Journal of the Geological Society, London, Vol. **143,** 1986, pp. 141–147, 3 figs. Printed in Northern Ireland

Correlation of the Rhenohercynian Variscides

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Abstract: Recent structural and stratigraphical data from the Rhenohercynian Variscides of Belgium, Germany and South Cornwall indicate tectonic continuity within this zone prior to disruption along a late Carboniferous dextral transcurrent fault. This extends from the Bristol Channel to the Vosges, parallel to similar lineaments of Variscan age in Europe and North America. Consequently, a tectonic model for south Cornwall is extrapolated to Europe and a plate tectonic setting for the evolution of the north European Variscides by the closure of an oceanic basin is discussed.

Resemblances between the Variscan sequences in Devon and Cornwall, the Rheinisches Schiefergebirge and the Harz mountains of Germany have been recognized for some time, notably:

(i) Similarities of stratigraphy, with comparisons made on the scale of single beds (Matthews & Thomas 1974; Matthews 1977).

(ii) Two peaks of volcanic activity, one in the Upper Devonian and one in the Lower Carboniferous (Franke & Engel 1982).

(iii) A northward migration of metamorphism accompanying deformation from Upper Devonian and Lower Carboniferous in the south to Upper Carboniferous in the north (cf. Dodson & Rex 1971; Ahrendt *et al.* 1983).

(iv) Shelf sequences containing reefal and pelagic limestones that were deposited on long-lived topographic highs separated by mudstone-dominated basins (Goldring 1962; Stewart 1981; Engel *et al.* 1983a; Franke & Walliser 1983).

(v) Clastic shelf sediments having a northerly provenance (Franke & Engel 1982; Selwood & Durrance 1983) overlain by southerly-derived flysch deposited in basins that migrated northwards. The flysch ranges in age from Lower to Middle Devonian in the south to Upper Carboniferous in the north (Whiteley 1981; Franke & Engel 1982; Kasig & Wilder 1983; Engel & Franke 1983; Engel *et al.* 1983*a*; Leveridge *et al.* 1984).

These features have fuelled speculation that there was sedimentary and tectonic continuity between these two parts of the Variscan belt (Franke & Engel 1982). However, the wide separation of the areas at present, and the interposed Ardennes Massif with its different sedimentary facies and tectonic history (Kasig & Wilder 1983) has lead Matthews (1977) and Badham (1982) to suggest that no continuity was possible.

Similarities between the Rhenohercynian zones of SW England and Germany

Recent work in Devon and Cornwall, and in the southern Rheinisches Schiefergebirge and Harz mountains has revealed further similarities in the tectonic evolution of these areas which strongly argue for continuity within the belt.

Deformation

Deformation within the areas, although polyphase, is typically co-axial (Rattey & Sanderson 1982; Weber & Behr 1983) and in its early phases is characterized by the NW transport of thrust nappes associated with NW-facing and verging asymmetric folds (Rattey & Sanderson 1982; Isaac *et al.* 1982; Engel *et al.* 1983*a,b*; Leveridge *et al.* 1984).

Mid-German Crystalline Rise

The Mid-German Crystalline Rise forms the southern margin of the Rhenohercynian zone in Germany (Fig. 1). It constitutes a thrust nappe of Variscan age that was transported northwards from the early Devonian onwards (Weber & Behr 1983) and acted as a sedimentary source for the Devonian to Carboniferous flysch of the Rhenohercynian Zone (Engel *et al.* 1983*c*; Walliser & Alberti 1983). Rb–Sr dating indicates cooling ages of about 370 Ma (Kreuzer & Harre 1975; Hellmann *et al.* 1982) and these are confirmed by the presence of Middle Devonian limestone resting unconformably on the Mid-German Crystalline Rise in the Saar 1 Borehole (Giese *et al.* 1983; Engel *et al.* 1983*c*). In south Cornwall a similar thrust nappe of crystalline basement, the Normannian Nappe (Fig. 1), acted as the sedimentary source for the Devonian flysch from the early Devonian onwards (Holder & Leveridge 1986). Dating of the only exposed segments of this nappe gives a Rb–Sr age of 369 ± 12 Ma for the Kennack Gneiss (Styles & Rundle 1984) and a K–Ar age of 375 ± 17 Ma for the Eddystone Gneisses (Miller & Green 1961).

