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Seismic profile LT-7 (northwest Poland): geological implications

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Abstract – Crystalline crust examined along the seismic profile LT-7 is subdivided into four blocks separated by distinct vertical fractures. The northeastern block belongs to the East European Craton (Baltica). Its three-layer structure is similar to that of the Svecofennian crust farther to the northwest. The southeastern block reveals typical, two-layer Variscan crust. Both central blocks have a peculiar structure not comparable with the crust of the Danish and North German areas: two lower layers, with velocities identical or close to that of the cratonic lower and middle layers, are extremely thin, and an upper layer, 8–11 km thick, shows surprisingly low velocities. This upper layer probably represents the folded and weakly metamorphosed Lower Palaeozoic sequences, although the connection with undeformed epicratonic cover cannot be excluded. Significant differentiation of crustal types in different segments of the Trans-European Suture Zone favours the concept of tectonostratigraphic terranes which collided with Baltica.

1. Introduction

Seismic refraction and wide-angle reflection profile LT-7 is the first profile in Poland providing a full record of the velocity distribution within the Earth's crust. The profile (560 km long) crosses eastern Germany (240 km) and northwestern Poland (320 km). Its geophysical results have been published by Guterch *et al.* (1994; and unpub. data). Four crustal blocks can be identified along the profile, labelled (from northeast to southwest): A, B′, B″ and C. Each of them is characterized by a specific crustal velocity structure. Fundamental differences exist between the blocks A and B′, and B″ and C whose boundaries are marked by distinct vertical discontinuities (crustal fractures). The differences between the blocks B′ and B″ are not as great, but a fracture at their boundary (at least in the lower crust) can also be presumed (see Guterch *et al.* 1994, fig. 4).

In the framework of the Zechstein–Mesozoic tectonic units (Figs 1, 2) the profile runs in Poland from the Łeba Elevation in the northeast through the Mid-Polish Trough to the Fore-Sudetic Monocline in the southwest. The Mid-Polish Trough, during the late Cretaceous/early Tertiary inversion, was subdivided into the Pomeranian Trough, the uplifted Mid-Polish Swell and the Szczecin Trough. The internal structure of the Zechstein–Mesozoic cover down to the Zechstein base, is fairly well examined by a dense net of commercial seismic reflection profiles controlled by numerous boreholes.

Taking into account the sub-Zechstein structural stages (Figs 1, 2), the northeastern segment of the profile (200–320 km) cuts the peripheral part of the Precambrian East-European Craton with relatively thick, flat-lying Cambrian through Silurian sedimentary cover. The top of the crystalline basement here has been investigated by means of shallow seismic refraction surveys and verified by boreholes. Near the boundary between blocks A and B the folded Ordovician and Silurian strata are probably thrust over the edge of the craton. In the same zone but slightly to the south a downfaulted, extensional horst-and-graben system of post-Carboniferous age overlies the folded Caledonian sequences. It is probably the northeastern part of a broader faulted platform built of epicratonic Devonian and Carboniferous clastics and

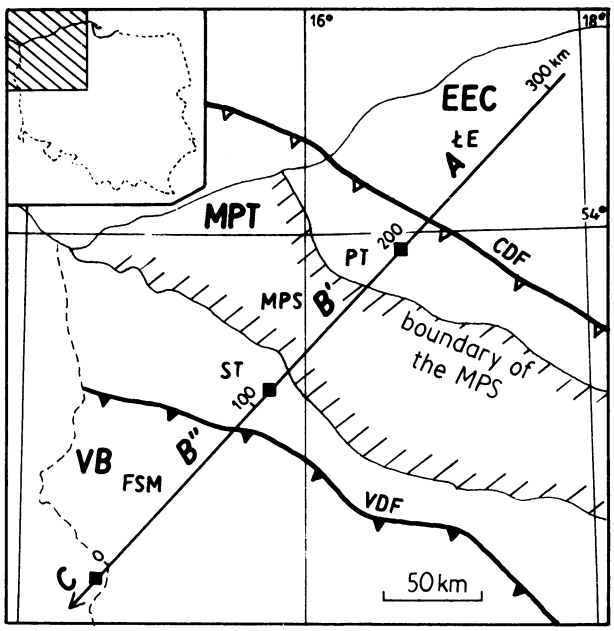


Figure 1. Location map. A, B′, B″, C – symbols of crustal blocks; CDF – Caledonian deformation front; EEC – East European Craton; FSM – Fore-Sudetic Monocline; ŁE – Łeba Elevation; MPS – Mid-Polish Swell; MPT – Mid-Polish Trough; PT – Pomeranian Trough; ST - Szczecin Trough; VB – Variscan Belt; VDF – Variscan deformation front.

