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Strike-slip movements in the Polish Lowlands

Seismic and borehole data from the Zechstein-Mesozoic structural complex have been explored from the viewpoint of possible strike-slip motions in the platform cover of the Polish Lowlands. This is the only source of information since reliable seismic data are lacking from beneath the Zechstein. Many places have been found in the Zechstein-Mesozoic complex where the axes of non-salt and salt anticlines are shifted in a left-lateral sense and NW–SE direction by a distance of a few kilometres (Figs. 1 and 2). Greater displacement of a group of anticlines has been noted at the boundary between the Pomeranian and Kujavian segments of the Mid-Polish Trough (MPT) which is coincident with a bend of the Mid-Polish Swell (MPS — see Figs. 1 and 3). However, because of lack of free space for accomodation of strike-slip movements in the syn-Alpine epoch, it is concluded that these displacements are apparent and that they were inherited after the earlier, syn-Variscan system. The latter was composed of a set of conjugate faults: major, right-lateral, trending NW–SE and minor, left-lateral, trending NE–SW. This system has been intermittently rejuvenated during the Permian-Mesozoic basin evolution (Figs. 4 and 7) and during its syn-Alpine inversion, mainly in a dip-slip sense, in a regime of vertical movements.

INTRODUCTION

The operation of strike-slip movements in the forefields of the European Hercynides (Variscides) and Alpides has long been discussed. For example, J. P. N. Badham (1982) coined the term "strike-slip orogen" for the European Hercynides. Earlier, F. Arthaud and P. Matte (1977) visualised a system of the Late Variscan right-lateral shear on a broad continental scale between the Appalachians and the Urals. P. A. Ziegler (1990) interpreted the right-lateral movements in the forefields of the Variscan and Alpine foldbelts in Europe. On a smaller scale, the problem was discussed by E. Norling and I. Bergström (1987), and by O. Vejbaek and C. Andersen (1987) in relation to the Mesozoic cover fringing the southern slopes of the Baltic Shield. In Poland, W. Jaroszewski (1972) assumed the existence of a regional right-lateral strike-slip zone as represented by the *en echelon* arrangement of faults and flexures in the Mesozoic cover north of the Holy Cross Mts. W. Pożaryski (1987) interpreted a set of wrench faults within the epi-Variscan platform of eastern and central Poland. On a smaller scale, E. Herbich (1984) analysed a system of faults in a limited area of Mesozoic cover; however, her results were hindered by the low quality of seismic data.

The problem of strike-slip movements appears to be difficult even in exposed terrains where not only the scale but also the sense of displacement are often subject to controversies (comp. numerous papers about the Great Glen Fault). This difficulty appears even more severe in the case of subsurface mapping where direct detailed field data are not available and even the very existence of strike-slip faults may be disputable.

The aim of this paper is to explore the subsurface evidence of strike-slip movements in the Polish Lowlands. The area is covered by the Quaternary deposits. Therefore, the tectonics of the underlying, very thick platform (cratonic) cover (Devonian through Tertiary) can be investigated solely by means of boreholes and seismic reflection data. Instead of conducting the direct field observations of faults, their directions, and sense and amount of slip vectors, we are limited to indirect suppositions based on records of secondary, mostly two-dimensional effects which are detectable in seismic cross-sections, contour maps and in the arrangement of local tectonic features. Moreover, the seismic data are reliable predominantly down to the Zechstein base only. The reflectors from beneath this boundary are rather scarce and difficult to correlate. The result of these constraints is that the traces of possible strike-slip features can be recorded in the Zechstein-Mesozoic structural complex only. Every reconstruction of the fault pattern and fault kinematics below the Zechstein base is a product of imagination rather than interpretation of facts.