Phyllite Zone

Along the northern flank of the Mid-German Crystalline Rise in Germany is another thrust nappe, the 'Northern Phyllite Zone' (Weber & Behr 1983; Fig. 1) consisting of Ordovician to Devonian metasediments and metavolcanics (Giese *et al.* 1983). Its peak metamorphic temperature (400–450 °C; Weber & Behr 1983) is intermediate between that of the crystalline basement rocks of the Mid-German Crystalline Rise, and of the low grade rocks (200–300 °C, Weber & Behr 1983) of the northern Rheinisches Schiefergebirge and Harz mountains. K–Ar and Rb–Sr ages of 312 ± 12 Ma and 312 ± 7 Ma for these phyllites were interpreted by Ahrendt *et al.* (1983) as indicating post-metamorphic uplift. Similar metasediments and metavolcanics are represented in SW England by the allochthonous (Hendriks 1939; Coward & McClay 1983; Day & Edwards 1983) mica- and chlorite-schists of the Start Complex. These rocks record a K–Ar age of about 305 Ma interpreted by Dodson and Rex (1971) to be a superimposed

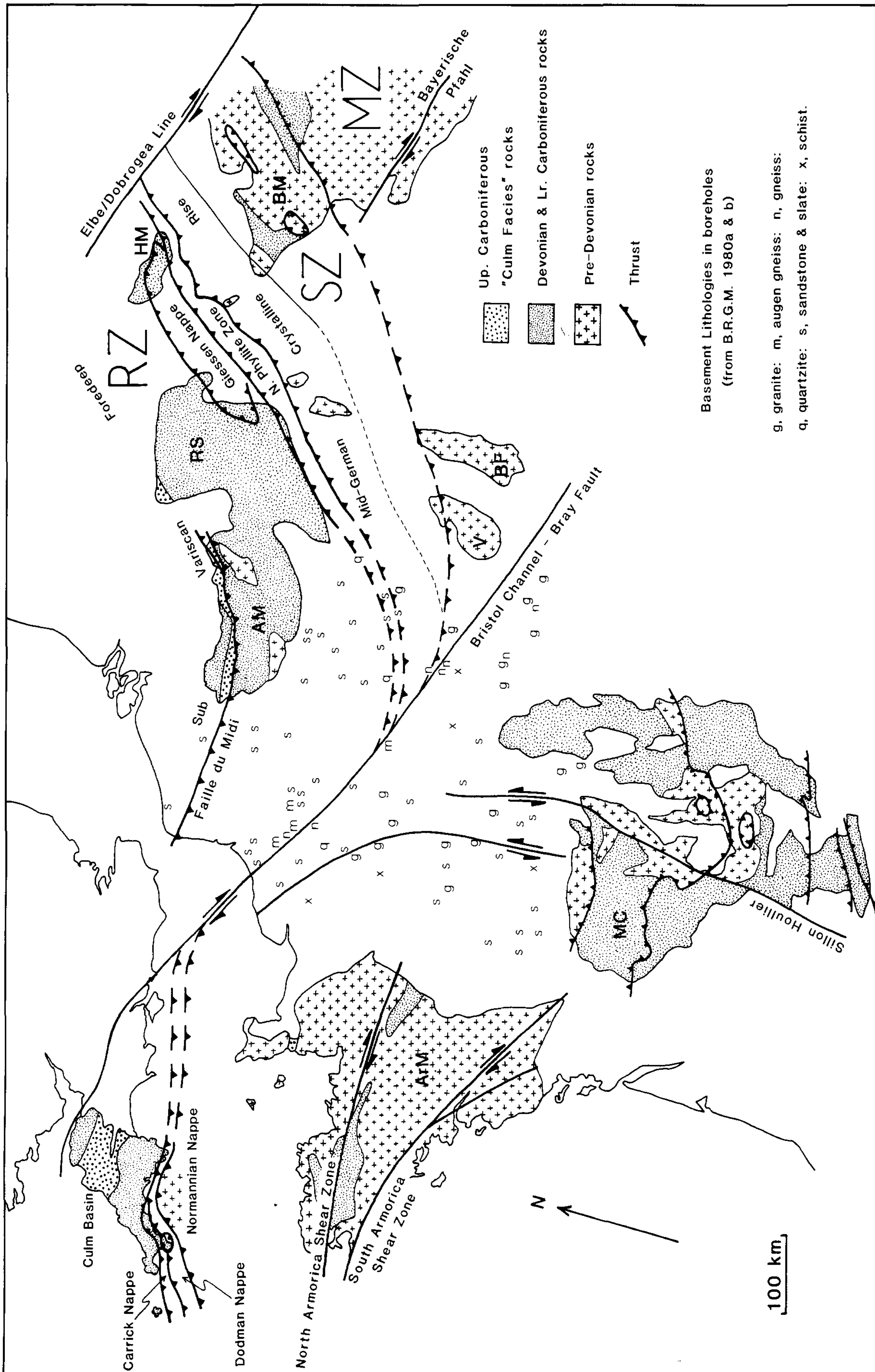

Fig. 1. A geological sketch map of the North European Variscides showing the position and displacement of the proposed Bristol Channel-Bray dextral fault zone. AM, Ardennes Massif; ArM, Armorican Massif; BF, Black Forest; BM, Bohemian Massif; HM, Harz Mountains; MC, Massif Central; MZ, Moldanubian Zone; RS, Rheinisches Schiefergebirge; RZ, Rhenohercynian Zone; SZ, Saxothuringian Zone; V, Vosges.