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carbonates. In the southwestern part of the profile (0–100 km), beneath the Fore-Sudetic Monocline, the folded and weakly metamorphosed Carboniferous strata of the external Variscan (Rhenohercynian) belt occur, predominantly overlain by the Rotliegendes sediments and volcanic rocks. The central segment of the profile (100–200 km) remains *terra incognita* because very few boreholes pierced the Permian in this subsided area. It is the southeastern corner of a territory which was once called by a prominent British geologist 'the Danish Triangle' (Ager, 1975), and was characterized by him as "... a vast and seemingly uninteresting lowland ... with complex and fascinating history ...". Some of its mysteries have been solved since, but many others have not.

2. Sedimentary cover

There are some contradictions between the velocity pattern and the geological data in the uppermost part of the profile LT-7, both within the Zechstein–Mesozoic and the Devonian–Carboniferous stages. Therefore the picture in this part of Figure 2 is rather independent of the velocity pattern.

At the northeastern end of the profile the velocities 2.2–3.8 km/s represent the Mesozoic and Silurian part of the sedimentary cover. The boundary between the layers with velocities 5.7 km/s and 6.3 km/s coincides roughly with the top of crystalline crust. However, further to the southwest the contrasting boundary (3.8 km/s versus 5.7 km/s) enters the Silurian strata obliquely, which is not easy to explain from the geological point of view because the Silurian rocks are homogeneous. Apart from depth differences the nature of high velocity layer is intriguing. Is it Cambrian/Vendian?

At the opposite end of the profile (Polish–German border) the velocities of 2.2–3.5 km/s agree rather well with the Mesozoic strata and velocities of 4.4 km/s with the Zechstein strata. However, further to the northeast the base of the latter layer enters the Zechstein strata and even the Mesozoic sequences. The difference between its position and the Zechstein base increases in the central part even to 2 km.

The geology below the Zechstein base of block B (Fig. 2) is problematic. At the southwestern end of block B (the boundary between the blocks B″ and C) a low velocity layer (3.9 km/s) occurs just below the Zechstein base. Its bottom lies at a depth of 5 km and deepens northeastwards to a depth of 7 km (layer **5** in Fig. 1). Further to the northeast (block B′) the base of this layer descends to a depth of 8 km while its upper part is laterally replaced by

