Originally published as:

McCann, T., Krawczyk, C. M. (2001): The Trans-European Fault: a critical reassessment. - Geological Magazine, 138, 1, 19-29.

DOI: 10.1017/S0016756801004915

The Trans-European Fault: a critical reassessment

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(Received 12 March 2000; accepted 31 August 2000)

Abstract – New deep seismic profiles in the southern Baltic region have failed to image the Trans-European Fault. Evidence for this structure, of suggested pre-Cadomian age, is critically re-examined. Localized geophysical anomalies are present, but these cannot be correlated with known structural features of the region. Based on the inconclusive evidence for this structure, we would therefore propose that the term ‘Trans-European Fault’ should not be used in the future, and that, to avoid confusion, authors use local names for local structures.

1. Introduction

The Northeast German Basin is situated between the stable Precambrian shield area of the Baltic Sea/Scandinavia to the north and the Cadomian/Caledonian/Variscan-influenced areas to the south (Fig. 1). The forelands of the North German-Polish Caledonides are formed by the Precambrian Fennoscandian Shield and its extension beneath the Baltic Depression and the stable East European Platform. The bulk of the Fennoscandian-Baltic craton was consolidated in pre-Grenvillian time (Ziegler, 1990). The Caledonian orogenic cycle (Late Cambrian to earliest Devonian) was governed by the sinistral oblique convergence and collision of the Laurentia-Greenland craton, the Fennoscandian-Baltic craton and Gondwanan-derived microcontinental fragments (Ziegler, 1989).

Two major NW–SE-striking deep fault zones occur to the north of Rügen, including the Caledonian Deformation Front and the Tornquist Zone comprising the Sorgenfrei-Tornquist Zone in the northwest and the Tornquist-Teisseyre Zone in the southeast (Fig. 1). The suspected Trans-European Fault (Pozarski, Brochwicz-Lewinski & Tomczyk, 1982; Berthelsen, 1984) separates Rügen from the North German mainland. Based on geological and geophysical evidence, this structure has been variously interpreted as a Cadomian feature (Berthelsen, 1984), the Avalonia–Baltica suture (Berthelsen, 1992a; EUGENO-S Working Group, 1988), the southern boundary of the Ringkøbing-Fyn High (Blundell, 1992), or the southern boundary of Baltica (Berthelsen, 1984; Blundell, 1992; EUGENO-S Working Group, 1988; Franke, 1990, 1993; Hoffmann, 1990; Krauss, 1994; Thybo, 1997). However, there has been a consistent problem with the identification and recognition of this structure (e.g. McCann, 1996a; Tanner & Meissner, 1996), despite the fact that it has

Figure 1. Map showing the main structural features and the locations of the deep seismic surveys in the region. The various trends of the Trans-European Fault are also indicated (1 – Pozarski, Brochwicz-Lewinski & Tomczyk, 1982 (but termed Caledonian Deformation Front); Berthelsen, 1984; BABEL Working Group, 1993; MONA LISA Working Group, 1997; 2 – EUGENO-S Working Group, 1988; 3 – Horst, Flueh & Börngen, 1994; 4 – Krauss, 1994; 5 – Franke, 1993). Inset map shows the locations of wells mentioned in the text. Key: CDF – Caledonian Deformation Front; EL – Elbe Lineament; RFH – Ringkøbing-Fyn High; STZ – Sorgenfrei-Tornquist Zone; TEF – Trans-European Fault.

been crossed by two previous large-scale seismic experiments (EUGENO-S, BABEL).

It has been suggested that the Trans-European Fault exercised considerable control on the tectonic evolution of the southern Baltic region, with reactivation occurring up into the Mesozoic (e.g. Berthelsen, 1984, 1992b). Berthelsen (1992b) suggested that the Late Silurian foreland basin was subdivided into fault-bounded segments by a fault splay from the Trans-European Fault.

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Subsequent lateral displacements along the Trans-European Fault may have occurred in relation to the possible Devonian inversion of the marginal basin north of the Caledonian Deformation Front. Krauss (1994) suggested that the southern Rügen area (that is, along the trend of the supposed Trans-European Fault) was the site of Lower Carboniferous rift-related volcanism and a sedimentary basin in Late Carboniferous times. It has also been suggested that the Trans-European Fault (or the Strelasund and Anklam faults which Bachmann & Hoffmann (1997) equate with the Trans-European Fault) defined the northern boundary of the subsiding basin in Early Permian times (Berthelsen, 1992*b*). This northern boundary, also termed the Grimmen High (see Katzung & Ehmke, 1993) has been interpreted by Reinhardt (1993) as a significant local NW–SE-trending structural feature influencing the post-Zechstein tectonic development of the area.

More recently BASIN'96 (Basin Analyses and Seismic Investigations in North Germany), comprising a combined onshore–offshore seismic survey of the Northeast German Basin and the southern Baltic region, involved the gathering of *c.* 800 km of marine reflection seismic profiles in a series of transects perpendicular to the major structural elements of the region (Fig. 1; DEKORP-BASIN Research Group, 1998, 1999; Meissner & Krawczyk, 1999). Of particular interest are the segments (PQ2-9.1, PQ2-9.3) which intersect the suggested trace of the Trans-European Fault. The present contribution proposes to critically re-examine, in the light of the new seismic data, all of the current evidence for this structure to determine whether or not it should continue to be used as a term of reference for the dynamic evolution of the region.

2. Deep-seismic database

In 1996 the deep-seismic BASIN'96 experiment aimed to image the entire Northeast German Basin and its margins on a lithospheric scale below the base of the Zechstein salt series using a combination of onshore and offshore near-vertical and wide-angle reflection and refraction seismic measurements. Initial results of this work, including information on seismic acquisition and processing, have been published elsewhere (DEKORP-BASIN Research Group, 1998, 1999; Krawczyk, Stiller & DEKORP-BASIN Research Group, 1999; Meissner & Krawczyk, 1999). The present work concentrates on the northern part of BASIN 9601 and the marine profiles PQ2-9.1 and PQ2-9.3 (Figs 1–5).