age. The relationship between the Start Complex and the Normannian Nappe is revealed in shallow reefs in Plymouth Bay where, along strike from the Start Complex, rocks of similar lithologies to the Start Schists are overlain by the Eddystone Gneisses [unpublished British Geological Survey (BGS) information]. West of the Plymouth Bay Fault (Day & Edwards 1983), greywackes that in part show similar metamorphic grades to the Start Schists are exposed in the Dodman Nappe (Leveridge *et al.* 1984; Fig. 1). These greywackes may correspond to those proved in boreholes in the south of the Northern Phyllite Zone (Engel *et al.* 1983*b*).

Devonian flysch nappes

Immediately to the north of this zone of phyllitic rocks both in south Cornwall and in Germany, the most southerly of the flysch sequences are exposed in thrust nappes: in south Cornwall in the Carrick Nappe (Leveridge *et al.* 1984) and in the Rheinisches Schiefergebirge and Harz mountains in the Giessen Nappe (Engel *et al.* 1983*b*; Fig. 1). Both nappes contain southerly-derived turbiditic greywackes deformed by folds associated with northwesterly nappe transport (Engel *et al.* 1983*b*; Leveridge *et al.* 1984). The situations of these two nappes differ in two respects:

(i) The Giessen Nappe only certainly contains flysch of Frasnian age (Engel *et al.* 1983*b,c*). Southerly-derived Middle Devonian (Meischner 1968) and possibly Lower Devonian (Bender *et al.* 1974) flysch is present in underlying nappes. The Carrick Nappe contains flysch of at least Emsian to Frasnian (Le Gall *et al.* 1985) age with possibly Givetian and younger breccias and olistostromes (Hendriks *et al.* 1971; Leveridge 1974). A restricted sequence of Eifelian pelagic limestone turbidites and radiolarian cherts (Holder & Leveridge 1986) is also included.

