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The Holy Cross area, Central Poland, in the Alpine cycle

ABSTRACT: Evidence is presented that a distinct elevation never existed in the area of the present Holy Cross Mts during Permian and Mesozoic time. This area as well as that of the present San anticlinorium were embraced within the Danish-Polish trough and were subsequently subjected to tectonic inversion at the turn of the Cretaceous and Tertiary. Thus, the whole Middle-Polish anticlinorium was generated in a similar way by Laramide movements on the site of the preceding Danish-Polish trough. Some other tectonic and paleogeographic problems, concerning mainly the Holy Cross Mts and the Middle-Polish anticlinorium, are also discussed.

INTRODUCTION

The main geological features of the Holy Cross Mts (Góry Świętokrzyskie) can be summarized as follows. The Paleozoic rocks crop out in a relatively small area which is called the Paleozoic core of the Holy Cross Mts (Fig. 1). On the NE, NW and SW this core is encircled by Triassic and Jurassic deposits which form the Mesozoic margin of the Holy Cross Mts. In the south the Paleozoic core is bordered by Miocene deposits of the Carpathian foredeep. As an orographic unit the Holy Cross Mts roughly include the area of both the Paleozoic core and its Mesozoic margin.

At present, no Mesozoic deposits occur within the Paleozoic core, and the Jurassic and Cretaceous are also missing in parts of the surrounding areas (Fig. 1). It has been recognized for a long time that some Mesozoic sediments were removed from the discussed region by erosion subsequent to late Cretaceous or Tertiary tectonic movements. However, on the assumption that some other Mesozoic and Permian sediments were primarily lacking in the central part of the Holy Cross Mts, it has been postulated by several authors that a distinct elevation existed here during some epochs of the Permian and Mesozoic. In several papers and maps concerning the Permian and Mesozoic paleogeography, it has been suggested that this area formed intermittently an elevation, peninsula or island, supplying adjacent sedimentary basins with detrital material (*e.g.* Książkiewicz & Samsonowicz 1952; Milewicz & Pawłowska 1961; Senkowiczowa & Szyperko-Śliwczyńska 1961; Pożaryski 1962a; Dadlez, Dayczak-Calikowska & Dembowska 1964; Książkiewicz, Samsonowicz & Rühle 1965). Similar opinions are advanced in some recent publications (*e.g.* Pożaryski 1970a, Cieśliński & Pożaryski 1970), although opposite opinions have been also expressed (Dadlez 1969, Hakenberg 1969, Kutek 1969, Karaszewski & Kopik 1970, Kopik 1970, Senkowiczowa 1970).

The aim of this paper is to show that no particular elevation existed during Permian and Mesozoic time at the site of the present Holy Cross Mts, and that they were produced as a distinct geologic and geomorphologic unit by post-Cretaceous tectonic movements (*cf.* Głazek & Kutek 1970, 1971).

Two publications deserve special attention as source of geological data discussed here. These are the Geological Atlas of Poland (Znosko 1968) and the fascicles 7—11 of the Geological Atlas of Poland, Stratigraphic and Facies Problems (Milewicz & Pawłowska 1961; Senkowiczowa & Szyperko-Śliwczyńska 1961; Pożaryski 1962a; Dadlez, Dayczak-Calikowska & Dembowska 1964; Areń 1964). The latter publications supply much valuable information on the facies and thicknesses of the Permian, Mesozoic and Tertiary sediments in Poland. Several paleogeographical interpretations, however, are highly conjectural, and some of them substantially differ from those proposed here.

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GEOTECTONIC SETTING OF THE HOLY CROSS MTS

Middle-Polish anticlinorium

It stretches NW-SE across Poland, from the Baltic Sea to the Carpathians. The well known „Pomerania-Kujawy swell", and farther south also the Holy Cross Mts and the San anticlinorium, are included within this large geotectonic unit (Fig. 1; Pożaryski 1964, 1969). The Cretaceous, and in some regions also the Jurassic, Triassic and Permian deposits, were removed by erosion from the Middle-Polish anticlinorium at the turn of the Cretaceous and Tertiary. They are still preserved in the Szczecin-Łódź-Miechów synclinorium and in the Border synclinorium which parallel the Middle-Polish anticlinorium from the SW and NE, respectively. All these geotectonic units were produced by Laramide movements which took place mainly during the Maestrichtian and Paleocene.

The Middle-Polish anticlinorium was formed, as a result of tectonic inversion, on the site of the preceding Danish-Polish trough. During the Upper Permian and Mesozoic this trough was a zone of strong subsidence where very thick sediments accumulated (Pożaryski 1957, 1964; Marek & Znosko 1972). The Upper Permian and Mesozoic sediments of the Danish-Polish trough are considered to have reached a thickness of 11 km in the Kujawy area (Pożaryski 1964, Znosko 1969), and more than 6 km in Pomerania (Dadlez & Dembowska 1965). The Upper Permian and Mesozoic subsidence was much lesser outside the Danish-Polish trough. Hence, the thickness of Upper Permian and Mesozoic deposits decreases more or less rapidly away from the Middle-Polish anticlinorium, both to the northeast and southwest (Figs 2—4) [1].

In general, the axis of the Middle-Polish anticlinorium clearly coincides with that of the Danish-Polish trough (Figs 1—4). However, slight shifting of the axis of maximum subsidence during the Mesozoic has been recognized in some regions (*e.g.* Dadlez & Dembowska 1965).

The subsidence in the Danish-Polish trough, and the forming of the Middle-Polish anticlinorium, were strongly influenced by deep-seated faults, some of them stretching parallel or subparallel to the axis of the anticlinorium (Pożaryski 1964, Dadlez & Marek 1969, Marek & Znosko 1972). In some regions, however, the conventional boundaries of the Middle-Polish anticlinorium with the bordering synclinoria (*i.e.* the boundaries of the Jurassic and Cretaceous belts — Fig. 1), do not strictly coincide with such faults.

[1] Only the existing thickness of the particular Permian and Mesozoic deposits is indicated in maps shown in Figures 2, 3, 4. The decreased thicknesses just at the margins of the Middle-Polish anticlinorium are due to erosion subsequent to the uplift of the anticlinorium. The occurrence of minor post-Cretaceous tectonic structures within the bordering synclinoria influences in the same manner the thickness of the Permo-Mesozoic cover.

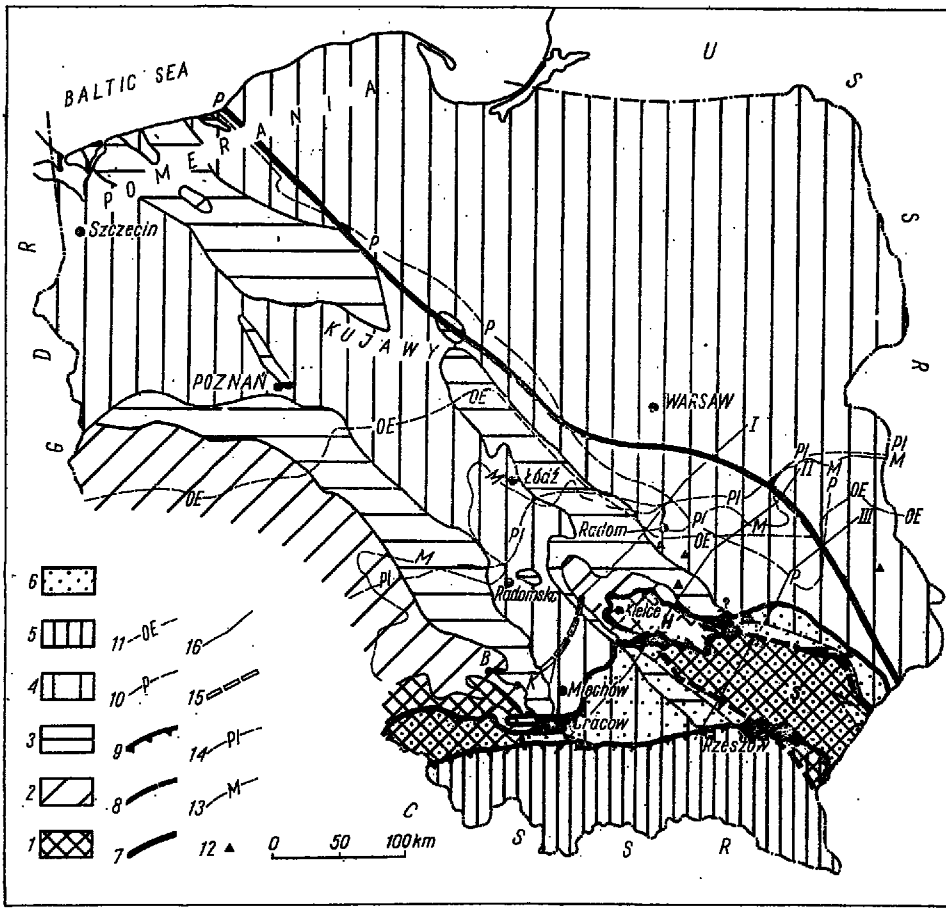


Fig. 1

Schematic geological map of Poland

1 Precambrian and Paleozoic (to Carboniferous), *2* Permian and Triassic, *3* Jurassic, *4* Cretaceous, *5* Carpathians, mainly Cretaceous and Tertiary Flysch, *6* marine Miocene of the Carpathian foredeep, *7* Tornquist-Teisseyre line, *8* important geologic boundaries: boundary of the Paleozoic and Precambrian of the Holy Cross Mts and the San anticlinorium, and the northern boundary of the Miocene of the Carpathian foredeep; *9* northern margin of the Carpathian nappes; *10—14* southern limits of Tertiary platform deposits: *10* Paleocene, *11* Upper Eocene and Oligocene, *12* isolated occurrences of Upper Eocene or Oligocene deposits, *13* Miocene, *14* Pliocene; *15* line of the section in Fig. 6, *16* lines of the sections shown in Fig. 5, *H* Holy Cross Mts, *S* San anticlinorium, *B* Brudzowice, *K* Kolbark

The Middle-Polish anticlinorium can be traced into the southernmost part of the Baltic Sea, and the Danish-Polish trough as far sa Denmark (Pożaryski 1957, 1970b; Dadlez & Młynarski 1967). In southeastern Poland and western Ukraine, it is buried under the Miocene of the Carpathian foredeep and/or overriden by the Carpathian Flysch nappes.

The Middle-Polish anticlinorium parallels the Tornquist line [2] from the southwest. This line is considered as a boundary of the ancient East--European platform with younger platforms, or as a boundary of the elevated part of this platform with a pericratonic depression of latest Precambrian age (Znosko 1962a, 1964, 1965, 1966, 1970; Pożaryski & Tomczyk 1968a, b; Bogdanov 1965, 1968a, b; Kölbel 1968). Notwithstanding the controversy concerning the geotectonic interpretation of the Tornquist line, it is evident that the forming of both the Middle-Polish anticlinorium and of the Danish-Polish trough must have been connected with this structural line.

The Middle-Polish anticlinorium, which is an epiplatformal geotectonic unit, has been termed a paranticlinorium (Znosko, *in* Sokołowski & Znosko 1960, Khain 1971). As placanticlines (boxfolds) are the most characteristic tectonic structures of that anticlinorium (Dadlez & Marek 1969), it was also called a placanticlinorium (Pożaryski 1970c). For similar reasons, the Szczecin-Łódź-Miechów synclinorium and the Border synclinorium can be called placosynclinoria. Although these terminological distinctions are of some importance, there seems to be little need for exclusive use of these elaborated terms. Since such simpler terms as *e.g.* „the Middle-Polish anticlinorium" should not lead to confusion when problems of classification of geotectonic units are not directly involved, they will be currently used hereafter.

As the Middle-Polish anticlinorium resulted from the tectonic inversion of the Danish-Polish trough, it does not seem justifiable to call it a rampart (*cf.* Pożaryski 1970c).

The German-Polish syneclise

This geotectonic unit which is also called the North-German-Polish basin, or the Central-European basin (Kölbel 1968), stretches roughly W-E from northern Germany into northern and Central Poland, occupying large parts of the Polish Lowland. The German-Polish syneclise was a site of strong subsidence during Upper Permian and Mesozoic times. In some parts of the Polish Lowland, included within this syneclise, almost continuous sedimentation occurred during the Upper Permian and the Mesozoic. Extensive Paleogene and Neogene formations occur in the area concerned.