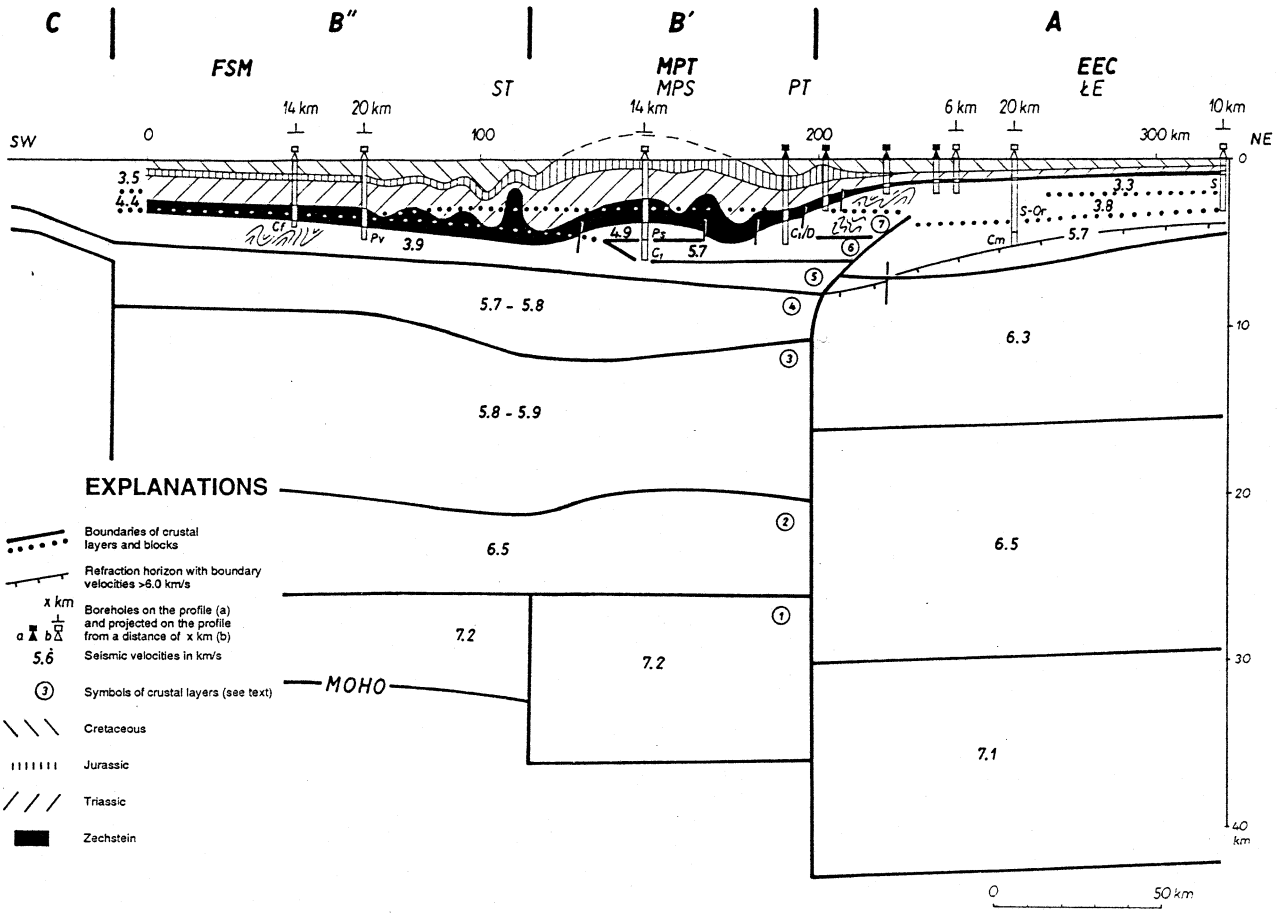


Figure 2. LT-7 profile – crustal structure and geology. Ps – Rotliegendes sediments; Pv – Rotliegendes volcanic rocks; Cf – Carboniferous, folded; C1 – Lower Carboniferous; D – Devonian; S–Or – Silurian and Ordovician; Cm – Cambrian. For other abbreviations see Figure 1.

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two layers of higher velocities: a lower one (layer **6**, 5.7 km/s) and an upper one (layer **7**, 4.9 km/s).

The first interpretation, taking into account the general geological situation, was to regard the low velocity layer as Upper Carboniferous/Rotliegendes clastic rocks. Accordingly, the overlying layers **6** and **7** would represent uppermost Carboniferous/Lower Rotliegendes intrusive and extrusive bodies. In another interpretation, layer **7** would still belong to the Zechstein and Upper Rotliegendes sedimentary sequences. However, these preliminary ideas do not tally with the results obtained from deep boreholes. Boreholes situated on block B″ encountered below the Zechstein either the folded and weakly metamorphosed Carboniferous strata of the Rhenohercynian Zone or Rotliegendes volcanic rocks. Boreholes located in block B′ found the lower Carboniferous/Upper Devonian shale and limestone sequences either directly below the Zechstein or separated from it by a thick series (1000 m) of the Upper Rotliegendes sediments. Thus, the low velocity layer cannot be the equivalent of the Upper Carboniferous rocks. Recent preliminary results of a new profile, TTZ-PL, which intersects the profile LT-7 at the point of 150 km, cast some doubts on the existence of this layer, at least in block B′. If layer **5** does not exist here, the interpreta-tion becomes easier because layers **7** and **6** would be equivalent, respectively, to the Rotliegendes and Lower Carboniferous/Upper Devonian sediments.

