TESZ


Svalbard
Barents Sea
Atlantic
Ocean
Caledonides
Pechora
Basin
Timanides
East-European Craton
T E S Z
V a r i s c i d e s
Alps
Carpathians
Pericaspian
Basin
Black Sea
Caspian Sea
Mediterranean

TRANS-EUROPEAN SUTURE ZONE

Phanerozoic Accretion and the Evolution of Contrasting Continental Lithospheres

by Tim Pharaoh (British Geol. Survey) and TESZ colleagues

The Trans-European Suture Zone (TESZ) is the most prominent geological boundary in Europe, separating mobile Phanerozoic terranes in the south and west from the Precambrian East European Craton. This complex fundamental structure crosses northwest-southeast through central Europe, from the North Sea to the Black Sea, a distance exceeding 2000 km. It is as clearly defined in the deep lithosphere as in the upper crust, Moho depths increasing across the TESZ from c. 30 km beneath Phanerozoic Europe to c. 45 km beneath the craton. Relatively high heat flow characterises Palaeozoic western Europe, in marked contrast to the thick, relatively cold, Precambrian eastern craton.

EUROPROBE studies of the crust and upper mantle along the TESZ and its margins are allowing new interpretations of the thermo-mechanical processes of Phanerozoic lithosphere accretion. The TESZ is a key enigmatic element in the evolution of the Palaeozoic orogens; together with EUROPROBE'S URALIDES project, TESZ will provide new insights into pre-Mesozoic plate tectonics and the assembly of Pangaea.

Understanding the contrasting signatures of European deep lithosphere requires detailed analysis of the Phanerozoic tectonic history across the TESZ and correlation of deep and shallow crustal structures. The Palaeozoic structures are largely obscured by Mesozoic and younger strata of the North Sea-Danish-North German-Polish Basin; a detailed analysis of this basin complex and its partial inversion is required to unravel the enigmatic early Phanerozoic history of this major suture zone. Reconstruction of the Palaeozoic history is also being much assisted by analysis of the numerous deep drillholes which penetrate the pre-Permian basement.

Highlights of EUROPROBE'S multidisciplinary TESZ project include:

1) Teleseismic and regional earthquake tomography experiments defining the complex suture in the mantle beneath the TESZ that appears to extend through the whole lithosphere into the asthenosphere.
2) Determination of variation in Moho depth and lithospheric velocity structure across this fundamental suture zone by seismic refraction – wide angle reflection experiments.
3) Correlation of deep and shallow structures of Proterozoic and Phanerozoic lithosphere by deep seismic reflection and magnetotelluric tomography experiments.
4) Deciphering the tectonothermal history of Palaeozoic terrane accretion in central Europe by multidisciplinary analysis of drillcores and outcrops.
5) Integrating the tectonothermal history of the TESZ with that of the better exposed Palaeozoic orogens of the Appalachians, Western Europe and the Uralides to better understand the assembly of Pangaea.
6) Comparison of Permian-Mesozoic subsidence and Cenozoic inversion of sedimentary basins overlying the contrasting lithospheres on each side of the suture.

Introduction

EUROPROBE'S Trans-European Suture Zone (TESZ) project is a coordinated multidisciplinary investigation into the nature and history of the fundamental lithospheric boundary separating southwestern and northeastern Europe. The thick (c. 45 km), cold Archaean and Proterozoic crust of the East-European Craton is separated from the thinner (c. 30 km), hotter Phanerozoic crust of western and southern Europe by a complex zone of Palaeozoic accretion, Permian-Mesozoic basin development and Cenozoic uplift (Fig. 4.1). Deciphering the Phanerozoic tectonic history is fundamental for an understanding of the deep geophysical signature of the lower crust and upper mantle and the thermo-mechanical processes that led to the development of these contrasting continental lithospheres. A wide range of geological, geophysical and geochemical research is underway. Reinterpretation of existing DSS profiles in Poland, and teleseismic studies, are in progress. Recent work on the Palaeozoic tectonic history of the western TESZ in eastern England and Belgium (Anglo-Brabant Massif) in areas largely covered by younger strata, has established a successful methodology (combining analyses of deep drillcores, potential field data and seismic profiles) for application further east. Likewise in northeastern Germany (Rügen) studies of deep drillholes provide new insights into the biostratigraphy, sedimentology and Caledonian tectonics. Much of the TESZ in central Europe, from the eastern margin of the Variscan belt in the northeastern part of the Bohemian Massif, the Sudetes Mountains and eastern Germany, to the East-European Craton, is only known from drillcore data and seismic profiles, much of it with reliable data only to base Zechstein. New applications of geochemical and other related studies, in particular isotopic dating, are essential for an understanding of the Palaeozoic evolution.

Development of the Research Plan

Research institutes in Austria, the Belarus Republic, Belgium, the Czech Republic, Denmark, France, Germany, Ireland, Netherlands, Norway, Poland, the Slovak Republic, Sweden, the United Kingdom and the Ukraine are involved in TESZ research. Scientific plans and priorities for research have been defined in several EUROPROBE workshops and study centres (Jabłonna, 1991; Nykøbing-Falster, 1992; Loučná, Liblice, 1993; Aachen, Kielce, 1994; Loucná, 1995). Two of these (Jabłonna and Liblice) resulted in ESF-sponsored volumes of TESZ-related papers. These multidisciplinary workshops have been supplemented by seismic modelling venues, and in collaboration with the Intra-Plate Tectonics and Basin Dynamics (ITBD) group, extensive analysis of the Polish – North German Basin. Polish colleagues have been particularly active, with leadership of new multinational DSS experiments and reprocessing of old reflection seismic (CMP) profiles. The Association for Deep Geological Investigation of Poland (ADGIP) has been formed to coordinate the acquisition of deep seismic and borehole data. An expansion of the project beneath the Carpathian Mountains into the Black Sea area is being prepared with Romanian colleagues. Reflection seismic profiling in the Baltic (BABEL) and more recently, in the eastern North Sea (MONA LISA), is providing new insights into the deep structure of the TESZ beneath the North Sea. DEKORP is planning (1996-7) a new reflection seismic line across the North

