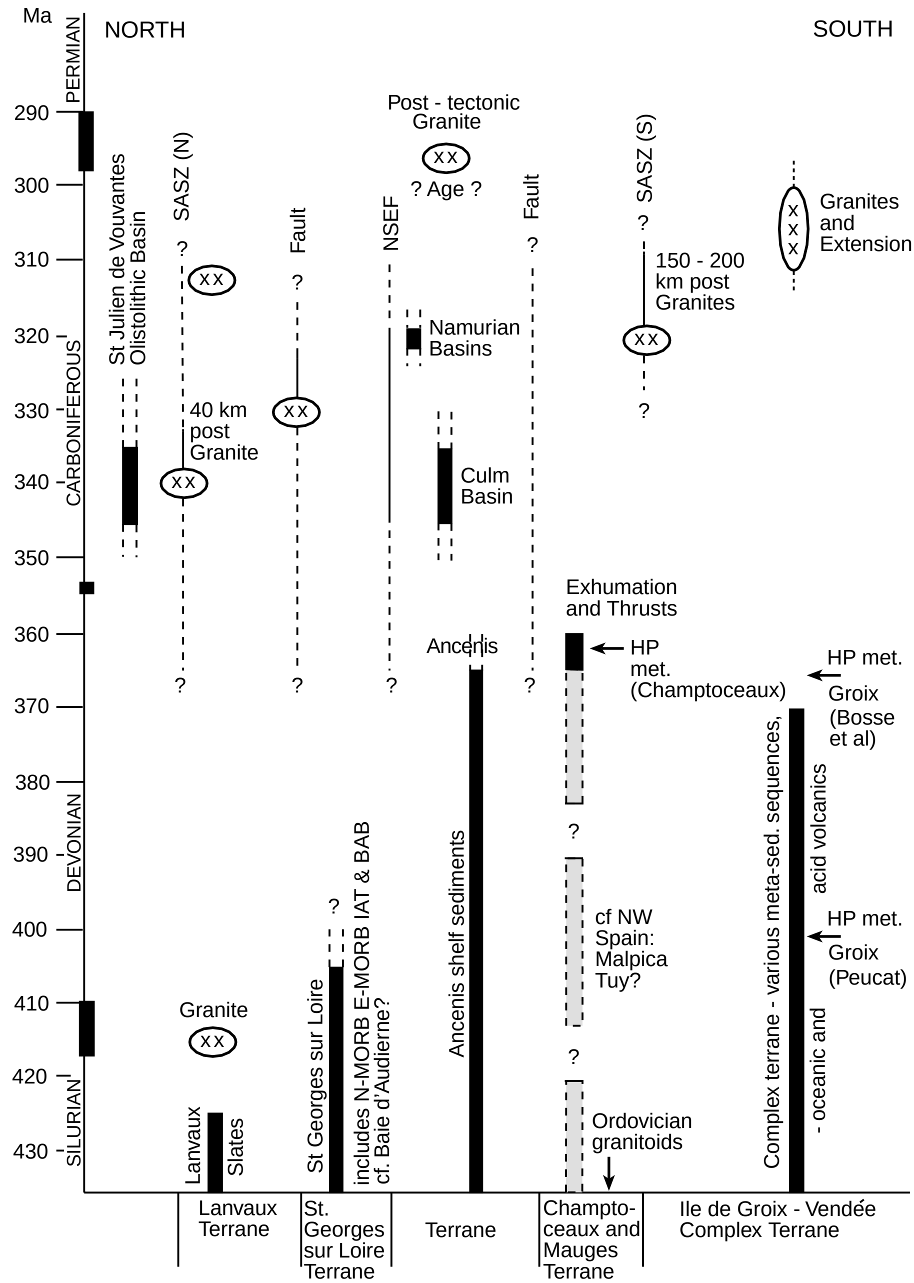

Fig. 6. Age relationships between Ancenis and neighbouring terranes, the bounding faults, and granitoids. Solid lines and blacked out areas indicate probable and certain ages, dashed lines possible and uncertain ages. SASZ (N) and SASZ (S) are the northern and southern branches of the South Armorican Shear Zone. NSEF is the Nort-sur-Erdre Fault. Terrane terminology is from Shelley and Bossière (2000). See text for further discussion.

including the Ordovician–Devonian sediments along the southern and northern rims and western and eastern extremities of the terrane, and almost the entire mass of Culm (Fig. 5), right up to its northern boundary (Diot, 1980).