The above discrepancies might also result from the fact that some boreholes were projected on the profile from greater distances (20 km) and their sections may not be representative for the profile itself. However, in such a case considerable lateral changes along individual zones would need to be assumed; this is rather improbable, keeping in mind the seqences of other boreholes located northwest and southeast of the profile.

Apart from these inconsistencies the connections between the general subdivision of crystalline crust and the tectonic units in sedimentary cover are rather obvious (Fig. 2). The late Permian through late Cretaceous Mid-Polish Trough, which was later inverted and transformed into the Mid-Polish Swell, is clearly limited to block B′. Particularly, the northeastern boundary of the trough is distinct, recorded by the rapid thickness increase of the Permian and all the Mesozoic systems. It is also marked by smaller inversion structures accompanying the main inversion unit (Mid-Polish Swell) which is visible further to the southwest. Below the Zechstein the northeastern boundary of the folded Ordovician/Silurian zone, as well as that of the faulted, rotated blocks built of Devonian and Carboniferous layers, are also related at depth to the fracture separating blocks A and B′. The opposite edge of the trough, related to the boundary between blocks B′ and B″, is also expressed by the thickness increase (especially of the Jurassic sequences) and the distribution of salt anticlines: the most strongly pierced salt diapirs lie above this crustal boundary.

In block B″ the problems of the northeastern extent of the folded Variscan (Rhenohercynian) belt as well as of the existence or non-existence of its foredeep in Polish territory remain unsolved. It is characteristic that, while the boundaries both between blocks A and B′, and B′ and B″ are coincident with distinct gravity gradients, the boundary between blocks B and C is not reflected in the gravity field. This boundary coincides with the southern edge of the Wolsztyn High, which is a sub-Zechstein elevation either devoid of the Rotliegendes rocks or with reduced thicknesses of conglomerate sequences. In the core of this elevation, metamorphic rocks of unknown age occur farther to the southeast. Thus, not only the external Variscan thrusts but perhaps also more internal units may extend into block B″. Franke, Hoffmann & Lindert (1995) claimed that the enormous thickness of the upper crust in block C is an effect of stacking of Variscan thrusts and nappes. However, it should be noted that the possible thrust piles extend at least 80 km further north beyond the boundary between blocks C and B″ and are underlain in B″ by a completely different type of crystalline crust than in block C.

3. Crystalline basement

The lower part of profile LT-7 has been compared with the results of seismic experiments in southern Sweden, Denmark and eastern Germany (EUGENO-S Working Group, 1988; Thybo, 1990; Aichroth, Prodehl & Thybo, 1992; BABEL Working Group, 1993). Simplified crustal columns placed upon the geographical and tectonic background are shown in Figure 3 while these same columns, arranged according to tectonic zones for easier correlation, are presented in Figure 4.

Block A reveals a typical cratonic (Precambrian) three-layer crust with Moho discontinuity at a depth of 42–43 km and with velocities 6.2–6.3 km/s in the upper layer, 6.5 km/s in the middle layer, and 7.1 km/s in the lower layer. It resembles the crust of Svecofennian age which is known near Bornholm and Öland and differs from the Sveconorwegian crust further to the northwest, which is generally composed of two layers (compare column 5 with columns 6 and 8–11 in Figs 3 and 4). The crust of block C, where the Moho lies at depths of 32 to 35 km, is divided into two layers (Guterch *et al.* 1994, fig. 4): the upper layer with a velocity of 6.2 km/s and the lower one with a velocity of 6.5 km/s. It is comparable with the Variscan (Rhenohercynian) crust further to the west except for greater thickness of the upper crust and the lack of local low velocity zones (compare columns 1 and 2 with 3 in Figs 3 and 4).