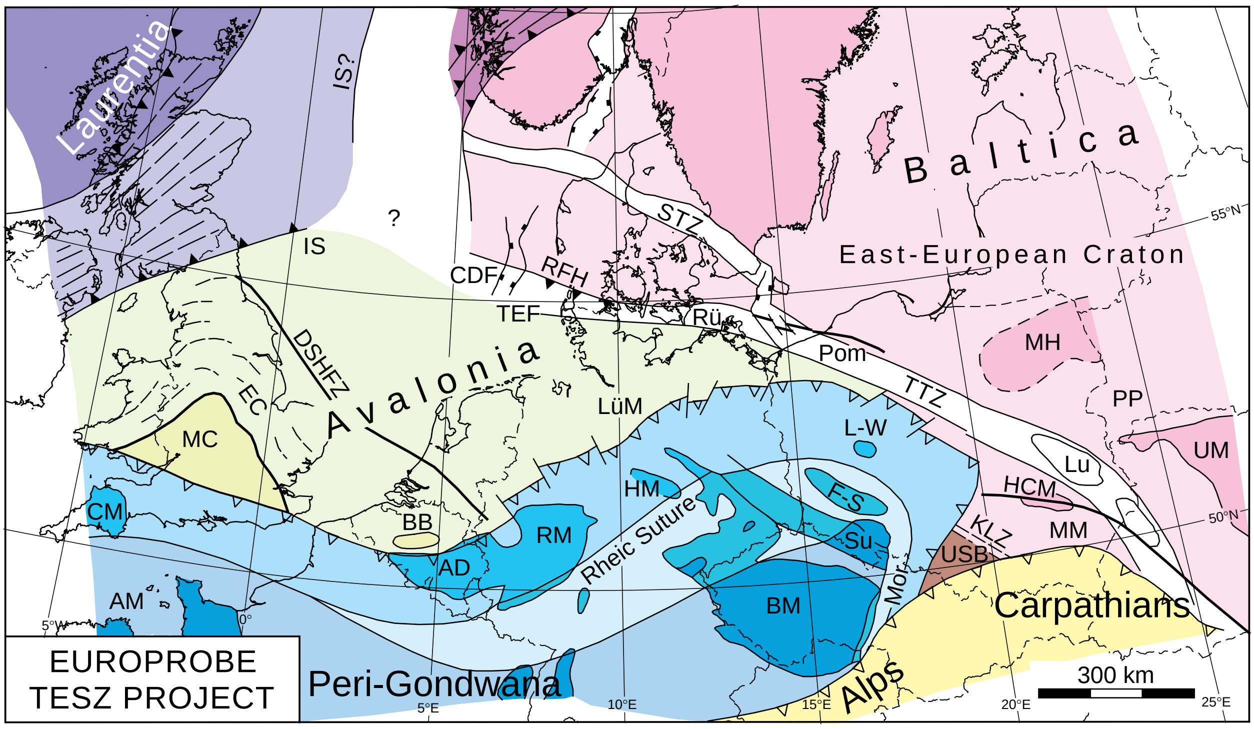

Figure 4.1: Basement tectonic sketch map of the TESZ and adjacent areas, slightly modified from Berthelsen (1994), in EUROPROBE Newsletter 5. The Central Polish Trough is located at the position of the letters TTZ on this map. Key: AD, Ardennes; AM, Armorican Massif; BB, Brabant Massif; BM, Bohemian Massif; C, Cadomia; CDF, Caledonian Deformation Front; CM, Cornubian Massif; DSHFZ, Dowsing-South Hewett Fault Zone; EC, Eastern English Caledonides; EEC, East-European Craton; F-S, Fore-Sudetic Block; HM, Harz Mountains; HCM, Holy Cross Mountains; IS, Iapetus Suture (Avalonia-Laurentia); IS?, uncertain location of Laurentia-Baltica Suture; KLZ, Kraków-Lubliniec Zone; Lu, Lublin Trough; LüM, Lüneberg Massif; L-W, Leszno-Wolsztyn Basement High; MC, Midlands microcraton; MH, Mazurska High; MM, Małopolska Massif; Mor, Moravia; Pom, Pomerania; PP, Pripyat Trough; RFH, Ringkøbing-Fyn High; RM, Rhenish Massif; Rü, Rügen Island; STZ, Sorgenfrei-Tornquist Zone; Su, Sudetes Mountains; TEF, Trans-European Fault Zone; TTZ, Teisseyre-Tornquist Zone; UM, Ukrainian Massif; USB, Upper Silesian Coal Basin.

German Basin, extending from the Harz Mountains to the Baltic Sea. Major contributions towards EUROPROBE TESZ activities are made through the priority programme of Deutsche Forschungsgemeinschaft (DFG) concerning "Orogenic processes, their quantification and simulation in the Variscan Belt". These projects are concerned with terrane accretion, oroclinal bending and transverse displacements along the margin of Baltica.

Geological Framework

The TESZ straddles the boundary between the Precambrian lithosphere of the East-European Craton (EEC), characterised by thick crust (c. 45 km), low heat flow and a tectonothermal age of c. 3000 to 800 Ma, and the Palaeozoic mobile belts of western Europe, with thinner crust (c. 30 km), higher heat flow and an age of 450 to 290 Ma (Fig. 4.1). These contrasting types of crust were juxtaposed by the Caledonian and Variscan orogenic episodes. Existing seismic data across the TESZ in Poland indicate that the latter has an expression at all levels of the lithosphere and deep into the asthenosphere. At the surface, the TESZ is largely concealed by sedimentary basins, developed by reactivation of basement structures within the suture zone during Permian-Mesozoic extension and Cenozoic inversion. The pre-Permian evolution of the craton and the mobile belts, and the location of the sutures has to be interpreted from isolated outcrops, hundreds of drillholes and a variety of geophysical data. These data demonstrate that the deep structure of the crust influenced the evolution of the sedimentary basins; they provide quantitative constraints on the velocity structure and heat flow which define the fundamentally different lithospheres separated by the TESZ.

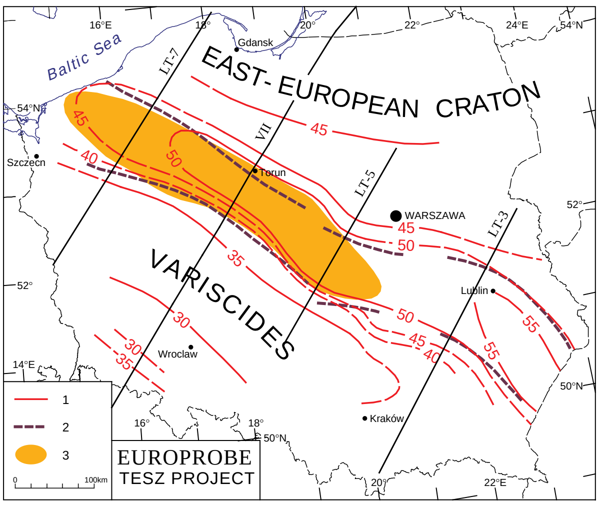

Figure 4.2: Crustal thickness map of the TESZ in Poland, showing the depth to Moho (slightly modified from Stephenson et al., 1995; A. Guterch, pers. comm.). Key: 1, Depth to Moho (km); 2, Extent of thickened crustal root; 3, Area of main Permo-Trias depocentre.

Lithospheric and asthenospheric mantle

Surface and body wave studies of distant earthquakes have demonstrated significant differences in the velocity structure of the asthenospheric and lithospheric mantle beneath the TESZ to depths of c. 400 km (Zielhuis and Nolet, 1994; Fig. 1.2). The transition from high S-wave velocity beneath the East-European Craton to low velocities beneath the mobile belts of central and eastern Europe is steep. This suggests that, contrary to current models which imply that the lithosphere and asthenosphere are decoupled, the TESZ has an expression within the asthenospheric mantle, the age and origin of which is uncertain.

Principal tectonic zones

The TESZ and its immediate neighbourhood can be divided into several tectonic zones. These reflect the present day physiography of the region, the relative importance of the Mesozoic-Cenozoic cover, and the superimposition of younger (Variscan and Alpine) orogenic belts, particularly towards the southeastern extremity of the zone in southern Poland, Germany the Czech Republic, Ukraine and Romania.

East-European Craton

The craton, exposed in the Baltic (Fennoscandian) and Ukrainian Shields, extends along the entire northeastern side of the TESZ (Fig. 4.1) and consolidated during several complex episodes of crustal accretion and reworking through Proterozoic time (Gaál & Gorbatschev, 1987). The relatively thin, undisturbed sedimentary cover ranges in age from Riphean to Cenozoic and is of epicratonic type. On the southwestern margin of the craton, for example in Denmark and Pomerania (northwestern Poland), thicker, basinal Silurian sequences are inferred to represent remnants of Caledonian foredeeps along the southern edge of the craton.

Anglo-Brabant Massif

Southern Britain and Belgium comprise Neoproterozoic crust of 'Avalonian' (peri-Gondwanan) affinity, overlain by an early Palaeozoic cover, thin on the Midlands microcraton and much thicker in the Caledonide basins of Wales, eastern England and Belgium. The sedimentary provenance changed from cratonic in Cambrian time to juvenile, volcanic arc-derived in Ordovician time, reflecting the isolation of Avalonia from more ancient continental provenances by the opening of the Iapetus, Tornquist and Rheic Oceans. Following closure of some of these oceans, localised Silurian deep water basins were once again fed from ancient cratonic sources, probably Laurentia and/or Baltica. These late basins were subsequently deformed during the Acadian Orogeny, producing a structural arc (Fig. 4.3) curving from northwest in eastern England to westsouthwest in Belgium. The massif formed a structural high for much of subsequent Phanerozoic history.

