Ministry of Economic Affairs, Adm. of Mines, Belgian Geological Survey
Annales de la Société géologique de Belgique, T. 111 - 1988
pp. 313-321 décembre 1988

Special volume : Centenary Symposium.
Société belge de Géologie
Belgische Vereniging voor Geologie.

DEKORP'S FIRST THREE YEARS : A REVIEW

by

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(6 figures)

ABSTRACT.- Based on many years of crustal studies by seismic reflection and refraction work in Germany the DEKORP field work started in 1984. Until the end of 1986 DEKORP had obtained more than 1000 km of high-quality reflection data along pure DEKORP and DEKORP-KTB lines in the area of the former Variscan orogeny in Germany. The most important result is the observation and mapping of thin-skinned thrusts or zones of detachment at the Variscan internides. These prominent fault zones can often be followed down to, and even inside, the lower crust. No crustal mountain roots like those below present-day orogenies are observed for the Variscan collision zones, but the tectonic pattern seems still to be preserved in the upper and middle part of the crust.

RESUME.- Les campagnes de terrain DEKORP, entreprises en Allemagne dès 1984, sont le prolongement de recherches qui ont fait l'objet, depuis de nombreuses années, d'études de la croûte continentale en sismique réflexion et réfraction. Jusqu'à fin 1986, le projet DEKORP avait permis d'obtenir des données de grande qualité sur plus de 1000 km de profils réflexion et ce à partir des traverses DEKORP et DEKORP-KTB recoupant le domaine affecté par l'orogenèse varisque en Allemagne. Le résultat actuellement le plus significatif concerne la définition et la cartographie de minces zones d'écaillage qui composent le domaine interne de cet orogène. Les zones faillées les plus représentatives peuvent souvent être suivies, en profondeur, jusqu'à la limite de la croûte inférieure, voire à l'intérieur de celle-ci. Aucune racine tectogénique du type de celles qui constituent les domaines inférieures des orogènes actuels n'a été discernée à l'aplomb des zones de collisions varisques; le cannevas tectonique semble cependant avoir été préservé dans la totalité de l'épaisseur de la croûte moyenne et supérieure.

1.- INTRODUCTION

About 3 years after the first DEKORP-reflection line was observed it seems appropriate to look back and critically review the data obtained so far. DEKORP = *De*utsches *ko*ntinentales *r*eflexionsseismisches *P*rogramm, was initiated by earth scientists from the Federal Republic of Germany within the framework of increased activity directed towards gaining a better knowledge of the continental crust in Central Europe. Hence, a very close tie exists with the German Deep Drilling Programme KTB (Kontinentales Tiefbohrprogramm) and the European Geotraverse. The idea of DEKORP was to collect high-resolution reflection data along lines of at least 200 km along and perpendicular to the main geological strike directions and to interpret these data together with other geophysical and geological data sets in the light of modern tectonics.

There was a solid background in Germany for making DEKORP a success : a dense network of crustal refraction lines had been observed since 1947 providing important velocity depth (V-z) constraints for many areas in Germany (see Giese *et al.* 1976). In addition, near-vertical reflection studies since the beginning of the 1960s had shown that many strong and reliable crustal reflections could be observed with only slight changes of recording parameters of conventional prospection techniques (Meissner, 1967; Dohr and Fuchs, 1967; Dohr and Meissner, 1975; Dürbaum *et al.*, 1971). Special short reflection lines across small but tectonically important structures were observed since the beginning of the 1970s, revealing a deep and steep-angle normal fault in