Analysis of the DEKORP-BASIN'96 data was undertaken in conjunction with re-examination of older seismic data from the region, including EUGENO-S, BABEL A and NIZUSE (Figs 1, 2, 5). The BABEL A profile was shot in two segments (A1, A2) with a short gap between them. In their initial interpretation of the data, the BABEL Working Group (1993; Fig. 1) indicated the trace of the Trans-European Fault running through this gap, suggesting that it existed, but was unimaged. The DEKORP-BASIN'96 Profile PQ2-9.1 effectively closes this gap.

Initial interpretation of the BASIN 9601 land profile and the correlated profiles PQ2-009.1 and PQ2-005 reveals a number of significant structures in the region. The Moho is a continuous structure across the entire profile (Fig. 2). It is located at the base of a *c.* 2–4 km thick reflector band which suggests a compositional or fabric change in the lower crust with respect

Figure 2. Interpreted line drawing of the northern segment of BASIN 9601 profile and its offshore extensions PQ2-9.1 and PQ2-5 showing the main tectonic and stratigraphic features. The Moho is a broadly continuous feature across the profile, located at the base of a *c.* 2–4 km-thick reflector band at 30 km depth. Below the Moho, a series of NE-dipping seismic reflectors (a) are similar to reflectors previously interpreted as the main Caledonian structure (BABEL Working Group, 1993; Meissner, Sadowiak & Thomas, 1994). Moderate amplitude SW-dipping reflectors (b) are observed from surface to *c.* 10 km depth southwest of the G-14 well, and extending beneath the northern part of the Northeast German Basin (c). This surface is interpreted as the Caledonian suture (DEKORP-BASIN Research Group, 1999). Southwest-dipping reflectors (d) may be related to later thrusting. Baltica crust is represented by the diagonally-shaded area.

to the overlying layer (Krawczyk, Stiller & DEKORP-BASIN Research Group, 1999). Towards the centre of the Northeast German Basin the reflective pattern of the Moho becomes more diffuse. This may be related to the southern extent of Baltica beneath the basin or suggest that processes affecting the petrophysical properties of the crust occurred prior to, or during, the early stage of basin formation, including modification by enrichment in mafic components (DEKORP-BASIN Research Group, 1999; Krawczyk, Stiller & DEKORP-BASIN Research Group, 1999).

Examination of the new profiles shows the presence of an array of broadly sinusoidal, coherent reflections between 3 and 7 s TWT (Figs 3, 4). On Figure 3 there is an antiform at CMP 7500 and a synform at CMP 6800. Beneath this band of reflectors there are weak NE-dipping reflectors (arrowed) which correlate with similar structures on the parallel BABEL A profile. These have been interpreted as the Caledonian Deformation Front in the region and are similar to reflectors previously interpreted as the main Caledonian suture (BABEL Working Group, 1993; Meissner, Sadowiak & Thomas, 1994). These structures, observed on three of the PQ-profiles (see Fig. 4), confirm the idea of NE-directed subduction but also suggest that the Caledonian event was a multiphase one.

Further evidence of the complexity of this event is provided by a series of moderate-amplitude SW-dipping reflectors which are observed from the surface to *c.* 10 km depth southwest of the G-14 well (Fig. 2). These reflectors extend along a band, at *c.* 20–25 km depth, beneath the northern third of the basin. This surface is interpreted as the Caledonian suture

(Krawczyk, Stiller & DEKORP-BASIN Research Group, 1999). The wedging suggests that Baltica crust extended much farther southward below northern Germany (that is, into Avalonia) than previously thought. Indeed, Baltica crust would appear to extend as far as the depocentre of the Northeast German Basin as is evident in refraction seismic data (Bayer *et al.* 1999). Overlying deformed and thrust Ordovician-age rocks are interpreted as an accretionary wedge deposited at the front of the advancing Caledonian thrust sheet. The SW-dipping structures may be related to later thrusting.

South of the Caledonian Deformation Front structure there is no evidence of any major crustal deformation although this is the supposed location of the Trans-European Fault. Analysis of a series of pre-1996 deep seismic profiles (BABEL, NIZUSE) for the region also reveals no evidence for any deep structure in the region of Rügen (Fig. 5). Indeed, while an earlier interpretation of the NIZUSE profile (see fig. 7 in Horst, Flueh & Börngen, 1994) indicated the presence of the Trans-European Fault, the authors noted that the structure was 'not imaged clearly on the NIZUSE profile' (Horst, Flueh & Börngen, 1994, p. 167).

3. Discussion

Examination of the new DEKORP-BASIN'96 data in conjunction with older deep-seismic profiles from the region reveals no image of any major geological structure in the region of the supposed Trans-European Fault. It is, therefore, necessary to critically examine the evidence which has been put forward for the existence of this feature.

Figure 3. Stacked section (a) and interpreted line drawing (b) of seismic profile PQ2-9.1 from the southern Baltic Sea. Note how the Permian Basin thins to the northeast and the presence of weak NE-dipping reflectors (arrowed). Localized faulting on the southwest part of the profile is in the region of the supposed Trans-European Fault. Evidence of faulting, however, is restricted to this profile, and there is no evidence of any deep root to the structure. See Figure 1 for location. (CMP – Common Mid-Point).

Figure 4. Stacked section (a) and interpreted line drawing (b) of seismic profile PQ2-9.3 from the southern Baltic Sea. Note the presence of weak NE-dipping reflectors (arrowed) and that there is no evidence of any structural displacement in the region. See Figure 1 for location. (CMP – Common Mid-Point).