In Poland, the Permian and Mesozoic sediments attain their maximum thickness in the Kujawy area where the axis of the German-Polish syneclise was crossed by that of the Danish-Polish trough (Figs 2—4).

The meta-Carpathian zone

In Poland, the German-Polish syneclise passes southwards into the meta-Carpathian zone.

The area that separated the German-Polish syneclise from the Carpathian Flysch geosyncline, will be considered as the meta-Carpathian

[2] This line is called by some Polish authors (Znosko 1969) the Teisseyre line.

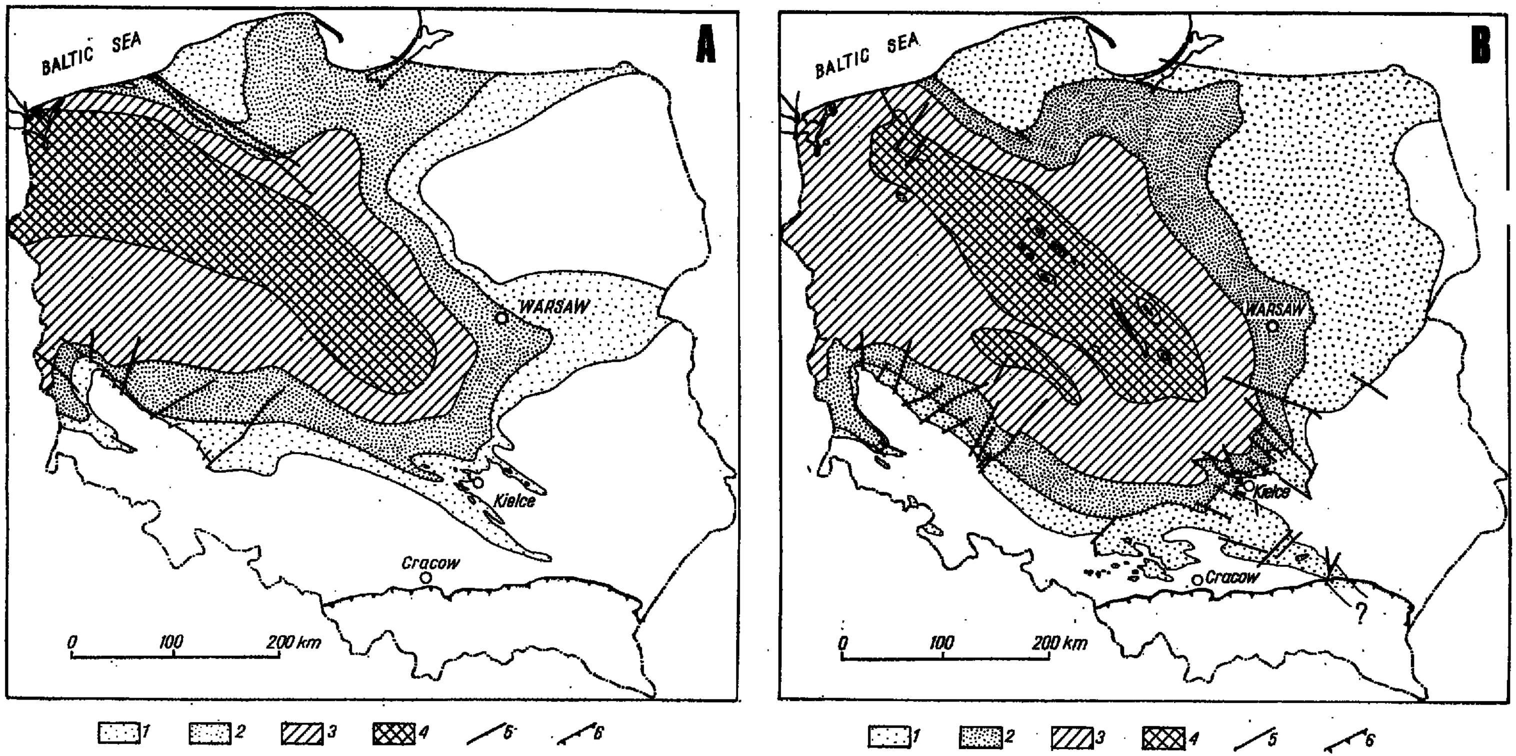


Fig. 2

A — Thickness map of the Zechstein deposits in Poland (simplified after Podemski, Wagner & Pawłowska in Znosko 1968)

1 0—200 m, *2* 200—500 m, *3* 500—1000 m, *4* over 1000 m, *5* faults, *6* northern margin of the Carpathian nappes

B — Thickness map of the Triassic deposits in Poland (simplified after Senkowiczowa & Szyperko-Śliwczyńska in Znosko 1968)

1 0—500 m, *2* 500—1000 m, *3* 1000—2000 m, *4* over 2000 m, *5* faults, *6* northern margin of the Carpathian nappes

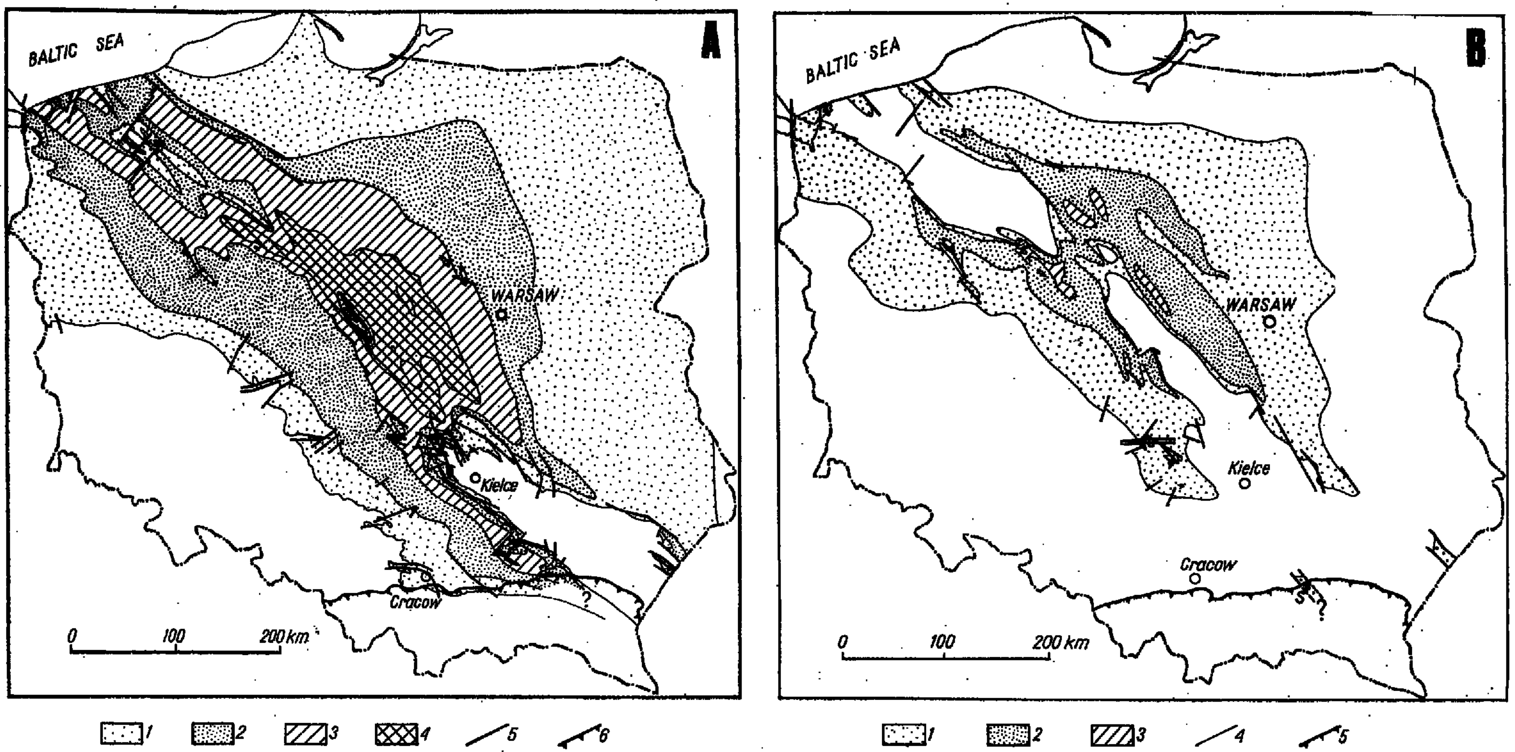


Fig. 3

A — Thickness map of the Jurassic deposits in Poland (simplified after Dadlez in Znosko 1968)

1 0—500 m, *2* 500—1000 m, *3* 1000—2000 m, *4* over 2000 m, *5* faults, *6* northern margin of the Carpathian nappes

B — Thickness map of the Lower Cretaceous deposits in Poland (simplified and slightly modified after Marek & Raczyńska in Znosko 1968)

1 0—200 m, *2* 200—500 m, *3* over 500 m, *4* faults, *5* northern margin of the Carpathian nappes

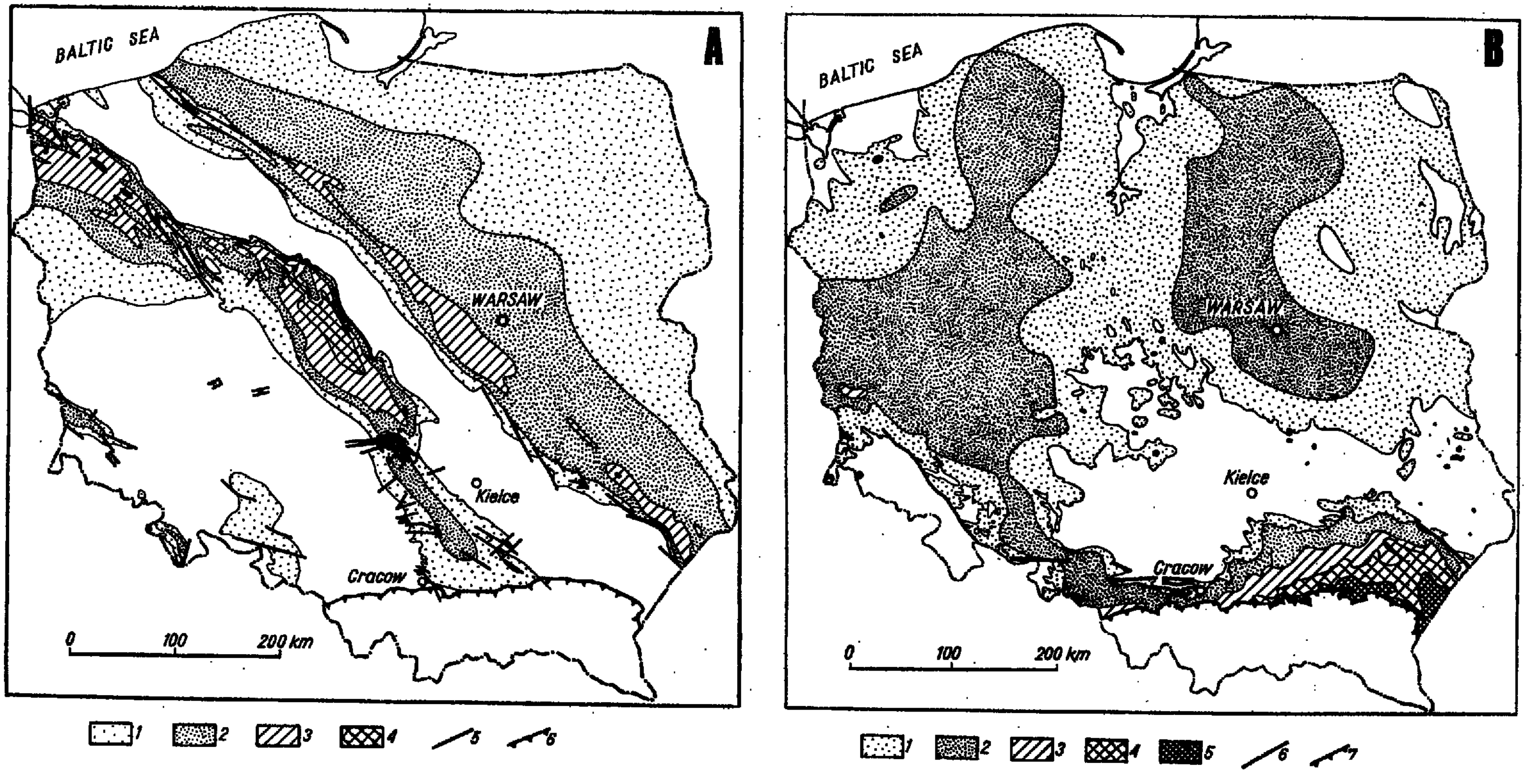


Fig. 4

A — Thickness map of the Upper Cretaceous deposits in Poland (simplified after Juskowiak & Krassowska in Znosko 1968)