(ii) The breccias and olistostromes of the Carrick Nappe contain large exotic clasts of Ordovician quartzite, Silurian to Middle Devonian limestones and basic volcanic rocks, and overlie the flysch with sedimentary continuity (Barnes 1983; Leveridge *et al.* 1984). In the Rheinisches Schiefergebirge exotic Ordovician quartzite, Silurian to Devonian limestones and Lower Devonian neritic clastic rocks are regarded as 'tectonic slices' below the Giessen Nappe (Engel *et al.* 1983*a,b*). The same lithologies in the Harz Mountains are interpreted as either tectonic or sedimentary mélange (see Walliser & Alberti 1983).

The thickness of the Carrick Nappe varies widely (Leveridge *et al.* 1984). In offshore seismic sections it appears to reach a maximum of 12 km while onshore its maximum is 6.7 km decreasing to 2.5 km north of the Lizard. This variation may be caused by the presence of footwall ramps in the Carrick Thrust cutting out stratigraphically lower parts of the flysch sequence (Leveridge *et al.* 1984). Such ramps are typical of large thrusts (Elliott & Johnson 1980; Boyer & Elliott 1982) and their presence in the Giessen Thrust may explain the absence of pre-Frasnian flysch in the exposed klippen. Pre-Frasnian flysch could, however, be present in the root zone of the nappe, which Engel *et al.* (1983*c*) suggested to be at the rear of the Phyllite zone but which, on available evidence, could lie beneath the Phyllite zone.

The Roseland Breccia Formation in the upper part of the Carrick Nappe represents sedimentary breccias and olistostromes formed by erosion of Ordovician to Devonian continental shelf deposits and metamorphic basement of the Normannian Nappe (Holder & Leveridge 1986). Olistostromes are also present beneath the Carrick Nappe in those areas where the thrust cut up to the penecontemporaneous surface and the nappe overrode its own erosional debris (Leveridge & Holder 1985).

The local admixture of 'tectonic slices' (Engel *et al.* 1983*a,b*) of exotic Ordovician to Devonian lithologies with widespread greywacke slices below the Giessen Nappe suggests an origin by the shearing and flattening of olistostromes. If so, breccias equivalent to the Roseland Breccias could be present on top of the Giessen greywackes in the nappe root zone. Unfortunately, lack of exposure does not permit discrimination between a sedimentary origin and the tectonic origin proposed by Engel *et al.* (1983*b*).

Carboniferous flysch nappes

North of the Giessen Nappe in the Rheinisches Schiefergebirge and Harz mountains is a belt of southerly-derived Upper Devonian to Lower Carboniferous greywackes (Engel *et al.* 1983*c*) forming the Hörre–Acker greywacke nappe (Engel *et al.* 1983*b*). Lower Carboniferous flysch is likewise present north of the Carrick Nappe in the allochthonous St Mellion outlier (Whiteley 1983). Comparisons of greywacke composition between Lower and Upper Carboniferous flysch in England and in Germany have revealed a similar decrease in the feldspar content of the greywackes with time (Whiteley 1983; Engel *et al.* 1983*b*).

Basic volcanicity

The geochemical characteristics of the basaltic rocks of south Cornwall and those of the southern Rheinisches Schiefergebirge and Harz mountains show similar trends. In south Cornwall the distributions of basalts with intraplate and ocean-floor chemistries (Floyd 1984) relate to the Carrick Nappe and the underlying parautochthon, respectively (Leveridge *et al.* 1984; Holder & Leveridge 1986). East of the Rhine, REE-depleted ocean-floor tholeiites lie at the base of the Giessen Nappe with intraplate basalts in the underlying parautochthon (Wedepohl *et al.* 1983).

Permian basins

Normal faulting related to the formation of the late Carboniferous(?) to Permian basin in Plymouth Bay has been interpreted as back-slip associated with the reactivation and reversal of the Dodman and Normannian Thrusts (Day, 1985). Behr *et al.* (1984) explain the formation of the late Carboniferous to Permian Saar–Nahe Basin by back-slip along the thrust at the base of the Mid-German Crystalline Rise.

