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Some key problems of the pre-Permian tectonics of Poland

Four tectonostratigraphic terranes have been distinguished outside the edge of the East European Craton (EEC) in Poland (Fig. 1a) on a map by W. Pożaryski and P. Karnkowski (1992) and in W. Pożaryski *et al.* (1992). Two of them (Pomeranian and Łysogóry Terranes) are questioned by the present authors. These areas are rather parts of the EEC passive margin (miogeocline), deformed in Late Caledonian times into a fold-and-thrust belt (Fig. 1b). The Małopolska Block and Upper Silesian Block are possible terranes, the former being of proximal character. It was detached from the EEC to the southeast of its present position, shifted northwestwards along a transform fault and re-accreted in the Late Caledonian epoch. The origin and tectonic nature of the Upper Silesian Block are disputable. Both terranes were covered by the Devonian-Carboniferous overlap sequence which was tectonically activated towards the end of the Variscan epoch.

Apart from the terrane problem, the extent of the outer Variscan foldbelt and its internal structure are considered. It is most probably a Namurian-Westphalian flysch zone with local intramontane depressions. Its front lies approximately along the line: Gorzów – Poznań – Wieluń, thus lying farther to the south than the Variscan front proposed on the discussed map.

Finally, some theoretical and methodological problems connected with the aforementioned map are also debated, e.g. the significance of dips measured in boreholes, the nomenclature of platform covers, the inaccuracy of "orogenic phases" and imperfections in the adaptation of the terrane concept.

INTRODUCTION

The recently published tectonic map of Poland (W. Pożaryski, P. Karnkowski, 1992), considered jointly with a paper which is a kind of explanatory note (W. Pożaryski *et al.*, 1992) and with an earlier paper by the senior author (W. Pożaryski, 1990), together present a consistent concept of the Palaeozoic tectonics of Poland (Fig. 1a). The map has been published in English and widely distributed abroad. However, it raises many reservations. Therefore, it would not be right for the reader of this map to think that it represents the only correct concept shared by the whole geological community in Poland, or even that it is an "official" idea of the Polish Geological Institute just because the map was published by this

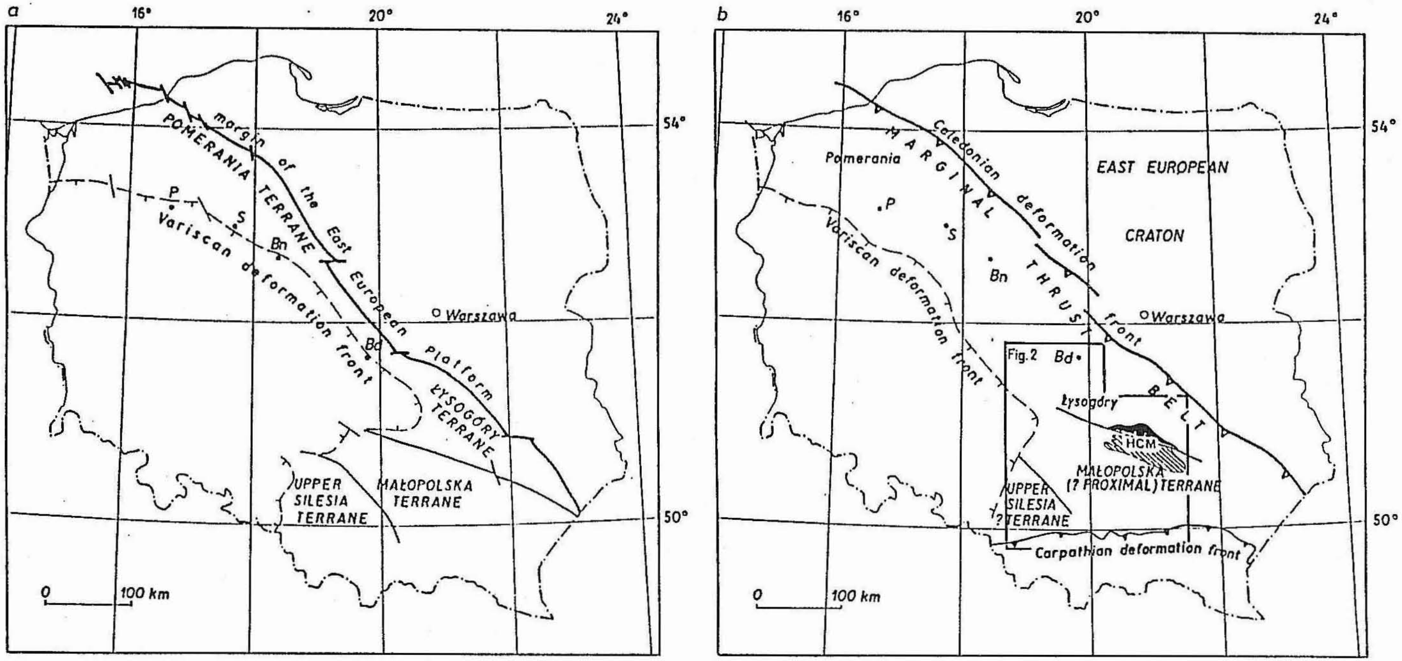


Fig. 1. Sketches of the tectonic units after W. Pożaryski *et al.* (1992) (a) and after the present authors (b)
Szkice jednostek tektonicznych według W. Pożaryskiego i in. (1992) (a) i według autorów (b)
Boreholes (otwory wiertnicze): Bd — Budziszewice IG 1, Bn — Byczyna 1, P — Piła IG 1, S — Szubin IG 1; HCM — Holy Cross Mts. (Góry Świętokrzyskie)

institution. For this reason we feel it necessary to provide a different view on some important issues (Fig. 1b). In the first part of this paper we make some general remarks concerning the philosophy of the mentioned map and in the second part we discuss selected regional problems.

METHODOLOGY AND THEORETICAL BACKGROUND

1. The authors of the map introduce a subdivision of the dip angles measured in boreholes into three categories: 0–15, 15–30 and above 30°. They claim the first category to correspond to "platform-type structure", the last to be the result of "orogenic folding and strongly dislocated, mainly strike-slip compressional zones", and the 15–30° dips to be "the transitional member" between the former categories (W. Pożaryski *et al.*, 1992, p. 643). It is an amazing classification. Do the authors truly think that such a rigid division of dip angles could be of any value for distinguishing between the folded and cratonic areas, let alone the highly inexact intermediate category? What sort of "transitional" areas between the orogen and the craton (platform) is it to represent?

We can readily give numerous examples of considerable dips in the Mesozoic formations in the Polish Lowlands and elsewhere (e.g. around salt diapirs). Does it automatically mean that these are orogenic complexes? And vice versa, is there any reason to believe that horizontal or subhorizontal dips cannot occur in the orogenic areas dominated by thrusts and nappes?

Dips are an essential indicator, but not the only one, of the tectonic style and tectonic nature of a given area. They always have to be taken as a statistical set of data (cf. J. Znosko, 1963) and must be always considered against the regional background, in conjunction with sedimentological features (tectofacies) and other factors, for example, cleavage and degree of metamorphism.

2. The authors maintain that the faults on the map "... have been marked and located strictly on the basis of borehole results and seismic data, and cannot be arbitrarily displaced in future works." (W. Pożaryski *et al.*, 1992, p. 643). If anything is arbitrary it is just such a statement. It is well known that faults in subsurface mapping are located, first of all, by joining the points on seismic cross-sections where the existence of faults is presumed from the disturbed pattern of seismic reflectors. In the first phases of research seismic cross-sections may run at a distance of some scores of kilometres one from another. When the net of cross-sections becomes more dense, corrections of the previous image of the fault system are — as a rule — inevitable.

Moreover, referring to seismic investigations as a base for the location of faults in the Variscan complex seems to be an exaggeration. Throughout the central part of the Polish Lowlands information about faults below the Zechstein base is absent. The existence of some of them can be inferred, assuming the posthumous character of faults in the overlying Zechstein-Mesozoic complex. And that is all. The apparently detailed net of Variscan faults in the map is — in this part of the country — a product of imagination rather than of interpretation of geological facts.