The structure of the crust in the blocks B′ and B″ (called TESZ crust) is quite different. When relating it to the more western areas we see that each crustal zone in German and Danish territories (Sorgenfrei-Tornquist Zone – STZ; Norwegian-Danish Basin – NDB; Ringköbing-Fyn High – RFH; North German Lowlands – NGL) is characterized by its own specific features, sometimes even changing along its strike. For example, at both ends of the Norwegian-Danish Basin (EUGENO-S

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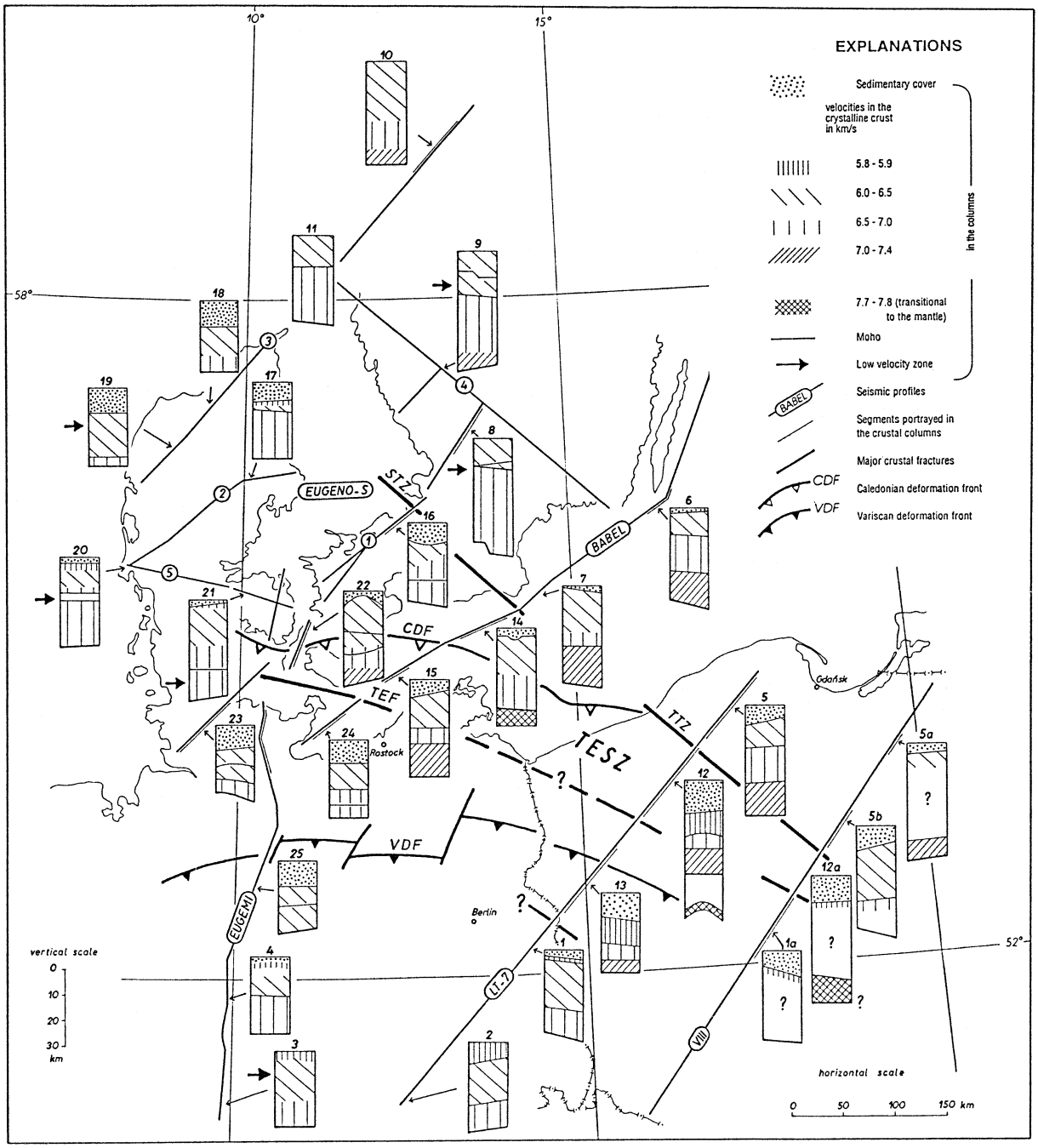


Figure 3. Crustal columns in the northwestern part of the Transeuropean Suture Zone. STZ – Sorgenfrei–Tornquist Zone; TEF – Trans-European Fault; TESZ – Trans-European Suture Zone; TTZ – Tornquist–Teisseyre Zone. For other abbreviations see Figure 1. Variscan Deformation Front in German territories after Franke *et al.* 1995.