5.1. The Culm sedimentary basin

The Culm deposits are faulted against all the other Paleozoic formations, and are wrapped around by transpressional shear zones, as described above. There is no particular sedimentary facies that characterises the margins or centre of the basin, and there is no description of systematic thickening of the Culm in relation to a depositional basin. The Culm is as easily described as a tectonically-bound block as a sedimentary basin. Nevertheless, the coincidence of the exposure of the marine Ordovician–Devonian sequence as a rim around the non-marine Culm does suggest Culm deposition took place in a localised fault-bound depression within which the Ordovician–Devonian sequence was locally

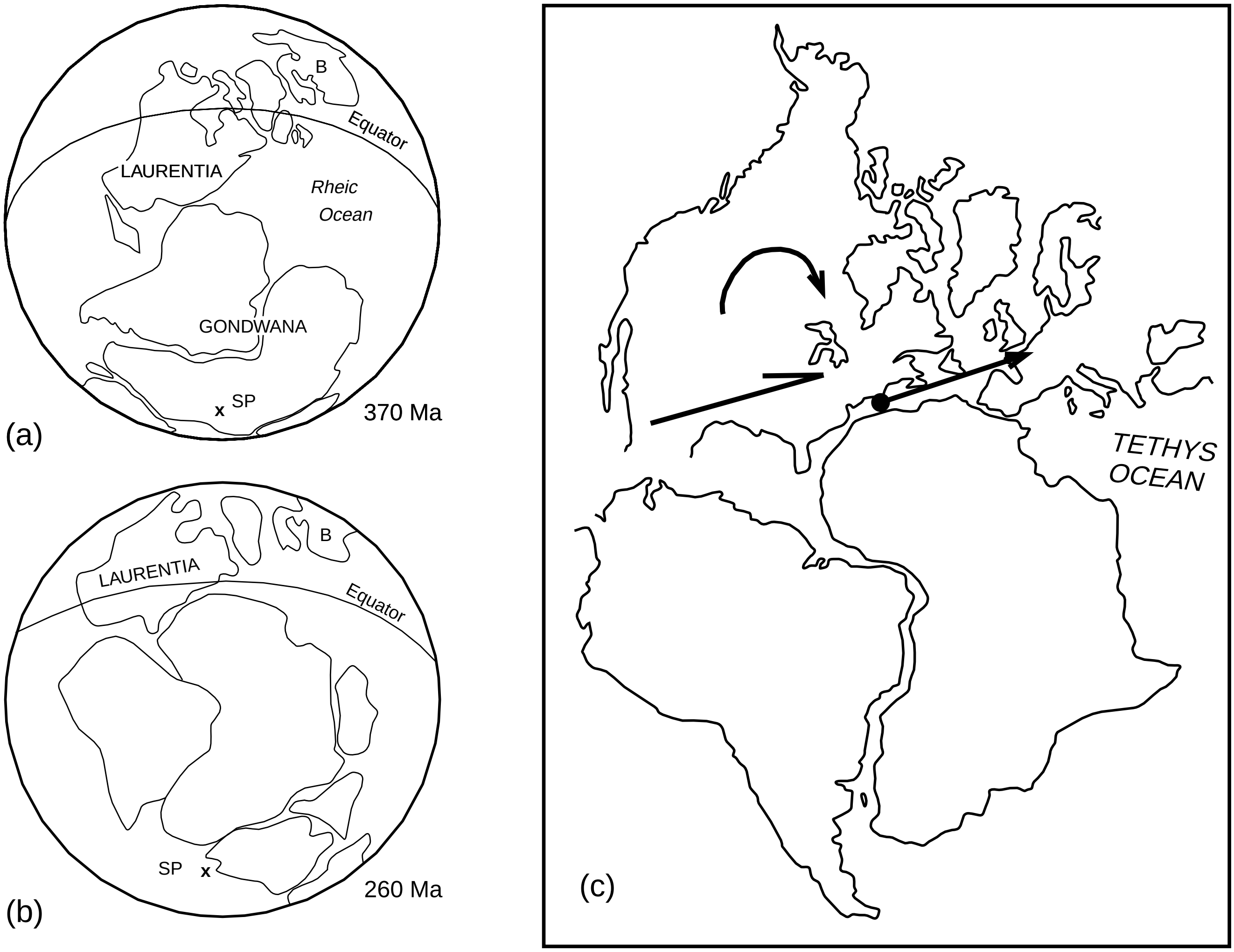

Fig. 7. Laurentia and its dextral shearing along the northern boundary of Gondwana to form Pangea and the Hercynian Orogen. SP = South Pole and B = Baltica. The Hercynian events at Ancenis, discussed in this paper, took place between 370 and 260 Ma, and (a) and (b) show that Laurentia moved dextrally with respect to Gondwana by several thousand kilometres during that time. In (c), the filled circle and arrow show how north Brittany may have been translated dextrally from NW Africa to its present site in response to the dextral translation of Laurentia, as discussed in Shelley and Bossière (2000). In addition to the massive dextral movement, Laurentia and Baltica must have rotated clockwise to form Pangea. (a) after Dalziel et al. (1994), (b) after Dalziel (1995), and (c) after Bullard et al. (1965).

protected from erosion through downfaulting and burial beneath the Culm. The non-marine nature of the Culm indicates the depression was localised within an area of general uplift.

5.1.1. Sinistral or dextral pull-apart?

Diot (1980) proposed that the Culm was deposited in a sinistral pull-apart basin. The rhomboidal shape of the present outcrop immediately suggests this (Fig. 1), but there are four major problems.