3.a. Historical background to the Trans-European Fault

According to Berthelsen (1984) the Trans-European Fault, a supposed major strike-slip feature, was proposed by Pozarski, Brochwicz-Lewinski & Tomczyk (1982) who defined it as a 'fundamental fault' separating structural blocks with differing crustal ages. However, examination of the original work reveals that Pozarski, Brochwicz-Lewinski & Tomczyk (1982) did not discuss, or name, this structure. Instead, their work concentrated on the development and evolution of the Tornquist-Teisseyre Zone. This is clearly shown in their figure 1 where the Tornquist-Teisseyre Zone is indicated, while the region located south of the Caledonian Deformation Front and extending westwards from Rügen to southern Denmark is termed part of the unsubdivided Caledonides, a term also used for the region by Franke, Hoffmann & Kamps (1989).

Figure 2 of Pozarski, Brochwicz-Lewinski & Tomczyk (1982), which indicated the trend of the Tornquist-Teisseyre Zone, was reproduced by Berthelsen (1984, his fig. 3) but renamed as the Trans-European Fault. As noted above, the structure originally discussed by Pozarski, Brochwicz-Lewinski & Tomczyk (1982) was the Teisseyre-Tornquist Zone,

which they suggested had formed in Early Ordovician times and involved a sinistral displacement of *c.* 2000 km. Thus, the definition provided by Berthelsen (1984) for the Trans-European Fault, that is, a pre-Cadomian transform boundary which runs 'between England and Scotland, south of the Ringkøbing-Fyn-Møn basement high in Denmark and join(ed) the border of the East European Platform in Poland on its way to the Black Sea region' (Berthelsen, 1984, pp. 128–9), refers to a structure which had been clearly indicated by Pozarski, Brochwicz-Lewinski & Tomczyk (1982), in the southern Baltic region, as being the Caledonian Deformation Front.

Berthelsen's Trans-European Fault definition was later modified to suggest that the structure was a curvilinear fault trending through Schleswig-Holstein, running south of Rügen and continuing, hidden, in the Tornquist-Teisseyre Zone through Poland to the Ukraine (EUGENO-S Working Group, 1988). Thus, the original work of Pozarski, Brochwicz-Lewinski & Tomczyk (1982) was misinterpreted, and a new structure came into being. The resultant considerable confusion about the precise trend, or indeed very existence, of this structure is clearly reflected in the literature (Fig. 1).

Figure 5. Reproduction (a) of the NIZUSE profile (from Horst, Flueh & Börngen, 1994) and interpreted line drawing (b). Horst, Flueh & Börngen (1994) suggested that the trace of the Trans-European Fault was located along the northern part of the profile (stippled area). See Figure 1 for location. (CMP – Common Mid-Point).

3.b. Geological and tectonic evidence

The Trans-European Fault, or its local equivalents, has been interpreted as a significant structural feature. Plate tectonic models (e.g. Berthelsen, 1984; Brockwicz-Lewinski, 1984; Pegrum, 1984*a,b*) have suggested that there is 'significant strike-slip movement along the Trans-European Fault or the Tornquist Zone' (EUGENO-S Working Group, 1988, p. 258, *our emphasis*). Berthelsen (1984) suggested that displacement occurred *c.* 800 Ma ago when the Trans-European Fault was initiated as a transform fault between the spreading axes of the pre-Cadomian ocean in Central Europe and the pre-Baikalian ocean east of Fennosarmatia. If this were the case, then the

fault might be expected to be vertical and thus invisible on normal incidence seismic sections. It would only be seen if it juxtaposed crustal units of contrasting seismic character (see Section 3.c).

It has also been suggested that the Trans-European Fault played a significant role in later tectonic development. Bachmann & Hoffmann (1997), for example, indicate that the Trans-European Fault (Strelasund and Anklam faults on their diagram) dipped to the south, extending down to middle to lower crustal levels and forming the boundary between the Cadomian-influenced region to the south and the Caledonian-influenced area to the north (see also Franke *et al.* 1989; Hoffmann, 1990). Berthelsen (1992*b*) suggested that the Late Silurian foreland basin and its substrate

were subdivided into fault-bounded segments when a WNW-widening splay of deep faults branched off the Avalonia–Laurussia suture at the Trans-European Fault in northwestern Poland. However, there is no direct evidence of this since Silurian-age strata are absent in northern Germany, apart from a thin succession, to the north of the Caledonian Deformation Front, in the G14 1/86 well (Fig. 1) (McCann, 1996b).

Berthelsen (1992b) also suggested that lateral displacements along the Trans-European Fault may have occurred in relation to the possible Devonian inversion of the marginal basin north of the Caledonian Deformation Front, although again there is little evidence of this. In the Rügen area, Devonian sedimentation was largely limited to the so-called Rügen Depression, a localized graben bounded by the Strelasund Fault/Grimmen High to the south (Katzung & Ehmke, 1993; Katzung *et al.* 1993; McCann, 1999). Lower Carboniferous magmatic activity, which resulted in a *c.* 600 m thick succession of alkaline mafic lavas and pyroclastics (Kramer & Korich, 1996), is noted from the Pudagla 1/86 and Loissin 1/70 wells (Fig. 1). Kramer & Korich (1996) suggest that the alkaline volcanic activity characterizes the area as extensional, with episodic magmatism, extension presumably being related to the previously mentioned Strelasund Fault. Volcanic activity in the Permo-Carboniferous was much more widespread across the region of northeast Germany. Geochemical differences in the lavas are interpreted in terms of basement heterogeneities within the Variscan foredeep and the Rhenohercynian orogenic zone (Benek *et al.* 1996).

Berthelsen (see fig. 15 in Berthelsen, 1992b) suggests that the Trans-European Fault defined the northern border of the subsiding North German Basin during Early Permian times. Examination of the sedimentary record, however, reveals that the northern boundary of the basin extended further to the northeast with Rotliegend strata being recorded from Rügen (e.g. Rügen 4/64, Rügen 2/67, Gingst 1/73) and in the southern Baltic Sea (e.g. K5, H2) (Fig. 1).