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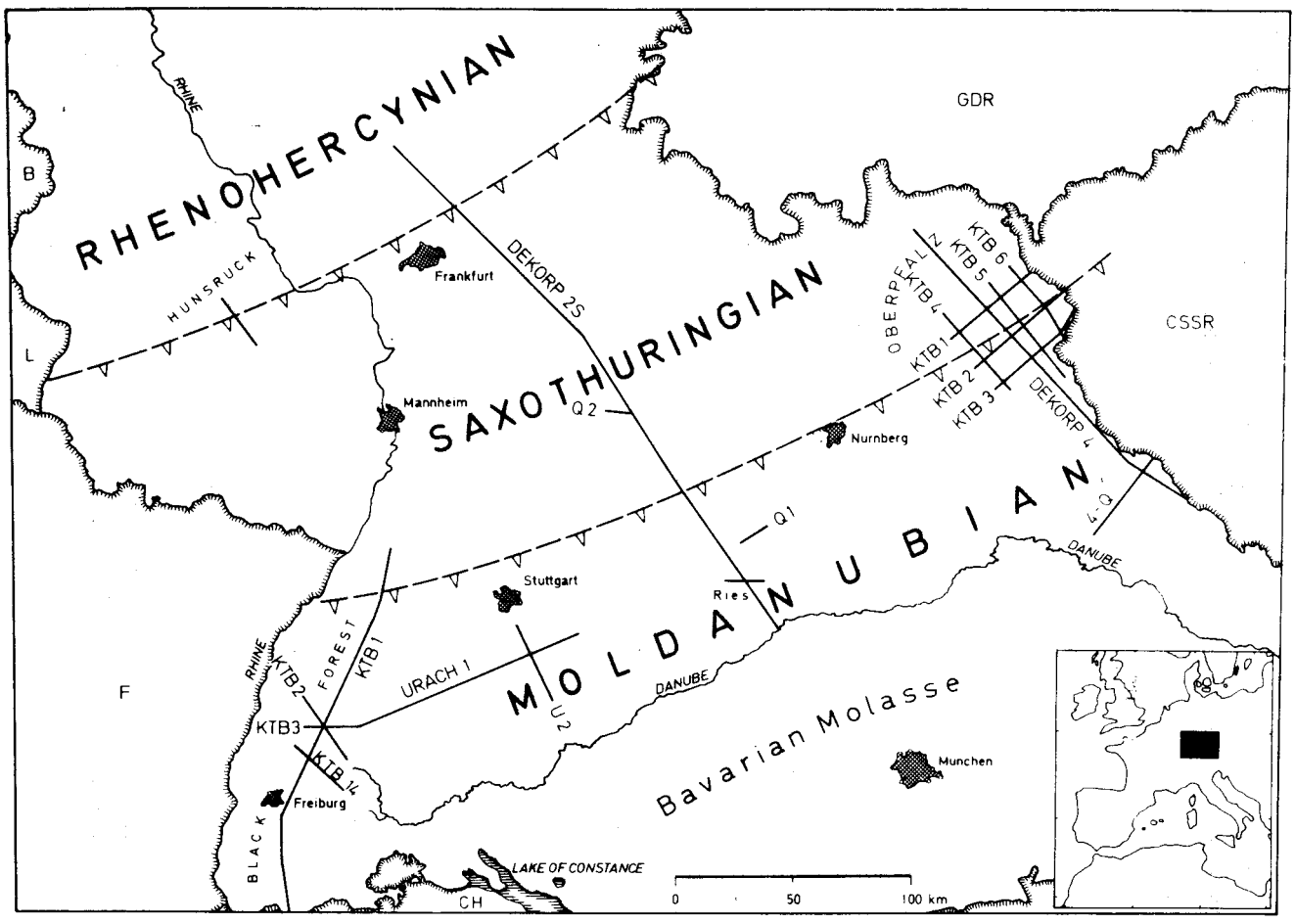


Fig. 1.- Main Variscan lineaments and situation map of reflection lines observed by DEKORP 1984-1986 : DEKORP-KTB network Black Forest (southwest), DEKORP 2 (middle), DEKORP-KTB network Oberpfalz (southeast).

the Hunsrück-Saar-Nahe area, thin-skinned tectonics along the North Variscan Deformation Front near Aachen and a prominent low-velocity body in the middle crust below the geothermal anomaly of Urach (Meissner, 1986). All these activities had paved the way towards the systematic recording of crustal reflections along a large network of profiles.

Figure 1 shows the network of pure DEKORP, KTB-DEKORP and some of the pre-DEKORP lines observed until the end of 1986 within the tectonic framework of the Variscides. In this article mainly a comparison of features along the lines DEKORP 2-S (Danube-Taunus), the Black Forest KTB lines and the Oberpfalz DEKORP-KTB lines will be carried out. A first interpretation of these lines is finished (DEKORP Res. Group, 1985, 1987; Lüschen *et al.*,1987) while DEKORP 2-N is in the final processing stage.

2.- DEKORP 2-S

For information on technical details, data processing and preliminary results see DEKORP Research Group (1985), or Meissner *et al.* (1987). The line has a length of about 250 km and was the first and only DEKORP line to be observed with explosives. *Figure 2* shows a line drawing of the data in the upper part and a migrated version of strong events below. Describing the important features of the line one may summarize :

(1) Except for some dipping events the upper crust is rather transparent down to about 5 s two way travel time (TWT). The two SSE dipping bands of reflections can be related to bundaries between Variscan subunits : the northern one to the boundary between the Saxothuringian (SN) and the Rhenohercy-