Late Variscan shearing

The sedimentary and tectonic similarities between Variscan rocks of SW England, and those of the Rheinisches Schiefergebirge and Harz areas are such that it is unreasonable to deny continuity between these areas during the Variscan. However, geophysical evidence shows that basement lineaments related to the main structural zones in Germany terminate against the Bray Fault [Bureau de Recherches Géologiques et Minières (B.R.G.M.) 1980*a*]. Similar truncation of magnetic and gravity anomalies

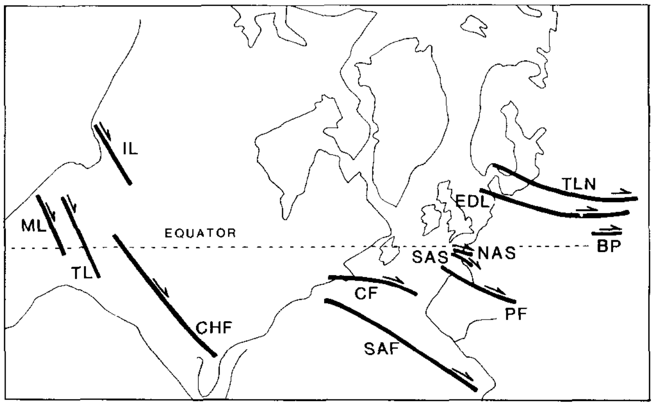

Fig. 2. Early Permian reconstruction of the continents around the Atlantic showing the distribution of shear zones of Variscan age (modified from Dewey 1982). BP, Bayerische Pfahl; CF, Chedabucto Fault; CHF, Choctaw Fault; EDL, Elbe/Dobrogea Line; IL, Idaho Line; ML, Mohave Lineament; NAS, North Armorican Shear Zone; PF, Pyrenean Fault; SAF, South Atlas Fault; SAS, South Armorican Shear Zone; TL, Texas Lineament; TLN, Tornquist Line.

associated with Variscan structures in SW England occurs against the fault in the English Channel [Institute of Geological Sciences (I.G.S.) 1978*a,b*]. The posthumous influence of the fault in mid-channel is indicated by termination and deflection of structures within Mesozoic and Tertiary rocks (I.G.S. 1977). Major oblique dextral transcurrent faults and shear zones are common within the Variscan belt of Europe (Fig. 2; Behr 1983; Arthaud & Matte 1977; Lefort *et al.* 1977). Dewey (1982, fig. 37) indicated dextral motion on several late Devonian to early Permian transform faults with trends between 270 and 310°N; these included the South Atlas Fault, the Chedabucto Fault and the Tornquist Line. It is therefore proposed here that a major dextral transcurrent shear of similar trend is responsible for the separation of the SW England and German Rhenohercynian.

The NW–SE-trending Bray Fault (Fig. 1), now known to be a major crustal fracture which displaces the Moho (Day 1985) separates two distinct basement regions. Southwest of the fault, basement lithologies are dominantly granitic with sporadic sedimentary cover, representing a continuation of the basement in Brittany. On the northwest side of the fault there is a northerly zone of sandstones and slates of Rhenohercynian affinities, and a southerly zone of granitic rocks similar to those of the Mid-German Crystalline Rise and Moldanubian block. Between the zones, quartzites encountered in boreholes possibly correspond to exotic lithologies of the southern Rhenohercynian. Largely limited to the line of the fault are 'augen gneisses' which could well be blastomylonites comparable to those of the Bayerische Pfahl (Behr 1983).

The onshore continuation of the Bray Fault in southern England is demonstrated by differences in the Upper Palaeozoic rocks occurring beneath the Triassic. In boreholes at Marchwood (BGS, SU 3991 1118) and in the Arreton no. 2 borehole (Gas Council, SZ 5320 8580) southwest of the fault, up to 880 m of red bed sequences, described as Devonian 'Old Red Sandstone' facies rocks, are encountered. In contrast, in a nearby borehole (Middleton no. 1, Pennzoil, SU 7390 1510) northeast of the fault some 520 m of Westphalian shales and sandstones have been penetrated. Along the northern boundary of the Hampshire Basin, Edwards & Freshney (in press) suggest that the WNW-trending drape folding of the Tertiary sediments has been caused by fault movements in the pre-Permian Variscan basement. This trend would place the shear zone along the line of the Mere Fault which separates Culm facies rocks to the south from time-equivalent shelf facies rocks to the north (Chadwick *et al.* 1983). Westwards, the fault separates Carboniferous Limestone shelf sequences at Cannington Park (I.G.S. 1982) from the Devonian succession of the Quantocks and separates distinct areas of differing magnetic signature along the line of the Britstol Channel Graben (Whittaker 1975; Kamerling 1979).