GEOLOGICAL BACKGROUND

Internal structure of the Zechstein-Mesozoic complex records the evolution of the Polish Basin which came into being in the Late Permian (Upper Rotliegendes time) at the contact between the East European Craton (EEC) and the Mid-European Platform (MEP), probably on the foundation of the earlier Late Variscan foredeep. The basement of the EEC was consolidated in the Late Precambrian, the basement of the MEP partly — in all probability — in the Caledonian epoch (as a result of collision between the exotic or proximal terranes and the EEC?) and partly in the Variscan epoch. Within the basin a narrower Mid-Polish Trough (MPT) individualized close to the craton edge during most of the time of the basin evolution. Platform-type (intracratonic) tectonic processes were active almost throughout its evolution. Particularly effective were the movements of the Zechstein salts in the central parts of the basin. The salts were mobilized there already in the Middle-Late Triassic times and have been since intermittently active, strongly modifying the thickness and facies pattern of the overlying strata. The front of salt deformations progressed with time towards the margins of the basin but they did not affect its extreme marginal parts where the overburden thickness was insufficient for salt mobilization. Evolution of narrow synsedimentary grabens with Upper Triassic, Jurassic and Lower Cretaceous sequences thicker than in adjoining areas went hand in hand with salt displacements. All these processes resulted in the present complicated picture of the mosaic of blocks, faults, flexures, structural and thickness gradients, non-salt anticlines (placanticlines), grabens, salt pillows and salt diapirs partly or entirely piercing through the sedimentary cover. Moreover, the axial MPT was regionally inverted in the latest Cretaceous-earliest Tertiary times to form the Mid-Polish Swell (MPS).

ZECHSTEIN-MESOZOIC DATA

When analysing the major tectonic features on the sketch of the Zechstein-Mesozoic structural complex (Fig. 1) one can recognize a number of non-salt and salt anticlines elongated roughly in NW–SE direction. Their axes are often displaced horizontally, the displacement being of the order of a few kilometres, in almost all cases left-lateral and trending SW–NE or WSW–ENE (Figs. 1 and 2B, C, D).