Southern North Sea

The Caledonide basement of the southern North Sea is concealed by Devonian and younger strata, thickest beneath the Anglo-Dutch Basin. Basement rocks have been proven by drilling highs along the periphery of the basin. The presence of metasedimentary and intrusive rocks, comparable with those of the Southern Uplands in Scotland, are used to infer the eastward continuation of the Iapetus Suture. The southern edge of the Baltic Shield is defined offshore by drillcores of metamorphic rocks similar to those of the Sveconorwegian Province (Frost et al., 1981). The Anglo-Dutch Basin is crossed by a number of deep seismic reflection and wide angle profiles, including recently acquired MONA LISA data (Figs. 4.4, 4.7). Interpretation of these profiles suggest that the basin is floored by basement equivalent to that (?Avalonian) beneath southern Denmark, northern Germany and northwestern Poland (Franke, 1995; Pharaoh et al., 1995). No clear suture between this basement and the Baltic Shield is observed on the MONA LISA or BABEL (Baltic Sea; Fig. 4.7) data, suggesting that the contact between these crustal units is steep.

Denmark, northern Germany and northern Poland

The nature of the crust underlying northern Germany is similarly uncertain. Berthelsen (1992a, b) invoked a cover of graphitic sediments of possible Cambrian age to the (?Avalonian) Lüneburg Massif (Fig. 4.1) to explain a major conductivity anomaly. The Ecker Gneiss Complex of the Harz Mountains may represent a sample of such crust, or more distal, Cadomian crust. Deep boreholes in Denmark, northern Germany and Poland define the Caledonian Deformation Front (CDF; Fig. 4.1), and a presumed suture between Avalonia and Baltica (Berthelsen, 1992a, b; Franke, 1995), the Trans-European Fault Zone (TEF).

In the vicinity of Rügen Island, drillholes encounter a thick, thrust and cleaved Ordovician succession of possible Gondwanan faunal affinity (Katzung et al., 1993) and a volcanic arc provenance (Giese et al., 1994). The Rügen sequence is thrust over Silurian basinal facies of Baltican affinity, representing a foredeep along the inferred margin of Baltica. Seismic profiles in the southern Baltic Sea and in Polish Pomerania show strongly deformed Ordovician strata overlain by less disturbed Devonian strata (Seifert et al., 1993: Dadlez, 1993). Seismic refraction profiling carried out for the EUGENO-S project (Thybo et al., 1990) showed that the Ringkøbing–Fyn High, immediately north of the TEF (Fig. 4.1), has slightly thicker crust (36 km) than the adjacent basinal areas in Denmark and northern Germany. The Mesozoic reactivated graben system of the Sorgenfrei-Tornquist Zone in northern Denmark, long regarded as the southern margin of the Baltic Shield, lies well northeast of the Caledonian Deformation Front (Fig. 4.1). The BABEL seismic reflection profile in the Baltic Sea is thought to have imaged crustal imbrication, interpreted to be the result of transcurrent movements along the Sorgenfrei-Tornquist Zone (BABEL Working Group, 1993; Fig 4.5). Towards northern Poland, the STZ and Caledonian deformation front converge into the ‘Tornquist fan’ of Berthelsen (1992a, b). The crustal root observed beneath the Polish Trough is much reduced here (Guterch et al., 1994; Fig. 4.6).

Polish Trough

In central Poland, Devonian and Carboniferous strata and the Caledonian basement are largely concealed by the thick Permian to Mesozoic fill of the Polish Trough. Thick Zechstein salt has hampered successful seismic reflection imaging of pre-Permian basement structure. Numerous deep seismic sounding (DSS) profiles have been acquired and a narrow (c. 75 km wide) zone of thickened crust (to c. 55 km), with near vertical margins coincident with the Teisseyre-Tornquist Zone (TTZ), has been identified (Fig. 4.2). The paucity of velocity information for the crustal part of such profiles prevents more detailed interpretations. Shallow seismic CMP profiles demonstrate the asymmetric nature of the trough and its inversion during the Alpine Orogeny (Dadlez, 1993; Antonowicz et al., 1994). There is uncertainty as to the affinity of the crust lying southwest of the trough, arising from imprecision in the location of the Variscan Front (Dadlez et al., 1994).

Southeastern Poland

The sedimentary fill of the Polish Trough thins onto Palaeozoic massifs, e.g. the Holy Cross Mountains (HCM) and Sudetes Mountains (SU) (Fig. 4.1). Numerous deep boreholes penetrate the basement beneath the post-orogenic cover, particularly towards the Upper Silesian Coal Basin. A complete early Palaeozoic succession of predominantly shallow-water, epicratonic aspect is found in the HCM, and is presumed to have a provenance in the EEC. Late Silurian flysch-like sequences (Dadlez et al., 1994) form the continuation of the Caledonian foredeep recognised in northern Poland. It has been proposed that the Holy Cross Fault, bisecting the HCM, represents a terrane boundary, but the two blocks are stratigraphically similar and share Baltican fauna. Palaeomagnetic evidence (Lewandowski, 1994), suggests that the southern block of the HCM (Małopolska Massif), is minimally displaced from its original position on the southeastern boundary of the EEC (Dadlez et al., 1994).

The Kraków-Lubliniec tectonic zone (KLZ), a relatively narrow (<20 km wide) belt of intense folding and faulting, separates the Małopolska Massif from the Upper Silesian Massif (Fig. 4.1), and is permeated by late Palaeozoic intrusive rocks. The KLZ may be a fundamental terrane boundary (Dadlez et al., 1994). A DSS experiment (LT-3) revealed the presence of four major offsets in the Moho, the most significant

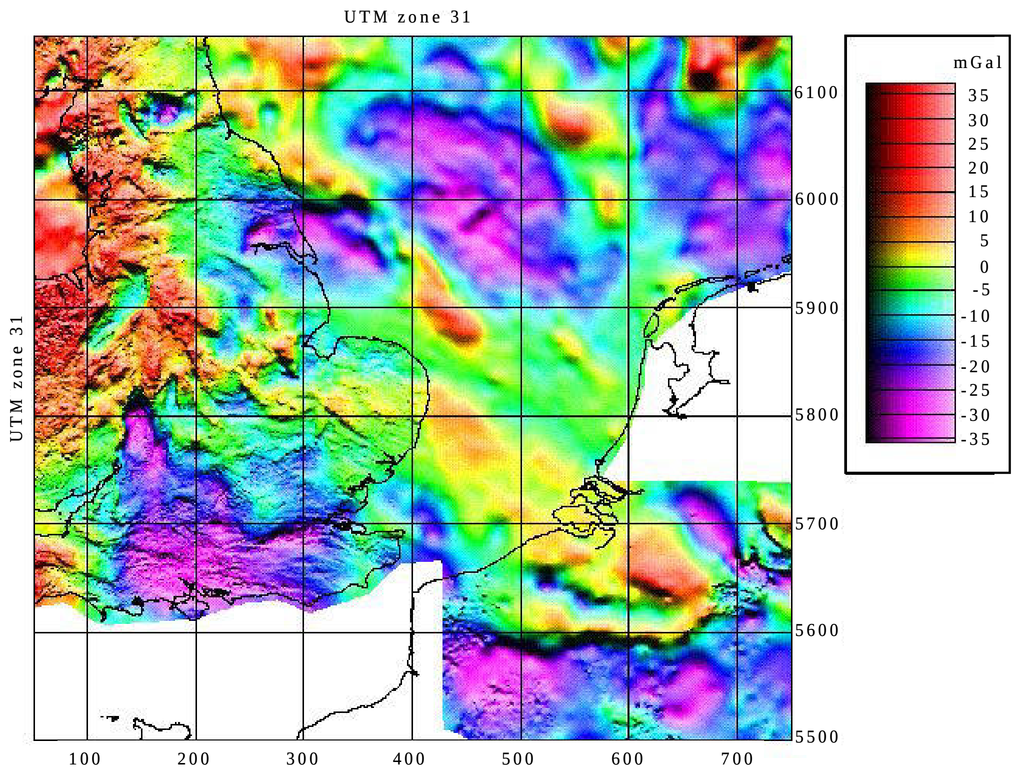

Figure 4.3a: Coloured pseudo-relief image maps of Bouguer gravity anomaly over the Anglo-Brabant Massif and the southern North Sea. From Lee et al. (1993), reproduced with permission from Geological Magazine (Cambridge University Press).