Variscan structures have suffered major wrench displacements along the line of the fault in the Paris Basin, whereas subsequent movements have been largely vertical and of smaller scale (see Chadwick *et al.* 1983). The exact timing of the fault movement is problematic but Freshney & Taylor (1980) suggest that movement on such a fault exerted control over Lower Carboniferous sedimentation in SW England. Moreover, palaeomagnetic evidence suggests a change in relative plate motion between the north and south Variscides from normal to oblique dextral closure in the Upper Devonian (Scotese *et al.* 1979). This corresponds in time to closure of the Rhenohercynian ocean basin in SW England (Holder & Leveridge 1986) and could, therefore, reflect the transfer of inter-plate motion to dextral strike-slip faulting.

The nature of the northern Variscan orogenic belt

The swing in strike of the Variscan belt in the western Ardennes is repeated by the Mid-German Crystalline Rise beneath the Paris Basin (B.R.G.M. 1980*b*). Assuming that metamorphic rocks lying just to the south of the Isle of Wight represent the along-strike continuation of the Lizard/Start rocks (McDonald & Smith 1982) the dextral displacement along a Bristol Channel–Bray Fault zone must be about 400 km. Displacing the two areas by this amount restores the continuity of the sub-zones within the Rhenohercynian (Fig. 3): i.e., the 'Old Red Sandstone'-derived clastic rocks of the southern Ardennes (Behr *et al.* 1984) correlate with the fluviatile to marine coarse clastic rocks of North Devon; the Rheinisches Schiefergebirge with central and southern Devon and Cornwall; the northern Phyllite Zone with the Start/Dodman phyllites; and the Mid-German Crystalline Rise with the Lizard and Eddystone Gneisses of the Normannian Nappe. Restored to this position the 'Bristol Channel Land Mass', which was the source for the Middle Devonian Hangman Grits of North Devon (Freshney & Taylor 1980; Dewey 1982), is seen to be a westward extension of the Ardennes Massif of northern France.

If this continuity of the belt is valid, the interpretations made by Holder & Leveridge (1986) for the evolution of south Cornwall should also apply to the German Variscides in the Rheinisches Schiefergebirge and the Harz mountains. The flysch basins represented by the Gramscatho Group and the Giessen greywackes would constitute a zone of flysch sedimentation stretching over 800 km along strike immediately to the north of the Mid-German Crystalline