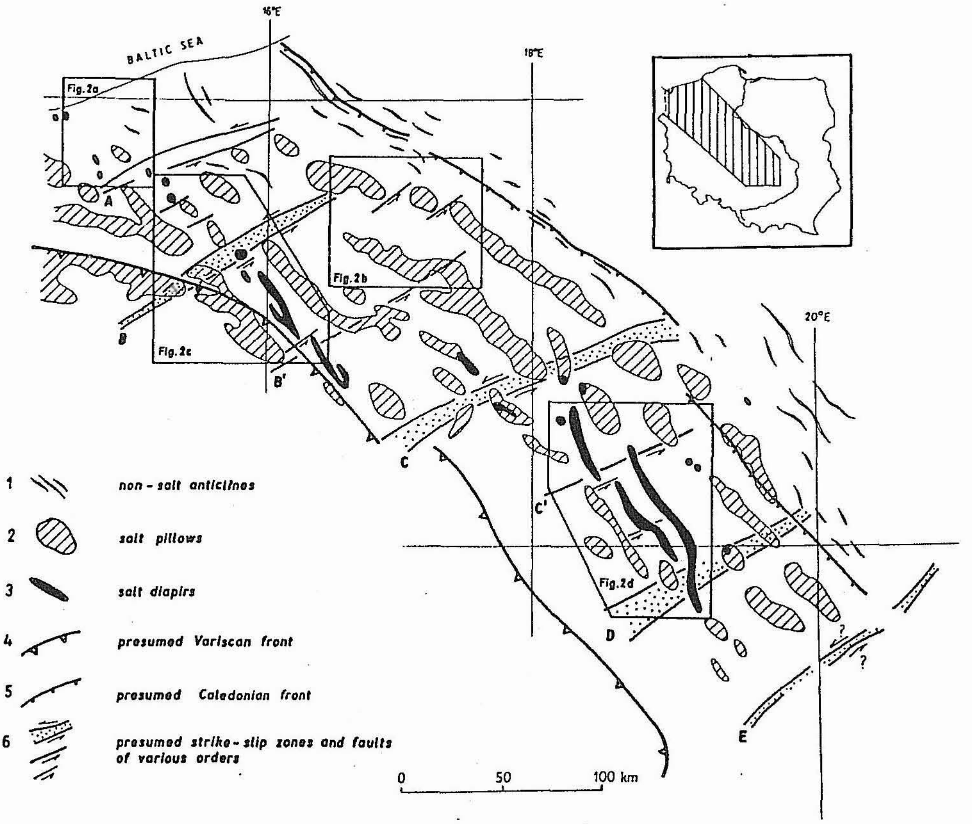

Fig. 1. Tectonic sketch of the Zechstein-Mesozoic complex
Szkic tektoniczny kompleksu cechsztyńsko-mezozoicznego
1 — antykliny niesolne, 2 — poduszki solne, 3 — diapiry solne, 4 — przypuszczalny front waryscyjski, 5 — przypuszczalny front kaledoński, 6 — przypuszczalne strefy i uskoki przesuwcze różnej rangi

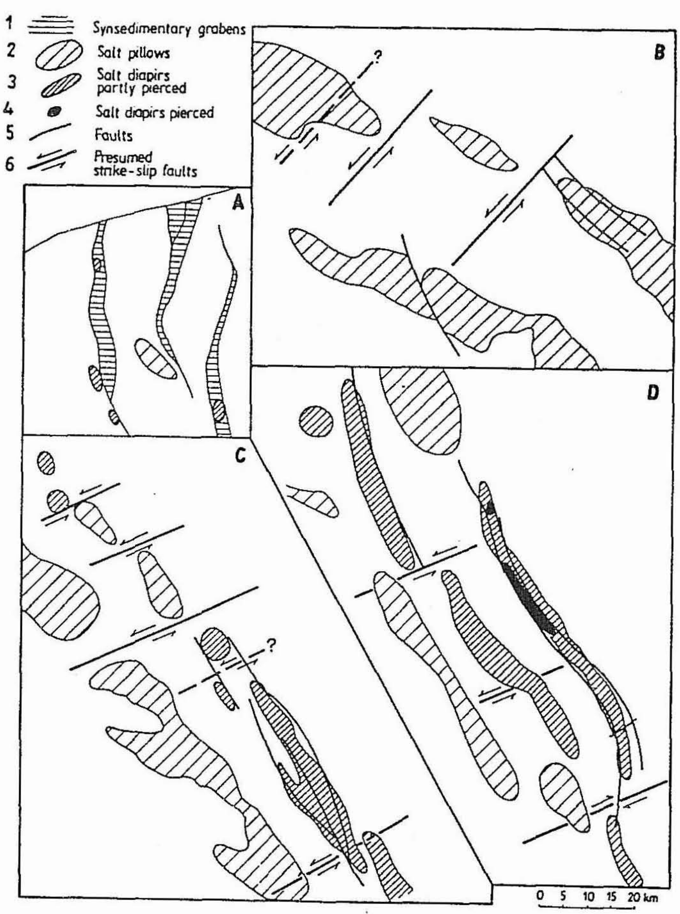

Fig. 2. Examples of horizontal displacements
Przykłady przemieszczeń poziomych
1 — rowy synsedymentacyjne, 2 — poduszki solne, 3 — diapiry solne częściowo przebite, 4 — diapiry solne przebite, 5 — uskoki, 6 — przypuszczalne uskoki przesuwcze

On a more regional scale a more prominent left-lateral shift (some scores of kilometres) of the whole assemblage of anticlines in the MPT is to be seen between its Pomeranian and Kujavian segments (line C in Fig.1 and 2). It coincides with a regional bend of the MPS which is visible even on a small-scale sub-Tertiary map of Poland (Fig. 3). It is also equivalent to the boundary between the more uplifted part (Pomeranian) of the MPS and its depressed (Kujavian) part. Moreover, its southwestern extension coincides with the possible break and displacement of the presumed Variscan front, and its northeastern extension — with the similar displacement of the craton edge, each of them being, however, opposite in sense (Fig. 1). Interesting is that within the craton itself the prolongation of the latter bounds from the northwest, a block with a well developed group of non-salt anticlines