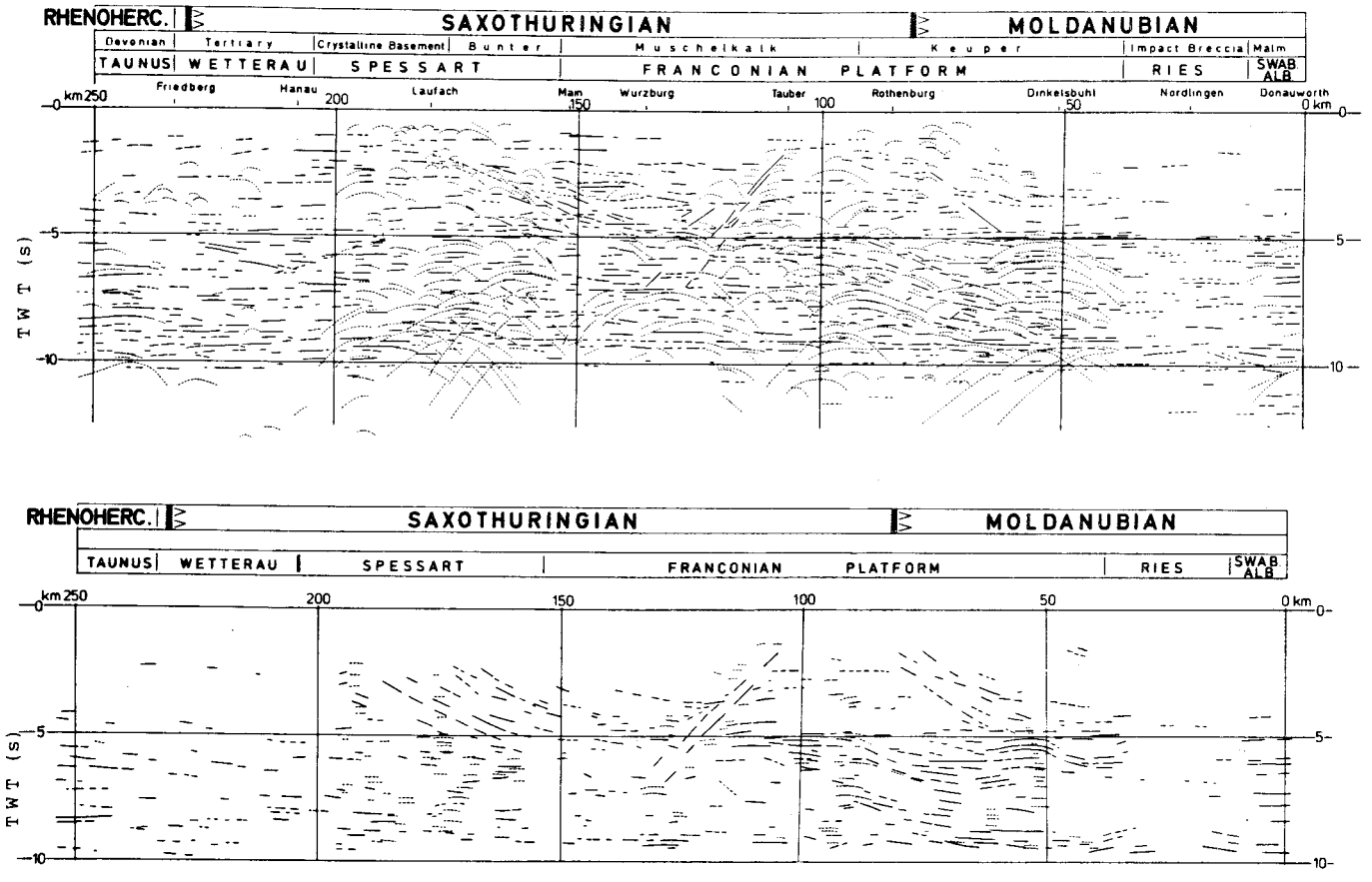


Fig. 2.- Line drawing of DEKORP 2-S, unmigrated (upper) and migrated (lower) version of strongest events. Diffractions are marked by dotted lines. The other lines are pre-DEKORP profiles described in the text.

nian (RH) with a collision age of about 320-350 my and the southern one to the boundary between the Moldanubian (MN) and the Saxothuringian (SN) at about 360-390 my. The dipping events hence have to be considered thrust faults. Further down they become slightly curved and mingle with the laminated lower crust.

(2) The lower crust between 5 an 9.5 s TWT is full of subhorizontal or slightly SSW dipping reflections and fits well into the picture of a laminated appearence of the Variscan lower crust as obtained by the pre-DEKORP, BIRPS and ECORS lines.

(3) Several clusters of surprisingly strong diffractions were observed as marked by dotted lines in Figure 2. Especially the one below Dinkelsbühl could be investigated in more detail because some additional 3-D like observations in this area were carried out during the DEKORP 2-S survey. It was found that many diffractions come from line diffractors outside the profile (Sadowiak, 1987). Their dips and their depths coincide with that of the boundary thrusts MN/ST.

In general, the profile DEKORP 2-S provides a strong argument that Variscan collisional tectonics with rather thin-skinned units overthrusting onto other units along zones of detachment took place also at the Variscan internides. We will look for similar structures on the other two groups of profiles which cross the same tectonic boundaries.

3.- THE BLACK FOREST KTB LINES

As seen from Figure 1 there are four lines in the Black Forest, the E-W line being a continuation of the Urach line 1 (Bartelsen et *al.*, 1982). After systematic comparisons of Vibroseis and explosives along segments of DEKORP 2-S and the Urach line 1 the Black Forest lines were the first DEKORP lines to be observed by Vibroseis. In the following only the long NS line will be discussed which crosses the boundary between the MN and the ST in its northern part, as seen on Figure 1. For details see Lüschen et *al.* (1987).

Figure 3 shows a line drawing of the NS-line. The

general appearence is similar to that of DEKORP 2-S, at least to its section in the MN. The upper crust again is much less reflective than the lower one, although some more dipping events in both directions are observed inside the MN. The boundary thrusts MN/ST on the left hand side of the line is seen not so strongly in the upper crust but more in the middle and even in the lower crust. A «span-like», south-dipping group of reflectors from the lower crust seems to pierce through the generally flat upper boundary of lower crustal lamellae. The lower crust, like the corresponding sections of DEKORP 2-S and the Urach lines, is full of reflectors, but in the Black Forest there are some slightly N-dipping events inbedded inside the generally subhorizontal lamellae. They have the appearence of shear structures with their flat parts at the bottom and near the top of the lower crust. By comparison with the intersecting profiles some of the dipping events may resemble line diffractors forming a small angle with the direction of the profile (Lüschen et *al.*, 1987). A synoptic treatment including ample refraction studies and other geophysical observations is found in KTB-Research Group Black Forest (1987).