First, evidence for sinistral movement consists of fold vergence in the Ordovician–Devonian metasediments near Pierre-Meslière (Diot, 1980) and sinistral shearing in the Brioverian basement (Diot and Blaise, 1978). The evidence is weak because fold vergence is not a reliable shear sense indicator (Bell and Johnson, 1992), dextral shearing also occurs near Pierre-Meslière (as we record above), and the Brioverian structures may be Cadomian.

Second, the shape of the present Culm outcrop cannot be simply related to a single structure such as a pull-apart because transpressive shear zones border both the southwestern and southeastern margins of the Culm, and the NSEF borders both the northwestern and northeastern margins. A sinistral pull-apart would, for example, be marked by transpressive shearing only along the southwestern and northeastern boundaries. Whatever kind of pull-apart the basin was, it has been subsequently deformed, and this is indicated also by the steepened dips of the Culm and its completely fault-bound nature.

Third, the faults of both south and north Armorica are generally dextral (Gapais and Le Corre, 1980). Both the SASZ-N (which is parallel to the NSEF) and the SASZ-S are major dextral faults. Fig. 6 shows that the SASZ-N was moving dextrally at the same time the Culm was deposited, the evidence being displacement of syntectonic granitoids. To the south, Guineberteau et al. (1987) proposed that the Mortagne Granite was emplaced at 315 Ma within a Hercynian sinistral pull-apart structure, but Román-Berdiel et al. (1997) have now shown that the granite was emplaced during dextral shear. It requires extraordinary pleading, therefore, to suppose the NSEF was a sinistral fault in this context of purely dextral faulting, and that it was a sinistral fault during Culm deposition, but dextral later.

Fourth, in a pull-apart basin, one expects the sediments to be rotated by listric normal faulting. If, therefore, the rhomb-shaped Culm outcrop represented a sinistral pull-apart, one would expect the Culm to have dipped either towards the NW or SE. If the pull-apart structure was subjected to N–S compression in conjunction with thrusting from the north, dips would have steepened and rotated towards the NNW or SSE. The Culm dips NNE (Fig. 5), however, seemingly incompatible with a sinistral pull apart.