3. The authors are very enthusiastic about tectonostratigraphic terranes but they seem not to know much about the concept itself. For example, they write: "... Caledonian belt ...

is a collage orogen composed of terranes. Strictly speaking these terranes should be taken as suspect terranes ..." (W. Pożaryski *et al.*, 1992, p. 643–644). Speaking most strictly, every terrane is by definition suspect. Every area in a mountain belt lying outside the craton edge (miogeocline) is "suspect" to be allochthonous (P. J. Coney *et al.*, 1980). Then, there is no specific class of "suspect terranes" within the broader term "terrane". "Suspect" is an attribute inseparable from "terrane".

Further on the authors describe the accretion of orogen by docking of terranes and write: "The age of accretion must be defined according to the youngest age of the consolidation of terranes ... " (W. Pożaryski *et al.*, 1992, p. 644). The wording is awkward. Do the authors refer to the age of basement consolidation in the terranes and connect it with the age of accretion? Such a conclusion results from further text and from Figure 3 in their paper: the age of basement consolidation is the main principle for distinguishing the terranes (cf. also W. Pożaryski, 1990). If this is the case, the statement is false because both processes: of basement consolidation in the terranes and of their accretion, have nothing in common. Consolidation can be older than accretion if, for example, the terrane is proximal, that is detached from the craton and then re-accreted to it. The lower age limit of accretion is defined by the age of the youngest rocks specific for a given terrane and the age of deformation at its boundaries. The upper age limit of accretion is set by the age of the oldest rocks transgressively overlying either neighbouring terranes or a terrane and the craton (P. J. Coney *et al.*, 1980; E. R. Schermer *et al.*, 1984).

4. Complete confusion appears in the nomenclature of the platform covers on the discussed map. The authors (W. Pożaryski, P. Karnkowski, 1992; W. Pożaryski *et al.*, 1992) use the terms: "Caledonian platform cover complex" (for Vendian, Cambrian, Ordovician and Silurian), "Variscan platform cover complex" (for Devonian and Carboniferous) and "Alpine platform cover complex" (for Permian and Mesozoic). It would be partly true if the prefix "syn-" would be added to indicate the synchroneity of these covers with the evolution of the Caledonian, Variscan and Alpine mountain belts respectively. However, even in such a case the term "syn-Alpine complex" which began with the Permian is false because the first foundations of the Alpine "geosyncline" (collapse of carbonate platforms) were noted only during the Triassic.

Such a nomenclature refers to the very old ideas of M. M. Tetyayev (1933) which were rejected shortly thereafter because of their ambiguity. Since then the decisions of international bodies, such as the editorial boards of tectonic maps prepared under the auspices of the Commision for the Geological Map of the World (e.g. G. Choubert, 1968; A. V. Peive *et al.*, 1981), have recommended the exact definition of the age of basement consolidation beneath platform covers (e.g. "covers in areas with Hercynian besement"). These covers should be named either according to their ages (e.g. "Devonian-Carboniferous platform cover" or "post-Palaeozoic platform cover") or after the age of basement (cratonic fundament) consolidation with appropriate prefixes (e.g. "post-" or "epi-Hercynian platform cover" — cf. also J. Znosko, 1970).

5. The authors frequently use the terms: "orogenic phases" or "orogenic movements" with names such as: Grampian, Taconic, Bretonic or Sudetic phases. It is also an out-dated approach, referring to the views of H. Stille (1924), disagreeing completely with the principles of the terrane concept and plate tectonic theory. It assumed that the orogenic phases were synchronous worldwide. This assumption was already doubted in the 50s and

we know now that just the opposite idea of diachroneity of deformations is an inherent part of plate tectonics.

6. One more questionable statement (concerning the Ludlovian of the craton marginal zone in Pomerania): "The sediment changes into a flysch-like one; it becomes medium and locally coarse grained. It is not flysch but Caledonian molasse ..." (W. Pożaryski *et al.*, 1992, p. 646). Apart from the well-known discussions of the notions "flysch" and "molasse" and of their tectogenetic significance (A. W. Bally, S. Snelson, 1980; A. D. Miall, 1990), if we regard both notions traditionally: flysch as synorogenic sediment and molasse as postorogenic sediment we cannot accept such a statement. It is not so easy to "reclassify" the discussed strata with one stroke of a pen from flysch to molasse. Coarser interlayers (not coarse-grained — siltstones and fine sandstones at most!) within the graptolitic shales compose the incomplete Bouma sequences, are undoubtedly deep water sediments — a product of turbidity currents — and have been defined by K. Jaworowski (1971) as distal, shaly flysch. It is interesting that they prograded with time north-eastwards from Wenlockian to mid-Ludlovian and that they were not involved in subsequent deformations. However, these problems can be resolved in terms of plate tectonics.

7. Finally, a few minor remarks:

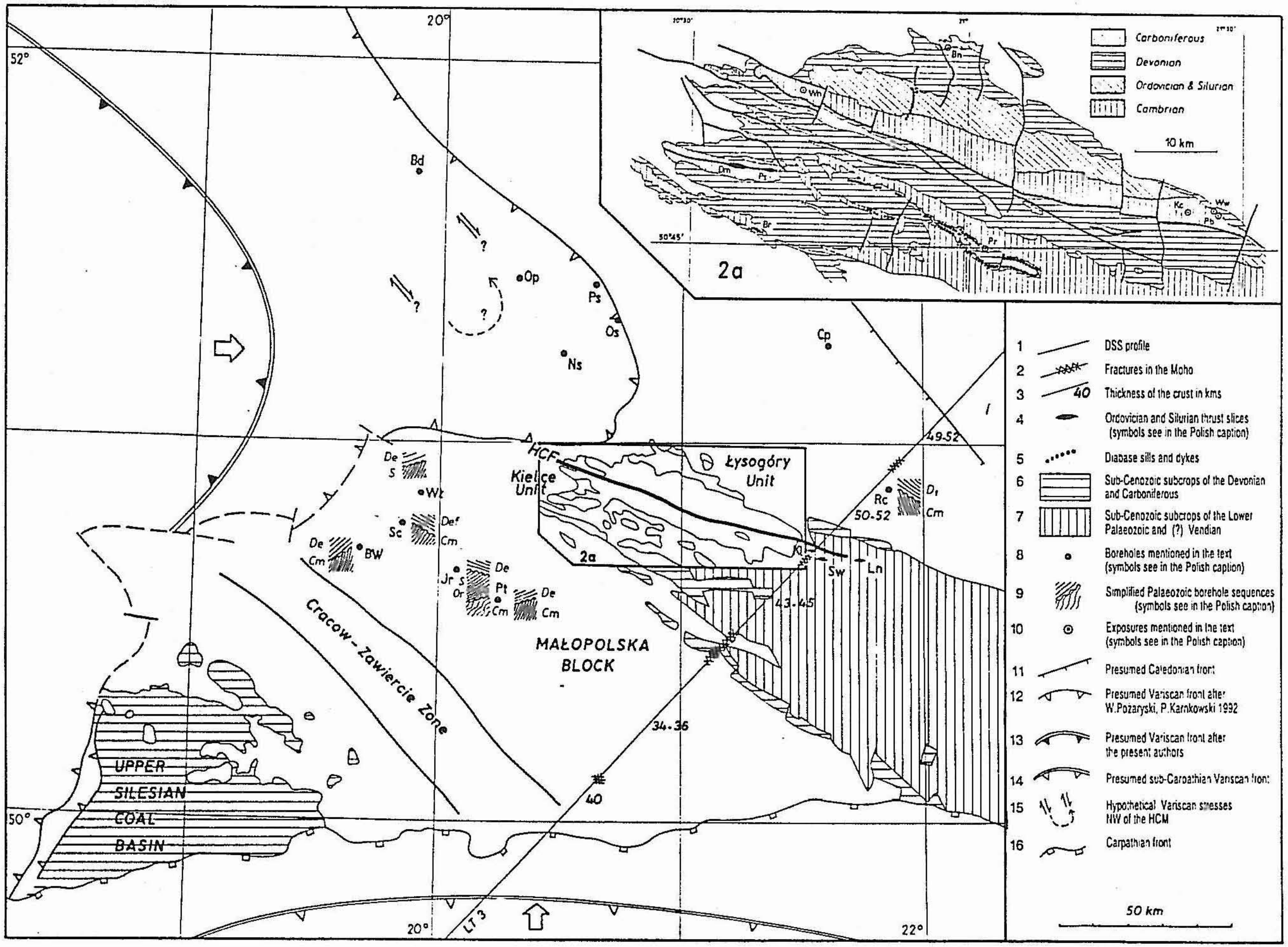
— Flower structures were not "... elaborated in Germany and presented in a paper by D. Betz (1986)" — W. Pożaryski *et al.* (1992, p. 648). They were described earlier by T. P. Harding and J. D. Lowell (1979) who also pointed to their tectonic significance. Their fundamental feature is not the fact that the Moho discontinuity lies deeper beneath the upthrown side of the surficial fault. It is only the flower-like pattern of faults rooted in a single fault in the "basement", indicating strike-slip movement along the system.