4.- DEKORP 4 AND THE KTB LINES OBERPFALZ

As seen in Figure 1, a network of intersecting lines was observed in the Oberpfalz area. It was planned around the alternative location for the German Deep Drilling Project which was finally selected to be pursued in the area of the intersection of profiles DEKORP 4 and KTB 8502. The tectono-geological setting is more complicated than that of the previously described areas because the seismic network is situated on the SW-flank of the old Bohemian Massif. Hence, in addition to a SE-NW directed Variscan thrusting around the boudary MN/ST there are prominent strike-slip faults and post Variscan extensional tectonics oriented SE-NW (e.g. the Frankonian line) which possibly started as a transpression. Also Tertiary extensional structures running SW-NE like the Eger-Graben are observed. First results of the Oberpfalz investigations are in DEKORP Research Group (1987a); a more synoptic treatment will be found in DEKORP Research Group (1987b).

Figure 4 shows a line drawing of line DEKORP 4. In contrast to other Variscan profiles also the upper crust is full of reflections. The lamination of the lower crust is restricted to the SE part of the profile; SE-diping layers dominate the reflection pic-

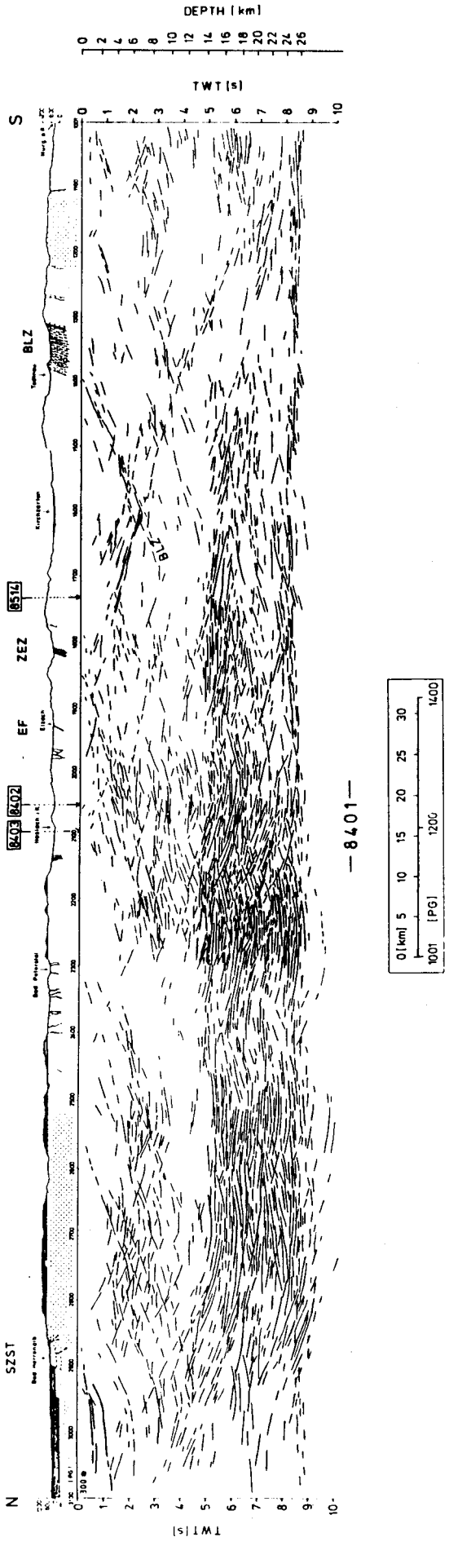


Fig. 3.- Line drawing of the N-S profile (line 1) of the Black Forest KTB network. Based on migrated seismogram.

ture in the lower crust, often contrasting to NW dipping sequences in the upper crust. It seems that thrusting from SE to NW affects the whole crust, a suggestion which is strongly supported by additional calculations of velocity layering by means of piggy-back wide-angle CMP observations : high-velocity layers seem to be thrusted toward the MN/ST boundary and even beyond it. This observation is in aggreement with geological mappings of several nappe relicts such as the Münchberger Massif (MM) and the zone of Erbendorf-Vohenstrauβ (ZEV) in the center of the KTB-drillhole. Shallow zones of detachments seem to be present in the NW-part of the profile in the upper crust.

Also the six smaller KTB profiles are of a strange character, showing strong indications of strike slip faults (KTB 8502 and 8503) and SE dipping reflectors (KTB 8505 and 8506) through the whole crust. Like on DEKORP 4, these latter two profiles show pronouced ramp and flat structures, strongly indicative of thrust planes. For details see DEKORP Research Group (1987b).

5.- CRUSTAL SHORTENING ALONG VARISCAN THRUSTS

Geological and paleomagnetic data for a long time indicated a convergence of southern and northern Pre-Variscan continental units, a gradual increase of metamorphic grades from NW to SE and also an increasing age of collisions from NW to SE (Ziegler, 1986, Behr et *al.*, 1980). The northernmost zone of collision, the North Variscan Deformation Front (NVDF), with a tectono-thermal age of 300 ± 15 my is well documented by 8 reflection lines from the Irish Sea in the NW through SW Britain, France, Belgium up to the area of Aachen. A compilation of these data are found in Brewer (1984) and Meissner et *al.* (1986).