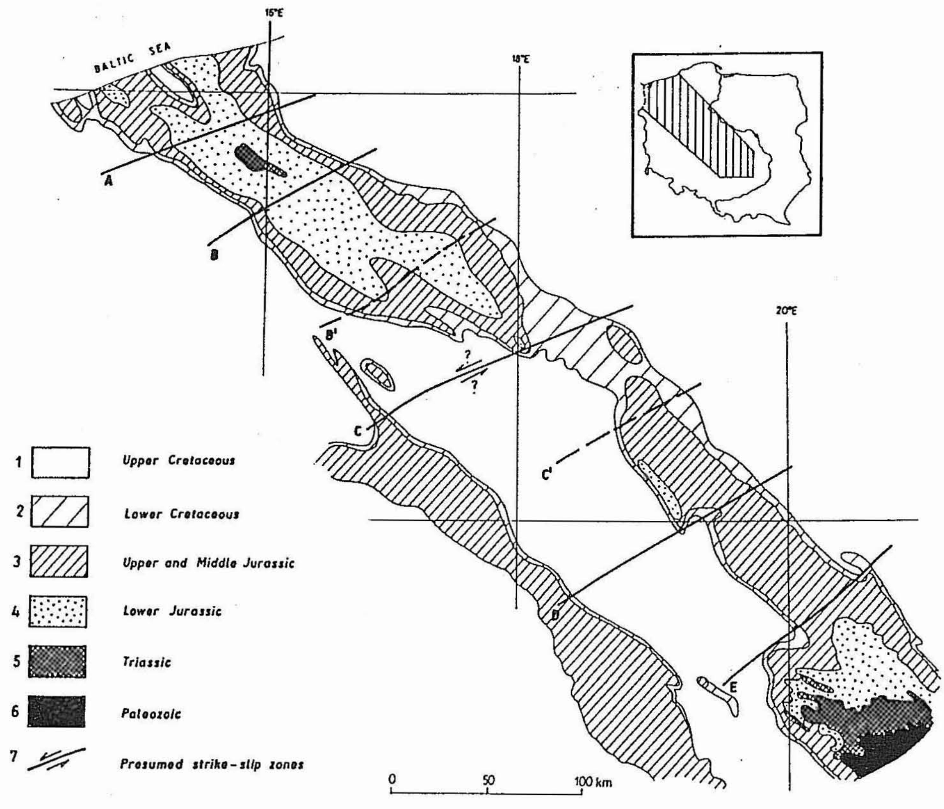

Fig. 3. Sub-Tertiary map
Mapa podtrzeciorzędowa
1 — górna kreda, 2 — dolna kreda, 3 — górna i środkowa jura, 4 — dolna jura, 5 — trias, 6 — paleozoik, 7 — przypuszczalne strefy przesuwcze

(Fig. 1) which indicates the greater mobility of this block. Finally, line C during some stages of evolution (mainly during the Jurassic) was also a boundary between the two parts of the MPT characterized by opposite asymmetry. Northwest of it, in the Pomeranian segment, thickness gradients along the northeastern flank of the trough were steeper than those along the southwestern one. Southeast of line C (in the Kujavian segment) the reverse was true.

Line C is one of several lines which mark the transverse segmentation of the MPS (Fig. 1): lines A and B bound the maximum elevation of the Pomeranian Swell, and lines C' and D — the probable maximum elevation of the Kujavian Swell. Line E is the boundary between the elevated block of the Holy Cross Mts. and relatively depressed Kujavian Swell. Line A bounds from the southeast the area where the Pomeranian Swell plunges northwest and bifurcates. Some of these transversal lines are accompanied by small scale lateral displacements of local anticlines and some are not.