The overwhelming evidence from the region as a whole is for Hercynian dextral shearing, and one can conclude that the Ancenis Culm was probably deposited in a dextral pull-apart. The fact that dextral faults and transpressional shear zones completely surround the Culm outcrop invites one to consider the shape of the outcrop and of the terrane as a whole in terms of the deformation. Is the shape a large scale analogue of a micafish or σ-type porphyroclast in sheared rock? Before we discuss this, we discuss the plate tectonic setting for these events.

5.2. Plate tectonic setting of the Ancenis Terrane in the Hercynian

According to Kent and Van der Voo (1990), Dalziel et al. (1994), Dalziel (1995), and Torsvik (1998), Laurentia was tucked in to the west of South America in the Devonian, a position that requires a massive dextral displacement of Laurentia along the northern margin of Gondwana to form the supercontinent Pangea (Fig. 7). This is the plate tectonic setting for the development of the Hercynian Orogen and the well known south Armorican dextral transcurrent faulting (Gapais and Le Corre, 1980; Rolet et al., 1994) that took place in the Carboniferous. Shelley and Bossière (2000, 2001) have modelled Gondwanan France and Iberia as slices of Gondwanan continental shelf and Rheic Ocean, shuffled together and shifted dextrally by thousands of kilometres. In Armorica, many of the faults cut or are cut by granites, or are sites of Carboniferous sedimentary basins. Thus, the SASZ-N was active 340 Ma ago (Bernard-Griffiths et al., 1985), since which time dextral movement has been approximately 40 km (see Fig. 6 and Jegouzo and Rossello, 1988); Faure and Cartier (1998) have shown that dextral shearing was still active 312 Ma ago within the Lanvaux Terrane, immediately south of the SASZ-N. The fault between the Lanvaux and St Georges-sur-Loire Terranes was active when granites were intruded along it about 330 Ma ago (Bernard-Griffiths et al., 1985); the displacement since then is not known. The NSEF was active during the Namurian (Diot and Blaise, 1978), around 320 Ma ago and during deposition of the Culm around 340 Ma ago, and it continued to be active in the Mesozoic (Lorenz and Lorenz, 1983), but the total amount of displacement is not known. The SASZ-S affects 320 Ma granites (Bernard-Griffiths et al., 1985), and on the basis of the width of mylonitised granite, Jegouzo and Rossello (1988) suggested that post-granite displacement is 150–200 km. South of the SASZ-S there are 300–310 Ma syntectonic granites (Bernard-Griffiths et al., 1985), associated, according to Gapais et al. (1993), with an extensional rather than transpressional régime. These data are shown in Fig. 6, which shows how granitic activity and the later stages of movement migrated from north to south.

The crucial point is that the data do not show when the faults were initiated. If they were initiated at the end of stable Gondwanan shelf sedimentation, towards the end of the Devonian, the time interval between then and the latest movements on the faults is sufficient to accommodate many thousands of kilometres of lateral displacement (Shelley and Bossière, 2000). Fig. 6 shows that there is at least 25 Ma, and possibly 30 Ma, between Devonian marine sedimentation and the end of development of the Culm basin (there are uncertainties in the age of the latest Devonian and the start and finish of Culm deposition). At modest rates of relative plate motion (5 cm/year) this allows up to 1500 km movement of the Ancenis Terrane prior to the end of Culm deposition; this becomes 3000 km if faster rates of 10 cm/year are contemplated. Between the end of Devonian sedimentation and the formation of the Namurian Basins, the time gap is approximately 40 Ma, allowing 2000–4000 km total movement. Although these figures show the complete adequacy of time available to effect major lateral displacements of the terranes, including Ancenis, they do not show exactly where the mega-displacements took place. Clearly the displacements were partitioned amongst all the dextral shears in the region, and we do not know whether a dextral fault to the south, such as the South Armorican Front or Suture (Lefort et al., 1997, fig. 12), acted as a master fault, taking up the bulk of the movement.