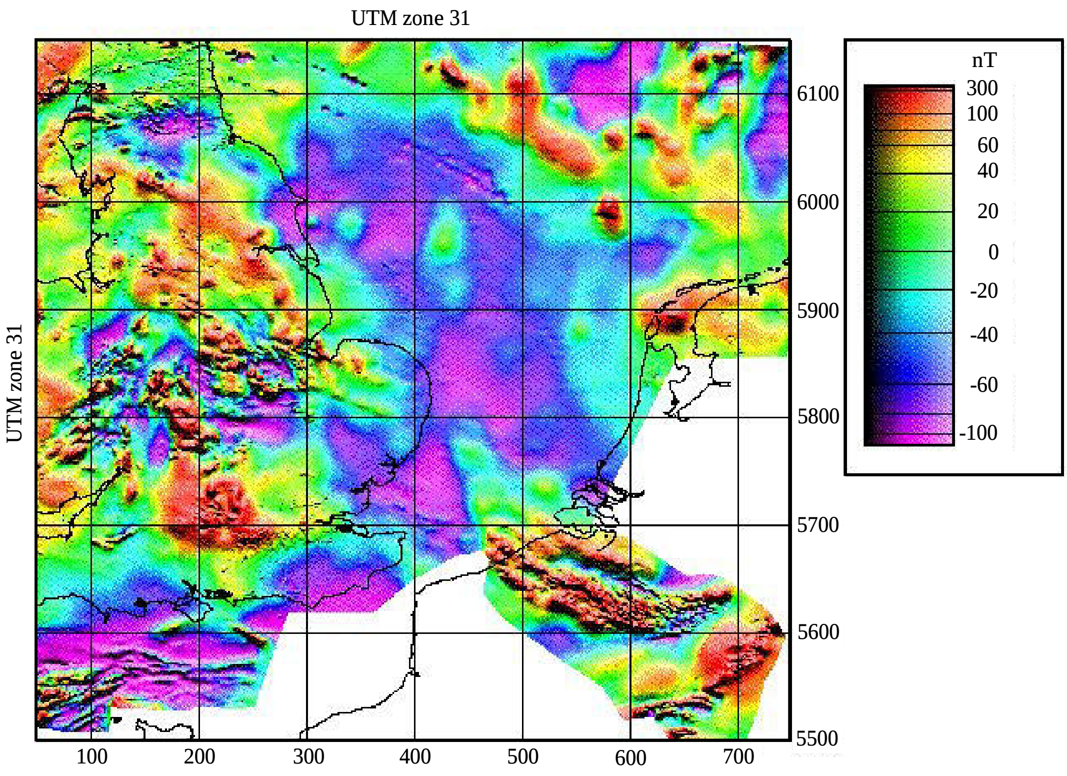

Figure 4.3b: Coloured pseudo-relief image maps of total field aeromagnetic anomaly over the Anglo-Brabant Massif and the southern North Sea. From Lee et al. (1993), reproduced with permission from Geological Magazine (Cambridge University Press).

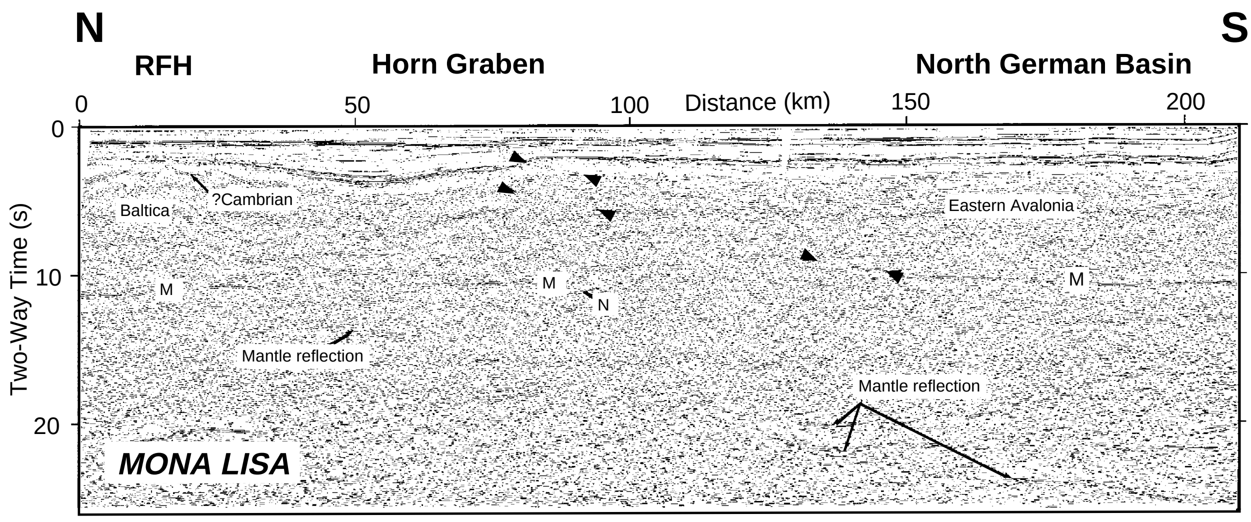

Figure 4.4: Unmigrated reflection seismic section and interpretation - portion of MONA LISA line 1. Position of data indicated by thickening of red line on Fig. 4.7. Inclined reflectors, highlighted by arrow heads, are interpreted as the position of the Caledonian Deformation Front (CDF). RFH: Ringkøbing-Fyn High; M: Moho. Diagram supplied by MONA LISA Working Group.

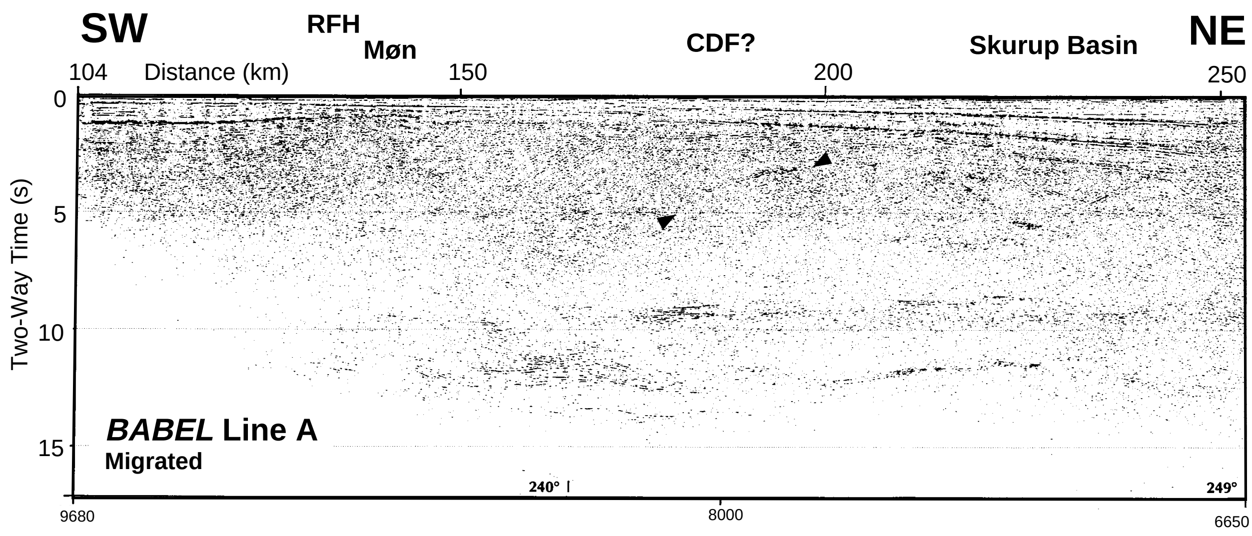

Figure 4.5: Migrated reflection seismic section - portion of BABEL line AC. Position of data indicated by thickening of red line on Fig. 4.7. Inclined reflector, highlighted by arrow heads, is interpreted as the position of the Caledonian Deformation Front (CDF). Moho corresponds to the bright reflection at c. 10 s two-way time. RFH: Ringkøbing-Fyn High. Diagram supplied by BABEL Working Group.

separating crust of very different thickness (c. 50 km in the north, c. 35 km in the south) in the two blocks of the HCM (Guterch et al., 1986). There is an apparent correspondence of the Moho feature with the Holy Cross Fault at the surface (Dadlez et al., 1994). South of Lublin, the crustal root of the TESZ may extend even deeper, perhaps to 55 km (Fig. 4.2).