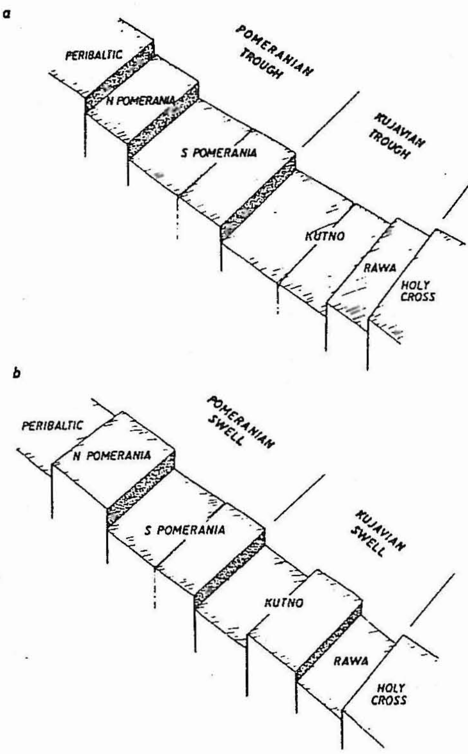

Fig. 4. Transversal segmentation of the MPT during sedimentation (a) and of the MPS after the inversion (b)
Poprzeczna segmentacja bruzdy środkowopolskiej (MPT) w czasie sedymentacji (a) i wału środkowopolskiego po inwersji (b)

Transversal segmentation was also characteristic of the Mesozoic evolution of the MPT — it was noted earlier by S. Marek and J. Znosko (1972), and R. Dadlez (1980). It is roughly sketched in Figure 4a. Subsidence of successive blocks — as recorded by the cumulative thickness of the Mesozoic, first of all of the Lower Triassic, Lower and Middle Jurassic and Lower Cretaceous — generally increased from the Baltic coast towards the Kutno Block and decreased further southeastwards. During the inversion this arrangement changed slightly, the North Pomeranian Block being uplifted most strongly (Fig. 4b).

It must be firmly stressed that all these transversal lines cannot be defined as single faults or even zones of minor faults in the Mesozoic cover. They can be characterized rather as zones of increased thickness (and subsidence) gradients and the zones on both sides of which the general character and trends of local anticlines change. Then, they can be a response of Mesozoic cover to the activity of probable sub-Permian faults. These faults accounted for the later, transversal subdivision of the MPT and MPS, mainly due to differentiated vertical movements. It is difficult to say (except for — perhaps — the C line) if strike-slip movements also acted there although the horizontal shifts of smaller structures seem to speak in favour of at least a strike-slip component. Most of these displacement become smaller towards the craton edge or they disappear altogether, as if the possible transverse strike-slip movements were accomodated against this edge in a northeastern direction.

The sense of motion along the lines D and E is unclear (Fig. 1). If the experiments by P. Tapponnier *et al.* (1982) are taken into consideration (impingement of orogenic arc against the craton), right-lateral transverse faults may be assumed in the Variscan epoch in the south-eastern part of the subsequently developed MPT.

The next indication of presumable strike-slip are the bends of northwestern segments of NW-trending faults in Pomerania (Fig. 2a) which are a reminder of the systems of splay faults at the terminations of strike-slip faults. They are accompanied there by narrow synsedimentary grabens which started to develop in the Late Triassic and continued during the Jurassic. Their later evolution is difficult to reveal because of the erosion of post-Jurassic strata due to regional inversion and uplift of the MPS. Nevertheless, their shapes in cross-sections, including the rooting in single faults in the basement, are of the type of flower structures described and related to wrench faults by T. P. Harding (1985). The occurrence of similar structures is proven farther eastwards in Mecklenburg (G. Beutler, F. Schüler, 1978) and may be suspected farther towards the centre of the basin where they are strongly obliterated by salt tectonics in the zone of salt diapirs.