1 0—500 m, *2* 500—1000 m, *3* 1000—2000 m, *4* over 2000 m, *5* faults, *6* northern margin of the Carpathian nappes

B — Thickness map of the Tertiary deposits in Poland (simplified and slightly modified after Areń in Znosko 1968)

1 0—100 m, *2* 100—500 m, *3* 500—1000 m, *4* 1000—2000 m, *5* over 2000 m, *6* faults, *7* northern margin of the Carpathian nappes zone. Consequently, two parts of this area, differing in their post-Early Miocene history, should be considered as belonging to the meta-Carpathian zone. Its northern part corresponds to the belt of the present Polish uplands (the Cracow-Silesian Upland, the northern part of the Nida Depression, the Holy Cross Mts, and the Lublin Upland); this is Nowak's (1927) meta-Carpathian arch. The southern part of the discussed area was strongly downwarped in the Miocene, and buried under Miocene sediments or Flysch nappes. It now constitutes the substrate of the Carpathian foredeep, and a part of that of the Carpathian Flysch nappes. From the Jurassic to the Early Miocene, during the existence of the Carpathian Flysch geosyncline, the meta-Carpathian zone was clearly delimited on the south. During Permian time and some parts of the Triassic, this zone was included within the northern part of the Beskidy arch.

The meta-Carpathian zone was uplifted during the Variscan orogeny. In the Alpine cycle, Permian and Mesozoic sediments accumulated in this area. In general, however, subsidence was lesser here than in the German-Polish syneclise. Moreover, the meta-Carpathian zone was repeatedly uplifted (in the Late Triassic, Liassic and early Middle Jurassic, in the Middle Tithonian, between Hauterivian and Albian time and during Paleogene time). As a consequence, the Bathonian or Callovian in this area rest on various Triassic or pre-Triassic rocks, and the Albian, Cenomanian or the Turonian on the Oxfordian or Kimmeridgian. Furthermore, minor intra-Triassic and intra-Cretaceous stratigraphic gaps are encountered in parts of the discussed area. The Permo-Mesozoic cover is, consequently, considerably thinner in the meta-Carpathian zone than in the German-Polish syneclise. No marine Paleogene sediments occur in the former area, except for some outliers of Paleogene sediments in the Lublin Upland (Figs 2—4).

The Holy Cross Mts are situated at the northern periphery of the meta-Carpathian zone.

THE PERMO-MESOZOIC COVER OF THE HOLY CROSS MTS AND ADJACENT REGIONS

Since Pożaryski's publication of 1957, it has been considered that the Kujawy and Pomeranian parts of the Middle-Polish anticlinorium resulted from the tectonic inversion of the Danish-Polish trough. In this region, it is evident that the axis of the anticlinorium coincides with that of maximum subsidence during Upper Permian and Mesozoic (Figs 1—6). It should be kept in mind, however, that the Holy Cross Mts and the San anticlinorium are also parts of the Middle-Polish anticlinorium. Thus, it may be reasonably presupposed that they had also been preceded by a trough where thick Mesozoic sediments accumulated. So far, however, such an opinion has not been accepted unanimously (*cf.* Pożaryski 1970a).

Thickness pattern of Upper Permian and Mesozoic sediments

Northwest of the Holy Cross Mts, the Upper Permian, Triassic and Jurassic sediments are preserved within the Middle-Polish anticlinorium. The axis of maximum thickness of these sediments, stretching NW-SE, is directed towards the Holy Cross Mts (Figs 2, 3). As for the Mesozoic sediments preserved southwest and northeast of the Holy Cross Mts and the San anticlinorium, the published maps suggest that these sediments generally increase in thickness from the southwest and northeast towards the axis of the Middle-Polish anticlinorium (Figs 2—4; Senkowiczowa & Szyperko-Śliwczyńska 1961; Pożaryski 1962a; Dadlez, Dayczak-Calikowska & Dembowska 1964; Karnkowski & Ołtuszyk 1968).

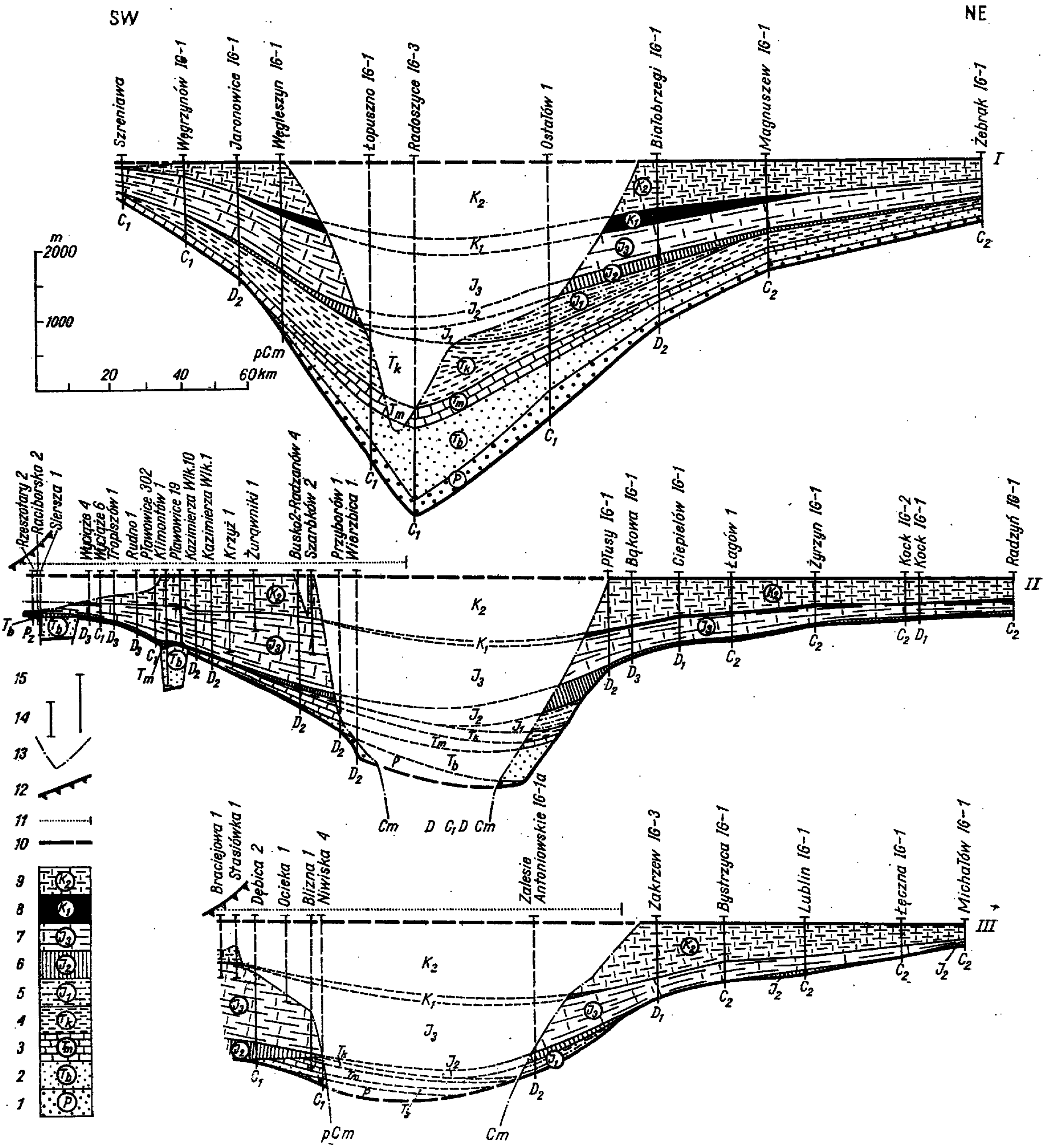
The thickness pattern of the Permo-Mesozoic cover is more clearly depicted in the sections shown in Figures 5 and 6. To compile these sections, data concerning about 300 boreholes as well as outcrops data have been examined by the authors. Only some of the boreholes situated at or near of the section lines are indicated in Fig. 5.

From the section shown in Figures 5 and 6 it follows that a distinct trough existed before the Tertiary at the site of the Holy Cross Mts and the San anticlinorium.

Stratigraphic gaps

In the southwestern margin of the Holy Cross Mts, Zechstein and Bunter deposits are present; the Bathonian or Callovian sediments rest on the Rhaetian, and those of Albian or Cenomanian age on the Upper Kimmeridgian (Milewicz & Pawłowska 1961; Siemiątkowska 1967, 1969; Kutek 1968; Hakenberg 1969; Senkowiczowa 1970; Kopik 1970). Within the Miechów synclinorium, the Röt is transgressive on Paleozoic rocks in some regions; while the Bathonian or Callovian deposits rest on the Upper, Middle or Lower Triassic and in some places directly on the Paleozoic or the Precambrian (Senkowiczowa & Szyperko-Śliwczyńska, *in* Znosko 1968; Karnkowski & Ołtuszyk 1968; Jurkiewicz, Kowalczewski & Wierzbowski 1968; Jawor 1970; Moryc 1971). At the southwestern border of the Miechów syncline, carbonate rocks representing uppermost Oxfordian or lowermost Kimmeridgian are overlain by the Albian, Cenomanian or Turonian (Głazek & Wierzbowski 1972, Marcinowski & Szulczewski 1972).

In the northeastern margin of the Holy Cross Mts, Upper Permian



Restored cross-section trough the Permian and Mesozoic deposits preserved southwest and northwest of the axial parts of the Holy Cross Mts and the San anticlinorium (section lines indicated in Fig. 1)

Pre-Permian substratum; *pCm* Precambrian (Late Proterozoic), *Pz* Paleozoic, *Cm* Cambrian, *S* Silurian, *D* Devonian (D_1 Lower, D_2 Middle, D_3 Upper), C Carboniferous (C_1 Lower, C_2 Upper); Permo-Mesozoic cover: *1* Permian, *2* Bunter, *3* Röt and Muschelkalk, *4* Keuper and Rhaetian, *5—7* Jurassic (*5* Lower, *6* Middle, *7* Upper); *8—9* Cretaceous (*8* Lower, *9* Upper); *10* the top of the Campanian used as marker horizon, *11* extent of the Miocene deposits of the Carpathian foredeep, *12* margin of the Carpathian nappes, *13* lines delimiting the Permian and Mesozoic deposits which escaped erosion, *14* drillings penetrating Permo-Mesozoic cover only, *15* drillings penetrating the pre-Permian substratum and Triassic, as well as Lower to Upper Jurassic rocks, are present (Milewicz & Pawłowska 1961, Senkowiczowa 1970, Kopik 1970, Karaszewski & Kopik 1970, Daniec 1970, Malinowska 1970). The Kimmeridgian rocks are overlain there by Middle Albian sediments (Pożaryski 1948, Cieśliński 1959a). Farther northeast, in parts of the Lublin Upland, Middle Jurassic or Oxfordian deposits rest on the Paleozoic, and those