The NVDF, the last great Variscan collision, belongs to the Variscan externides. It shows thinned-skinned tectonics apparently all the way from the Irish Sea (studies by BIRPS) up to the Hohes Venn area near Aachen. The zones of detachment appear especially clear in the BIRPS SWAT lines and on ECORS 1 where they can be followed from the uppermost crust down to more than 20 km depth as ramp and flat structures with generally smooth dips. (BIRPS and ECORS, 1986, Bois *et al.*, 1986). Similar structures are indicated on the brute stacks of profile DEKORP 2-N, shot in 1986 and being in the processional stage. This line starts in the Taunus area, crosses the Rhenish

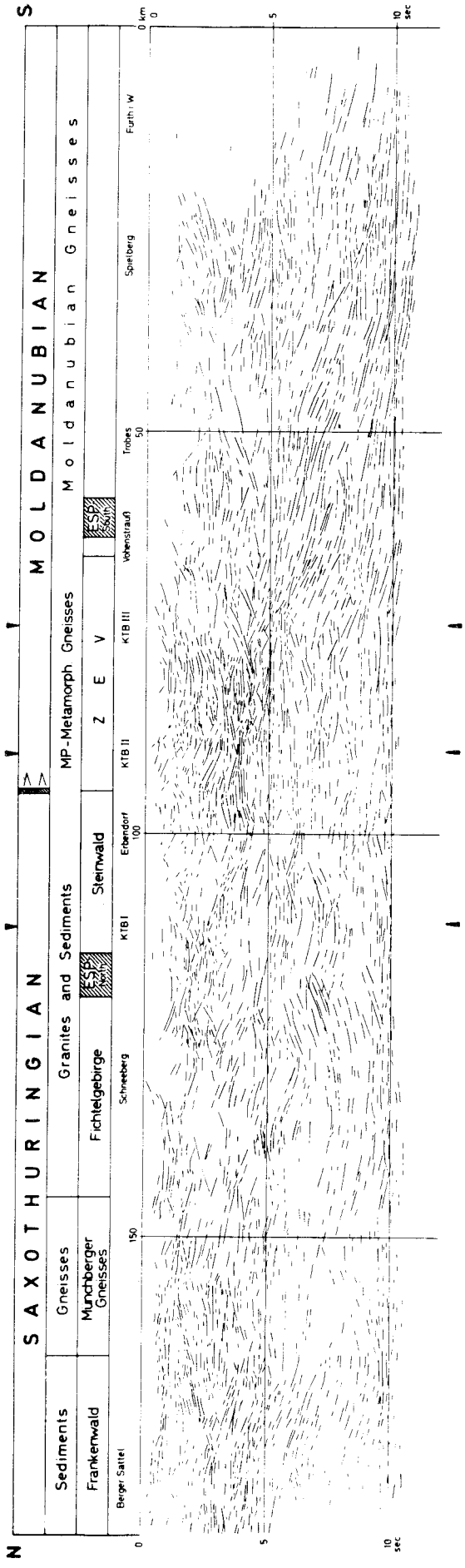
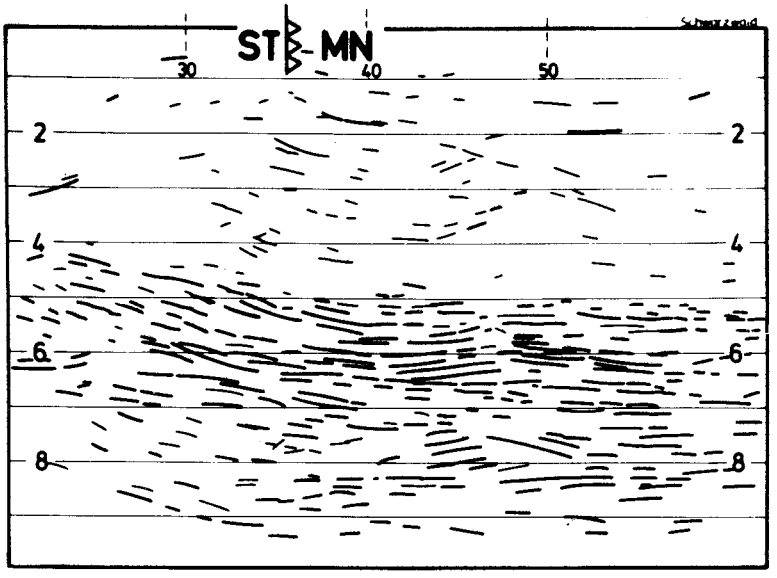
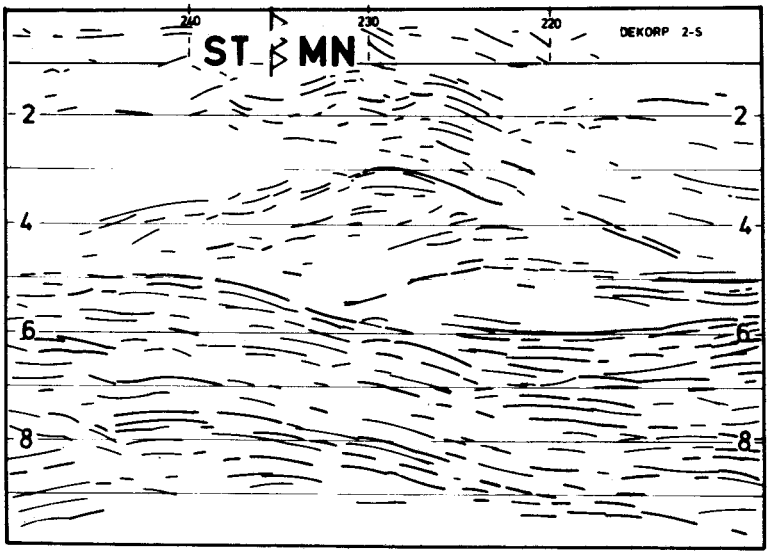