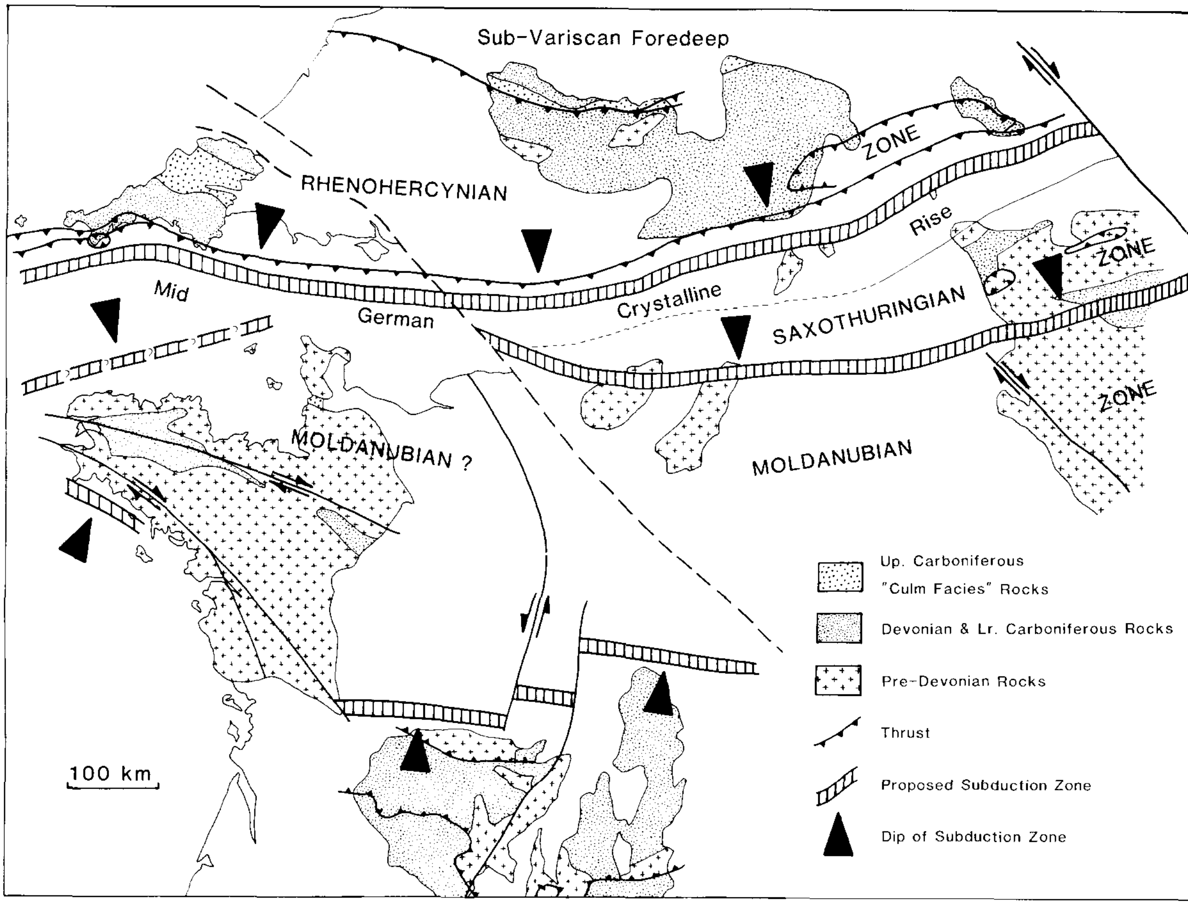

Fig. 3. Reconstruction of the North European Variscides prior to movement on the Bristol Channel–Bray Fault. Subduction zones along the northern edge of the Massif Central are after Bard *et al.* (1980) and Matte & Burg (1981) and the westward extension of the Saxothuringian/Moldanubian subduction zone is after Behr *et al.* (1984).

Rise/Normannian Nappe. Northward overthrusting has preferentially-covered representatives of deeper water or oceanic basin environments in the south of the Rhenohercynian zone leaving it apparently dominated by shallow water shelf sediments. However, an ocean basin within the Variscan belt is suggested by palaeomagnetic evidence (Van der Voo 1983; Scotese *et al.* 1979) and by the division of Cambrian to Devonian faunas between north and south Europe reported by Burrett and Griffiths (1977) although Cocks & Fortey (1982) indicated that the Mid-European Rheic Ocean opened in Silurian times. The presence of a piece of ocean floor represented by the Lizard ophiolite (Strong *et al.* 1975; Floyd 1984) at the northern edge of the Mid-German Crystalline Rise/Normannian Nappe, and high pressure-low temperature metamorphism in the Northern Phyllite Zone (Massonne & Schreyer 1983), implies that this margin is probably a suture (cf. Weber 1978; Behr *et al.* 1984). Despite the apparent lack of calc-alkaline volcanism, possibly due to the erosion of a continental arc from the Mid-German Crystalline Rise and its incorporation into the flysch, and contrary to subfluence theories (see Murata and Weber 1983), it is likely that some oceanic crust has been consumed there.