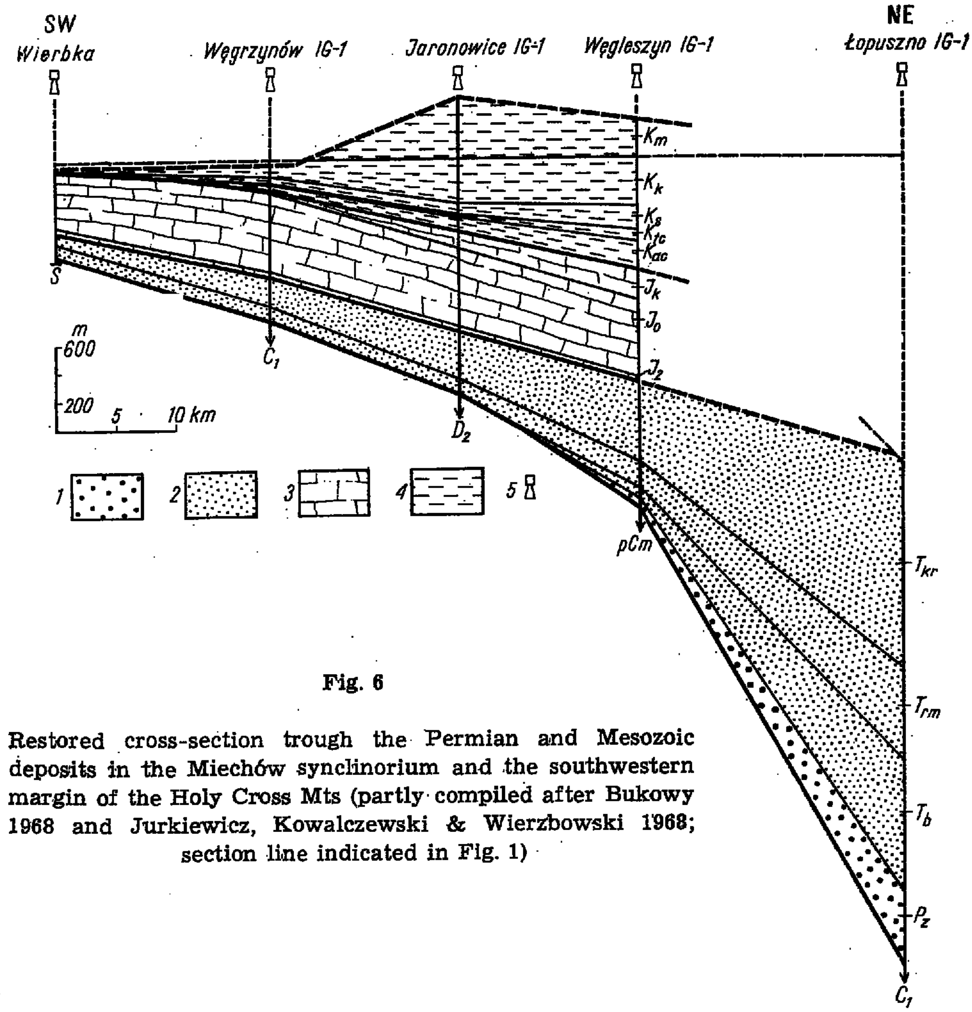


Fig. 6

Restored cross-section trough the Permian and Mesozoic deposits in the Miechów synclinorium and the southwestern margin of the Holy Cross Mts (partly compiled after Bukowy 1968 and Jurkiewicz, Kowalczewski & Wierzbowski 1968; section line indicated in Fig. 1)

1 Permian: *Pz* Zechstein; 2 Triassic: *Tb* Bunter, *Trm* Röt and Muschelkalk, *Tkr* Keuper and Rhaetian; 3 Jurassic: J_2 Middle Jurassic, *Jo* Oxfordian, *Jk* Kimmeridgian; 4 Cretaceous: *Kac* Albian and Cenomanian, *Ktc* Turonian and Coniacian, *Ks* Santonian, *Kk* Campanian, *Km* Maestrichtian; 5 boreholes. Pre-Permian substratum: *pCm* Precambrian (Late Proterozoic), *S* Silurian, D_2 Middle Devonian, C_1 Lower Carboniferous

of the Cenomanian on the Oxfordian (Pożaryski 1962a, Żelichowski 1969, Niemczycka 1971).

In parts of the southwestern margin of the San anticlinorium, Zechstein and Bunter deposits are encountered. In this margin, the Upper Triassic rocks are overlain by the Bathonian or the Callovian, and the Upper Kimmeridgian by Cenomanian sediments, a thin Neocomian (and Upper Tithonian?) sequence intervening just at the border of the Flysch Carpathians, in the borehole Stasiówka (Wdowiarz 1954, Karnkowski & Głowacki 1961, Karnkowski & Ołtuszyk 1968, Kutek 1968, Moryc 1971). The Oxfordian and Kimmeridgian deposits attain here their maximum thickness in Poland. The occurrence of the Neocomian and the Tithonian just at the northeastern border of the San anticlinorium (Moryc & Waśniowska 1965, Niemczycka 1971) is another striking feature.

From the foregoing account it follows that the Permo-Mesozoic cover is stratigraphically more complete near the Holy Cross Mts and the San anticlinorium, than farther southwest and northeast. Some of the Permian and Mesozoic deposits which are preserved in the margins of the Holy Cross Mts and the San anticlinorium, completely wedge out to the southwest and northeast. Thus the opinion that a sedimentary trough preceded the Holy Cross Mts and the San anticlinorium, is confirmed by stratigraphic evidence. This trough, which axis coincides with that of the Middle-Polish anticlinorium, should be regarded as part of the large Danish-Polish trough.

Other factors influencing distribution of the Permian and Mesozoic sediments

Although the aggregate thickness of the Permian and Mesozoic generally increases towards the Holy Cross Mts and the San anticlinorium, the distribution of these sediments is more complex in details.

The meta-Carpathian zone was repeatedly uplifted during the Mesozoic. Some of the tectonic movements leading to large undations were accompanied by block-faulting and tilting of the Permian and Mesozoic strata. As a consequence, some sediments were removed by erosion from the upfaulted portions of the area concerned (Senkowiczowa & Szyperko-Śliwczyńska, *in* Znosko 1968, Karnkowski & Ołtuszyk 1968, Jawor 1970, Moryc 1971). On the other hand, synsedimentary faulting has been recognized in some regions. For instance, in the area of the Miechów synclinorium, Bunter sediments 1 km thick accumulated in synsedimentary grabens (Fig. 5; Moryc 1971).

In the meta-Carpathian zone, the Upper Permian and Triassic deposits are relatively thin, and they were affected by synsedimentary or postsedimentary tectonic movements during the Late Permian, Triassic and Early Jurassic. As a result, the distribution of the Upper Permian and the Triassic is less regular than that of the Jurassic and the Cretaceous (Figs 2—6).

In the northeastern margin of the San anticlinorium as well as in the easternmost part of the northeastern margin of the Holy Cross Mts and the area situated farther northeast, the Jurassic rest directly on Paleozoic rocks. As these areas were subjected to pre-Jurassic erosion, it is now difficult to evaluate exactly the primary extent of the Triassic deposits. There should be no doubt, however, that large parts of the San anticlinorium were once covered by the Triassic, and at least a part of this area was included into a zone of marked subsidence during Triassic (? and Late Permian) time.

In some parts of the meta-Carpathian zone, the thicknesses of the transgressive Upper Permian and Mesozoic sediments were strongly influenced by paleorelief (*e.g.* the Upper Permian in the Holy Cross Mts and the Triassic, Middle Jurassic and Albian to Turonian sediments in the Cracow-Silesian monocline — Różycki 1937, 1953; Pawłowska, *in* Milewicz & Pawłowska 1961; Kostecka 1966; Marcinowski 1970; Wyczółkowski 1971; Marcinowski & Szulczewski 1972).

The Late Permian and Mesozoic sedimentation in the meta--Carpathian zone was also controlled by some lineaments, especially by the Holy Cross one.

The Holy Cross lineament

A distinct structural line stretches WNW along the northeastern margin of the San anticlinorium and across the Paleozoic core of the Holy Cross Mts, extending farther WNW up to the Radomsko region (Fig. 1). Within the Paleozoic core this line divides the Łysogóry zone from the Kielce zone (Czarnocki 1950, Samsonowicz, *in* Książkiewicz & Samsonowicz 1952). This structural line is named here the Holy Cross lineament (Polish name: rozłam świętokrzyski).

The geotectonic significance of this line has been pointed out by several authors. In Stille's (1950) and Znosko's (1962a, 1964, 1965a, b, 1966) opinion it was a boundary between the Caledonian and Variscan chains in the Holy Cross Mts. Pożaryski and Tomczyk (1968a) considered it to be the northern boundary of the Baikalian Małopolska massif. The line was termed a lineament by Krilov (1971).

The Holy Cross lineament existed at least from the end of the Cambrian. This can be inferred from the diversity in the development of the Paleozoic sediments belonging to the Łysogóry and Kielce zones. The Cambrian to Lower Carboniferous rocks of these zones markedly differ with respect to facies, thickness and stratigraphic gaps (Czarnocki 1950; Samsonowicz, *in* Książkiewicz & Samsonowicz 1952). According to Rubinowski (1971), the sediments representing the particular systems of the Paleozoic attain the following thicknesses in the Łysogóry and Kielce zones, respectively: Cambrian — 2500—3000 m against 1700 m, Ordovician — 340 m against 100—150 m, Silurian — 1000—1500 m, against 470 m, Devonian — 2000 m, against 700 m; Lower Carboniferous — more than 625 m, against 260—350 m. Only minor stratigraphic gaps are discernible in the Łysogóry zone, whereas large regional stratigraphic gaps occur in the Kielce zone (between the Ordovician and the Middle or Lower Cambrian deposits, and between Emsian and Silurian deposits). These gaps are connected with the Late Baikalian and Late Caledonian tectonic movements (Znosko 1962a, 1964, 1965a, b; Pożaryski & Tomczyk 1968a, 1969).

A similar contrast in the development of Paleozoic deposits is displayed by much larger areas, situated south and north of the Holy Cross lineament. For instance, in the area extending south of the Holy Cross Mts to the Carpathians, stratigraphic gaps testifying to uplifts at the turn of the Cambrian and Ordovician and in the Early Devonian, are commonly encountered (Karnkowski & Ołtuszyk 1968). In general, in most parts of the Paleozoic, the area south of the Holy Cross lineament suffered less subsidence than, or was intermittently uplifted against, the area situated north of the lineament.

The Holy Cross lineament was also active in the Mesozoic. In the southern margin of the Holy Cross Mts the Bunter attains a thickness of 200—300 m, whereas north of the lineament its maximum thickness is more than 1000 m (Senkowiczowa 1966, 1970). In the southwestern margin of the Holy Cross Mts and the San anticlinorium, the Bathonian or the Callovian rest on the Upper Triassic, and the Upper Kimmeridgian is overlain by Upper Albian or Cenomanian sediments. North of the Holy Cross lineament thick Liassic and early Middle Jurassic sequences intervene; in the northernmost part of the Holy Cross area the Liassic is 1000 m thick (Senkowiczowa & Szyperko-Śliwczyńska 1961; Dadlez, Dayczak-Calikowska & Dembowska 1964; Kutek 1968; Hakenberg 1969; Karaszewski & Kopik 1970; Daniec 1970). The occurrence of Middle Albian sediments in the northeastern margin of the Holy Cross Mts is another significant fact (Cieśliński 1959a). As a sequence of the WNW trend of the Holy Cross lineament, the Lower and early Middle Jurassic deposits, as well as the Middle Albian ones, extend farther south in the northeastern than in the southwestern margins of the Holy Cross Mts.

In some parts of the Mesozoic, *e.g.* in the Middle Triassic, the areas south and north of the Holy Cross lineament were not distinctly contrasted with respect to subsidence. The Oxfordian and Lower Kimmeridgian deposits are even a little more thick in some areas south of the lineament than farther north. In other parts of the Mesozoic, however, especially in times when terrigenic sedimentation prevailed, the area situated south of the Holy Cross lineament suffered less subsidence, or was being uplifted against, the northern side.

From the foregoing account it follows that the Holy Cross lineament acted in the Mesozoic in a similar way as it did during the Paleozoic.

As all the sections in Fig. 5 have been drawn along lines crossing both the Holy Cross lineament and the Middle-Polish anticlinorium (the Holy Cross Mts or the San anticlinorium), the Permian and Mesozoic sediments depicted in the northeastern parts of these sections represent those which were laid down north of the Holy Cross lineament, and northeast of the axis of the Danish-Polish trough.