3.c. Geophysical evidence

The region of the Tornquist Zone is one of clear geophysical contrast from north to south (Berthelsen, 1998; Zielhuis & Nolet, 1994). However, further south the situation is not so clear. Geophysical measurements have indicated a variety of anomalous situations trending parallel to the proposed Trans-European Fault. The EUGENO-S profile 1 records a transition in terms of crustal character from the area of the Ringkøbing-Fyn High to the Schleswig-Holstein area to the south. This is associated with a change in the velocity contrast at the Conrad discontinuity, occurring close to shotpoint SP1 to the north of Kiel (Fig. 1). Southwest of shotpoint SP1, the velocity

is 6.1–7.0 km/s, whereas it is 6.4–6.7 km/s from the Ringkøbing-Fyn High towards the northeast. The EUGENO-S Working Group (1988) interpreted the velocity difference in terms of variations in the Conrad and the lower crust in the region of shotpoint SP1. However, Bouguer gravity anomalies along the same profile indicate only two highs, one corresponding to the Ringkøbing-Fyn High and a second beginning at the Sorgenfrei-Tornquist Zone and continuing northwards for *c.* 120 km into the Baltic Shield (Wybraniec *et al.* 1998). Thus, it was suggested that the anomalous ‘lower crust’ was delimited by the deep trace of the Trans-European Fault (EUGENO-S Working Group, 1988). Ansorge, Blundell & Mueller (1992), however, have suggested that the area around the CK shotpoint (same location as the SP1 shotpoint) corresponds to the Caledonian Deformation Front.

A magnetic anomaly map of the region suggests the presence of a NW–SE-trending anomaly in central Rügen (Wonik & Hahn, 1990) although no precise values are provided. The authors do not consider the anomaly to be important and no further reference is made to it in their text. The European Geotraverse Atlas (Wonik *et al.* 1992), however, shows a strong magnetic gradient across Rügen, implying that there is a sharp lateral contrast high in the crust (Fig. 6). This could mark the surface expression of a boundary. In addition, viewing the anomalies more generally, it is clear that high-amplitude, sharply defined (bounded by steep gradients) anomalies covering much of Scandinavia become muted to the south of the line on the tectonic map drawn by Berthelsen as the surface trace of the Trans-European Fault. However, magnetic anomalies of lower magnitude and gradient, implying they are from sources deeper in the crust, persist southward to the Elbe Lineament.

Grosse *et al.* (1990), Grosse & Conrad (1990) and Conrad (1996) note the presence of a NW–SE-trending gravity high in central Rügen. This positive gravity axis, while along strike with the Ringkøbing-Fyn High, is not connected with it. Furthermore, although the flanks of the gravity axis are symmetrical, they have different origins; the southern edge marks the northern margin of the North German Basin while the northern one is related to density contrasts in the sub-Ordovician basement (Grosse *et al.* 1990). The presence of a gravity gradient along the coast south of Rügen has been attributed to the Trans-European Fault (Grosse *et al.* 1990). They also note that there is no gravimetric indication for any westward continuation of this feature, which would suggest that it is much more localized and may more easily be related to the Strelasund Fault/Grimmen High. It should, however, be noted that the magnetic evidence indicates a westward continuation (Wonik *et al.* 1992).

A Moho map of the same region (Hoffmann, Stiewe & Pasternak, 1996) shows a Moho high (< 30 km) in northeastern Germany, with its northern border along

Figure 6. Magnetic (a) (Wonik *et al.* 1992) and gravity (b) (Conrad, 1996) anomaly maps of the Rügen area.

the Anklam Fault (that is, Trans-European Fault), while to the north in the Usedom region the Moho dips to a depth of >32 km. However, in the text, Hoffman, Stiewe & Pasternak (1996) somewhat puzzlingly suggest that the significant differences in Moho depth reported by Thybo *et al.* (1990) across the Trans-European Fault are not confirmed by their study, although their figure 5 and supporting data would appear to contradict this statement. Rabbel *et al.* (1995) reported an area of increased crustal thickness in the region of the Ringkøbing-Fyn High which corresponds to a *c.* 7 km deepening of the Moho. They suggest that the southern boundary of this Moho low corresponds with the postulated Trans-European Fault trend. More recently, Thybo (1997), in discussing variations in depth to Moho in the southern Baltic region, suggested a correlation between the Grimmen High and the Trans-European Fault, although more recent work (Eilts *et al.*, unpub. data), analysing Moho trends in the Baltic based on the DEKORP-BASIN'96 dataset, suggests that this is not the case.

To the east, deep seismic surveys in Poland and parts of the USSR (Guterch *et al.* 1983, 1984, 1986; Pozarski, Brochwicz-Lewinski & Tomczyk, 1982) have revealed the existence of a 50–90 km wide belt with unusual crustal thicknesses (*c.* 50–60 km), and including a 10–15 km deep Moho trough, in the vicinity of the Tornquist-Teisseyre Zone in Poland. Berthelsen (1984) suggested that the origin of this feature should be ascribed to the formation of the Trans-European Fault. However, such an interpretation would suggest that the Moho trough persists westwards along the southern border of the Ringkøbing-Fyn High, which is clearly not the case.

The region of northern Germany is a geologically complex one, predominantly because northern

Germany is formed on Avalonia crust which differs from the older, and colder, Baltica crust to the north. The BABEL Working Group (1993) noted that in the North German lowlands the crystalline crust below the 10 km thick post-Caledonian sedimentary sequence is only 20 km thick and has velocities of between 6.0 and 6.9 km/s. Recent deep-seismic data has confirmed that during Caledonian evolution, Baltica's Precambrian crust protruded into the docking Avalonian terrane as a major crustal flake structure, with Baltica extending further beneath Avalonia than previously thought (DEKORP-BASIN Research Group, 1999) (Figs 1, 2). Similarly, the crustal pattern for the overthrust Avalonia crust can also be traced from beneath the northern margin of the Northeast German Basin, extending northwards to beyond the G-14 borehole.