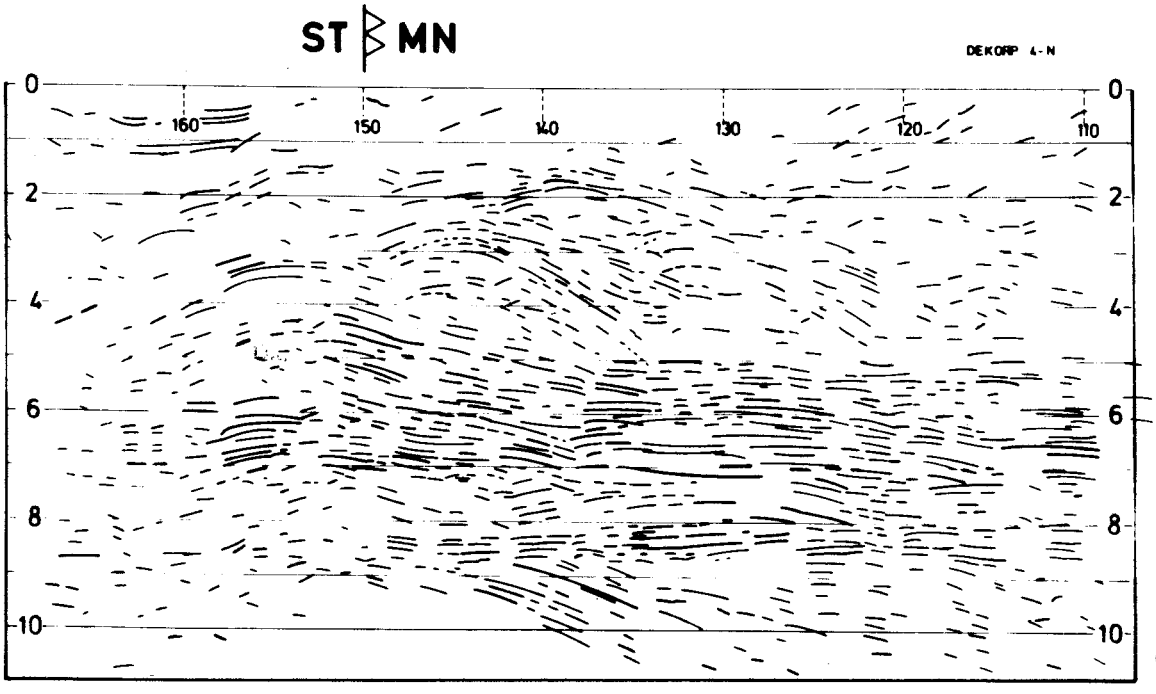
Fig. 4.- Line drawing of profile DEKORP 4 in the Oberpfalz area.


ST
MN
30
40
50
2
4
6
8

a


ST
MN
240
230
220
DEKORP 2-S
2
4
6
8

b


ST
MN
DEKORP 4-N
160
150
140
130
120
110
0
2
4
6
8
10

c

Massif and runs into the Münsterländer Bucht, where it diverges into two segments.

When the DEKORP Programme started it was still an open question whether the Variscan internides, i.e. the collision zones of the ST/RH and the MN/ST, were also characterized by thrust faults or zones of detachment down to greater depths. The MN/ST collision zone was observed on all three DEKORP surveys mentioned so far; in the Black Forest on the left hand side of the long profile (Figure 3), in DEKORP 2-S (Figure 2) and in DEKORP 4 (Figure 4) on the right hand part of the profiles and also on the smaller KTB-lines 8505 and 8506.

Figure 5 shows a compilation of the 3 lines crossing the MN/ST boundary. The thrusting of the MN onto the ST is observed on all three lines. In the Black Forest it is seen mainly as a kind of upwelling of the lower crust, slightly north of the petrologically determined MN/ST boundary; along DEKORP 2-S it also shows up clearly as an upwelling of the lower crust but also in the middle (and upper) crust a number of clear SSE dipping reflectors appear. In the Oberpfalz also an upwelling of the lower crust is observed but here the whole crust seems to be involved in the thrusting and crustal shortening process with SSE dips in the middle and lower crust accompanied by many NNW dipping layers in the upper crust. The decreasing heat flow from W to E supports the idea that below the (warm) Black Forest with its pronounced lower crustal lamellae the memory of former thrust events and Moho depths has been lost, at least in the lowermost crust. (Strehlau and Meissner, 1987). In the (cold) Oberpfalz area, on the other hand, at least some of the Variscan thrust tectonics is still preserved in the (more rigid) lower crust with its lack of strong lamination. But here also the upper crust shows a definite reflectivity pattern, sometimes reversed (back slip?) dips with regard to the lower crustal dips. It is speculated that the Bohemian Massif might have provided a ramp along which thrusting and transpression concentrated. The general reflectivity picture of the Oberpfalz area is slightly similar to that of the Belgian BELCORP profile through the London Brabant Massif with its decreasing reflectivity with depth and its lack of strong Moho reflections (Boukaert, pers. com.). This profile, however, is in the middle of an old massif; its reflections are more similar to a shield-reflectivity patter, whereas the Oberpfalz network is more on the flanks of an old massif.