Working Group, 1988) the proportions between the lower and upper crust change: the upper crust is very thick in its northwestern part, while it is extermely thin in its southeastern part (Figs 3, 4; columns 17–19). The differences along the Ringköbing-Fyn High are much the same. The Grindsted Block (column 20) is characterized by a thick lower crust, while in the Glamsbjerg Block (columns 21 and 22) the thickness of the upper crust increases gradually southeastwards. It is interesting that in the eastern part of the Glamsbjerg Block a thin layer with velocities more than 7.0 km/s appears. Below the Mön High which is the southeastern extension of the Ringköbing-Fyn High the thickness of this layer attains 13 km (BABEL Working Group, 1993).

Crystalline crust in the middle segment of the LT-7 profile (block B) is composed of three layers (columns 12 and 13 in Figs 3 and 4, see also Fig. 2). Lower layer (**1** in Fig. 2) is characterized by a velocitiy of 7.2 km/s. The velocity is approximately the same as in the cratonic lower crust but the thickness is smaller (11 km in block B′ and 6–7 km in block B″, versus 13 km in the craton), and the Moho lies much higher (36 and 31 km, respectively, versus 42–43 km). The middle layer (**2** in Fig. 2), with velocity identical to that in the middle layer of the cra-

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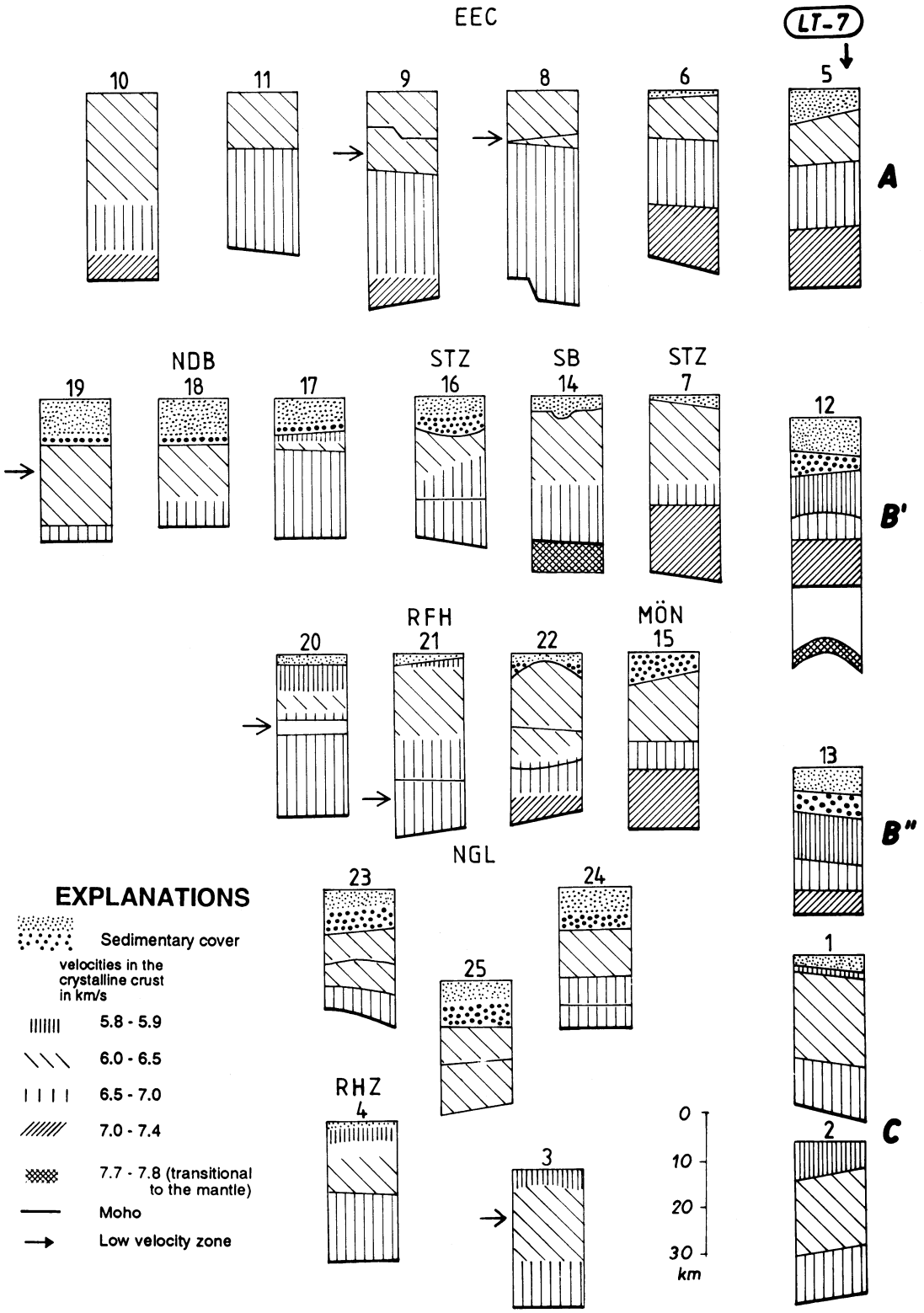