— How can an anteclise exist on a terrane (W. Pożaryski *et al.*, 1992, p. 647). This is an obvious contradiction — the usage of one term excludes the usage of the other. Anteclises are broad uplifted structures in cratonic platform covers with radii of at least hundreds of kilometres.

REGIONAL PROBLEMS

A fundamental tectonic problem is the existence or non-existence of tectonostratigraphic terranes outside the edge of the East European Craton (EEC). If they exist, their characteristic stratigraphic sequences and their boundaries should be defined. It is well-known that there are some necessary criteria for distinguishing tectonostratigraphic terranes (P. J. Coney *et al.*, 1980; E. R. Schermer *et al.*, 1984; D. G. Howell, 1989). The features of their sequences and their palaeogeography must contrast sharply with that of neighbouring units. These contrasts cannot be explained in terms of normal, gradational facies changes, gradual changes in structural style or in the character of metamorphism. The boundaries between them must be distinct structural junctions: deep crustal faults, often strike-slip, ophiolite sutures, zones of tectonic melanges or of high-pressure metamorphism.

W. Pożaryski *et al.* (1992) distinguished four terranes in the southeastern forefield of the EEC: the Pomeranian, the Łysogóry, the Małopolska and the Upper Silesian Terranes. Let us examine if the areas in question meet the requirements mentioned previously.


Carboniferous
Devonian
Ordovician & Silurian
Cambrian
10 km
2a
Łysogóry Unit
Kielce Unit
HCF
MAŁOPOLSKA BLOCK
Cracow - Zawiercie Zone
UPPER SILESIAN COAL BASIN
52°
50°
20°
22°
LT 3
49-52
50-52
43-45
34-36
40
1 DSS profile
2 Fractures in the Moho
3 Thickness of the crust in kms
4 Ordovician and Silurian thrust slices (symbols see in the Polish caption)
5 Diabase sills and dykes
6 Sub-Cenozoic subcrops of the Devonian and Carboniferous
7 Sub-Cenozoic subcrops of the Lower Palaeozoic and (?) Vendian
8 Boreholes mentioned in the text (symbols see in the Polish caption)
9 Simplified Palaeozoic borehole sequences (symbols see in the Polish caption)
10 Exposures mentioned in the text (symbols see in the Polish caption)
11 Presumed Caledonian front
12 Presumed Variscan front after W.Pozaryski, P.Karnkowski 1992
13 Presumed Variscan front after the present authors
14 Presumed sub-Carpathian Variscan front
15 Hypothetical Variscan stresses NW of the HCM
16 Carpathian front
50 km

Holy Cross Mountains (HCM) is the most important area in this respect. It is an isolated (only one in a radius of hundreds of kilometres), relatively small (90 x 30 km) territory with numerous outcrops of deformed Palaeozoic rocks. It was obliquely cut out and uplifted from beneath the Mesozoic cover (rejuvenated) as a block (half-horst?) in the latest Cretaceous-earliest Tertiary. It is divided by the Holy Cross Fault (HCF) into two units: northern Łysogóry Unit and southern Kielce Unit (Fig. 2).

The internal deformations of the HCM Palaeozoic core have been interpreted in various ways. The Łysogóry Unit was claimed to have been deformed in the Variscan epoch while the Kielce Unit — in the Caledonian epoch (J. Znosko, 1962*b*). Consolidation of both units during the "Baikalian" or "Assyntian" (= Cadomian) movements was postulated by W. Pożaryski and H. Tomczyk (1968). The possibility of any orogenic processes after the Cambrian was denied (M. Szulczewski, 1977). Recently the main controversy appeared between the advocates of main Caledonian folding (e.g. J. Znosko, 1974, 1984; Z. Kowalczewski, 1981) and those of main Variscan folding (e.g. W. Mizerski, 1979; E. Stupnicka, 1992).

A new concept is offered now by W. Pożaryski *et al.* (1992) who visualise two Caledonian terranes in this area (Fig. 1a): the Łysogóry Terrane exposed in its southern part as the Łysogóry Unit of the HCM, and the Małopolska Terrane exposed in its northwestern part as the Kielce Unit of the HCM. The latter has a "... weakly metamorphosed basement of Early Caledonian-Grampian consolidation..." (W. Pożaryski *et al.*, 1992, p. 645). As to the terrane origin of the Łysogóry Unit the case is, however, not so clear because it was defined in an earlier paper (W. Pożaryski, 1990) and mentioned in the explanatory text (W. Pożaryski *et al.*, 1992, p. 645 and Fig. 3) while on the main map and on the inset map presenting the European background (W. Pożaryski, P. Karnkowski, 1992) it disappears completely and the area belongs to the "Late Caledonian platform cover" continuous with the EEC. Confusion grows because of the following statement: "... the Łysogóry Terrane has not been studied down to the folded basement; sediments recognized down to the Late Cambrian have platform-type features ..." (W. Pożaryski *et al.*, 1992, p. 645). Then, there

Fig. 2. Holy Cross Mts. and adjacent areas

Cm — Cambrian, Or — Ordovican, S — Silurian, D_1 — Lower Devonian, De — Emsian, Def — Eifelian; HCF — Holy Cross Fault

Góry Świętokrzyskie i obszary przyległe

1 — profil głębokich sondowań sejsmicznych, 2 — pęknięcia w powierzchni Moho, 3 — grubość skorupy w kilometrach, 4 — łuski ordowiku i syluru pośród kambru (Br — Brzeziny, Dm — Dyminy, Kl — Kleczanów, Ln — Lenarczyce, Ps — Posłowice, Sw — Święcica), 5 — sille i dajki diabazów, 6 — podkenozoiczne wychodnie dewonu i karbonu, 7 — podkenozoiczne wychodnie starszego paleozoiku i (?)wendu, 8 — otwory wiertnicze wymienione w tekście (Bd — Budziszewice IG 1, BW — Biała Wielka IG 1, Cp — Ciepielów IG 1, Jr — Jaronowice IG 1, Ns — Nieświn IG 1, Op — Opoczno IG 1, Os — Ostałów IG 2, Pt — Potok Mały IG 1, Ps — Przysucha 1, Rc — Rachów 1, Sc — Secemin IG 1, Wł — Włoszczowa IG 1), 9 — uproszczone profile paleozoiku w otworach wiertniczych (Cm — kambr, Or — ordowik, S — sylur, D_1 — dewon dolny, De — ems, Def — eifel), 10 — odsłonięcia wymienione w tekście (Bn — Bronkowice, Kc — Kochówka, Pb — Pobroszyn, Pr — Prągowiec, Wn — Wiśniówka, Ww — Wąworków), 11 — przypuszczalny front kaledoński, 12 — przypuszczalny front waryscyjski według W. Pożaryskiego i P. Karnkowskiego (1992), 13 — przypuszczalny front waryscyjski według autorów, 14 — przypuszczalny podkarpacki front waryscyjski, 15 — hipotetyczne naprężenia waryscyjskie na północny zachód od Gór Świętokrzyskich, 16 — front karpacki; HCF — uskok świętokrzyski