Whereas the boundary MN/ST was observed along all three DEKORP surveys and generally provided a strong argument for crustal shortening and thrusting, the boundary ST/RH about in the middle between the NVDF and the MN/ST boundary was only observed by DEKORP 2-S (left hand side of Figure 2). It is well documented by dipping events in the upper crust below the crystalline Spessart mountains. The lower crust shows many diffraction clusters in this area. While the Variscan compressional tectonics dominates, at least in the upper crust, about 100 km WSW from this area there is the post-Variscan Saar Nahe trough, an extensional feature developed in the Permian. One of the short pre-DEKORP profiles, observed in 1973, had revealed a huge normal fault crossing the whole crust, even offsetting the Moho (Meissner *et al.* 1980). It is an example for a change from a compressive to an extensional stress system : only the latest strong tectonic pattern is preserved in the seismic signature. *Figure 6* shows the contrasting picture of the ST/RH boundary in detail.

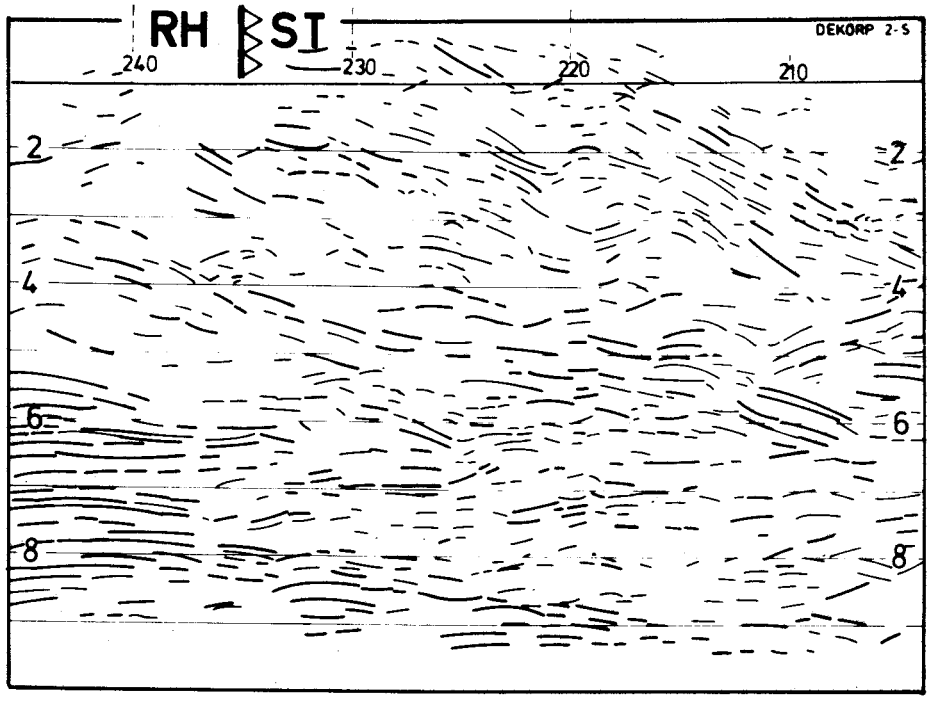
Also the northernmost boundary of the Variscan compressional tectonics the NVDF, does not look uniform, at least not on both sides of the Rhine embayment near Köln. The thin-skinned tectonics dominating from Ireland to the Hohes Venn near Aachen seems to stop and to be changed into a more steeply oriented fault pattern, especially in the Ruhr area, where many observations from the mining industry are available. Slightly farther east where DEKORP 2-N leaves the Rhenohercynian, again thin-skinned tectonics seem to dominate as seen from a very first interpretation. But this picture needs further confirmation.

The change of tectonic style along the NVDF and also along the ST/RH boundary are compatible with the general picture of Matte's indenter theory (Matte, 1986). It also shows the importance of ramps provided by older, more stable platforms within the Variscan orogeny. The London-Brabant massif and the Welsh massif may have acted as rather stable units, their southern and southwestern flanks acting as deep-seated obstacles against the northward pushing deformation front.

6.- CONCLUSIONS

So far the DEKORP studies have revealed major zones of detachments at the boundaries of Variscan subunits the MN/ST and the ST/RH. Not

◀ Fig. 5.- Compilation of line drawings (unmigrated) across the Moldanubian/Saxothuringian (MN/ST) thrust pattern, (a) Black Forest, (b) near Rothenburg (DEKORP 2-S), and (c) Oberpfalz (DEKORP 4).