In the southeastern part of the MPT, along the northeastern border of the Holy Cross Mts., a block which was uplifted at the same time as the MPS, similar bends have been observed (W. Jaroszewski, 1972), in this case — of the southeastern terminations of NW-trending faults and flexures. Synsedimentary grabens are absent there.

No sings of strike-slip displacements have been noted along the NW–SE direction, parallel to the MPS axis, except for the mentioned presumable flower structures masked by salt diapirs. It seems obvious since NW–SE is the trend of the main facies boundaries, isopachs and structural features. The displacements along this direction would be visible only if they were of a very large scale. All rapid changes in the pattern of the above features are much easier to observe along the transverse, NE–SW direction.

However, assuming that the latter resulted from the secondary left-lateral shear, they seem to confirm the existence of the primary, right-lateral, NW–SE trending shear and, in all, of the conjugate system of faults (F. Arthaud, P. Matte, 1977) comparable with the Riedel shear system (Fig. 5). Major faults, as yet not evidenced, would be right-lateral and would trend NW–SE whereas presumably recorded subordinate faults are left-lateral and trend NE–SW. It is necessary to stress once more that none of the observed shifts of local structures is the proven strike-slip fault. They are only supposed strike-slips based on the record of secondary effects mentioned in the introductory remarks.

DISCUSSION

The fundamental problem is the question of timing of the postulated strike-slip movements: whether they started their activity only at the end of Mesozoic, during the syn-Alpine deformations and inversion, or were they inherited — in form of dip-slip or oblique-slip faults or flexures — after an earlier syn-Variscan strike-slip system? The answer is not

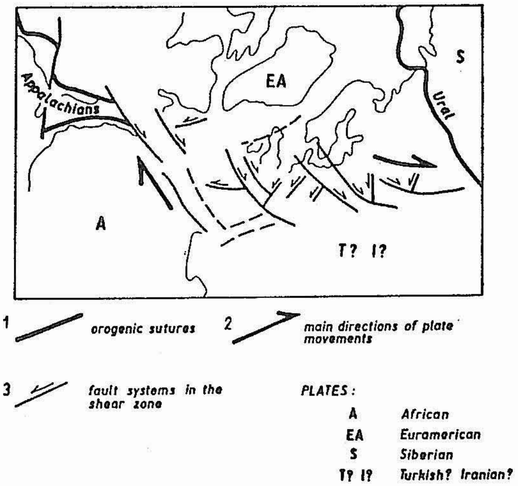

Fig. 5. Late Variscan shear zone between the Ural and the Appalachians (after: F. Arthaud, P. Matte, 1977)

Późnowaryscyjska strefa ścięcia między Uralem a Apallachami (według: F. Arthaud, P. Matte, 1977)

1 — szwy orogeniczne; 2 — główne kierunki ruchów płyt; 3 — systemy uskokowe w strefie ścięcia; płyty: A — afrykańska, EA — euramerykańska, S — syberyjska, T? I? — turecka? irańska?

simple because of lack of sub-Zechstein data mentioned above. Sub-Zechstein faults are not observed directly while indications of possible strike-slip appear in the Mesozoic. However, judging from borehole and seismic data, major horizontal stresses did not operate during the Mesozoic. The deformations of strata are predominantly mild (except for in the vicinities of salt diapirs), normal extensional faults prevail, reverse faults are exceptional. The latter can be explained also in terms of vertical motions (cf. the experiments of A. R. Sanford, 1959). On a mesotectonic scale no signs of stylolitic sutures perpendicular to bedding have been noted in carbonate sequences.

Two problems must be taken into account while considering the question of timing: first, stress patterns in relevant epochs and second, the problem of free space necessary for accomodation of strike-slip motions.