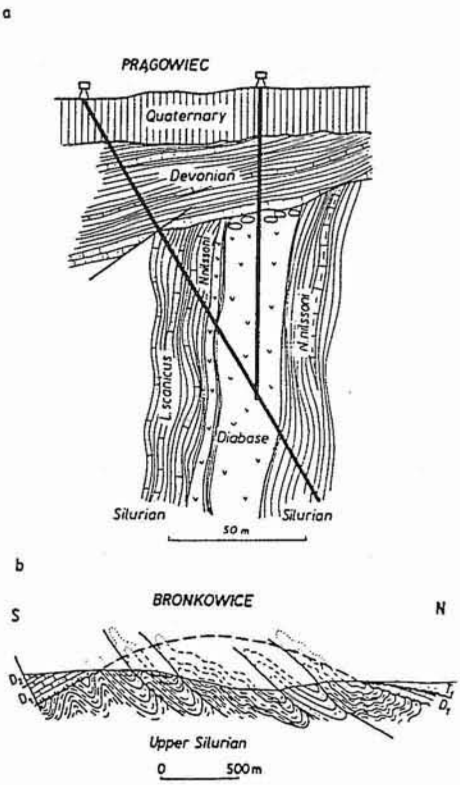


Fig. 3. a — Diabase sill within the Silurian and the sub-Devonian angular unconformity — Kielce Unit (after Z. Kowalczewski, R. Lisik, 1974, simplified); b — Sub-Devonian angular unconformity — Łysogóry Unit (J. Znosko after the data in J. Czarnocki, 1957 and E. Mariańczyk, 1973)
D_1 — Lower Devonian, D_2 — Middle Devonian, T_1 — Lower Triassic; for localities see Fig. 2
a — Sill diabazu w sylurze i poddewońska niezgodność kątowa — jednostka kielecka (według Z. Kowalczewskiego, R. Lisika, 1974, uproszczone); b — poddewońska niezgodność kątowa — jednostka łysogórska (J. Znosko według danych z J. Czarnockiego, 1957 i E. Mariańczyk, 1973)
D_1 — dewon dolny, D_2 — dewon środkowy, T_1 — trias dolny; lokalizacja na fig. 2

is a contradiction because the same area cannot be a terrane and a part of the craton at the same time.

Much research has been carried out in the HCM over more than 70 years. Paradoxically, the main disadvantage is that boreholes are so scarce in the Palaeozoic core. They have not been made merely because there are a lot of outcrops in the area and they seemed to be unnecessary, although they would be very helpful for revealing the deeper structure of the territory. Besides, even the superficial geology is effectively masked by the Cenozoic deposits — in fact, the outcrops, though numerous, are predominantly small and dispersed, in the eastern part limited to stream beds, the rocky hills being often covered with forest. All these circumstances hamper field work. Finally, modern sedimentological investigations and isotopic/geochronological data are almost completely absent. The result is that the number of open questions grows in parallel to the number of problems solved. Below is a concise list of both.

— The only profile of deep seismic soundings crossing the HCM (profile LT-3, A. Guterch *et al.*, 1984) revealed four main fractures in the Moho (Fig. 2). One of them lies precisely beneath the HCF, dividing the crust to the northeast, 50–52 km thick, from the crust to the southwest, 43–45 km thick. This block of intermediate crustal thickness is bounded to the southwest by the next fracture — just as significant as the former one — which runs within the Małopolska Block just beneath the southwestern boundary of the uplifted Palaeozoic core. Southwest of this fracture the crust is 34–36 km thick. In general, it is a stepwise arrangement of crustal blocks downfaulted towards the craton. The northeastern block seems to belong to the EEC. The refraction horizon which marks the top of the cratonic basement (V_p = 6000–6200 km/s) and reaches from the northeast to the first fracture (A. M. Żelichowski, 1979) confirms this assumption. The above connections between the Moho fractures and near-surface faults are true only if the intracrustal fractures are vertical. If they are not, many other connections are possible. There are no deep seismic reflection data to check this problem.

— Several formations in the Palaeozoic sequence have been claimed to be flysch or flysch-like: (1) so-called "Vendian" (now mainly Lower Cambrian — cf. Z. Kowalczewski, 1993); (2) Upper Cambrian in the Łysogóry Unit; (3) uppermost Silurian; (4) Visean. According to recent data the flysch origin, probably of the Lower Cambrian, and undoubtedly of the latest Silurian series of alternating shales and greywackes, occurring in both units and attaining a thickness of 1300–1500 m (J. Malec, 1993*a*,*b*), seems to be justifiable. Otherwise, the Early Palaeozoic successions are of epicontinental character in both HCM units. Sedimentary development in the Łysogóry Unit is comparable with that of more internal parts of the EEC, only the thickness being greater, in some cases (such as Ordovician and, especially, Upper Cambrian) much greater. In the Kielce Unit the lateral differentiation is more distinct, particularly in the Ordovician (W. Bednarczyk, 1971): condensed carbonate and limestone/sandstone shallow neritic profiles occur there next to the more complete sequences of graptolitic shales. Abundant interlayers of tuffites and bentonites are characteristic (Z. Kowalczewski, 1974; R. Chlebowski, 1971). Nevetheless, the similarities between both units can be observed so that a tripartite palaeogeographic zonality instead of sharp subdivision into two units along the HCF seems to be more adequate, at least in some periods (H. Tomczyk, M. Turnau-Morawska, 1967; M. Szulczewski, 1977).