The Poznań-Rzeszów lineament

This lineament borders the San anticlinorium and a part of the Holy Cross area on the southwest. Farther northwest, it crosses obliquely the Szczecin-Łódź-Miechów synclinorium in the Radomsko region, extending to the northwest along the southwestern margin of the Łódź synclinorium (Pożaryski 1971). In the Radomsko region, several brachyanticlines of Laramide age occur at the junction of the Holy Cross lineament with that of the Poznań-Rzeszów one (Fig. 1).

Southeast of the Radomsko region, a distinct belt of Lower Carboniferous deposits follows the Poznań-Rzeszów lineament (*cf.* Znosko & Pajchlowa, *in* Znosko 1968).

The area southwest of the Holy Cross Mts

The Holy Cross lineament does not appear to extend west of the Radomsko region (Fig. 1; *see also* Znosko & Pajchlowa, *in* Znosko 1968). Accordingly, some Mesozoic deposits (especially the Liassic and early Middle Jurassic, but also some Triassic), show a distinct southward extention, comprising the northwestern part of the Miechów synclinorium and the northern part of the Cracow-Silesian monocline (Senkowiczowa & Szyperko-Śliwczyńska 1961; Znosko 1962b; Dadlez, Dayczak-Calikowska & Dembowska 1964). Also Albian deposits extend farther south along the southwestern border of the Miechów synclinorium than in its northeastern border (Cieśliński 1959b, Hakenberg 1969, Marcinowski & Szulczewski 1972). All this complicates the general pattern of the distribution of Mesozoic deposits in south central Poland.

It is of interest that a paleogeographic role, similar to that of the Holy Cross lineament, was played in some epochs of the Mesozoic by the largely conceived Brudzowice-Kolbark structural zone [3]. Extensive Liassic and early Middle Jurassic deposits do no extend south of this zone (Różycki 1953; Znosko 1962b; Dadlez, Dayczak-Calikowska & Dembowska 1964). Also some Triassic deposits show increase in thickness and facies changes north of it (Senkowiczowa & Szyperko-Śliwczyńska 1961). Several local complexities in the distribution of Mesozoic sediments are due to paleorelief and intra-Mesozoic tectonic movements (Różycki 1953, Wyczółkowski 1971, Marcinowski & Szulczewski 1972).

PALEOGEOGRAPHIC EVIDENCE

As argued in the foregoing section of this paper, the distribution of the Permian and Mesozoic sediments in the meta-Carpathian zone strongly suggest that this area, which was embraced within the Danish--Polish trough, did not form an elevation during Late Permian and Mesozoic time. This problem will be discussed now from the paleogeographic point of view.

Late Permian time

At the close of the Early Carboniferous, the Holy Cross area was affected by the Variscan movements which resulted in general uplift, folding and faulting of the Paleozoic rocks. During Late Carboniferous and Early Permian time the area was subjected to erosion. It was invaded by the Zechstein sea in the Werra cycle (Pawłowska 1970).

As a result of diversified relief, the earliest Permian sediments in the Holy Cross area were laid down in depressions. The more elevated zones were covered by sediments at later times. Some ridges remained uncovered by deposits throughout the Late Permian, and were subsequently buried under Triassic sediments. Conglomerates consisting of pebbles derived from adjacent ridges accumulated in parts of the depressions (Czarnocki 1923, Czarnocki & Samsonowicz 1915, Kostecka 1966, Pawłowska 1970).

In the Polish Lowland, in some areas belonging to central parts of the Zechstein basin, the thickness of Permian deposits exceeds 1000 m (Fig. 2*A*). Several horizons of chloride deposits (rock salt and magnesium-

[3] This zone, in which a WNW trend is clearly discernible, stretches obliquely across the middle part of the Cracow-Silesian monocline, extending ESE at least to the western border of the Miechów synclinorium. In detail, it displays an intricate structural patern. Both the NW and WNW trending faults seem to have been active there during the Paleozoic, intra-Mesozoic and Laramide movements; moreover, faults displaying westerly and northerly strikes, most probably Miocene in age, were superimposed onto earlier structures. The paleogeographical significance of the Brudzowice-Kolbark structural zone during Paleozoic time is not yet clearly understood.

-potassium salts), have been recognized. Contrarywise, in the Holy Cross area, the thickness of Permian deposits is generally less than 100 or 200 m and salt deposits do not occur here. Thus it is clear that the Holy Cross area was situated at the periphery of the Zechstein basin (Pawłowska 1970).

Owing to the sinuous boundary of the present occurrences of the Permian in the Holy Cross Mts, several "embayments" are commonly distinguished. Some minor embayments penetrate into the Paleozoic core of the Holy Cross Mts from the northwest. This core is bordered on the northeast and southwest by two much larger embayments, the Opatów and the Zbrza-Chmielnik ones (Fig. 7). Several authors regarded these

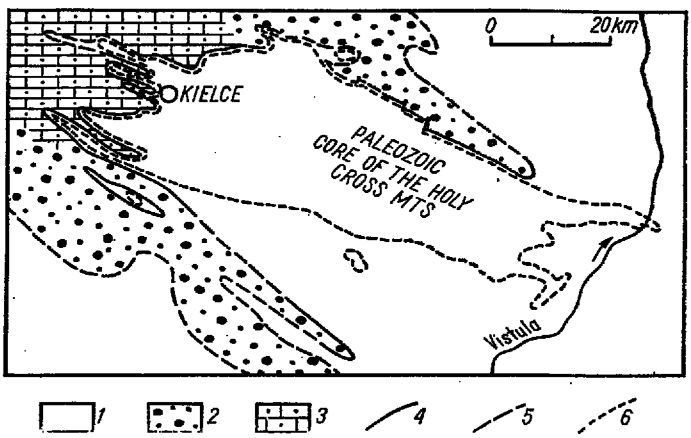


Fig. 7

Permian deposits in the Holy Cross area (reinterpreted after Pawłowska 1970 and Jurkiewicz 1970)

1 areas without Permian deposits, 2 exclusively terrigenic Permian deposits, mainly conglomerates, 3 demonstrable marine deposits of Zechstein age, locally also conglomerates, 4—5 extent of Permian deposits: 4 stated, 5 inferred; 6 boundary of the Paleozoic core of the Holy Cross Mts

embayments as strictly corresponding to those of the Zechstein sea, this paleogeographic interpretation implying existence of a Late Permian peninsula at the site of the Paleozoic core of the present Holy Cross Mts (*e.g.* Czarnocki 1951; Samsonowicz, *in* Samsonowicz & Książkiewicz 1952; Pawłowska 1970). In our opinion, a different paleogeographic interpretation may be suggested, based on the following evidence.

The Opatów and the Zbrza-Chmielnik embayments correspond to Laramide tectonic zones, depressed with respect to the Paleozoic core of the Holy Cross Mts. Triassic and Jurassic deposit are still preserved in these zones. At the border of the Paleozoic core, the present boundary of the Permian is in most places clearly erosive in character. From this it may be inferred that the Permian deposits must have covered large parts of the area of the Paleozoic core, and were subsequently removed by post-Cretaceous erosion.

At the northeastern boundary of the Opatów embayment and at the southwestern boundary of the Zbrza-Chmielnik one, the Triassic deposits, which display sedimentary continuity with the Upper Permian, overstep the Permian to the northeast and southwest, respectively. This suggests that the external boundaries of these embayments do coincide with primary boundaries of the Zechstein sedimentary basin (*see also* Jurkiewicz 1970).

Within the Permian deposits preserved northwest of the Paleozoic core the axis of maximum thickness stretches NW-SE; it clearly abuts against the northwestern border of the Paleozoic core (Fig. 2*A*). Moreover, demonstrable marine Zechstein deposits are only encountered on that border of the Paleozoic core (Fig. 7). These deposits, which are locally associated with conglomerates of marine or continental origin, are developed as limestones, dolomites, marls, shales and gypsum or anhydrite. Northeast and southwest of the Paleozoic core, the Zechstein is only represented by terrigenic deposits, nearly exclusively developed as conglomerates (Fig. 7).

The following paleogeographic interpretation can be suggested on the data presented above. In the Permian, the Holy Cross area was downwarped and included into the Danish-Polish trough. The area subjected to downwarping was invaded by the Zechstein sea. The area of the Paleozoic core as well as the Opatów and Zbrza-Chmielnik "embayments" were embraced within a large embayment of the Zechstein sea, which axis coincided with that of the Danish-Polish trough, and stretched across the area of the Paleozoic core.

As indicated by small thicknesses of the Permian deposits, the Holy Cross area was but slightly downwarped in the Late Permian. The area on which the Zechstein sea encroached displayed a marked relief which was being increased most probably by Late Permian and Early Triassic synsedimentary faulting. As a consequence, some ridges in the central part of the Holy Cross area escaped burial by Upper Permian sediments.

The controversy of interpretations, concerning the Late Permian paleogeography in the Holy Cross area, is shown in Fig. 8. It is not drawn to scale and the ridges of the pre-Permian substrate are purely schematic. They are not meant to indicate the particular ridges and tectonic structures in the area under consideration.

Some other problems concerning the Permian and lowermost Triassic in the Holy Cross Mts need some comment as well.

1. The problem of the origin and the age of the Zygmuntówka conglomerate, which is the lowermost Permian rock-unit in some parts of the Holy Cross Mts, is

still subject to discussion. Most authors regarded this conglomerate as a marine or continental to marine deposit of Zechstein age (*e.g.* Czarnocki 1923, Samsonowicz 1929, Pawłowska 1970, Radwański & Roniewicz 1972). On the other hand, the Zygmuntówka conglomerate was interpreted as a Rotliegendes deposit by Kozłowski (1962) and Kostecka (1966).

The Zygmuntówka conglomerate is overlain by marine deposits containing fossils of Early Zechstein age. From this, however, it does not necessarily follows that this conglomerate is pre-Zechstein in age. It may or may not correspond to the Rotliegendes.

If interpreted in terms of geotectonics, the Permian conglomerates from the Holy Cross Mts markedly differ from the Rotliegendes deposits in the Cracow-Silesian Upland and in the Sudetic basins. In those regions, the Rotliegendes is associated with volcanic rocks, and partly overlies the Upper Carboniferous. The latter accumulated in subsiding basins formed in a late stage of the Variscan cycle, and represent an early Variscan molasse, while the overlying Rotliegendes deposits can be interpreted as a late Variscan molasse. In the Holy Cross area, neither Upper Carboniferous nor demonstrable Lower Permian deposits occur. No Late Carboniferous intramontane basins developed here. On the contrary, the whole area was uplifted and subjected to erosion during Late Carboniferous and most of Early Permian time. Moreover, the Upper Permian sediments in the Holy Cross Mts pass

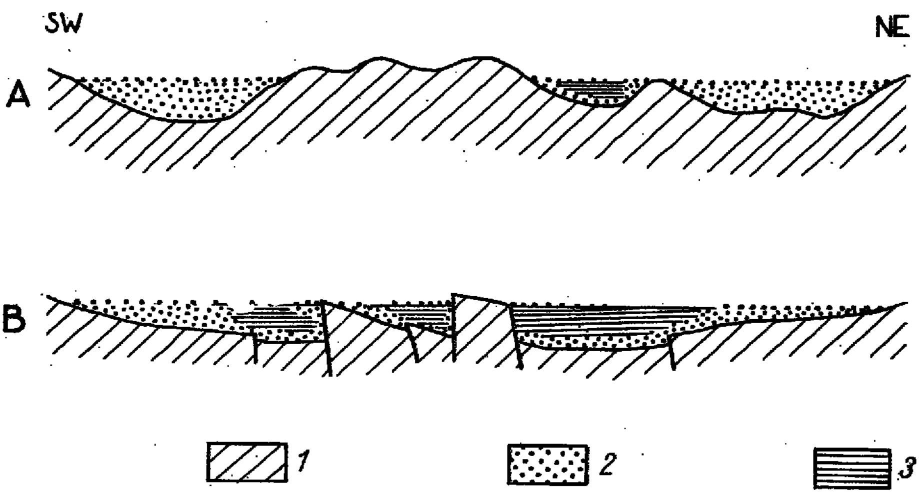


Fig. 8

Diagrammatic representation of the different interpretations of the Late Permian paleogeography in the Holy Cross area

A — Classical interpretation: a peninsula at the site of the Paleozoic core of the Holy Cross Mts is bordered by the Opatów and the Zbrza-Chmielnik "embayments" of the Zechstein sea

B — Interpretation proposed by the writers: the area of the Paleozoic core is also embraced within a large embayment of the Zechstein sea. Some ridges in the central part of this embayment are not inundated. The contrast between the ridges and depressions is partly due to inherited relief, and partly to synsedimentary faulting

1 pre-Permian substratum, *2* conglomerates, *3* other Permian sediments with sedimentary continuity into the Triassic. Thus it is clear that the Permian rocks in the Holy Cross Mts belong to the Alpine cycle.