During the Carboniferous, the principal shortening direction observed in Armorica swings around from WNW–ESE to N–S (Rolet et al., 1994; Edel and Weber, 1995). The same swing occurred in Iberia at the end of the Carboniferous (Kollmeier et al., 2000; Weil et al., 2000). This is consistent with the swing in attitude of the shear planes from the earlier E–W NSEF and WNW–ESE SASZ-N to the later NW–SE SASZ-S, and it is consistent with late Carboniferous thrusting from the north along the NSEF (Diot and Blaise, 1978; Marchand et al., 1988). The change in shortening direction was accompanied by clockwise rotation of the dextral shears by up to 50° to form part of the curved Ibero–Armorican arc (Perroud 1986; Edel, 1987). The bending is consistent with extension along the arc length (e.g. Bouchez

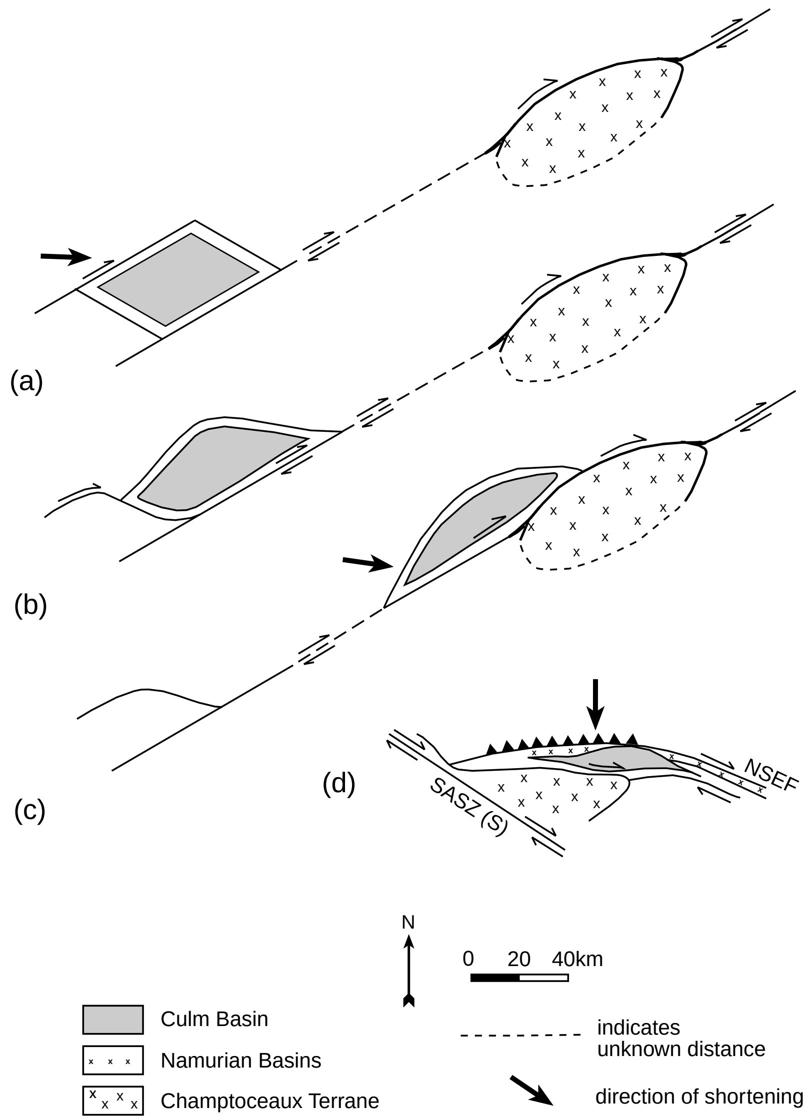

Fig. 8. Cartoon to show: (a) formation of the Ancenis Culm basin as a dextral pull-apart at some unknown distance from its present site, in association with NE–SW transcurrent faulting; (b) detachment of the basin from the former host terrane by shearing along its southern boundaries; (c) dextral translation as an exotic duplex (with its concentric pattern of Brioverian basement and Ordovician–Devonian shelf sediments protected by burial under the Culm), and juxtaposition against the Champtoceaux Terrane; and (d) rotation of the terrane by up to 50° clockwise, shortening from the N–S which causes flattening against Champtoceaux, and curvature of the terrane tails as dextral shearing takes place along the SASZ-S and NSEF. The teeth along the NSEF indicates dip of the fault plane where thrusting occurred.

and Blaise, 1976), and consistent with the transpressional shear zone along the southern boundary of the Ancenis Culm, which displays significant amounts of sinistral as well as dextral shearing.