Evidence for an oceanic environment within the Variscan belt is re-inforced by the presence of ocean-ridge tholeiites within the Giessen/Carrick Nappes and intraplate tholeiites in the underlying shelf sequences (Floyd 1982) although this arrangement has been interpreted by Wedepohl *et al.* (1983) as merely indicating a high heat flow.

Ocean environments within the Rhenohercynian zone render the formation of the time-equivalent thrust belt of the Saxothuringian (Weber & Behr 1983) by intracontinental processes unlikely. Instead, contrary to the proposals of Johnson (1978) and Bard *et al.* (1980), the southern margins of the Rhenohercynian and Saxothuringian zones probably represent the sites of two oceanic basins isolating the Mid-German Crystalline Rise/Normannian Nappe as a continental microplate. This argument is strongly supported by Behr *et al.* (1984) who described the Saxothuringian Zone sediments as an accretionary wedge in a trench setting where subduction commenced in Ordovician times. The NW-polarity of structures within the Rhenohercynian and Saxothuringian Zones suggest that subduction was to the south in both areas (Weber 1978; Johnson 1978; Bard *et al.* 1980; Behr *et al.* 1984; Leveridge *et al.* 1984) and this is supported to some extent by late Variscan calc-alkaline volcanism on the Moldanubian block (Floyd 1982). To the west of the Bohemiam Massif, Johnson (1978), Bard *et al.* (1980), and Behr *et al.* (1984) suggested that the northern boundary of the Moldanubian block extends into the north of the Vosges and Black Forest, and farther west, joins the suture on the northern margin of the Normannian Nappe.

Lateral continuity of the Normannian Nappe with the Mid-German Crystalline Rise would refute this model. The suture at the northern margin of the Moldanubian zone may, however, extend westwards to join a line of ophiolites in the southern Channel and SW Approaches identified by Lefort (1977) (Fig. 3). Alternatively, the Saxothuringian zone may terminate westwards.

Closure of the oceanic basins in the northern Variscides is suggested by Johnson (1978) and Bard *et al.* (1980) to have taken place in late Carboniferous and early Carboniferous times, respectively. However, Holder & Leveridge (1986) propose that closure of the Rhenohercynian ocean was marked by overthrusting of the southerly-derived flysch onto the northern continental margin neritic sediments in the Upper Devonian, with post-closure deformation continuing until the late Carboniferous. This timing is supported by the palaeomagnetic evidence of Van der Voo (1983) which indicates the proximity of Armorica and the Saxothuringian, Rhenohercynian and Moldanubian zones in the mid to late Devonian.

Closure of the northward dipping Variscan suture zone along the northern boundary of the Massif Central is thought by some workers to pre-date (Bard *et al.* 1980; Matte & Burg 1981), and by others (e.g., Johnson 1978) to post-date, closure of the adjacent southward dipping sutures in the Rhenohercynian Zone and Saxothuringian Zone. However, Behr *et al.* (1984) suggested that closure of all these oceanic basins may have been synchronous and interference between them may have lead to alternations of movement between the northward- and southward-directed subduction.

The continuity within the Rhenohercynian zone, the late-Variscan age of the dextral transcurrent faulting and the lack of reliable supporting palaeomagnetic evidence (see also Behr *et al.* 1984) question the validity of Badham's (1982) model of colliding microplates and strike-slip basins at least for this part of the Variscan belt. Nevertheless the presence of contemporaneous northward-directed subduction in south Brittany and the Massif Central (Matte & Burg 1981) and western Iberia (Badham 1982), and southward subduction in the northern Variscides, implies the presence of several plates in the collision zone with complex inter-relationships.

The authors wish to thank British Geological Survey colleagues, notably E. C. Freshney, for their valuable contributions in discussion, and W. Franke and T. J. Chapman for their constructive comments on the manuscript. This paper is published by permission of the Director, British Geological Survey, Natural Environment Research Council.

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Received 26 November 1984; revised typescript accepted 22 September 1985