In Variscan times the juxtaposition of the arcuate foldbelt and its presumable foredeep against the rectilinear margin of the EEC was a favourable condition for the formation of strike-slip faults, mainly parallel or oblique to the trends of both structures. Thus, just before the initiation of the MPT the area remained in the field of compressional stresses directed SW–NE from the Variscan deformation front towards the craton, and of shear stresses induced by them which were particularly easily accomodated along the trend of a narrow ledge situated between the deformation front and the craton.

On the contrary, in the Alpine epoch the Carpathian segment of the Alpine foldbelt was situated far to the south and ran obliquely to the edge of the EEC, roughly in east-west direction. Compressional stresses were directed northwards. An additional structural unit was then the rigid Bohemian Massif which strongly modified the stress pattern in the forefield of the Alpine chain (Fig. 6). The stresses in the Polish basin were aligned obliquely or almost parallel to the craton edge but the whole area beneath the Polish Lowlands was then already consolidated. The conditions for strike-slip motions were again favourable but the possibilities of their accomodation were very limited. The nearest mobile zones were the closing small Tethyan oceans and the opening North Atlantic.

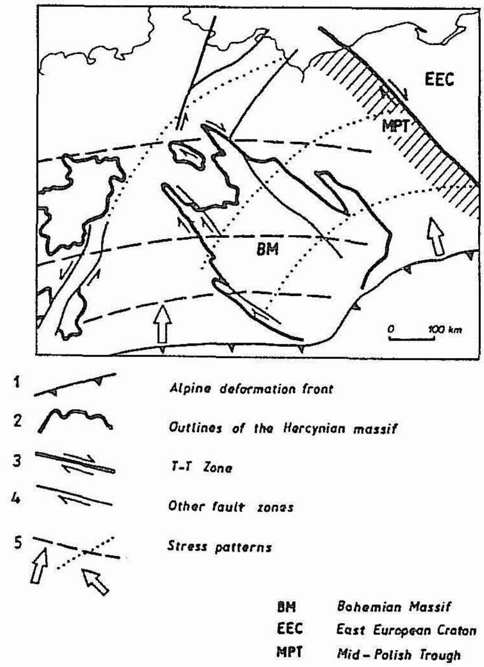

Fig. 6. Syn-Alpine stress pattern in the Middle Europe (after: W. Stackenbrandt, H. J. Franzke, 1989)
Synalpejski rozkład naprężeń w Europie środkowej (według: W. Stackenbrandt, H. J. Franzke, 1989)
1 — front deformacji alpejskich, 2 — zarysy masywów hercyńskich, 3 — strefa T–T, 4 — inne strefy uskokowe, 5 — układy naprężeń, BM — masyw czeski, EEC — platforma wschodnioeuropejska, MPT — bruzda środkowopolska

It results from the above considerations that the problem of free space is the main reason to accept the concept of the Mesozoic to post-Mesozoic rejuvenation — mainly in a dip-slip regime — of an earlier, syn-Variscan strike-slip fault system. For example, looking at the case of the chain of salt pillows located in the northern marginal zone of the former Zechstein basin (Fig. 2B) we notice — moving southeastwards — a lateral shift of every successive pillow towards the NE by a presumed strike-slip fault. These faults seem to have formed later than the pillows, during the syn-Alpine movements. However, they might have originated in the Variscan epoch as well. We may assume that the above mentioned Late Variscan system of conjugate, longitudinal and transversal strike-slip faults later became a structural frame of the Zechstein basin. The faults, continuously reactivated in an oblique-slip or dip-slip sense, divided the basin into blocks. The marginal part of the basin was composed of segments arranged roughly parallel to the margin but also shifted perpendicularly to its main trend (Fig. 7). They formed a new system, of palaeogeographic steps which governed the facies and thickness pattern. Above one of these steps the carbonate or anhydrite platform developed and below it the thickness of salt and its overburden reached such a critical value as to mobilize the salts and to form salt pillows. The present configuration of pillows reflects then an apparent syn-Alpine shift but in fact is a secondary effect of syn-Variscan motions.