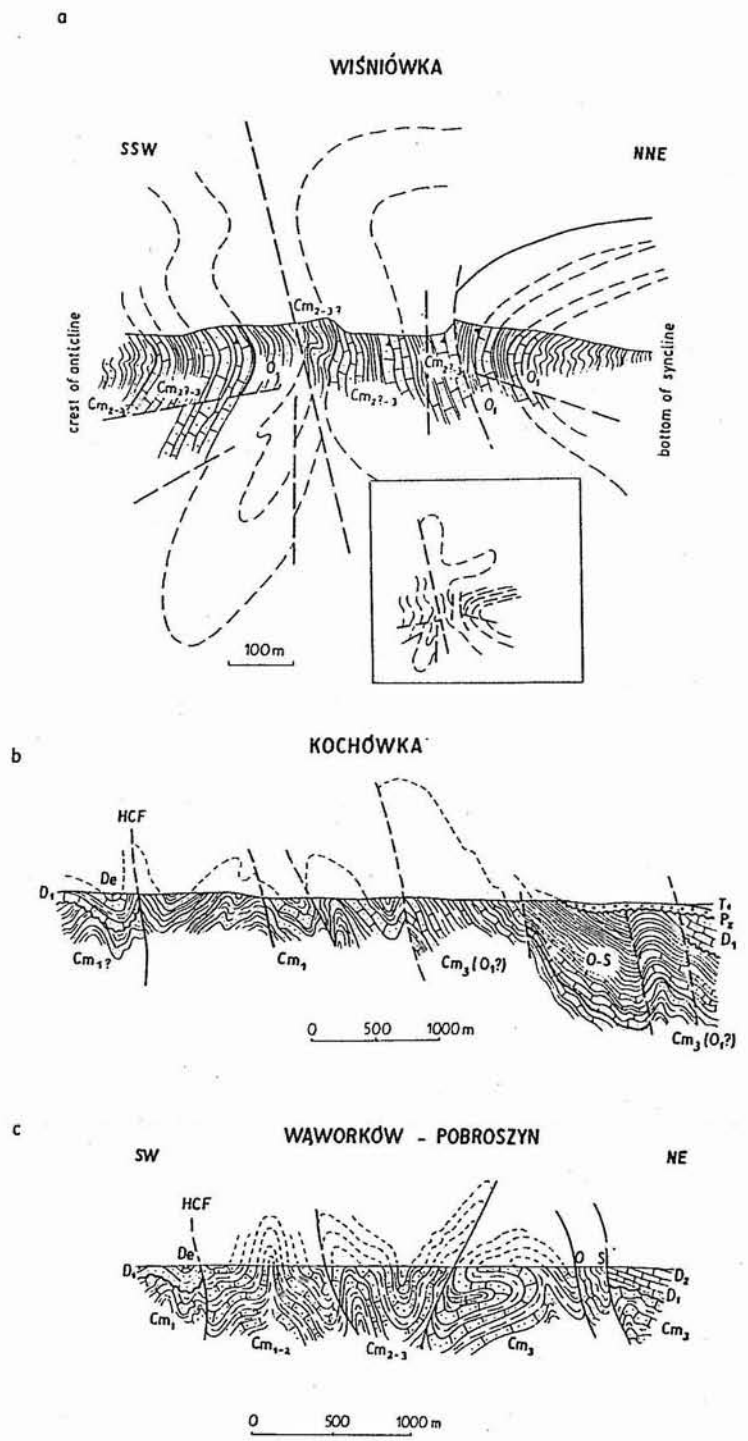
— Many "orogenic phases" have been distinguished in the Palaeozoic of the HCM and Małopolska Block (e.g. H. Tomczyk, 1974; P. Karnkowski, 1983). These are: the Małopolska phase between the Precambrian and Cambrian, the Holy Cross phase between the Early and Middle Cambrian, the Sandomierz phase (= Early Caledonian, "Grampian" — before the Arenigian), the Łysogóry phase within the Ordovician, the "Taconian" phase between the Ordovician and Silurian, the Cracovian phase within the Silurian, the "Ardennian" phase (= Late Caledonian) towards the end of Silurian a.s.o. The majority of these "phases" were based on the occurrence of stratigraphic/sedimentary gaps or even on cyclicity of sedimentation and facies changes. On the other hand, unquestionable angular unconformities have been found at three levels: below the Arenigian (beyond doubt in the Kielce Unit only), below the Emsian-Siegenian (in the Łysogóry Unit in places only) and below the Permian. The second of these unconformities immediately followed the probable period of flysch sedimentation.

— Boundary sequences between the Silurian and Devonian in the Łysogóry Unit are either continuous with gradual passage from marine to fluvial sedimentation and/or insignificant gaps with penecordant contacts, or are marked by a distinct angular unconformity between the Devonian and older strata. The first case has been noted for example, in the Ciepielów borehole (H. Łobanowski, T. Przybyłowicz, 1979; E. Turnau, L. Jakubowska, 1989). The second case is exemplified by unconformities both in outcrops (Bronkowice Anticline — E. Mariańczyk, 1973) and in boreholes (Rachów 1 — A. Tokarski, 1958 — see Fig. 2). In contrast, the contact in the Kielce Unit is, as a rule, discordant (Fig. 3) and this unconformity is clearly independent from the older, sub-Arenigian one. It has been already observed and excellently illustrated by J. Czarnocki (1919, 1939). This situation extends over the entire Małopolska Block as shown by the boreholes in the Nida Trough (H. Jurkiewicz, 1974, see also Fig. 2).

— Palaeozoic igneous activity was meagre in the HCM area. Its manifestations are limited to small diabase or lamprophyre sills and dykes (Fig. 2). The general geological situation of the majority of them indicates pre-Emsian age (Z. Kowalczewski, R. Lisik, 1974). However, some of them also pierce Devonian rocks (Z. Kowalczewski, 1974). No reliable isotopic/geochronological investigations have been made. The signs of subduction-related magmatism of intermediate or basic type have been found neither within the marginal zone of the EEC, nor in the HCM territory, although the pyroclastic material in the Ordovician of the HCM reveals a rhyolitic origin and the relative proximity (30 km?) of volcanic sources (R. Chlebowski, 1971).

— Separation of syn-Alpine deformations from the Palaeozoic ones remains one of the crucial problems. The young, block-like uplift of the HCM core caused a strong tectonic activity along its southwestern boundary which is evidenced by reverse faults with the Ordovician in hanging walls and Upper Jurassic in foot walls (Z. Deczkowski, H. Tomczyk, 1969). The scale of deformations within the core itself is impossible to reconstruct because of the removal of the Mesozoic cover. A similar problem is that of the separation of the syn-Hercynian (syn-Variscan) tectonism from the Caledonian event.

Taking into account all these facts (and also uncertainties) we may assume that the Łysogóry Unit and the territories northeast of it, as far as the presumed Caledonian front (Fig. 2), were closely connected with the EEC and have not changed their position since the Late Precambrian. This corresponds to palaeomagnetic data (M. Lewandowski, 1993).


a
WIŚNIÓWKA
SSW
NNE
crest of anticline
bottom of syncline
100m
b
KOCHÓWKA
HCF
De
Cm1?
Cm1
Cm3 (O1?)
O-S
0 500 1000m
Cm3 (O1?)
c
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SW
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Cm1
Cm1-2
Cm2-3
Cm3
0 500 1000 m

However, this area did not belong, during the Early Palaeozoic, to the craton *sensu stricto* and the sedimentation there cannot be regarded as "platform-type" (W. Pożaryski *et al.*, 1992, p. 645). Thick Early Palaeozoic successions (1000 m of the Upper Cambrian alone, 1500 m of the uppermost Silurian) are in places strongly deformed (tight folds, including overturned or recumbent folds — see Fig. 4) revealing the features of plastic strain (boudinage in quartzites). Thus, they do not bear an intracratonic character. This area was part of the passive margin of the EEC (miogeocline) where thick, partly deeper shelf sediments were laid down on the strongly downwarped continental crust of the outermost part of the craton. They were later involved, in places, in the Late Caledonian (latest Silurian-Early Devonian) folding while elsewhere there remained remnant basins with continuous sedimentation.

According to the rules of the terrane concept, the presence of terranes can be allowed only outside this zone. Thus, the Małopolska Block (including the Kielce Unit) could be a terrane. But also, in this case, the similarities between the two units in the Early Palaeozoic force us to put a question mark on the terrane origin of this region (Fig. 1b).

The most essential difference between both HCM units is an earlier folding in the Kielce Unit during the latest Cambrian-earliest Ordovician times. It is confirmed by the distinct sub-Arenigian angular unconformity. Nevertheless, this area was also affected by the Late Caledonian folding which, in turn, is shown by the occurrence of the Ordovician and Silurian thrust slices wedged among the Cambrian strata. They are known from several localities: Dyminy, Posłowice and Brzeziny in the western part of the unit, and Kleczanów, Święcica and Lenarczyce in its easternmost part (Fig. 2, see also J. Czarnocki, 1938). Therefore, the "Grampian" consolidation of the area in question (W. Pożaryski *et al.*, 1992, p. 645) must be excluded. The ubiquitous occurrence of the Lower Cambrian (and problematic Vendian) on the pre-Tertiary surface in the eastern part of the Małopolska Block is due to deeper truncation only. In its plunging western part (the Kielce Unit) the younger folded strata have been preserved.