The continuation of the Baltica and Avalonia crustal patterns across the region would strongly suggest that there is no strike-slip fault present in the Rügen area. While a vertical fault cannot be imaged directly on a normal-incidence seismic reflection section, the presence of a significant transform fault should be evidenced by the presence of sharp lateral changes in the reflective character of the crust. Such abrupt changes in crustal continuity could be considered as indirect evidence of a vertical fault that has juxtaposed contrasting crustal units (e.g. Baltica crust against Avalonia crust). An excellent example of such a structure is provided by the image of the Caledonian suture on the BIRPS NEC line off the east coast of England (Freemant, Klemperer & Hobbs, 1988). If, however, the two crustal units juxtaposed by a vertical fault have the same character, or are devoid of characteristic reflection patterns, there is no lateral contrast and the fault remains invisible. However, the key argument against the existence of such a structure is the

new evidence from the BASIN'96 profiles which clearly show an inclined boundary through the crust which can be identified as the suture between an over-riding Avalonia crust and an underlying wedge of Baltica crust (Fig. 2). As noted earlier, the evidence indicates that, deep in the crust, Baltica extends further south than had previously been supposed. The suture between Baltica and Avalonia is at a relatively low angle and is thus capable of being imaged on normal-incidence reflection profiles (Krawczyk, Stiller & DEKORP-BASIN Research Group, 1999), and is not a vertical boundary as Berthelsen postulated. Furthermore, refraction seismic data of Bleibinhaus *et al.* (1999) show a high-velocity layer in the lower crust beneath the northeast German mainland which is interpreted as evidence of a genetic relationship to Baltica crust. A wedge-shaped structure rather than a vertical boundary is also found in the receiver function analyses from the TOR data of Gossler *et al.* (1999).

The precise location of the southwestern edge of Baltica (that part of Baltica to the south of the Sorgenfrei-Tornquist Zone) is not known. This is largely a result of masking by younger sediments (Tanner & Meissner, 1996), and led to the suggestion that the Trans-European Fault formed this boundary (Berthelsen, 1984; EUGENO-S Working Group, 1988; Franke, 1990, 1993; Hoffmann, 1990). Indeed, Dadlez (1997) in his examination of the Polish LT-7 profile notes that the crystalline crust may be separated into distinct zones. The central zone, which Dadlez (1997) calls TESZ crust, corresponds in part to the trend of the Trans-European Fault, and has a peculiar structure which is not comparable to that of the zones to the northeast and southwest. The structure involves two thin lower crustal layers with velocities identical or equal to that of the cratonic lower and middle layers, and an upper layer (8–11 km thick) with lower velocities. While the changes across this area are not as marked as elsewhere along the profile, it is still of some significance. Gravity analysis confirms the presence of an anomaly in the same location, although it is less marked than other anomalies in the area (Krolikowski & Petecki, 1997). This anomaly could be due to the overlying sediments or possible deeper structures. The precise nature, however, is not clear.

Recent ideas favour a terrane accretional model rather than fault movement to interpret the observed geology of the region (Ziegler, 1990; Berthelsen, 1992a; Torsvik *et al.* 1993; Meissner, Sadowiak & Thomas, 1994; Tanner & Meissner, 1996). Such a model envisages the northward convergence and accretion of Gondwana-derived continental fragments to the southern margin of the newly-forming Laurussian super-continent (Ziegler, 1989). Two possible boundaries have been suggested for the Avalonia–Baltica suture: the Caledonian Deformation Front and the Elbe Lineament (Tanner & Meissner, 1996), the latter being recognized on magnetic and

gravimetric maps as negative anomalies in the investigated areas. According to Pharaoh *et al.* (1997) the Elbe Lineament, at least in its shallow expression, represents a late Variscan, relatively brittle structure. This was presumably imposed on earlier orogenic sutures.

Arguments favouring the Elbe Lineament as the northeastern boundary of East Avalonia include the recognition of the geological and geophysical continuity between Baltica and part of northern Germany (Tanner & Meissner, 1996; Cocks & Fortey, 1998). Such evidence includes the increased crustal velocities in the area extending from the Baltic Shield to the Elbe Lineament (Rabbel *et al.* 1995). There is a sharp velocity contrast in the lower crust between the regions southwest and northeast of the Elbe Lineament (Rabbel *et al.* 1995; Thybo, 1990). To the southwest the velocities range from 5.9–6.6 km/sec, and increase in the northeast up to 6.9–7.5 km/sec. Between the Ringkøbing-Fyn High and the Sorgenfrei-Tornquist Zone the velocities are 6.9–7.0 km/sec on EUGENO-S (Thybo *et al.* 1990) and 6.9–7.2 km/sec on BABEL (Thybo & Flueh, 1992). Such high velocities are characteristic of old shield or platform regions (Fountain, Arculus & Kay, 1992) or thinned continental crust present at some passive continental margins (Scrutton, 1982a,b) where magmatic underplating may have taken place. Additional information on the complexity of this region is provided by the initial evaluation of teleseismic data which has revealed that there is a zone of strong heterogeneity between the Caledonian Deformation Front and the Elbe Lineament (Gossler *et al.* 1999) related to the presence of blocks of Baltica-derived high-velocity lower crust which became detached and displaced.

Dohr, Dürschner & Edelmann (1989) and Wonik & Hahn (1990) have both noted that the character of gravity and magnetic anomalies changes markedly along the Elbe Lineament. Furthermore, Blundell (1992) notes that the area is the general location of the deep lithosphere/upper mantle changes noted by Nolet (1990) from his two-dimensional model derived from waveform inversion analysis. Further geophysical anomalies have been reported by Aichroth, Prodehl & Thybo (1992), Bosum & Wonik (1991), Brink, Dürschner & Trappe (1992) and the EREGT Group (1990). Thus, the Elbe Lineament may mark the true boundary between Baltic Shield and European Phanerozoic crust. Accepting this, the area located between the Caledonian Deformation Front and the Elbe Lineament can, following Tanner & Meissner (1996), be interpreted as a thrust onto the passive margin of Baltica. The region, therefore, between the Caledonian Deformation Front and the Elbe Lineament is a complex one with affinities to both Baltica and East Avalonia (see Cocks & Fortey, 1998). This is supported by the observation of Berthelsen (1998) that there is no clear correlation between the Caledonides of the Rügen area and northern Poland.