Southwestern Poland and northeastern Czech Republic

The basement of the Upper Silesian Massif, mostly known from deep boreholes, comprises clastic metasediments, igneous intrusions and gneissose and schistose rocks of "Cadomian" affinity (Dadlez et al., 1994). The basement of the Sudetes and Jeseniky Mountains in the northeastern part of the Bohemian Massif, is similarly diverse. Crustal blocks, showing great contrasts in stratigraphy and metamorphic grade, are separated by major ductile shear zones. There is, however, considerable disagreement over the identity and affinity of individual terranes, and the relative importance of early and late Palaeozoic orogeny in their amalgamation. Do these blocks represent separate terranes sequentially accreted to the Baltica margin (Oliver et al., 1993; Cymerman and Piasecki, 1994) or dismembered parts of larger units seen further west in central Europe (Matte et al., 1990; Franke et al., 1993)? Despite this debate, it is clear that the basement of the Upper Silesian Massif and Sudetes Mountains is extremely complex, and unlike that of the EEC and Małopolska Massif.

Carpathian Mountains and Romania

Along the southern border of Poland, the TESZ is overthrust by the Carpathian thrust-belt of Alpine age, and direct geological observation is not possible. However, a few drillholes have sampled Devonian and older rocks in the basement below the Carpathian Nappes. The TESZ reappears in the Carpathian foreland of Romania as the Dobrogea Zone.

General Evolutionary Model

Various hypotheses for the tectonic evolution of the TESZ are entertained today, ranging from the more static, requiring Phanerozoic reworking of Precambrian crust, to the more mobile, involving Caledonian and Variscan terrane accretion. Biostratigraphical and palaeomagnetic evidence support the latter, indicating that the essential character of the TESZ was established during the assembly of Pangaea by collision of Baltica first with Gondwana-derived microcontinents (Avalonia, Armorica-Bohemia and Iberia) and then with the Gondwana supercontinent itself (Ziegler, 1990). However, the relationships between Avalonia and Baltica remain enigmatic, particularly in areas of southern Poland and the Slovak Republic where "Cadomian" crust underlies Vendian

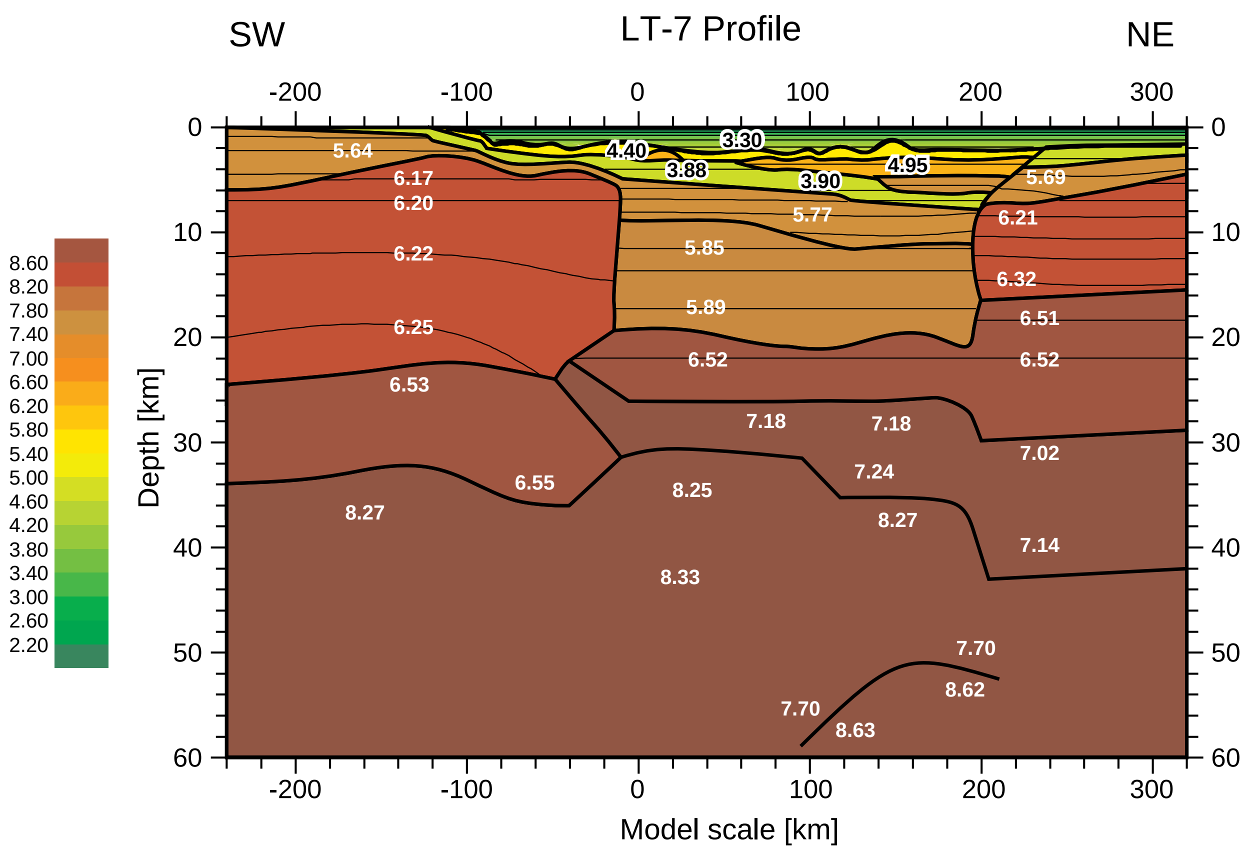

Figure 4.6: Crustal velocity model across the TESZ derived from DSS profile LT-7 (Fig. 4.2; Guterch et al., 1994).

and Cambrian strata containing an Acado-Baltic fauna. Faunal provincialism (Cocks and Fortey, 1982) supports the presence of a major ocean (Tornquist Sea) along the southern margin of Baltica during early Ordovician. They inferred that it closed by the end of Silurian, an interpretation which is not contradicted by the palaeomagnetic evidence (Bachtadse et al. in Dallmeyer et al., 1995). The crust accreted to the margin of Baltica during this period included Neoproterozoic terranes which had originated as Pan-African volcanic arcs and marginal basins along the margin of Gondwana. Juvenile lithosphere, formed from Ordovician ophiolitic and volcanic arc material (Oliver et al., 1993), was also accreted within the TESZ. Amalgamation of Laurentia, Baltica and Avalonia to produce Laurussia was completed by mid-Devonian. Much less certain is the identity and affinity of individual terranes involved in this accretion, the magnitude of their linear displacement and rotation during transport, and the timing of their docking to Baltica and other larger palaeocontinents. Subsequent crustal reworking by the Variscan Orogeny, the final climactic collision between Gondwana and Laurussia, completed the aggregation of Pangaea in late Carboniferous time.

Outstanding Features

It follows from the above description that the TESZ exhibits many similarities to the better known Caledonian and Variscan orogenic belts of western Europe. The degree of involvement of suspect terranes may be comparable to that of the Cordilleran orogenic belts. The superimposition of the Variscan Orogeny onto a Caledonian suture zone has resulted in a rheologically weak lithosphere along the TESZ, with important consequences for Permian to Cenozoic basin evolution. Distinguishing features of the TESZ include:

1) Strong contrasts in lithospheric character across a narrow zone, and deeper signatures in the mantle.
2) A deep crustal root zone, locally extending to 55 km along the craton margin.
3) A zone of collision in both the Caledonian and Variscan Orogenies.
4) Major sedimentary basins developed above the crustal root zone, with significant proven and potential hydrocarbon reserves.
5) A zone of significant latest Cretaceous and Palaeocene (Alpine) basin inversion.