The mentioned similarities between both units would favour the definition of the Małopolska Block as a proximal terrane (Fig. 1b) — a crustal sliver detached from the EEC southeast of its present position, displaced not by a great distance along a transform fault and accreted again. Such a conclusion is in line with the palaeobiogeographical data which indicate a certain endemicity of some faunal groups in relation to the Baltic province (J. Dzik, 1983; W. Bednarczyk, 1988; S. Orłowski, 1988), yet without fundamental differen-

Fig. 4. Style of the Lower Palaeozoic deformations in the Łysogóry Unit: a — after Z. Kowalczewski *et al.* (1986) simplified, b — after Z. Kowalczewski *et al.* (1976) simplified, c — J. Znosko after the data in J. Samsonowicz (1934) and Z. Kowalczewski *et al.* (1976)

Cm_1 — Lower Cambrian, Cm_2 — Middle Cambrian, Cm_3 — Upper Cambrian, O_1 — Lower Ordovician (Tremadoc), O — Ordovician, S — Silurian, D_1 — Lower Devonian, D_2 — Middle Devonian, De — Eifelian, Pz — Zechstein, T_1 — Lower Triassic, HCF — Holy Cross Fault; for localities see Fig. 2

Styl deformacji dolnego paleozoiku w jednostce łysogórskiej: a — według Z. Kowalczewskiego i in. (1986), uproszczony, b — według Z. Kowalczewskiego i in. (1976), uproszczony, c — J. Znosko według danych J. Samsonowicza (1934) i Z. Kowalczewskiego i in. (1976)

Cm_1 — kambr dolny, Cm_2 — kambr środkowy, Cm_3 — kambr górny, O_1 — ordowik dolny (tremadok), O — ordowik, S — sylur, D_1 — dewon dolny, D_2 — dewon środkowy, De — eifel, Pz — cechsztyn, T_1 — trias dolny, HCF — uskok świętokrzyski; lokalizacja na fig. 2

ces. It is also in agreement with the palaeomagnetic conclusions of M. Lewandowski (1993) although the time of accretion would be earlier — in accordance with the previous opinion of the same author (M. Lewandowski, 1987) and with other palaeomagnetic arguments (J. Nawrocki, 1993).

Concerning the original position of the Małopolska (?)Terrane, a working hypothesis can be put forward that it was situated in a closing back-arc basin, initially (in the Cambrian) under the influence of passive margin and later (in the Ordovician) in closer proximity to a volcanic arc. Its movement along the EEC border and its re-accretion took place in the Late Silurian and earliest Devonian.

The Devonian of the HCM is developed in epicontinental facies, initially mainly fluvial-alluvial, later mainly in siliciclastic shelf and carbonate platform (with carbonate buildups) environments. It forms a part of the typical overlap sequence which extends from Wolhynia on the EEC through the HCM area to the front of the Moravian-Silesian branch of the Variscides west of the Upper Silesian Coal Basin, and thus defines the (?pre-) Early Devonian age of accretion of the whole assemblage of underlying crustal blocks. Syn-Variscan deformations — of block-fault character with occasional open box-folds — differ in their brittle style from the Caledonian ones. A "Variscan orogeny" in this area is out of the question, although this relatively young craton was strongly reactivated beginning in the Famennian (see below).

Upper Silesian Coal Basin is a Variscan foredeep filled in with paralic to limnic Late Carboniferous molasse which formed in the forefield of the Moravo-Silesian and sub-Carpathian branches of the Variscides (J. Znosko, 1992). The coal-bearing Upper Carboniferous is underlain by the siliciclastic marine deposits of the Upper Visean/Namurian A and by the marine, epicontinental Devonian which is the westernmost part of the overlapping platform mentioned earlier. These in turn are underlain by epicontinental Cambrian. A major part of the Dinantian, and the whole of the Ordovician and Silurian are missing. All these strata lie rather flat although the idea of folding and thrusting of the Cambrian, encountered in two boreholes (Goczałkowice IG 1 and Sosnowiec IG 1), has also been expressed (Z. Kowalczewski *et al.*, 1984; Z. Kowalczewski, 1993). This idea was recently denied by one of the earlier co-authors (M. Moczydłowska, 1993) and it remains a matter of dispute.

The basement of the Upper Silesian Block (USB) — a part of the so-called Brunnia-Upper Silesian Massif (A. Kotas, 1985) — is highly diversified. It is known from boreholes in the southern part only where (?Cadomian) gneisses and crystalline schists intruded by granitoids and gabbros occur along with weaker metamorphosed metapelites, metapsammites and metaconglomerates.

USB is separated from the Małopolska Block by the Cracow-Zawiercie tectonic zone (Fig. 5). It is a relatively narrow (barely 20–25 km wide) belt of strongly laterally differentiated and highly tectonically involved (folded and thrusted) ?latest Precambrian to Silurian rocks (S. Bukowy, 1982). They were developed mainly in the epicontinental domain displaying close affinities to the sequence of the Małopolska Block, both in the facies (the Upper Silurian greywackes included) and in the presence of the pre-Arenigian unconformity. The rocks below this unconformity are either slightly metamorphosed or unmetamorphosed in neigbouring profiles, while above it they are — as a rule — unmetamorphosed (B. Szymański, oral inf.). Devonian-Carboniferous strata lie over the Lower

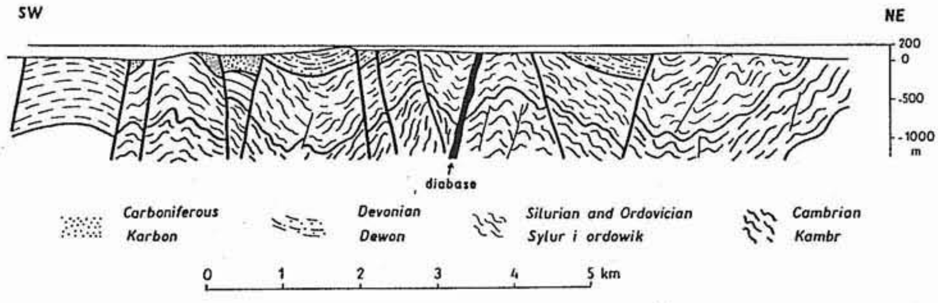

Fig. 5. Geological section across the Cracow – Zawiercie tectonic zone (after F. Ekiert, 1971)
Przekrój geologiczny przez strefę tektoniczną Krakowa – Zawiercia (według F. Ekierta, 1971)

Palaeozoic discordantly, are more weakly deformed and completely unmetamorphosed. Both complexes are cut by bimodal intrusives, mainly of Late Palaeozoic age, and covered again discordantly by thin Mesozoic formations.

Cracow – Zawiercie Zone fits well with the concept of a terrane boundary along which the USB and the Małopolska Block were sutured at the end of the Early Palaeozoic. This suture was reactivated in Late Variscan times as a response to the adjacent folding.

Thus, the USB can be regarded as a terrane because of the peculiarities of its stratigraphic sequence and of its northeastern boundary. This conclusion seems to be confirmed by the palaeobiogeographic and palaeomagnetic data although the question of whether it is a proximal or exotic terrane remains open. Some arguments speak more in favour of its Avalonian (Gondwanian) provenance than in the case of the Małopolska Block.

Sudetes and the external Variscan belt. It is astonishing that the authors of the discussed map — such fervent advocates of the terrane concept — have not noticed the most probable terrane assemblage in the Palaeozoic of Poland: the Western Sudetes. Surprisingly enough, one of the authors (A. Grocholski, 1987) was the first to accept such a possibility. The Sudetian mosaic of crustal blocks fits the terrane concept very well, revealing such features as: great contrasts in stratigraphic sequences and grades of metamorphism between particular blocks, deeply rooted shear zones of predominantly strike-slip character (boundaries of blocks) presumable stitching plutons. Therefore this area has been interpreted as a terrane assemblage, both by Polish authors (Z. Cymerman, 1991; W. Narębski, 1993; Z. Cymerman, M. A. J. Piasecki, 1994) and by foreign scientists (P. H. Matte *et al.*, 1990; G. J. H. Oliver *et al.*, 1993). From three to six terranes have been distinguished there, their accretion being either a Variscan process or a combination of activity of the (Early?) Caledonian south-dipping subduction zone with the reorganization of the terranes during Variscan times. We do not intend — because of lack of space — to explore this topic in detail and refer the reader to the above papers and to many other works quoted therein, as well as to the special volume devoted to the Sudetes (J. Don *et al.*, 1990).

Two problems concerning the Variscan external belt, as presented on the discussed map, should be taken into account. First, the internal structure of this zone and second, the location and course of the Variscan front.