The geophysical anomalies observed in the Caledonian Deformation Front/Elbe Lineament region, therefore, may be interpreted in terms of variable crustal properties across the area.

4. Conclusions

Analysis of recently shot deep seismic profiles in the southern Baltic region have failed to image the Trans-European Fault. While our new seismic data would not necessarily image a steep Trans-European Fault structure, we must therefore rely on regional geological and geophysical datasets to support our contention that there is little evidence for a significant structural lineament across the southern Baltic. Geological structures, for example, the Grimmen High south of Rügen, are present in parts of the region but there is no evidence for their extension along strike into Poland or Denmark. Furthermore, although there is geophysical evidence of an anomaly in the region of the supposed Trans-European Fault there is no evidence of any particular geological basis to this, unlike the anomalies further south along the Elbe Lineament. Therefore, based on the confusing and inconclusive evidence for the existence of the Trans-European Fault, we would propose that it not be used as a term of reference in the future.

Acknowledgements. We would like to thank Derek Blundell and Richard England for their thorough and helpful reviews. Andreas Hendrich and Manuela Dziggel prepared all of the diagrams.

References

- AICHROTH, B., PRODEHL, C. & THYBO, H. 1992. Crustal structure along the Central Segment of the EGT from seismic-refraction data. *Tectonophysics* **207**, 43–64.
- ANSORGE, J., BLUNDELL, D. & MUELLER, ST. 1992. Europe's lithosphere – seismic structure. In *A Continent Revealed – The European Geotraverse* (eds D. Blundell, R. Freeman and St. Mueller), pp. 33–69. Cambridge University Press.
- BABEL WORKING GROUP. 1993. Deep seismic reflection/refraction interpretation of crustal structure along BABEL profiles A and B in the southern Baltic Sea. *Geophysical Journal International* **112**, 325–43.
- BACHMANN, G. H. & HOFFMANN, N. 1997. Developments of the Rotliegend Basin in Northern Germany. *Geologisches Jahrbuch* **D103**, 9–31.
- BAYER, U., SCHECK, M., RABEL, W., KRAWCZYK, C. M., GÖTZE, H.-J., STILLER, M., BEILECKE, T., MAROTTA, A.-M., BARRIO-ALVERS, L. & KUDER, J. 1999. An integrated study of the NE German Basin. *Tectonophysics* **314**, 285–307.
- BENEK, R., KRAMER, W., MCCANN, T., SCHECK, M., NEGENDANK, J. F. W., KORICH, D., HUEBSCHER, H.-D., TOBSCHALL, H. J. & BAYER, U. 1996. Permo-Carboniferous magmatism and related subsidence of the NE German Basin. *Tectonophysics* **266**, 379–404.
- BERTHELSEN, A. 1984. The early (800–300 Ma) crustal evolution of the off-shield regions of Europe. In *First EGT Workshop. The Northern Segment* (eds D. A. Galson and St. Mueller), pp. 125–42. Strasbourg: European Science Foundation.
- BERTHELSEN, A. 1992a. Mobile Europe. In *A Continent Revealed – The European Geotraverse* (eds D. Blundell, R. Freeman and St. Mueller), pp. 11–32. Cambridge University Press.
- BERTHELSEN, A. 1992b. From Precambrian to Variscan Europe. In *A Continent Revealed – The European Geotraverse* (eds D. Blundell, R. Freeman and St. Mueller), pp. 153–64. Cambridge University Press.
- BERTHELSEN, A. 1998. The Tornquist Zone northwest of the Carpathians: an intraplate pseudosuture. *Geologiska Föreningens i Stockholm Förhandlingar* **120**, 223–30.
- BLEIBINHAUS, F., BEILECKE, T., BRAM, K. & GEBRANDE, H. 1999. A seismic velocity model for the SW Baltic Sea derived from BASIN'96 refraction seismic data. *Tectonophysics* **314**, 269–83.
- BLUNDELL, D. 1992. Integrated lithospheric cross section. In *A Continent Revealed – The European Geotraverse* (eds D. Blundell, R. Freeman and S. Mueller), pp. 102–9. Cambridge University Press.
- BOSUM, W. & WONIK, T. 1991. Magnetic anomaly pattern of Central Europe. *Tectonophysics* **195**, 253–9.
- BRINK, H. J., DÜRSCHNER, H. & TRAPPE, H. 1992. Some aspects of the late and post-Variscan development of the Northwestern German Basin. *Tectonophysics* **207**, 65–95.
- BROCKWICZ-LEWINSKI, W. 1984. Sinistral strike-slip movements in central Europe in the Palaeozoic. *Publication of the Institute of Geophysics, Polish Academy of Sciences, A-13* **160**, 3–13.
- COCKS, L. R. M. & FORTEY, R. A. 1998. The Lower Palaeozoic margins of Baltica. *Geologiska Föreningens i Stockholm Förhandlingar* **120**, 173–9.
- CONRAD, W. 1996. Die Schwerekarte ($\Delta g''$) der Länder Brandenburg, Mecklenburg-Vorpommern, Sachsen, Sachsen-Anhalt und Thüringen. Bemerkungen zur Bearbeitung und Interpretation. *Geoprofil* **6**, 1–56.
- DADLEZ, R. 1997. Seismic profile LT-7 (northwest Poland): geological implications. *Geological Magazine* **134**, 653–9.
- DEKORP-BASIN RESEARCH GROUP. 1998. Survey provides seismic insights into an old suture zone. *EOS* **79**, 151, 159.
- DEKORP-BASIN RESEARCH GROUP. 1999. Deep crustal structure of the Northeast German Basin: New DEKORP-BASIN'96 deep-profiling results. *Geology* **27**, 55–8.
- DOHR, G., DÜRSCHNER, H. & EDELMANN, H. A. K. 1989. Exploration geophysics in Germany. *First Break* **7**, 153–72.
- EREGT GROUP. 1990. An electrical resistivity transect from the Alps to the Baltic Sea (Central Segment of the EGT). In *Proceedings of the 6th EGT Workshop: Data compilation and synoptic interpretation* (eds R. Freemann and St. Mueller), pp. 299–313. Strasbourg: European Science Foundation.
- EUGENO-S WORKING GROUP. 1988. Crustal structure and tectonic evolution of the transition between the Baltic Shield and the North German Caledonides (the EUGENO-S project). *Tectonophysics* **150**, 253–348.
- FOUNTAIN, D. M., ARCULUS, R. & KAY, R. W. 1992. *Continental Lower Crust, Developments in Geotectonics*, vol. 23. New York: Elsevier.
- FRANKE, D. 1990. The northwest part of the Tornquist