Industrial Significance

The TESZ project area encompasses the hydrocarbon provinces of the North Sea, North German Basin, Polish Trough and Carpathian foredeep. The Permian oil and gas province of Germany and Poland has Carboniferous sources and Permian reservoirs, rather like the southern North Sea. Considerable modification of existing traps was caused by Alpine inversion. In the Carpathian Mountains, the main hydrocarbon accumulations are within the flysch nappes and foreland basins beneath the orogenic pile. It is anticipated that the multidisciplinary geological and geophysical studies to be carried out within the TESZ project will provide much new information on the role of pre-Permian basement structure in controlling the thermo-tectonic evolution of these hydrocarbon-prospective basins.

The Upper Silesian Coal Basin, forming part of the foredeep of the Variscan Orogen, also has significant coal bed methane potential. Coal rank in the basin ranges from high volatile bituminous to anthracite, and methane contents are high. The structural studies presently underway should cast new light on the thermo-tectonic evolution of the structurally complex coal basin.

With regard to metallic ore deposits, it is now recognised that many are concentrated in shear-zones, both internal to, and bounding, terranes. Current work in the Sudetes Mountains indicates an intimate relationship between shear-zones and known gold and metal sulphide mineralisations and may lead to a model for predicting future discoveries.

TESZ RESEARCH

1. Trans-TESZ deep seismic reflection and wide-angle refraction profile in southeastern Poland *(Warsaw [PAS, U], Copenhagen [U], ADGIP, Cambridge [BIRPS]).*
A major objective of the TESZ project is the acquisition of a c. 350 km long deep seismic reflection profile and associated refraction-wide angle reflection studies. The main profile will cross the TESZ from the EEC, over the Holy Cross Mountains and Małopolska Massif to the Upper Silesian Coal Basin (Fig. 4.7). The project will determine the velocity structure of the upper part of the lithosphere and changes in the depth of the Moho across the suture. The reflection profile will define the reflectivity characteristics of the two types of lithosphere and record the geometries of reflectors within the EEC and the mobile belts of western Europe. It will also define the structure of the overlying Permian-Cenozoic basin and its relationship to the deep structure of the suture and the deep crustal root beneath the TTZ. Data from other subprojects will contribute to the interpretation of this profile which is a key to understanding the transition from the EEC to the mobile belts, and the tectonic processes responsible for their formation.

2. Seismic refraction – wide angle reflection profiling along the margins and across the Polish Trough *(Warsaw [PAS, U], ADGIP, El Paso [U], Copenhagen [U], Helsinki [U], Potsdam [GFZ]).*
Three NW-SE wide angle profiles are proposed along the margins of the Polish Trough, forming a grid with existing DSS profiles (Fig. 4.7). These will provide better 3-D control on the structure of the basin and identify the relationship between the crustal root and axis of basin inversion. Also a possible offset of basin structures with respect to the deep TTZ features will be tested. Two profiles will provide constraints on the crustal structure of the EEC. The third will define the crustal structure of the Palaeozoic platform beneath the Variscan Front. A NE-SW profile will provide 3-D control on velocity structure. The main acquisition phase, using European and American (PASSCAL) recording equipment, is planned for 1997.

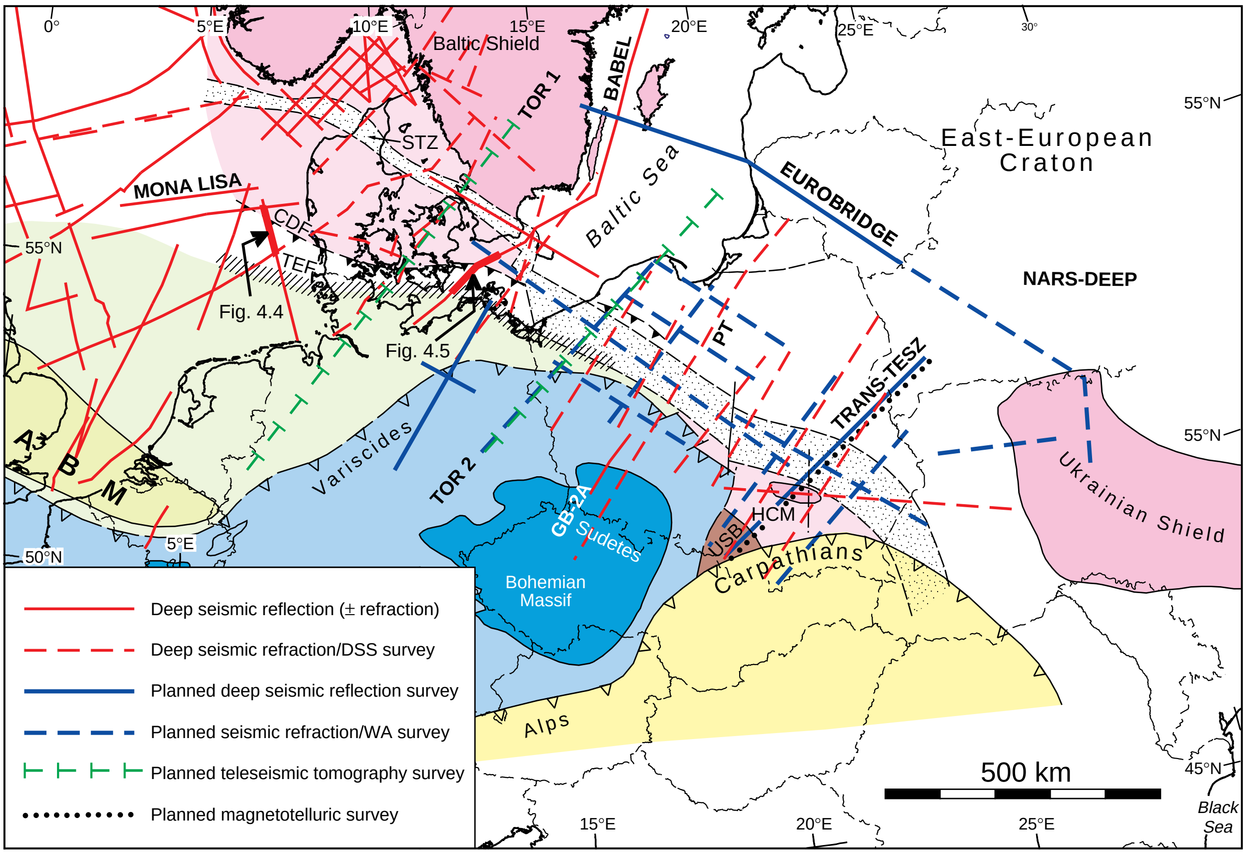

Figure 4.7: Geophysical experiments, undertaken and planned in the TESZ project area. Existing DSS/seismic refraction (dashed lines) and deep seismic reflection profiles (continuous lines) shown in red. Planned experiments in various blue linetypes as shown in the key. Base map supplied by A. Guterch. For key to labels and tectonic zones see Fig. 4.1.

3. Trans-TESZ deep reflection profile, North German Basin *(Potsdam [GFZ], Hannover [BGR], DEKORP).*
DEKORP plans to record in 1996/97 a deep combined steep and wide angle reflection/refraction profile extending from Rügen to the Harz Mountains. Additional profiles will be recorded in the western Baltic Sea. This profile crosses the Caledonian and Variscan deformation fronts and will provide new information on the crustal configuration of the North German Basin and the dynamics of the evolution of this intracratonic basin which extends over different crustal domains and hosts major hydrocarbon reserves. Results of this profile will be compared with the profiles crossing the Polish Trough, straddling the TTZ.