The external Variscan zone (externides), almost 200 km wide, is built — according to the authors of the map — of alternating flysch belts of two generations (Upper Devonian-

Lower Namurian and Namurian-Lower Westphalian) and internal molasses also of two generations (Westphalian and Stephanian-Autunian). The belts are separated by north-east verging thrusts, both flysches being thrusted over the earlier molasse and vice versa. Consequently, the last episode of folding must have taken place after the Westphalian.

Such a pattern of Variscan externides is a new solution, most certainly requiring additional comments of the authors which, again, are missing. First of all, we doubt the validity of the subdivision into flysch and molasse (because of lack of sedimentological research) as well as the accuracy in defining the age of strata, at least in parts of the boreholes within the zone. But, even leaving aside these criteria, the mechanism of formation of the described pattern needs explanation. For example, one could assume that the flysch was thrusted far to the north over the molasse and that the later erosion uncovered the molasse from beneath the flysch in tectonic windows. Or, that the molasse was deposited upon the flysch in intramontane depressions; but the structures infilled with molasse are separated on the map by thrusts, not by normal faults as they should be in this case. Unless such explanations are provided, we may suspect that the only basis for the separation of flysch from molasse was stratigraphic (i.e. Early Westphalian or earlier = flysch, Late Westphalian or later = molasse). Therefore we support our previous opinion (J. Znosko, 1974) that the entire external zone is built of flysch with limited possibilities of the occurrence of intramontane deeps.

The northern and northeastern extension of the Variscan foldbelt (= Variscan front), including its easternmost embayment reaching eastwards to the northern border of the HCM, also needs explanation of the criterions and mechanisms of their formation. The northern and northeastern front is based on three boreholes extending over a distance of 400 km (Fig. 1). One of them (Piła IG 1) encountered — in one core — steeply dipping (60–80°) siltstones and shales, probably Upper Carboniferous in age. However, 70 km to the east, in borehole Szubin IG 1, similar shales of unknown age occur with 40–45° dips. Why, then, has the former been placed in the folded belt while the latter — on the epi-Caledonian platform? In the remaining two boreholes (Byczyna 1 and Budziszewice IG 1) longer sequences have been penetrated: in the first case Lower Carboniferous with average dip 60°, in the second case — Upper Carboniferous with variable dips, from 20° to vertical. But in the latter the Zechstein strata are also dipping steeply, so the rejuvenation of an earlier fault cannot be excluded as the cause of these deformations. Besides, the Carboniferous rocks in both cases do not seem to reveal flysch features, although detailed sedimentological investigations have not been made.

The sharp bend of the Variscan front in the easternmost embayment (Fig. 1a) implies, at first glance, an unusual radial stress pattern. On the other hand, the low-angle contacts between the Variscan front and the internal thrusts of the foldbelt suggest that the present shape of the bend could be post-erosional, being a remnant of the earlier broader arc. Still another explanation would be a secondary oroclinal bending of the previously broader arc. There are no such alternative considerations related to the discussed map.

Therefore we remain, for the time being, with our earlier interpretation of the Variscan front lying farther to the south (K. -B. Jubitz *et al.*, 1986), approximately along the line Gorzów – Poznań – Wieluń (Fig. 1b). It was substantiated by some geophysical data and reconstructed mainly according to the posthumous tectonic structures in the Permian-Meso-

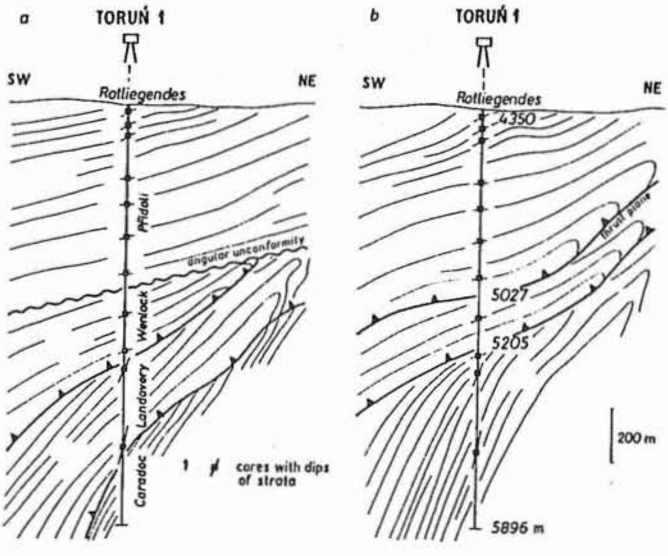

Fig. 6. Two interpretations of the Toruń 1 borehole sequence: a — after W. Pożaryski *et al.* (1992), b — after the present authors

Dwie interpretacje profilu otworu wiertniczego Toruń 1: a — według W. Pożaryskiego i in. (1992), b — według autorów

1 — rdzenie z upadami warstw

zoic cover dividing the more rigid terrains to the southwest from the more mobile areas (Variscan foredeep?) to the northeast.

Nevertheless, the undoubtedly strong tectonic involvement of the Carboniferous strata, found in boreholes north of the HCM (Ostałów IG 2, Opoczno IG 1, Nieświn IG 1, Przysucha 1 — Fig. 2) remains a problem. A thorough sedimentological examination of these rocks is necessary to decide if they are really flysch, as on the discussed map. If they are not, and belonged to an epicontinental domain, there is yet another possible explanation of their tectonic involvement, assuming the existence of a separate sub-Carpathian Variscan arc with northern vergence (J. Znosko, 1992) — a hypothesis based on the abundant occurrence of coal exotics in the Carpathian flysch. This arc met with the Moravo-Silesian arc, the Upper Silesian Coal Basin being situated in a corner between the two. In this case the whole triangle bounded by these arcs and the rectilinear edge of the EEC would be placed in a very complicated stress field with possible (anticlockwise?) rotations and strike-slip displacements (Fig. 2). Even so the whole area belonged to the outer, depressed and reactivated part of the young craton.

P o m e r a n i a . The idea of the "Taconian Pomeranian Terrane" (W. Pożaryski, P. Karnkowski, 1992; W. Pożaryski *et al.*, 1992) is based on the interpretation of a sequence in the Toruń 1 borehole. An angular discordance between the almost flat-lying Přidoli of epicontinental development and the folded older strata was claimed earlier by the same author (W. Pożaryski *et al.*, 1980). Recently the discordance has been moved downwards to the Ordovician-Silurian boundary, thus becoming a "proof" of the "Taconian Terrane".

Examining the plain facts (Fig. 6, cf. also R. Dadlez, 1982), the discussed sequence is documented only by infrequent cores, without continuous dipmeter measurements. The dips increase downwards in successive cores, but they also increase in the topmost cores. Two discontinuities are marked by distinct anomalies on geophysical logs but their character points rather to the existence of faults or thrusts than to unconformity. A stratigraphic gap comprising the Ludlovian was recorded above the higher discontinuity.

According to our opinion the whole sequence represents a stack of overturned folds with squeezed out lower limbs, folded together at the end of Silurian. We are against the "Taconian folding" which recently (W. Pożaryski, A. Witkowski, 1990) has been treated as fact and extrapolated to the whole Pomeranian foldbelt, the southern Baltic included, but again with angular discordance within the Silurian. We oppose also the idea of the "Pomeranian Terrane" because we can not see any evidence for the boundary between this terrane and the craton.

Folded strata known from almost thirty boreholes in Pomerania, reaching in age from the Llandeilo to Přidoli (R. Dadlez, 1978) were earlier most probably deposited — as were their equivalents in the Łysogóry Unit of the HCM — on the downwarped crust of the EEC, along a passive margin (miogeocline) and were later transformed into a folded belt (Fig. 1b — cf. also the concept of a marginal thrust belt by A. Berthelsen, 1992). The recent results of research on the Rügen Ordovician (G. Katzung *et al.*, 1993), pointing — on the basis of acritarch assemblages — to Avalonian provenance of the folded series, suggest a different approach but are not yet decisive for Pomerania. Both regions are difficult to correlate because the borehole sequences only partly stratigraphically overlap and contain coarser clastics in Rügen, absent in Pomerania.