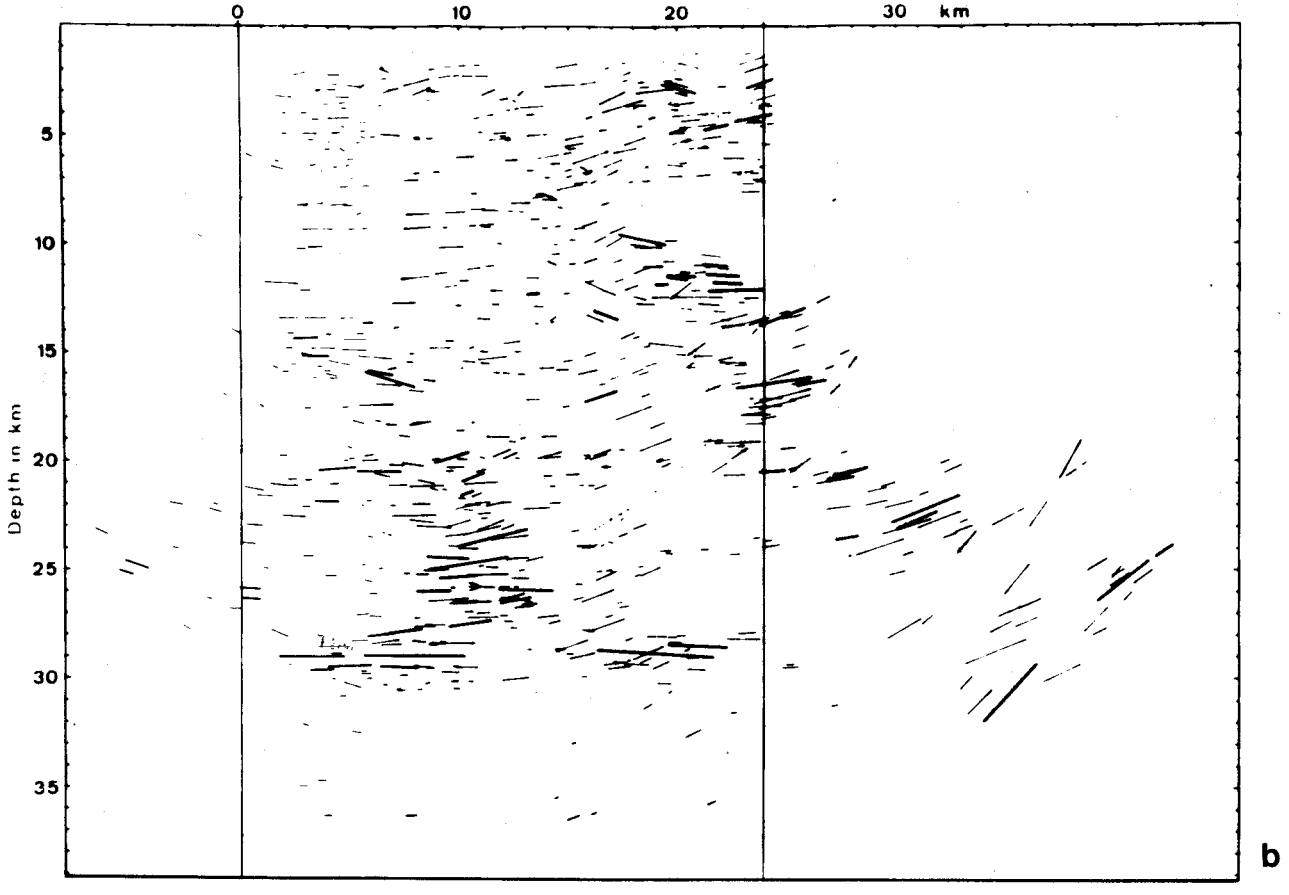


Fig. 6.- Comparison of line drawings across the Saxothuringian/Rhenohercynian (ST/RH) fault pattern : (a) thrusting in the Spessart area (DEKORP 2-S) (b) normal fault in the Hunsrück-Saar-Nahe area, 100 km WSW of the Spessart. (This profile had to be migrated in order to reveal 2 blocks of different dips with fault controlled half-graben structures on the right side).

only the Variscan externides, also the internides show rather thin-skinned nappes near the surface which can be followed down to the lower crust. The ramp and flat appearence of the MN/ST boundary is slightly different between the Black Forest and the Oberpfalz, an observation, which may be related to decreasing heat flow, i.e. temperature, and to the special transpressional stress regime in the Oberpfalz on the flanks of the Bohemian Massif. But all the three boundary crossing profiles show a similar upwelling of the lower crust. The ST/RH boundary, on the other hand, is completely different between the post-orogenic extensional Saar-Nahe trough and the Spessart mountains. Also the NVDF looks very different on both sides of the Rhine : thin-skinned tectonics in the west, steep-angle, apparently thick-skinned, tectonic in the east. In general, it is the latest strong tectonic event which is preserved in the seismic sections, especially in the rigid upper crust and only occasionally in the lower crust. Any former Variscan mountain root is flattened out. No sign of it is preserved in the compressional zones of the old boundaries, and only in the Oberpfalz area and the Saar-Nahe through a small offset of the Moho may be observed. Future DEKORP profiles will further clarify the complicated structural pattern of the Variscan tectonics.

7.- ACKNOWLEDGEMENT

Thanks are due to Margrit Kurpiela for typing, Dipl.-Geol. Barbara Tanner and Dipl.-Geophys. Thomas Wever for their great support in collecting and selecting the DEKORP material used for this review.

Publication No. 347 from Institut für Geophysik, Universität Kiel.

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