4. Interpretation of existing seismic reflection profiles *(Warsaw [PAS, U, GRE], Wrocław [PGI]).*
Seismic reflection profile GB-2A (Fig. 4.7), shot in 1994, runs NE-SW for 100 km between the Fore-Sudetic Monocline and the Karkonosze-Izera crystalline block. The project provides information on the crustal structure at the boundary between the Rhenohercynian and Saxothuringian Zones. The profile crosses three main crustal blocks bounded by deep-seated northwest-southeast orientated fault zones: the Middle Odra Fault Zone, the Sudetic Marginal Fault and the Main Intrasudetic Fault. Processing of this profile is in progress. Other profiles will be reprocessed.

5. Lateral variation of the deep lithosphere across the TESZ *(Copenhagen [KMS, U], Aarhus [U], Potsdam [GFZ], Uppsala [U], Zürich [ETH], Kiel [U], Warsaw [U]).*
A teleseismic field experiment (TOR), crossing the TESZ in Sweden, Denmark, Germany and Poland, will record distant earthquakes for a high resolution tomographic study of the lithosphere and asthenosphere to depths of 200-300 km. The scale of lithospheric anisotropy within the TESZ will be examined using novel data treatments. A pilot experiment was carried out in 1995, and the main experiment will be carried out in 1996/97.

6. Deep lithospheric structure of the East-European Platform *(Utrecht [U], Kiev [IG], Minsk [IG], Moscow [IEPT], St. Petersburg [U]).*
A Network of Autonomously Recording Seismographs (NARS-DEEP) was deployed on the EEP for a period of 4 years, commencing in 1993, to image the crustal and upper mantle structure. The aim is to investigate the seismicity of the platform, facilitate comparison with the deep structure of the TESZ and evaluate the cause of the rapid increase in asthenospheric S-wave velocity across the latter.

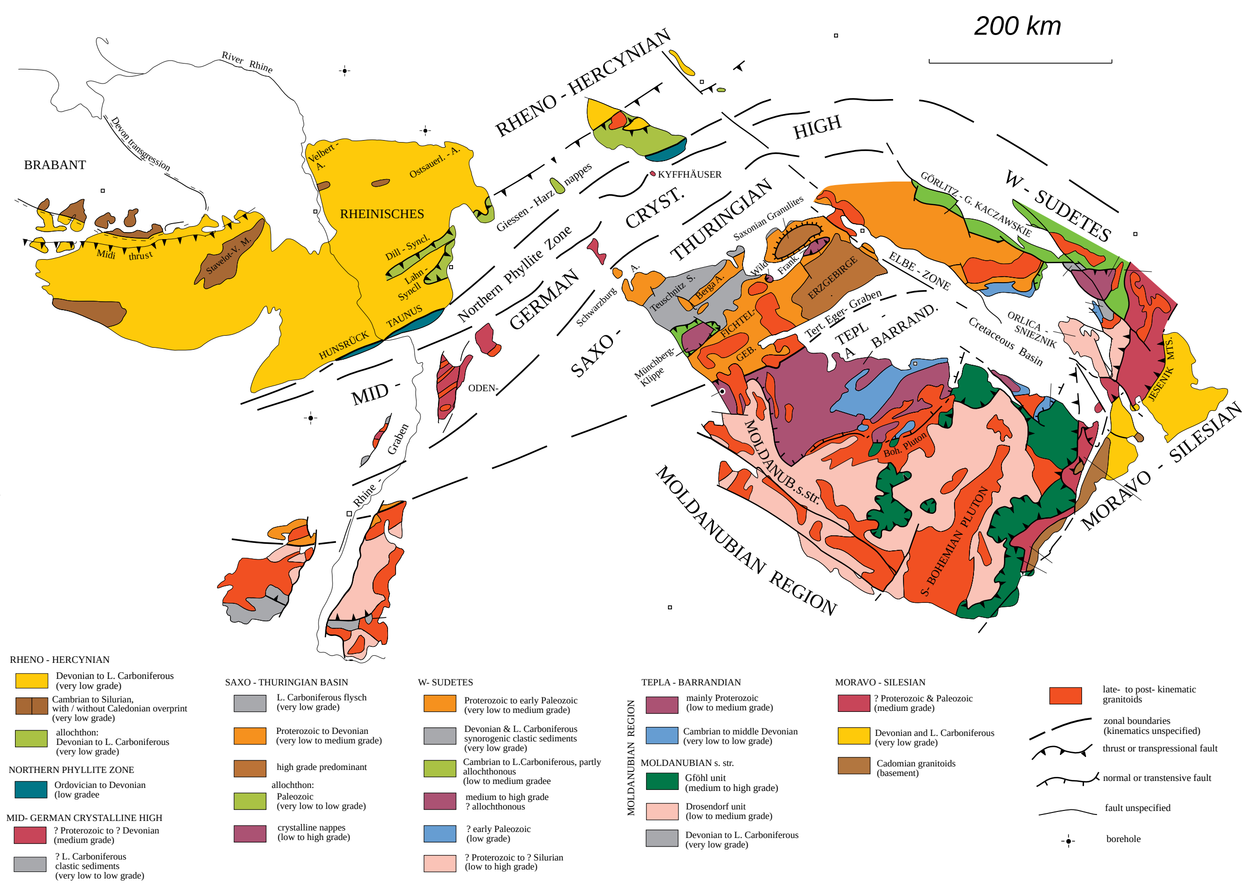

Figure 4.8: Map of tectonostratigraphy of the central and eastern European Variscides (from Franke, in Dallmeyer et al., 1995)

7. Trans-TESZ Magnetotelluric profile *(Warsaw [PGI], Münster [U], Uppsala [U], Kiev [IG], Prague [U], Moscow [SU]).*
A MT profile, coincident with the planned Trans-TESZ reflection profile, is proposed. The project aims at understanding the gross conductivity structure of the crust and uppermost mantle, and correlate conductivity anomalies with reflection seismic signatures. Simulation, using synthetic data, will guide acquisition parameters. Additional shorter profiles and geomagnetic depth sounding may be required if major deviation from two-dimensionality is inferred. A MT profile acquired by PGI across the HCM in 1995 will help plan the larger experiment. An attempt will be made to resolve the electrical asthenosphere by means of very long period measurements at sites west and east of the Polish trough.

8. Compilation of gravity and magnetic data, modelling and structural analysis *(Keyworth [BGS], Warsaw [PGI], Kiev [IG], Hannover [BGR]).*
Digital gravimetric and magnetic data bases, covering the entire TESZ project area, will be compiled and integrated. Gravity compilations from Britain, Ireland, Belgium, the Netherlands, Germany, Norway, Denmark and Poland are nearly complete. Magnetic compilations are under way. Processing of the gravity and magnetic data will allow the distinction between shallow and deep crustal anomalies. Resulting maps, calibrated by outcrop and well data, will permit the correlation of tectonostratigraphic units and terrane boundaries, as defined in the outcropping massifs, through zones of thick Mesozoic and younger sedimentary cover. Preliminary results indicate that available tectonic maps of the Variscan and Caledonian fold belts of western and central Europe require considerable revision. Integrated gravity and magnetic (GRAVMAG) modelling will be carried out along key transects and particularly along the planned seismic profiles.

9. In-situ stress orientation from boreholes in Poland *(Warsaw [PGI], Amsterdam [VU], Karlsruhe [U], Potsdam [GFZ], Bochum [U], Budapest [U]).*
Determination of in-situ stress from borehole breakout analysis continues. New measurements were made in boreholes within the TTZ in 1995. The first estimate of the stress tensor in Poland from hydrofracturing tests and data processing will be made in 1996. Models of the lithosphere and 2-D horizontal stress of the area from the front of the Carpathians to the Baltic Sea are planned.