It is reasonable to suppose that the downwarping of the Holy Cross area enabling permanent deposition of Permian sediments, had but slightly preceded the ingression of the Zechstein sea. This suggest that the Zygmuntówka conglomerate is late Rotliegendes or early Zechstein in age. As for other Permian conglomerates in the Holy Cross Mts, they either interfinger with demonstrable marine sediments of Zechstein age, or are overlain with sedimentary continuity by Triassic sediments. These conglomerates are clearly Zechstein in age.

2. Layers of gypsum and anhydrite have been recognized in boreholes within Zechstein deposits in the western part of the Holy Cross Mts, not far from the Paleozoic core (Szaniawski 1965, Kostecka 1966, Pawłowska 1970). Some of these boreholes are situated very close to the outcrops of Zechstein deposits (*e.g.* the borehole Gałęzice *6* at a distance of 250 m). So far, gypsum and anhydrite have not been encountered in outcrops. However, some observation suggest that the discussed evaporates were dissolved at the surface, as a result of suberosion.

3. Small synsedimentary grabens filled with deposits of the lowermost Bunter can be observed in the Jaworznia quarry, near Kielce. Most probably synsedimentary faulting on a larger scale also occurred in the Holy Cross area during the Late Permian and Early Triassic.

4. Remnants of the Bunter are encountered within the Paleozoic core in a number of karst-holes, developed in the Devonian limestones or dolomites. Since these karst phenomena seem to be in most cases of Tertiary age, it is by no means certain that all the Triassic sediments concerned were primarily deposited on Devonian rocks.

The Bunter sandstone

Bunter deposits, consisting of allochthonous detrital material, surround the Paleozoic core from the north, west and south. Thus it has been recognized for a long time that the Bunter accumulated in the area of the Paleozoic core (Czarnocki 1923, Samsonowicz 1929), this implying that a depression had existed in this area. This is confirmed by paleocurrent indices observable in the Bunter (Fig. 9*B*; Senkowiczowa & Ślączka 1962).

Röt, Muschelkalk and Upper Triassic

In the Röt, the sea encroached on most parts of the meta-Carpathian zone. Marine sediments accumulated in the southern part of the Holy Cross area, while marine to continental ones in the northeastern part of this area (Senkowiczowa 1970). The line dividing the two facies zones stretched across the area of the Paleozoic core (Fig. 9*A*). Detrital material was delivered to the Holy Cross area from the northeast, *i.e.* from the East-European platform.

In the Muschelkalk time, the whole area of the Paleozoic core was submerged.

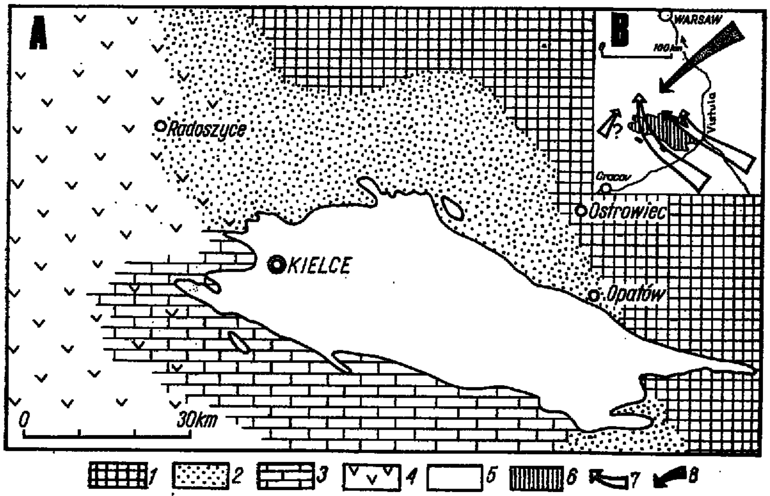


Fig. 9

Early Triassic sedimentation in the Holy Cross area

A — Facies map of the Röt (slightly modified after Senkowiczowa 1970)

1 assumed land area, 2 terrigenic-carbonate facies, 3 carbonate facies, 4 carbonate-sulphate facies, 5 boundary of the present Paleozoic core

B — Direction of transport of detrital material (after Senkowiczowa & Ślączka 1961)

6 Paleozoic core, 7—8 directions of transport: 7 in Bunter time, 8 in the Röt

Before the Rhaetian, the Holy Cross area was subjected to differential uplift. As a consequence, the Rhaetian sediments rest either on the Lower Keuper or on the Muschelkalk, and locally even on the Röt. The area of maximum uplift did not coincide, however, with that of the Paleozoic core (Fig. 10, *in* Senkowiczowa 1970).

As suggested by Kopik (1970), the Carpathian sea was intermittently connected with the German-Polish basin during Rhaetian via the Holy Cross area.

Early Jurassic

The recent publications by Dadlez (1969, 1970) and Karaszewski & Kopik (1970) supply much evidence suggesting that a separate elevation did not exist in the Holy Cross area in the Early Jurassic. Within the Liassic deposits preserved in the northern part of the Holy Cross Mts, the axis of maximum thickness stretches SE, towards the Paleozoic core.

A similar pattern is displayed by marine Liassic deposits (Fig. 10). Sedimentological data indicate that detrital material was transported from the south and northeast towards the Holy Cross area (Dadlez 1962, Unrug 1962) in that time.

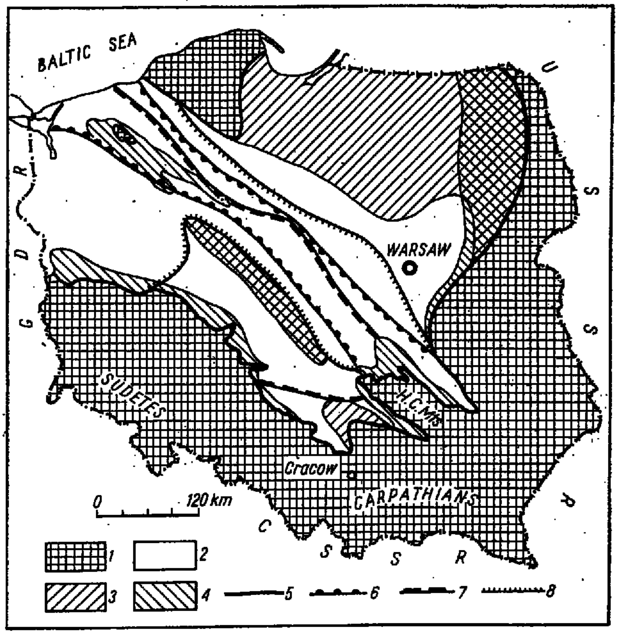


Fig. 10

Lower Jurassic deposits in Poland (after Dadlez, *in* Osika 1970)

1 areas devoid of Lower Jurassic deposits (occurrences in the Carpathians omitted), 2 lower and upper parts of the Lower Jurassic present, 3 lower part of the Lower Jurassic absent, 4 upper part of the Lower Jurassic absent, 5 present boundary of Lower Jurassic deposits, 6 extent of marine intercalations in lower part of the Lower Jurassic, 7 extent of marine--brakish facies in the Lower Pliensbachian, 8 extent of marine facies in the Lower Toarcian

At present, the Liassic is nearly completely absent from the area south of the Holy Cross Mts (Pawłowska 1962). More extensive Liassic deposits probably existed here (Karaszewski & Kopik 1970), but they were removed by erosion subsequent to some phases of Early or Middle Jurassic uplift.

Middle and Late Jurassic

Aalenian to Callovian deposits are preserved north of the Holy Cross lineament (Daniec 1970). In the southern part of the Holy Cross Mts, the Triassic rocks are covered by the Bathonian or Callovian. At the southern border of the Paleozoic core, at Miedzianka, Callovian deposits of deep-neritic facies are encountered at a distance of 250 m from outcrops of the Devonian. This suggests that the whole area of the Paleozoic core was submerged at that time.

In what concerns the Oxfordian and the lowermost Kimmeridgian (the Oxfordian, Rauracian and Astartian of the old stratigraphic division), it is commonly accepted that the Holy Cross area was covered by sea during this time. Nevertheless, some features of the Late Jurassic paleogeography in Poland are worth of note.

In the Lublin Upland, towards the Ukrainian shield, the Oxfordian is largely represented by red-beds, bog deposits, dolomites, marls and anhydrite (Niemczycka 1966, 1971). It is evident that these sediments accumulated near the shore line of the Oxfordian sea. Upper Jurassic sediments containing much terrigenic material also occur in northern Poland, near the Baltic shield (Dembowska; *in* Dadlez, Dayczak-Calikowska & Dembowska 1964). In the margins of the Holy Cross Mts, the Oxfordian is represented by marine limestones. Only in the northeastern margin there occur some thin intercalations of dolomites (Fig. 11).

The Oxfordian and the lowermost Kimmeridgian calcareous sediments of Central Poland can be attributed to two megafacies, namely to a deep-neritic "spongian megafacies" and a shallow-water "corallian-oolitic megafacies" (Kutek 1969). The latter represents an intricate patchwork of sediments of Bahaman type, among which oolites and sediments with corals or numerous bivalves are the most characteristic. In eastern Poland, at the East-European platform, the shallow-water megafacies appears at or near the base of the Upper Jurassic. Troughout the Oxfordian the southwestern boundary of this facies environment was being shifted to the south and southeast, the deep-neritic megafacies persisting longer in the southwestern areas (Fig. 11 illustrates the distribution of facies at the turn of the Middle and the Late Oxfordian). Thus, the megafacies concerned display a distinct diachronic pattern, the same pattern being recognizable in the Holy Cross area and farther north.

In the margins of the Holy Cross Mts and in large parts of Central and Northern Poland, upper parts of the Lower Kimmeridgian and the Upper Kimmeridgian are largely represented by layers of marls and shales, which increase in number and thickness from the Holy Cross area towards northwest. Thus it is evident that terrigenic material was not delivered from the central parts of the Holy Cross area (Kutek 1969).

It follows from the above data that the Holy Cross area was not individualized as a distinct paleogeographic unit during the Oxfordian and Kimmeridgian. On the other hand, such ancient geotectonic units as the Baltic shield and the Ukrainian shield, clearly manifested themselves in the Late Jurassic paleogeography.