The same mechanism might have acted in the case of pierced salt anticlines (Figs. 2C and 2D). On a broader scale, the apparent horizontal displacement along the line C might have resulted from the vertical differentiation across this line. Predominant strike-slip motions in the Late Variscan epoch were replaced by predominant dip-slip motions in the

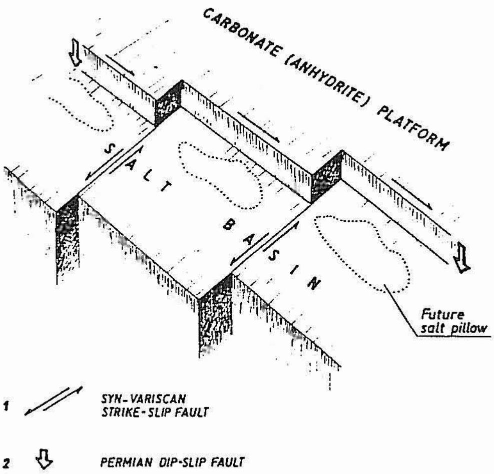

Fig. 7. Simplified sketch of the block arrangement in the Zechstein
Uproszczony szkic układu bloków w cechsztynie
1 — synwaryscyjski uskok przesuwczy, 2 — permski uskok zrzutowy

same zone both during the Permian-Mesozoic evolution of the basin and during its latest Mesozoic-earliest Tertiary inversion.

CONCLUSIONS

1. In the Variscan epoch a system of conjugate strike-slip faults originated within the narrow zone between the rectilinear edge of the East European Craton and the arcuate front of the Variscan belt. Major right-lateral faults ran NW–SE, minor left-lateral faults ran NE–SW. The displacements were of the order from several kilometres to some scores of kilometres.

2. This system was continuously rejuvenated during the Permian and Mesozoic sedimentation and influenced the thickness and facies pattern. It was also active during the latest Mesozoic deformations and inversion. However, vertical movements dominated at these both stages, strike-slip displacement being of a much lesser scale (hundreds of metres up to a few kilometres) because of the rigidity of the area and lack of free space. They were the result of limited accomodation to a new stress field.

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RUCHY PRZESUWCZE NA NIŻU POLSKIM

Streszczenie

Przeanalizowano dane wiertnicze i sejsmiczne z cechsztyńsko-mezozoicznego kompleksu strukturalnego na Niżu Polskim pod kątem ewentualnych ruchów przesuwczych w pokrywie platformowej. Jest to jedyne źródło informacji, ponieważ spod cechsztynu brak wiarygodnych danych sejsmicznych. W wielu miejscach stwierdzono w kompleksie cechsztyńsko-mezozoicznym lewoskrętne przesunięcie osi antyklin niesolnych i solnych, w kierunku NW–SE, na odległość kilku kilometrów (fig. 1 i 2). Większe przemieszczenie grupy antyklin zanotowano na granicy między pomorskim a kujawskim segmentem bruzdy środkowopolskiej (MPT). Zgadza się ono z wygięciem wału środkowopolskiego (MPS — patrz fig. 1 i 3). Z powodu braku swobodnej przestrzeni dla kompensacji ruchów przesuwczych w epoce synalpejskiej wysunięto jednak wniosek, że te przemieszczenia są pozorne i że są one odziedziczone po wcześniejszym systemie synwaryscyjskim. Ten ostatni składał się z serii uskoków zespolonych: większych, prawoskrętnych, o rozciągłości NW–SE, i mniejszych, lewoskrętnych, o

rozciągłości NE–SW. System ten był okresowo odmładzany w czasie jego synalpejskiej inwersji, głównie jako system zrzutowy, w reżimie ruchów pionowych.