CONCLUSIONS

Since the times of H. Stille and E. B. Bailey, 70 years ago, a dispute has been under way in Europe between the adherents and opponents of the existance of the Caledonian foldbelt along the southwestern margin of the EEC. One of the most consequent advocates of the Caledonian folding in the Polish segment of this zone was J. Znosko who — since his first papers on this topic (J. Znosko, 1962*a*) — has defended such a view. Initially based on the observations in the exposed HCM and on scarce boreholes in southern Poland, this view was quickly confirmed by the profiles of boreholes on Rügen and in Pomerania. However, the former were initially interpreted by German geologists in terms of Variscan fault-block tectonics (D. Franke, 1967) whereas the latter were regarded either as results of the Caledonian folding (R. Dadlez, 1974) or as "paratectonically disturbed" formations deposited in the "pericratonic depression" (W. Pożaryski, 1969).

The Rügen-Pomeranian data together with later results of boreholes in the southern North Sea (T. C. Frost *et al.*, 1981) seemed to be convincing evidence in favour of the Caledonian deformations, as was the discovery of a belt of anomalous crust (A. Guterch *et al.*, 1975) recently called the Transeuropean Suture Zone. Nevertheless, the separate branch of the North German-Polish Caledonides has long not been widely accepted. For example, as late as the late 70s a paper appeared (W. Pożaryski, Z. Kotański, 1978) with an interpretation of this zone in terms of rifts, aulacogens and mantle plumes.

Finally, several years after the advent of plate tectonics, various mobilistic hypotheses began to appear trying to explain the tectonics of the discussed zone. Strangely enough, some of the fomer opponents changed their minds, and outright, into the extremely opposite standpoints of major intracontinental wrench fault (W. Brochwicz-Lewiński *et al.*, 1981) or strike-slip orogen and terranes (D. Franke *et al.*, 1989; W. Pożaryski, 1990). There are also other hypotheses e.g.: (1) the idea of the Late Proterozoic transform fault operating along the southern margin of the Laurentian-Baltic plate, which later changed into a passive margin folded in the Caledonian times (A. Berthelsen, 1984) and (2) the concept of the Late Caledonian transform fault (R. M. Pegrum, 1984). No version, however, doubts the Caledonian age of deformations.

It is striking that contradicting interpretations are often based upon the same facts. The point is that the facts are scarce and sometimes equivocal, allowing an ambiguous approach. The controversies remain although now in another sense. The acceptance or rejection of geotectonic hypotheses may fall into the category of faith rather than of scientific reasoning. Adhering to the former standpoint — as we have been for many years on the mobilistic, Caledonian side of the battle front — we may accept the idea of terranes but we can also argue against the terrane character of the particular area.

Perhaps it is a waste of time now to play cards with geotectonic hypotheses while we — in this country — are so delayed in some fields in applying modern research techniques to rocks. Perhaps the time has come to concentrate at collection of new facts and re-evaluation of the old ones with the use of modern methods and modern research strategies.

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NIEKTÓRE KLUCZOWE PROBLEMY PRZEDPERMSKIEJ TEKTONIKI POLSKI

Streszczenie

Wydana ostatnio mapa tektoniczna Polski (W. Pożaryski, P. Karnkowski, 1992) i towarzysząca jej nota objaśniająca (W. Pożaryski i in., 1992) wywołują wiele zastrzeżeń, tak od strony teoretyczno-metodycznej, jak i w kwestii interpretacji regionalnych. Jeżeli chodzi o pierwszą grupę zagadnień, sztywna klasyfikacja upadów, pomierzonych w rdzeniach wiertniczych (0^o–15^o–30^o– ponad 30^o) nie może być sama w sobie podstawą do rozróżniania obszarów orogenicznych i platformowych, bez uwzględniania tła regionalnego i innych czynników. Nomenklatura pokryw platformowych, a także wyróżnianie faz orogenicznych są ujęciami przestarzałymi. To drugie jest przy tym niezgodne z regułami tektoniki płyt (diachronizmem deformacji) i akrecją terranów. Z kolei podstawy wyróżnienia terranów są niewystarczające i świadczą o nieznajomości zasad samej koncepcji terranów tektonostratygraficznych. Wreszcie dystalny, ilasty flisz sylurski z Pomorza został nieprawidłowo zaklasyfikowany jako molasa, bez uwzględnienia jego jednoznacznych cech sedymentologicznych.

W problematyce regionalnej skoncentrowano się na wydzielonych na dyskutowanej mapie terranach. Uważamy, że nie udowodniono terranowego charakteru obszarów: łysogórskiego i pomorskiego, a także „takońskiej" konsolidacji tego ostatniego. Sądzimy, że są one fragmentami tej samej pasywnej krawędzi (miogeokliny) kratonu wschodnioeuropejskiego, gdzie grube osady starszego paleozoiku odkładały się na silnie ugiętej skorupie kontynentalnej skrajnie zewnętrznej strefy kratonu i zostały pod koniec syluru zdeformowane, tworząc marginalny pas fałdowo-nasunięciowy.

Nie udowodniono także „grampiańskiej konsolidacji" regionu kieleckiego Gór Świętokrzyskich. Ten region — wraz z całym blokiem małopolskim — może być terranem, lecz ze względu na znaczne podobieństwa rozwoju do regionu łysogórskiego — terranem typu proksymalnego. Byłby to fragment kratonu, położony pierwotnie dalej ku południowemu wschodowi, który oderwał się od kratonu, przesunął wzdłuż uskoku transformacyjnego i został ponownie przyłączony w późnym sylurze. Również blok górnośląski z nadbudowanym na nim zagłębiem węglowym może być terranem, choć jego bliższa natura i pochodzenie są niejasne. Strefa tektoniczna Krakowa – Zawiercia odpowiada najbardziej definicji granicy między terranami.

Brzeżna strefa kratonu prekambryjskiego, blok małopolski i górnośląski są przykryte typową sekwencją przekraczającą dewonu i karbonu, rozwiniętą w warunkach epikontynentalnych, w obszarze młodego kratonu (na obu wymienionych blokach) silnie aktywizowaną tektonicznie w epoce waryscyjskiej.

Najbardziej oczywistym zespołem terranów — jednak nie zdefiniowanym w ten sposób przez autorów dyskutowanej mapy — są Sudety Zachodnie. Ta kwestia nie jest szerzej rozpatrywana w artykule, gdyż istnieje na ten temat szereg publikacji.

Wewnętrzna struktura eksternidów waryscyjskich (niezrozumiały podział na flisz i molasę, wergencja nasunięć) oraz ich zasięg ku północy i wschodowi są na rozpatrywanej mapie słabo udokumentowane. Pozostajemy zatem przy poprzednich koncepcjach głównie fliszowego charakteru tego pasma i przebiegu frontu waryscyjskiego dalej ku południowi; wynika on z obserwacji potomnych procesów sedymentacyjnych i tektonicznych oraz niektórych danych geofizycznych. Silne deformacje karbonu na północ od Gór Świętokrzyskich mogą być rezultatem skomplikowanego układu naprężeń przed frontem dwóch łuków orogenu waryscyjskiego: morawsko--śląskiego i sub-karpackiego.

Konkludując uważamy — jako wieloletni zwolennicy deformacji kaledońskich wzdłuż południowo-zachodniej krawędzi kratonu, które długo były zwalczane nawet przez ich dzisiejszych gorących popleczników — że możemy zaakceptować koncepcję terranów, możemy jednak równocześnie przeciwstawiać się terranowemu charakterowi konkretnych regionów. Jesteśmy zdania, że wobec zapóźnienia geologii polskiej na wielu polach, użyteczniejsze byłoby — zamiast żonglerki hipotezami geotektonicznymi — skoncentrowanie się na zbieraniu nowych faktów i reinterpretacji starych przy użyciu nowoczesnych metod i strategii badawczych.