5.3. From dextral pull-apart to deformed duplex

One way to understand the possible progressive development of the Ancenis Terrane is to try, progressively, to undo the deformations imposed on it. The likely effects of Namurian and post Namurian tectonism were:

1. Shearing along the entire northern boundary of the terrane, the NSEF, as indicated by development of narrow Namurian basins from west of Nort-sur-Erdre to the far east of the terrane.
2. Dextral shearing, concurrent with the development of the SASZ-S, so that the western extremity of the terrane curves and merges with the SASZ-S, and the eastern extremity curves around towards NW–SE.
3. Compression, including thrusting from the north, so that the NSEF becomes inclined, at least in the western part of the terrane, overriding the terrane at Nort-sur-Erdre to produce an embayment on the fault line.
4. Transpression and stretching along the length of the Ibero–Armorican arc, and wrapping of the terrane around the rigid meta-plutonic complex of Champtoceaux. Along the southwestern boundary of the Culm

outcrop, the transpression caused the phyllites and quartzites of Pierre-Meslière to be squeezed up from depth. In contrast, the unmetamorphosed sediments at Chateaupanne were in a zone not subject to significant uplift, and which was probably never buried to any great depth. The Chateaupanne area can be viewed rather like a pressure shadow in the eastern lee of the terrane, east of the massive Champtoceaux block.

It is not clear what the displacement is along the southern or northern boundaries of the terrane, post development of the Culm basin, but according to the above scenario, by the time the Pierre-Meslière metamorphics were squeezed up, the Chateaupanne area must have been east of Champtoceaux. If there were major lateral displacements along the southern boundary, greatly in excess of 10 km, they must have been contemporaneous with Namurian basin development or earlier.

5.3.1. Ancenis—an exotic duplex

It is its remarkably simple concentric pattern of formations (Fig. 1) that leads us to suggest the Ancenis Terrane is an exotic duplex. The pattern indicates that the Ordovician–Devonian covering strata were preserved during Hercynian uplift only because those strata were protected by the Culm. This shows that most of the transpression and faulting affecting the terrane took place concurrently with, and subsequent to, Culm Basin formation. In effect, the Ancenis Terrane exists only because of the Culm Basin, and its contrasting geological relationships with neighbouring terranes shows it must, therefore, be an exotic duplex. The initial pull-apart basin must have developed within a larger terrane, and split off in the manner envisaged by Woodcock and Fischer (1986), and illustrated by Park (1988, fig. 6.5). The idea, applied to Ancenis is illustrated in Fig. 8.

According to this model the original rhomb-shape of the pull-apart would have been destroyed during the early stages of its exotic development. The relatively rigid nature of the meta-plutonic Champtoceaux Terrane may have played an important part in later developments. These would probably have been:

1. A general flattening and reshaping of the Culm basin as the terrane was wrapped around Champtoceaux. This may explain, in part, the combination of sinistral and dextral shearing in the transpressional shear zone at the southern boundary and the long tails of the terrane.
2. During the later stages of wrapping around Champtoceaux, the regional shortening direction had changed to N–S, perpendicular to the Champtoceaux–Ancenis terrane boundary. This would have induced rocks to be squeezed up along this boundary, as exemplified by the exhumation of the Pierre-Meslière phyllites and quartzites.
3. In this model, the present rhomb-shape reflects the natural recurvature of the southern terrane boundary, to be expected on the eastern side of the rigid Champtoceaux mass (Fig. 8).
4. The other reason for reshaping of the Culm basin is Namurian dextral shearing and formation of the SASZ-S. Thus, the tails of the terrane were rotated into a NW–SE orientation along the SASZ-S and along the NSEF east of the massive Champtoceaux Terrane, as described above in Section 5.3. The final effect is a shape rather like a mica-fish in a mylonite.