10. Palaeomagnetism of early Palaeozoic terranes between Baltica and Avalonia *(Warsaw [PAS, U], Brussels [BGD], Dourbes [U], Gent [U], Prague [U], Trondheim [NGU], München [U]).*
This project aims to understand the accretion of terranes in pre-Variscan times in northern Europe adjacent to the TESZ. Apparent polar wander paths for the Lower Palaeozoic in these terranes will elucidate the relative movements of Baltica, the northern and southern blocks of the Holy Cross Mountains (HMC), and the Anglo-Brabant Massif. Work is underway in the HCM where, despite a Variscan overprint, a primary component of remanent magnetization can be identified. A palaeomagnetic study of Middle Ordovician to Middle Devonian rocks of the Barrandian area, and Devono-Carboniferous of the Moravian-Silesian Zone will be carried out to evaluate the palaeogeographic history of these areas in pre-Variscan to Variscan time. New palaeomagnetic data will be correlated with palaeontological and geochemical data.

11. Pre-Carboniferous crystalline basement of the central North Sea *(Keyworth [BGS], Brussels [BGD], Haarlem [NGS], Hannover [BGR], Copenhagen [DGU], Stavanger [OD]).*
Deep boreholes, penetrating the Caledonian crystalline basement of the North Sea region constrain interpretations of deep seismic reflection datasets e.g. MONA LISA. This project involves collaboration between the Geological Surveys of the nations bordering the North Sea. It aims to document available samples of cores and cuttings providing a foundation for new petrographic, structural, geochemical and isotopic analyses.

12. Caledonian Deformation Front and foreland in Denmark, Germany, Poland and Sweden *(Greifswald [U], Aachen [RWTH], Copenhagen [U, MNH], Göttingen [U], Warsaw [PGI], Liège [U], Lund [U]).*
Knowledge of the central European Caledonides comes from deep drillings and geophysical investigations. Deep boreholes are situated in Jylland, Sjaelland (Denmark), Schleswig, Rügen, Vorpommern (Germany), Pomorze and Mazowsze (Poland). At present the age of the folded Palaeozoic is loosely constrained by graptolites and acritarchs. Studies of sedimentary petrology, provenance, biostratigraphy, tectonics and metamorphism in the Rügen Ordovician section have been published and work in other areas is in progress. Related studies of the Danish and German seismic data are providing new structural interpretations. The project will lead to a synthesis of the evolution of this key segment of the TESZ.

13. Ecker Gneiss Complex, northern Harz Mountains *(Potsdam [GFZ], Clausthal [TU], Prague [U]).*
The Ecker Gneiss Complex is a 7 km long inlier of presumed Precambrian gneisses, metamorphosed in the amphibolite facies with granulite facies enclaves. The complex is to be investigated by geochemical, isotopic and geophysical methods as a suspected analogue for the peri-Gondwanan crystalline basement of the North German Basin and southern North Sea.

14. Proterozoic evolution of the EEC Margin *(Stockholm [U], Warsaw [U], Kiev [IGS], Minsk [IGS]).*
Geochemical, particularly isotopic, studies of deep drillcores along the Polish margin of the EEC are providing constraints on the Proterozoic basement evolution and character of the cratonic crust which, immediately to the southwest, is modified by Vendian rifting and Palaeozoic accretion.

15. Terranes and their boundaries in southwestern Poland and the northeastern Czech Republic *(Keele [U], Wrocław [PGI, U], Praha [CGU, U], Dublin [UCD], Giessen [U], Sosn owiec [PGI], Montpellier [U]).*
On-going structural investigations focus on the kinematic history and isotopic dating of major ductile shear zones which bound tectonostratigraphic domains (terranes) in the eastern Variscides (Fig. 4.8). The structural / geochemical control of metalliferous mineralisation is of particular interest. A parallel aim is to provide information on timing of terrane motion during the Palaeozoic, particularly along the boundary between the Upper Silesian and Małopolska Massifs (the Kraków – Lubliniec Zone, KLZ), which may represent a suture between the EEC and Gondwana-derived terranes.

16. Tectonometamorphic evolution of Sudetes eclogites and blueschists *(Warsaw [PAS, U], Wrocław [U], Montpellier [U], Prague [U], Rennes [U], Clermont-Ferrand [U], Palisades [U]).*
Omphacite granulites, eclogites and blueschists of the western Sudetes Mountains underwent ultra high pressure (UHP) and high pressure (HP) events followed by retrogressive metamorphism. Detailed mineralogical, structural, geochemical, geochronological and fluid inclusion studies will further investigate the UHP and HP evolution, define the age of HP metamorphism and establish the P–T–t trajectory during exhumation of these rocks.

17. Thermomechanical processes along the eastern transpressive margin of the Bohemian Massif *(Prague [U], London [IC], Cardiff [U]).*
Interplay of transpression and rotation during late Palaeozoic orogeny defined the eastern margin of the Bohemian Massif and its juxtaposition with the Carboniferous foreland basin. This project studies the thermal and mechanical processes occurring during assembly of the metamorphic allochthons and their emplacement northeastwards onto the Cadomian basement with its Devono-Carboniferous cover.

18. Petrological and geochemical features of the lower crust and upper mantle in the Bohemian Massif *(Prague [U], Wisconsin [U], Rennes [U]).*
Petrological, geochemical and geochronological studies of granulites and peridotites in the Bohemian Massif will determine the nature of lower continental crust and upper mantle in Palaeozoic and Neogene lithosphere. Both xenoliths and tectonically emplaced rocks are being studied. Preliminary results indicate that significant differences in lithospheric thermal history and geochemistry exist between the northern and southern parts of the massif.

19. Lower Palaeozoic biostratigraphy and palaeobiogeography north of the Variscan Front *(Gent [U], London [BMNH], Kielce [PGI], Leicester [U], Liège [U], Sosnowiec [PGI], Prague [U], Uppsala [U], Warsaw [U]).*
Critical to the understanding of the history of the different terranes north of the Variscan foldbelt during Vendian and early Palaeozoic time is the age of their sedimentary sequences. New biostratigraphical studies of acritarchs, chitinozoa, conodonts and graptolites will yield the most precise biozonation possible. The relative palaeobiogeographical position of the different terranes can be deduced from benthic faunas by comparing the degree of endemism of fossil assemblages at well defined biostratigraphical intervals. Combination of the studies with lithofacies analysis will allow definition of palaeoclimatological constraints.

20. Sedimentary basin studies to unravel post-Carboniferous tectonic evolution of the TESZ *(Warsaw [PGI], Aarhus [U], Copenhagen [DGU], Potsdam [GFZ], DEKORP, Mainz [U], Kiel [U], Hannover [BGR], Amsterdam [VU], Haarlem [NGS], Basel [U], Oxford Brookes [U]).*
The basins overlying the TESZ in Germany, Denmark and Poland constitute a sensitive recorder of the structural evolution of the zone since the Carboniferous. Basin modelling studies integrate diverse datasets and have a bearing on understanding the hydrocarbon potential. The main objectives encompass: restoration of late Variscan lithospheric architecture and thermomechanical conditions; understanding the influence of Stephanian-Autunian magmatic events on basin origin and development; defining the relationship of tectonic (and halokinetic) events in the TESZ basins to the North Atlantic and Tethyan-Alpine geodynamic evolution; synthesizing crustal evolution during Mesozoic and Cenozoic time. Existing shallow reflection (CMP) profiles across the Polish-North German-Danish Basin, in combination with drillhole data, are particularly important for this project. A DEKORP initiative to carry out deep CMP profiling across the North German Basin into the Baltic Sea will provide new constraints on the basin modelling.

21. Mesozoic and Cenozoic magmatic activity in the Tesz area *(Potsdam [GFZ], Leeds [U], Lund [U], Wrocław [PGI]).*
Troughout extra-Alpine Phanerozoic Europe there are scattered occurrences of Mesozoic magmatic activity. Cenozoic extrusive and intrusive magmatism is more wide spread. Although considerable work has

been carried out in the past, a comprehensive inventory of Mesozoic and Cenozoic magmatic activity in the Tesz area is lacking. Additional geochronological, geochemical, isotope and trace element analyses are required in an effort to determine the timing, mechanisms and levels of magma generation and assess whether and when possible changes in the potential temperature of the upper asthenosphere occurred.

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