- Teisseyre Zone – platform margin or intraplate structure? *Zeitschrift für angewandte Geologie* **36**, 45–8.
- FRANKE, D. 1993. The southern border of Baltica – a review of the present state of knowledge. *Precambrian Research* **64**, 419–30.
- FRANKE, D., HOFFMANN, N. & KAMPS, J. 1989. Alter und struktureller Bau des Grundgebirges im Nordteil der DDR. *Zeitschrift für angewandte Geologie* **35**, 289–96.
- FREEMANN, B., KLEMPERER, S. L. & HOBBS, R. W. 1988. The deep structure of northern England and the Iapetus Suture zone from BIRPS deep seismic reflection profiles. *Journal of the Geological Society, London* **145**, 727–40.
- GOSSLER, J., KIND, R., SOBOLEV, S. V., KÄMPF, H., WYLEGALLA, K., STILLER, M. & TOR WORKING GROUP. 1999. Major crustal features between the Harz Mountains and the Baltic Shield derived from receiver functions. *Tectonophysics* **314**, 321–34.
- GROSSE, S. & CONRAD, W. 1990. Map of the Bouguer field of Germany and conterminous areas. In *The European Geotraverse: Integrative Studies* (eds R. Freemann, P. Giese and St. Mueller), pp. 131–3. Strasbourg: European Science Foundation.
- GROSSE, S., CONRAD, W., BEHR, H. J. & HEINRICHS, T. 1990. Major gravity axes and anomalies in central Europe. In *The European Geotraverse: Integrative Studies* (eds R. Freemann, P. Giese and St. Mueller), pp. 135–46. Strasbourg: European Science Foundation.
- GUTERCH, A., GRAD, M., MATERZOK, R., PAJCHEL, J., PERCHUC, E. & TOPERKIEWICZ, S. 1984. Deep structure of the earth's crust in the contact zone of the Palaeozoic and Precambrian platforms and the Carpathian Mts. in Poland. *Acta Geophysica Polonica* **32**, 25–41.
- GUTERCH, A., GRAD, M., MATERZOK, R. & PERCHUC, E. 1986. Deep structure of the earth's crust in the contact zone of the Palaeozoic and Precambrian platforms in Poland (Tornquist-Teisseyre Zone). *Tectonophysics* **128**, 251–79.
- GUTERCH, A., GRAD, M., MATERZOK, R. & TOPERKIEWICZ, A. 1983. Structure of the earth's crust of the Permian basin in Poland. *Acta Geophysica Polonica* **36**, 121–38.
- HOFFMANN, N. 1990. Zur paläodynamischen Entwicklung des Präzechsteins in der Norddeutschen Senke. *Niedersächsische Akademie des Geowissenschaften Veröffentlichungen* **4**, 5–18.
- HOFFMANN, N., STIEWE, H. & PASTERNAK, G. 1996. Struktur und Genese der Mohorovicic-Diskontinuität (Moho) im Norddeutschen Becken – ein Ergebnis langzeitregistrierter Steilwinkelseismik. *Zeitschrift für angewandte Geologie* **42**, 138–48.
- HORST, W., FLUEH, E. R. & BÖRNGEN, M. 1994. NIZUSE: a deep seismic reflection line in north-eastern Germany. *Geologische Rundschau* **83**, 161–9.
- KATZUNG, G. & EHMKE, G. 1993. *Das Prätertiär in Ostdeutschland. Strukturstockwerke und ihre regionale Gliederung*. Köln: Verlag Sven von Loga.
- KATZUNG, G., GIESE, U., WALTER, R. & VON WINTERFELD, C. 1993. The Rügen Caledonides, northeast Germany. *Geological Magazine* **130**, 725–30.
- KRAMER, W. & KORICH, D. 1996. Unterkarbonischer mafischer Magmatismus im Bereich Usedom des Tornquist-Fächers. *Zeitschrift für geologische Wissenschaften* **24**, 539–49.
- KRAUSS, M. 1994. The tectonic structure below the southern Baltic Sea and its evolution. *Zeitschrift für geologische Wissenschaften* **22**, 19–32.
- KRAWCZYK, C. M., STILLER, M. & DEKORP-BASIN RESEARCH GROUP. 1999. Reflection seismic constraints on Paleozoic crustal structure and Moho beneath the NE German Basin. *Tectonophysics* **314**, 241–54.
- KROLIKOWSKI, C. & PETECKI, Z. 1997. Crustal structure at the Trans-European Suture Zone in northwest Poland based on gravity data. *Geological Magazine* **134**, 661–7.
- MCCANN, T. 1996a. The PrePermian of the Northeast German Basin. *Geological Journal* **31**, 159–77.
- MCCANN, T. 1996b. Silurian facies in northeast Germany. *Zeitschrift der Deutschen Geologischen Gesellschaft* **147**, 209–19.
- MCCANN, T. 1999. Middle to Late Devonian basin evolution in the Rügen area, NE Germany. *Geologie en Mijnbouw* **78**, 57–71.
- MEISSNER, R. & KRAWCZYK, C. M. 1999. Caledonian and Proterozoic terrane accretion in the southwest Baltic Sea. *Tectonophysics* **314**, 255–68.
- MEISSNER, R., SADOWIAK, P. & THOMAS, S. A. 1994. Avalonia, the third partner in the Caledonian collisions: Evidence from deep seismic data. *Geologisches Rundschau* **83**, 186–96.
- MONA LISA WORKING GROUP. 1997. MONA LISA – Deep seismic investigations of the lithosphere in the southeastern North Sea. *Tectonophysics* **269**, 1–19.
- NOLET, G. 1990. Partitioned waveform inversion and two-dimensional structure under the Network of Autonomously Recording Seismographs. *Journal of Geophysical Research* **95**, 8499–512.
- PEGRUM, R. M. 1984a. The extension of the Tornquist Zone in the Norwegian North Sea. *Norsk geologisk Tidsskrift* **64**, 39–68.
- PEGRUM, R. M. 1984b. Structural development of the south-western margin of the Russian-Fennoscandian Platform. In *Petroleum Geology of the North European Margin* (eds A. M. Spencer *et al.*), pp. 359–69. Norwegian Petroleum Society. London: Graham & Trotman.
- PHARAOH, T. C., ENGLAND, R. W., VERNIERS, J. & ZELAZNIEWICZ, A. 1997. Introduction: geological and geophysical studies in the Trans-European Suture Zone. *Geological Magazine* **134**, 585–90.
- POZARYSKI, W., BROCHWICZ-LEWINSKI, W. & TOMCZYK, H. 1982. O Heterochroniczności linii Teisseyre'a-Tornquista. *Przegląd Geologiczny* **11**, 569–74.
- RABEL, W., FÖRSTE, K., SCHULZE, A., BITTNER, R., RÖHL, J. & REICHERT, J. C. 1995. A high velocity layer in the lower crust of the North German Basin. *Terra Nova* **7**, 327–37.
- REINHARDT, H.-G. 1993. Darstellung struktureller Zusammenhänge beim Anschluß land- und seeseismischer Meßergebnisse im regionalen reflexionsseismischen Kartenwerk. *Zeitschrift für geologische Wissenschaften* **21**, 319–26.
- SCRUTTON, R. A. 1982a. Passive continental margins: A review of observations and mechanisms. In *Dynamics of Passive Margins* (ed. R. A. Scrutton), pp. 5–11. AGU Geodynamic Series, vol. 12. Washington: American Geophysical Union.
- SCRUTTON, R. A. 1982b. Crustal structure and development of sheared passive continental margins. In *Dynamics of Passive Margins* (ed. R. A. Scrutton), pp. 133–40. AGU Geodynamic Series, vol. 12. Washington: American Geophysical Union.
- TANNER, B. & MEISSNER, R. 1996. Caledonian deformation