It is not clear whether the terrane boundaries acted as independent shears along which lateral movements were concentrated, or whether the wide zone of transpressional shear, particularly obvious in the diverse lithologies of the Paleozoic, incorporated much of the lateral movement. Possibly it is a combination of the two, with a partitioning of lateral movement along the boundary, and partitioning of the pure shear and vertical extension into the wide zone of transpression.

Interestingly, the concept of transformation from dextral pull-apart to transpressional duplex is shown in fig. 19 of Rolet et al. (1994). However, there are two problems with this figure. First, it is at odds with the text which describes the structure only in terms of a sinistral pull-apart. Second, it portrays the Armorican shear zones as static features throughout the Hercynian Orogeny.

6. Conclusions and discussion

Our conclusions, based on new field data and observations and reinterpretation of the existing literature using tectonostratigraphic terrane modelling, are:

1. The Ancenis Terrane of the Hercynian Orogen is set amongst different and incompatible neighbouring terranes within the South Armorican Dextral Shear Zone. A probable plate tectonic setting for the shear zone is the dextral translation of Laurentia by thousands of kilometres along the northern boundary of Gondwana to form Pangea.
2. The Ancenis Terrane is a lozenge-shaped complex bordered by dextral faults and a wide zone of transpressional shear. Its overall shape is mimicked internally by numerous smaller lozenge-shaped blocks of Paleozoic sediment within which bedding dips to the north, and which are enveloped by shear zones with subvertical foliation, vertical penetrative stretching, and vertical and horizontal shearing.
3. The terrane, including its Culm basin, has a complex history, and before the nature of the Culm basin can be judged, it is necessary to remove the substantial tectonic effects that post date basin formation.
4. The Culm basin did not form as a sinistral pull-apart basin. Dip directions of the Culm, and the regional setting of dextral shears, both indicate a dextral pull-apart.

5. The extraordinary concentric pattern of the terrane and shearing along all its boundaries indicates that the dextral pull-apart basin did not form in situ. It is most easily explained in terms of an exotic duplex where shearing was contemporaneous with the formation of the Culm basin and its separation from the host terrane.
6. We interpret the Culm basin, therefore, as having formed at a substantial but unknown distance to the west. During its subsequent dextral translation we suggest it became wrapped around the rigid Champtoceaux massif. In this model, the present rhomb shape bears little relation to the original shape of the pull-apart.
7. In the later stages of its development during N–S shortening, the Ancenis Terrane was subject to further dextral shearing along its northern boundary, the NSEF. The tails of the terrane were curved towards NW–SE at this time, concurrent with activity along the southern branch of the South Armorican Shear Zone. This gave the terrane a shape similar to a mica-fish.
8. During this period of N–S shortening, relatively deep-seated rocks (the Ordovician phyllites and quartzites of Pierre-Meslière) were squeezed up along the southern terrane boundary. These are in marked contrast to unmetamorphosed sediments found in the eastern part of the terrane.

Interpretation of Ancenis as an exotic duplex leaves a lot open to speculation about its early history and site of development. Such speculation is inevitable, however, almost by definition: it would not be a tectonostratigraphic terrane otherwise. In Shelley and Bossière (2001), we have developed a detailed model for the displaced terranes of Gondwanan Iberia and France, but in that paper we have not explored the relationships of Iberian and French terranes with areas further east, such as Bohemia. It is an important point for further discussion whether the lower Paleozoic faunal affinities between Ancenis and Bohemia simply indicate easy communication along the outershelf environment, or whether Bohemia and Ancenis were originally closer together, with Bohemia sheared dextrally to its present position.

Acknowledgements

This work was made possible by the Université de Nantes, which invited DS to Nantes as a visiting professor, and by the University of Canterbury for its provision of study leave. We wish to thank the following for their assistance: Michel Robardet, whose constructive critical comments during the review process were greatly appreciated; Hervé Diot, who very generously provided Fig. 2c, which comes from his thesis; John Bradshaw, for useful critical comments at various stages in the development of this paper; and Messieurs Binet and Plumejeau for providing every assistance in visiting the Chateaupanne Quarry.

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