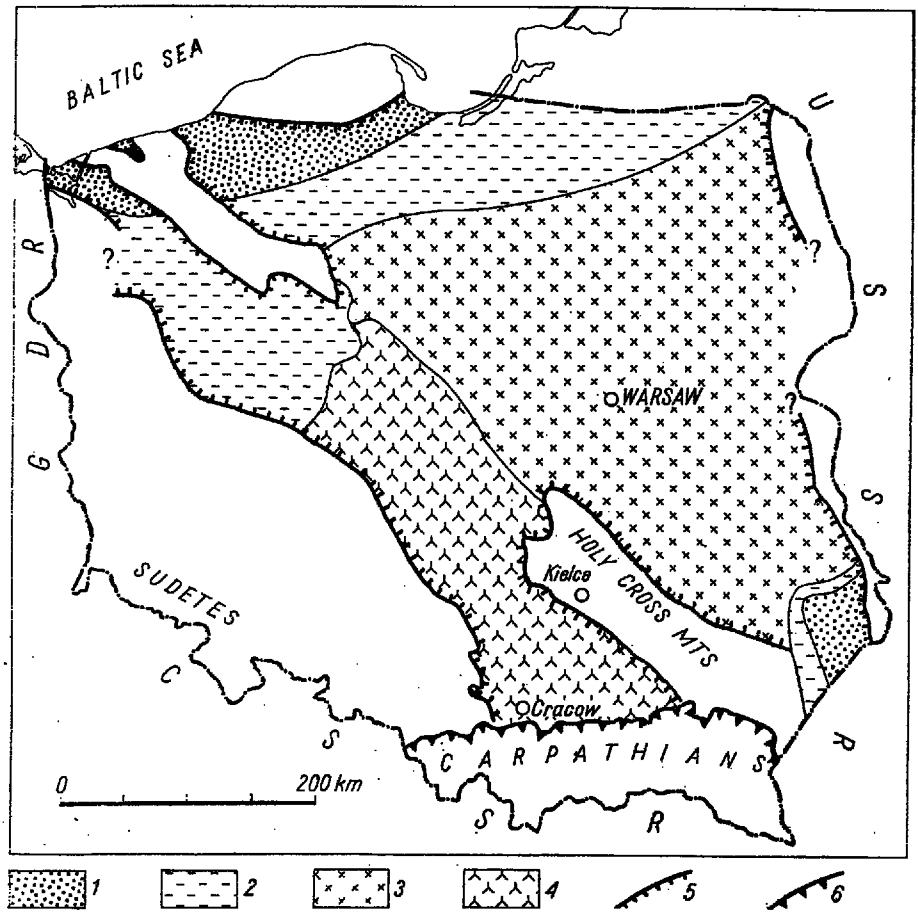


Fig. 11

Facies map of the lowermost Upper Oxfordian (approximately lower part of the Bimammatum Zone) in Poland (after Dembowska, *in* Dadlez, Dayczak-Calikowska & Dembowska 1964, and Niemczycka 1970, generalized and reinterpreted)

1 sands and siltstones (in southeastern Poland redbeds and bog deposits), *2* predominantly marly deposits, *3* shallow-water calcareous sediments, locally also dolomites, *4* deep-neritic calcareous sediments, *5* present limits of the Upper Oxfordian deposits, *6* northern margin of the Carpathian nappes

Albian and Cenomanian

It has been suggested (*e.g.* Pożaryski 1962, Cieśliński & Pożaryski 1970), that a peninsula existed in the area of the southern part of the Holy Cross Mts in the Albian and Cenomanian, which was gradually encroached by the sea from the southwest, north and northeast, and subsequently covered by marine sediments in the Turonian. However, another paleogeographic interpretation can be suggested.

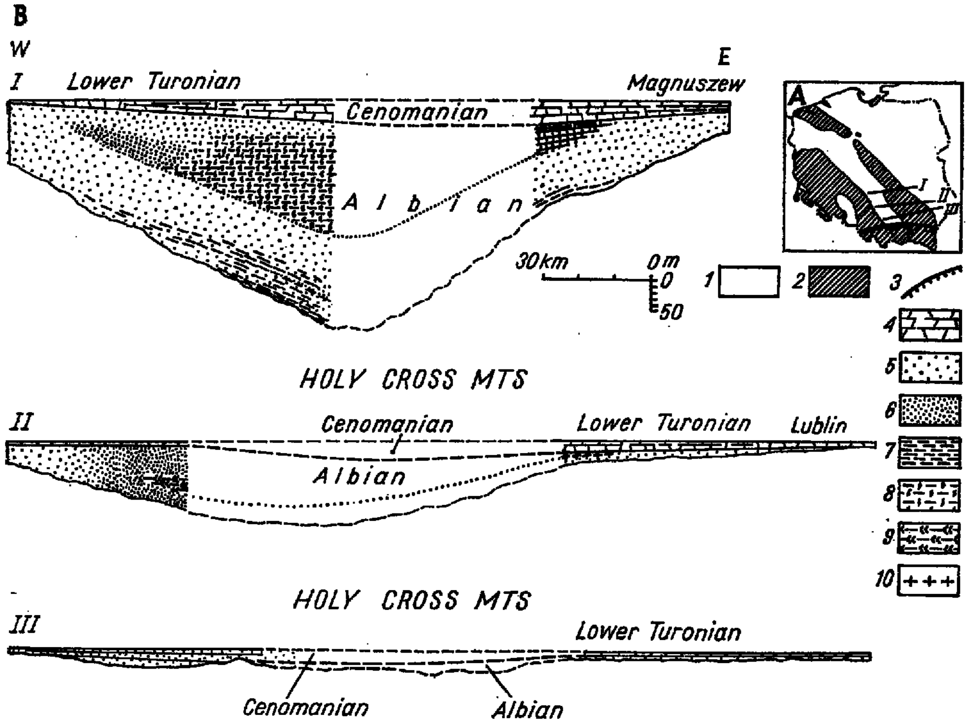


Fig. 12

Restored cross-section through the Albian and Cenomanian deposits preserved southwest and northeast of the Middle-Polish anticlinorium (modified after Cieśliński 1959b)

Explanations to the location map: *1* epicontinental Cretaceous deposits, *2* older deposits and Carpathian Flysch, *3* northern margin of the Carpathian nappes; explanations to sections: *4* marls, *5* sands, *6* sandstones, *7* clays, *8* gaizes, *9* spongiolites, *10* phosphorites

In the northern part of the Holy Cross Mts, north of the Paleozoic core, the Albian and Cenomanian sediments display a distinct pattern of facies (Fig. 12; Cieśliński 1959b). Their thickness increases, and the sands are partly replaced by clays, spongiolites and gaizes, from the northeast and southwest towards the axis of the Middle-Polish anticlinorium. This indicates that it coincides here with that of Albian and Cenomanian subsidence. South of the Paleozoic core, the Albian and Cenomanian sediments are relatively thin. Moreover, their distribution was influenced by paleorelief, and possibly also by synsedimentary tectonic movements. As a consequence, the thickness pattern of this sediments is complex in details. In general, however, the thickness do not decrease towards the Holy Cross Mts; the reciprocqual is rather true (Fig. 6). It should be also noted that nowhere the Turonian overstep the Cenomanian towards the central part of the Holy Cross Mts.

Within the southwestern margin of the Holy Cross Mts, in the Bolmin syncline, marine Upper Albian is encountered, whereas farther south the Kimmeridgian substrate is covered only by Cenomanian sediments (Hakenberg 1969). This suggests that the Middle Cretaceous sea encroached upon this area from the north, *i.e.* from the area of the Holy Cross Paleozoic core.

In the Holy Cross area, the Albian is largely represented by quartz sands and gravels. It was suggested that the quartz material had been derived from central parts of that area. In the margins of the massif, however, the Albian rest on Neocomian, Volgian or Kimmeridgian rocks, which are developed as limestones, marls, shales and siltstones. Thus there is no evidence available suggesting that some rocks that could have supplied quartz detrital material, were exposed at the surface at that time.

The data presented suggest that a distinct peninsula did not exist in the Holy Cross area during the Albian and Cenomanian. There should be no doubt, however, that the Holy Cross lineament was active at that time. As a consequence, only the northern part of the Holy Cross area was submerged in the Middle Albian, and the sea encroached the area south of the Holy Cross lineament in the latest Albian and the Cenomanian (*cf.* Hakenberg 1969). It is most probable, however, that the southern part of the Holy Cross area was entirely submerged at the end of the Cenomanian.

The detrital material, which was transported in the Albian across the Holy Cross area to the north (*cf.* Hakenberg 1969), was possibly derived from the Carpathian area. A similar opinion with respect to the Cenomanian and Turonian gravels of the Cracow region was expressed by Sujkowski (1929).

Late Cretaceous

It has been suggested that the Holy Cross area and that of the San anticlinorium were emerged during the Santonian and continued to form a peninsula in the Campanian and Maestrichtian (*e.g.* Pożaryski 1960, 1962a; Cieśliński & Pożaryski 1970). This supposition is based mainly on a relatively abundant quartz material encountered together with flora near Radom, in Santonian and Campanian rocks classified as calcareous gaizes. It should be mentioned, however, that the region of Radom lies at the northern periphery of the Holy Cross area. Neither Santonian nor Campanian rocks, similar to those encountered in the Radom region, have been recognized east of the Paleozoic core, and along southwestern margin of the Holy Cross Mts.

A different paleogeographic interpretation is supported by the following data. The Turonian to Maestrichtian deposits generally increase in thickness from the northeast and southwest towards the Holy Cross Mts and the San anticlinorium (Fig. 5; Pożaryski 1962a, 1966). No significant stratigraphic gaps have been encountered in the deposits concerned near the Holy Cross Mts (*cf.* Cieśliński & Pożaryski 1970), whereas at the southwestern border of the Miechów synclinorium there occurs a major stratigraphic gap between the Lower Turonian and the Santonian (Marcinowski & Szulczewski 1972). The uniformity in facies, displayed by the Upper Cretaceous deposits near the Holy Cross Mts (Cieśliński & Pożaryski 1970), is another significant feature. All these data suggest that from the Turonian to the Campanian the Holy Cross area and that of the San anticlinorium were embraced within the subsiding Danish-Polish trough, and did not emerge before the Maestrichtian.

There should be no doubt as to the fact that these areas began to rise in the Maestrichtian. It is still an open question, however, whether they were subjected to a general uplift as early as in the Early Maestrichtian. Sandy intercalations and flora have been recorded from Lower Maestrichtian deposits occurring southwest of the Holy Cross Mts (Cieśliński & Pożaryski 1970), but this does not necessarily imply a general uplift of that area. The occurrences of sand can possibly be a result of supply of material from the southwest (*cf.* Rutkowski 1960), or of some minor synsedimentary tectonic disturbances.

Conclusions

Throughout the Late Permian and the Mesozoic, there never existed a distinct elevation, coinciding in shape and size with the present Holy Cross Mts, or with the Paleozoic core. At some times, however, the area south of the Holy Cross lineament was markedly elevated against the northern part of the Holy Cross area.

TECTONICS OF THE HOLY CROSS MTS

Tectonic movements in the Holy Cross area

Distinctive folds or fold-fault structures were produced here by the Late Baikalian, Late Caledonian, Variscan and Laramide movements. These movements occurred at the beginning of the Ordovician, at the end of the Silurian and in the Early Devonian, after the Early Carboniferous and at the turn of the Cretaceous and the Tertiary, respectively. As a consequence, distinct angular unconformities are encountered in the Holy Cross area below the Ordovician, Devonian, Permian and Tertiary rocks (Samsonowicz, *in* Książkiewicz & Samsonowicz 1952; Znosko 1962a; Pożaryski & Tomczyk 1968a, 1969; Kowalczewski 1971; Orłowski 1971).

Other Paleozoic, Mesozoic and Tertiary movements, some of which were synsedimentary in type, resulted only in large undations, or in faulting and slight tilting of strata.

In older publications, the Variscan movements were considered to have been of utmost importance in the Holy Cross area (*e.g.* Czarnocki 1919; Samsonowicz, *in* Samsonowicz & Książkiewicz 1952). It was also suggested that the Variscan structures in the Paleozoic core had been but slightly modified by later movements. Strong Laramide disturbances were recognized in both the Mesozoic and Paleozoic sequences at the border of the Paleozoic core, but it was believed that they had not much affected structurally the inner parts of the Paleozoic core. Moreover, some authors considered the Paleozoic core as a stable block, controlling the pattern of the surrounding Laramide folds (*e.g.* Czarnocki 1962, Pożaryski 1969).

In recent publications, however, the importance of the Baikalian, Caledonian and Laramide movements is stressed (Znosko 1962a, 1964, 1965, 1970; Pożaryski & Tomczyk 1968a, b, 1969; Kowalczewski 1971).

Extent of Paleozoic structures

The folded Paleozoic rocks now exposed in the Paleozoic core are known to pass unconformably beneath the surrounding Permo-Mesozoic cover; they have been encountered in boreholes north, west, south and east of the core. Thus, the Paleozoic tectonic structures clearly extend beyond the area of the Paleozoic core. In most cases, the boundaries of the Paleozoic core do not coincide with those of important Paleozoic structural zones (Fig. 13).

Tectonic style of the Holy Cross Mts

As far as structural disturbances in Devonian to Permian and Mesozoic rocks are concerned, assymetrical anticlines formed over reverse faults (ridgelike folds and unilateral boxfolds — Beloussov 1962), anticlines bounded on both sides by faults or flexures (bilateral boxfolds), and flexures not associated with anticlines can be regarded as the most characteristic tectonic structures in this area. Most of the anticlines are brachyanticlines when seen in horizontal section (*cf.* Czarnocki 1938, 1953).