- upon southwest Baltica and its tectonic implications: Alternatives and consequences. *Tectonics* **15**, 803–12.
- THYBO, H. 1990. A seismic velocity model along the EGT profile – from the North German Basin into the Baltic Shield. In *The European Geotraverse: Integrative Studies* (eds R. Freemann, P. Giese and St. Mueller), pp. 99–108. Strasbourg: European Science Foundation.
- THYBO, H. 1997. Geophysical characteristics of the Tornquist Fan area, northwest Trans-European Suture Zone: indication of late Carboniferous to early Permian dextral transtension. *Geological Magazine* **134**, 597–606.
- THYBO, H. & FLUEH, E. R. 1992. Interpretation of coincident seismic reflection and refraction data across the Tornquist Fan in the southern Baltic Sea. In *The BABEL Project, First Status Report* (eds R. Meissner, D. Snyder, N. Balling and E. Staroste), pp. 151–5. Brussels: European Commission.
- THYBO, H., KJØRBOE, L. L., MØLLER, C., SCHÖNHARTING, G. & BERTHELSEN, A. 1990. Geophysical and tectonic modelling of EUGENO-S profiles. In *Proceedings of the VI Workshop on the European Geotraverse Project* (eds R. Freemann and St. Mueller), pp. 93–104. Strasbourg: European Science Foundation.
- TORSVIK, T. H., TRENCH, A., SVENSSON, I. & WALDERHAUG, H. J. 1993. Palaeogeographic significance of mid-Silurian palaeomagnetic results from southern Britain – major revision of the apparent polar wander path for eastern Avalonia. *Geophysical Journal International* **113**, 651–68.
- WONIK, T., GALDÉANO, A., HAHN, A. & MOUGE, P. 1992. Magnetic anomalies. In *A Continent Revealed: The European Geotraverse* (eds D. Blundell, R. Freemann and St. Mueller), Atlas Map 10. Cambridge University Press.
- WONIK, T. & HAHN, A. 1990. Preliminary map of Aeromagnetic anomalies for the EGT central segment. In *The European Geotraverse: Integrative Studies* (eds R. Freemann, P. Giese and St. Mueller), pp. 147–56. Strasbourg: European Science Foundation.
- WYBRANIEC, S., ZHOU, S., THYBO, H., FORSBERG, R., PERCHUC, E., LEE, M., DEMIANOV, G. & STRAKHOV, V. N. 1998. New map compiled of Europe's gravity field. *EOS* **79**, 437, 442.
- ZIEGLER, P. A. 1989. *Evolution of Laurussia – a study in Late Palaeozoic plate tectonics*. Dordrecht: Kluwer Academic Publishers.
- ZIEGLER, P. A. 1990. *Geological Atlas of Western and Central Europe*. Shell Internationale Petroleum Maatschappij B.V., The Hague.
- ZIELHUIS, A. & NOLET, G. 1994. Deep seismic expression of an ancient plate boundary in Europe. *Science* **265**, 79–81.