Figure 4. Correlation of crustal columns. NDB – Norwegian-Danish Basin; NGL – North German Lowlands; MÖN – Mön High; RFH – Ringköbing–Fyn High; RHZ – Rhenoherzynian Zone; SB – Skurup Basin. For other abbreviations see Figures 1 and 3.

tonic crust (6.5 km/s), is only 4–6 km thick. Finally, the upper layer (**3** in Fig. 2, velocities 5.8–5.9 km/s) is about 8–9 km thick in block B′ and maximum 11 km in block B″, its bottom lying at depths, respectively, of 20–21 km and 19–21 km.

The upper layer of profile LT-7 has no counterpart in the remaining areas of the Trans-European Suture Zone. The velocities are slightly higher in it than in the undeformed and non-metamorphosed Lower Palaeozoic sediments beneath the Norwegian–Danish Basin (columns 17–19) and slightly lower than that in the folded and weakly metamorphosed Lower Palaeozoic rocks

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beneath the North German Lowlands (columns 23–25). Comparable velocities are noted locally in much thinner layers of the uppermost crystalline basement both in the Norwegian-Danish Basin and Ringköbing-Fyn High (columns 17, 20 and 21). The structure and thickness of the two remaining layers of block B are like that in the periclinal part of the Mön High and in the neighbouring Sorgenfrei-Tornquist Zone on the BABEL profile (compare columns 12 and 13 with 7 and 15). However, the lower layer of block B′ is thick in comparison to the eastern part of the Ringköbing-Fyn High (column 22), let alone the western part where it is absent. On the contrary, the middle layer is extremely thin, which is also in conflict with the data from the Ringköbing-Fyn High area.

The middle layer of the BABEL profile was earlier regarded (BABEL Working Group, 1993) as a crustal wedge of Precambrian crust indenting the Avalonian crust. If this is correct, the nature of the crust of the Mön High would be different from that of the Ringköbing-Fyn High. The interpretation of the crustal wedge could be extended into block B′ but not into the block B″, among other reasons because of the laminated structure of the middle layer in the latter (Guterch *et al.* 1994). The alternative interpretation would be that both the lower and middle layers in block B′ are reworked cratonic crust (cf. Dadlez *et al.* 1995).

The upper layer of blocks B′ and B″ is here tentatively interpreted – in spite of some reservations – as a complex of folded and weakly metamorphosed Lower Palaeozoic rocks. Another possibility would be that it represents non-deformed Lower Palaeozoic sequences. What is the reasoning in each of these cases? Major vertical discontinuities delimiting blocks B′ and B″ suggest their terrane character (transpressional terranes?) and regional extent of deformation. From the other side, the Trans-European Fault seems to run in the direction of the boundary B′/B″ which would imply that block B′ is a part of the East European Craton, being the most external, downfaulted zone of the craton. The deformations along its northeastern boundary would be then of local character. However, it could be a proximal terrane as well: a sliver detached from the East European Craton further to the southeast and reaccreted to it in late Caledonian times (see also Dadlez, 1995; Franke, 1994; Pożaryski *et al.* 1992). The position of block B″ is still more enigmatic. It is overlain by external Variscan thrusts. Nevertheless, this does not preclude its earlier (Caledonian) terrane character.

The small differences in velocity between layers **3** (5.8–5.9 km/s) and **4** (5.7–5.8 km/s; see Fig. 1) are striking. The boundary between these layers, lying at depths of 9–12 km, is here accepted as a boundary between the sedimentary cover and weakly metamorphosed basement. However, it cannot be ruled out that layer **4** also belongs to the basement. In such a case the base of the cover would be the boundary between the layers **4** and **5**, marked by a very sharp velocity contrast (3.9 versus 5.7 km/s) and lying at depths of 5–8 km. In the old shallow refraction profiles the traces of a horizon with boundary velocities of 5.8 km/s were in places recorded below the Mid-Polish Trough, but the depths to that horizon are ambiguous (6–7 km northwest of the LT-7 profile, 8–10 km southeast of it; along the profile itself there are no data). So, these old data are not decisive, the more so as they were then interpreted either as basement top or as a top of Dinantian and Devonian carbonate/shale sequences.

The last open problem concerns a layer with velocities of 7.7–7.8 km/s which occurs at the crust/mantle boundary (at a depth of 45–55 km) on profiles VII and LT-2 in central Poland (Guterch *et al.* 1986; see also Fig. 3, column 12a). On these profiles, Moho discontinuity is indicated below this layer. On the BABEL profile a layer of the same velocity was found at a shallower depth beneath the Skurup Basin (column 14 in Figs 3 and 4), again at the crust/mantle boundary; in this case the Moho is located above this layer. Moreover, between the two areas, on the LT-7 profile (block B′, column 12) such a layer was recorded within the uppermost mantle at depths similar to that on the profile VII (47–55 km). Is the origin of this layer in all three localities the same? It was earlier interpreted on profile VII (Dadlez *et al.* 1995) as a product of mantle injection lying between the present Moho (above) and the palaeo-Moho (below).

4. Conclusions

(1) The questions posed by the results of the LT-7 profile are more numerous than the problems which were solved. Among the most important questions are: (a) the geological nature of the layers **3**, **4** and **5**; (b) the geodynamic relations between the cratonic crust and the crust in the block B; (c) the explanation of the small thicknesses of the lower and middle layers in the block B.

(2) Integrated geophysical interpretation (particularly a comparison of the seismic refraction studies with gravity modelling) is necessary. Near-vertical reflection profiling with modern techniques is badly needed. These geophysical data could provide the basis for location of a new borehole, situated at about the point of 80 km on the LT-7 profile. It could reach layer **4** at a depth of 6–7 km.

(3) Differentiated crustal models along the Trans-European Suture Zone, between the Sorgenfrei-Tornquist Zone and Tornquist-Teisseyre Zone from one side and the Trans-European Fault from the other, imply a complicated mosaic of crustal blocks and favour the concept of tectonostratigraphic terranes. In particular, the fundamental differences between the LT-7 and BABEL profiles recall the old ideas of so-called Oder Line, postulated some 50 years ago (Kutscher, 1942), which would run meridionally along the Odra river and would divide the eastern from western areas causing these differences which are also recognizable in the sedimentary cover (e.g. the different types of Lower Carboniferous sequence, the lateral shift of the axes of Polish Basin and North German Basin).

(4) The present data suggest that the Trans-European Fault runs towards the boundary between blocks B′ and B″. This would mean that the former belongs to the most

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external, strongly reworked zone of the East European Craton. However, this interpretation is not necessarily correct because of the transverse segmentation of the Trans-European Suture Zone, mentioned above.

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