Distinct synclines are not altogether absent where faults or flexures are relatively densely spaced, but several depressed tectonic structures can be labelled as mere tracks of subhorizontal or gently dipping strata. All the fold structures are complicated by numerous transverse and oblique faults. As far as faults dissecting Upper Paleozoic and Mesozoic rocks are concerned, they all seem to be vertical or high-angle. Evidence for the occurrence of low-angle upthrusts involving rocks of this age is totally lacking.

Some of the faults are strike-slip faults (for a discussion on the significance of wrench-faults in the Holy Cross area — *see* Jaroszewski 1972).

In accordance with Beloussov's (1962) terminology, the Laramide and the Variscan structures of the Holy Cross Mts can be regarded as representative of the intermediate type of folding. The structures concerned are distinctly germanotype in character.

In the Holy Cross area, the Cambrian to Silurian sequences display some features implying intense folding (close spacing of folds, imbricate structure), but it is still an open question whether the Lower Paleozoic rocks were affected by structural disturbances of alpine type (important data concerning Early Paleozoic tectonics of the Holy Cross Mts will be found in an extensive work by Kowalczewski, as yet unpublished).

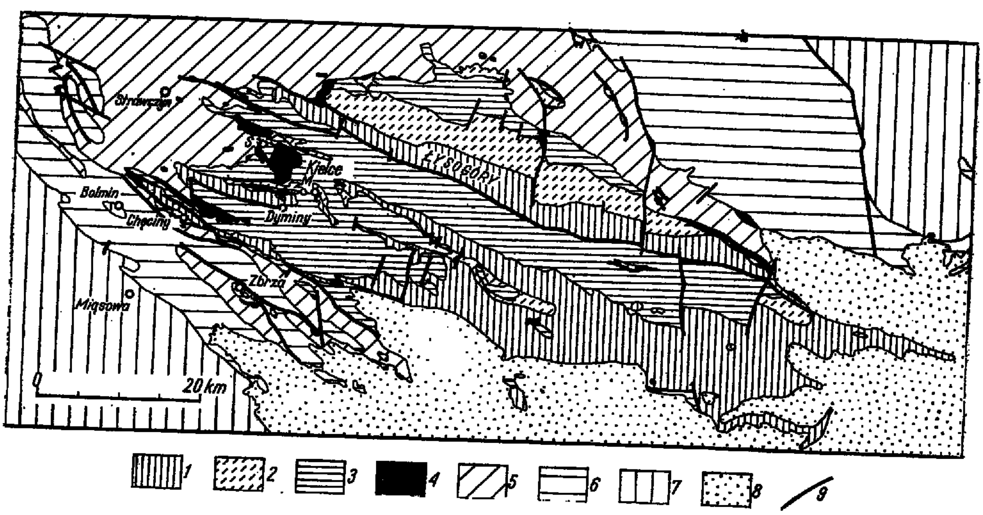


Fig. 13

Geological sketch map of the Holy Cross Mts (northernmost part omitted)
1 Cambrian (locally also uppermost Precambrian), 2 Ordovician and Silurian, 3 Devonian and Lower Carboniferous, 4 Permian, 5 Triassic, 6 Jurassic, 7 Cretaceous, 8 Upper Miocene, 9 faults and flexures, *M* Mójcza, *S* Słuchowice

Laramide versus Variscan structural disturbances

It seems to be evident that the Variscan structures of the Paleozoic core were strongly affected by Laramide structural disturbances (Znosko 1962a, Bednarczyk, Chlebowski & Kowalczewski 1971, Kowalczewski 1971). Even such much advertized "Variscan" structures as the Śluchowice fold and the Łysogóry upthrust must to some extent be interpreted as Laramide structures (Kowalczewski 1971).

In the Holy Cross Mts there exists a distinct Variscan unconformity but, as recognized by Znosko (1962a), the primary Variscan dips, measured in Paleozoic strata against the Variscan unconformity, are rather gentle; nowhere are they known to exceed 35°. This is a rather surprising fact, because even in regions, affected by germanotype disturbances only, considerable dips can be expected to occur within some fault zones. In the Holy Cross Mts, however, in all the zones where the Paleozoic strata are strongly upturned, the Mesozoic ones, if present, also display considerable dips.

On the other hand, strongly upturned and overturned Mesozoic strata are commonly encountered. From this it can be inferred that, in the Holy Cross area, the Laramide structural disturbances were stronger than the Variscan ones.

The Variscan and the Laramide Chęciny anticline

A good example of the relations of Laramide to Variscan disturbances is supplied by the Chęciny anticline, which is situated at the southwestern border of the Paleozoic core (Figs 13, 14).

In some places, *e.g.* in the western part of the southern flank of this anticline, both the Paleozoic and Mesozoic strata are strongly tectonized (Fig. 14, sections *III, IV, VI, X, XIII, XIV, XVI, XVII*). Steeply upturned and overturned strata are associated with several longitudinal faults and flexures, and décollement is commonly observed at the contacts of competent and incompetent rocks. As a consequence, the primary attitude of the strata at the Variscan unconformity cannot be recognized.

This is, however, possible in other parts of the anticline, *e.g.* in its northern flank. Here the Variscan unconformity can be clearly recognized in several sections (Fig. 14, sections *V, VII, VIII, XI, XII, XV*). The primary Variscan dip, as measured in Prepermian rocks against this unconformity, does not exceed 35°. In some sections the dip is less than 10°, and in the section IX the Permian appears to overlie nearly concordantly Lower Carboniferous strata.

From the sections it follows that the Chęciny anticline can be considered as a Variscan one rejuvenated during Laramide movements. It very gently sloping limbs were subsequently steepened, and localy even overturned, as a result of the Laramide movements.

From the sections it should be also clear that, at the borders of the Paleozoic core, the boundary of the present occurrences of Permian deposits is largely erosive in character.

Geotectonics of the Holy Cross area

It is commonly accepted that the Holy Cross area did not develop under geosynclinal conditions in the Alpine cycle. The same can be suggested for the Variscan cycle on the following evidence. First, the Variscan structures cannot be regarded as alpinotype ones. Second, no distinctive geosynclinal facies are encountered in this area in the Devonian and the Lower Carboniferous. For instance, the Kulm in the Holy Cross area is not developed as flysch or molasse, and it is relatively thin. In this respect, it conspicuously differs from the deposits occurring west of the Upper Silesian Coal Basin (Żakowa 1970, Dembowski & Unrug 1971).

Znosko (1964, 1965, 1966), considered only the Kielce zone of the Holy Cross Mts as an area of Caledonian consolidations while the Łysogóry one was regarded as part of a Variscan geosycline. A nongeosynclinal interpretation of the latter zone is suggested by that author recently (Znosko 1970), and a similar opinion was expressed by Pożaryski and Tomczyk (1968b).

In the Holy Cross area, in its S part at least, geosynclinal conditions did not continue beyond the Caledonian (Znosko 1962a, 1964, 1965, 1970), or the Baikalian cycles (Pożaryski & Tomczyk 1968). This area can also be interpreted as a part of large pericratonic depression, developed as early as in the Baikalian cycle southwest of the Tornquist-Teisseyre line (*cf.* Pożaryski 1969, Kolchanov & al. 1970).

Structural trends in the Holy Cross area

In the discussed and some adjacent areas, most of the principal tectonic structures trend WNW-ESE or NW-SE. As the first trend prevails within the Paleozoic core, whereas the second one in the Mesozoic margins, they are sometimes referred to as the Variscan and the Laramide trends, respectively.

All the tectonic structures trending WNW-ESE are obviously connected with the Holy Cross lineament. They occur only in a zone some scores of kilometres large, extending from the northeastern border of the San anticlinorium to the Radomsko region (Fig. 1). It should be stressed that not only Baikalian, Caledonian and Variscan structures, but also several rejuvenated by the Laramide movements (*e.g.* the Chęciny anticline, the Łysogóry fault zone), display this trend.

On the other hand, several pre-Laramide tectonic structures trend NW-SE. As the Tornquist-Teisseyre line was in existence as early as in the latest Precambrian, it can be expected that some parallel subsidiary tectonic structures were generated in the area farther southwest as early as in the Paleozoic. Indeed, some Caledonian structures trending NW are known to occur east of the Paleozoic core (Znosko 1965), and distinct Variscan structures, displaying the same trend, have been recognized northeast and southwest of the Holy Cross Mts (in the Lublin Upland and in the substrate of the Miechów synclinorium — Bukowy 1964, Miłaczewski & Żelichowski 1970). Moreover, it can be inferred from the map by Znosko & Pajchlowa (*in* Znosko 1968), that the Rzeszów-Poznań lineament, which borders the San anticlinorium and part of the Holy Cross Mts on the southwest, was active during the Variscan tectonic epoch. Accordingly, it may be expected that the Paleozoic structures which underlie the folded Permo-Mesozoic cover in the Mesozoic margins of the Holy Cross Mts, also trend NW-SE.

More or less distinct interference of the tectonic structures trending NW or WNW can be observed in several parts of the discussed region. It is clearly visible in the Radomsko region where a set of Laramide brachyanticlines was formed at the junction of the Holy Cross lineament with the Rzeszów-Poznań one — Fig. 1 (Pożaryski 1971). A less spectacular example is supplied by the boundary which separates the Jurassic of the southwestern margin of the Holy Cross Mts from the Cretaceous of the Miechów synclinorium. As it may be seen in detailed geological maps, changes in trend from NW to WNW repeatedly occur along this boundary. Tectonic structures striking WNW-ESE clearly predominate within the Paleozoic core, but some faults and structural zones striking NW are discernible in this area (*e.g.* in the zone of Suków, Bukówka, and Mójcza, in the Padół Strawczyński and in the Oblęgorek Belt — Czarnocki 1931, 1938). As for the northeastern part of the Holy Cross Mts, interference of structures trending NW and WNW was pointed out by Samsonowicz (1934, Samsonowicz, *in* Książkiewicz & Samsonowicz 1952).

It is also worth of note that the Middle-Polish anticlinorium is exceptionally wide where crossed by the Holy Cross lineament.

Thus, the principal structural trends in the Holy Cross area do not differ in age. They can be regarded as a result of pre-existing deep-seated fractures. Structures stretching WNW distinctly prevail in the zone of the Holy Cross lineament, whereas those striking NW predominate in the fracture zones which border the Middle-Polish anticlinorium on the northeast and southwest.

In the Holy Cross area, some tectonic structures diverge from the principal structural trends (*e.g.* some anticlines west of the Padół Strawczyński, the Dyminy anticline). In the northeastern part of the Holy Cross area, some structures, generally stretching NE-SE display *en coulisse* arrangement (Jaroszewski 1972). These are, however, but minor complexities in the general picture.

Origin of the Laramide fold structures

The Laramide (and the Variscan) fold structures in the Holy Cross Mts can be considered as being formed in response to block movements in the deep substrate (Kowalczewski 1971, Stupnicka 1971). Relatively narrow fault zones, in which the Paleozoic and Mesozoic strata are steeply upturned or overturned, alternate with broader belts of gently dipping strata. Thus, the tectonic style of the Holy Cross Mts fits well this interpretation.

It should be stressed, however, that only the crystalline Precambrian rocks of the deep substratum of the Holy Cross Mts could have acted as rigid blocks during the Laramide tectogenesis. As for the Paleozoic and Mesozoic sequences in this area, they are composed of alternating layers of competent and incompetent sedimentary rocks (*e.g.* Upper Jurassic limestones, Middle and Upper Devonian dolomites and limestones, Lower Devonian sandstones, Upper Triassic, Silurian and Lower Cambrian shales). The rocks of Late Proterozoic age, which underlie the Cambrian in the Holy Cross area, are sedimentary ones, but slightly affected by epizonal metamorphism (*e.g.* quartzites and phyllites). Moreover, the Paleozoic and Mesozoic rocks attained great thicknesses in the area concerned. At the end of the Cretaceous, prior to the tectonic inversion of the Danish-Polish trough, the maximum thickness of these rocks was about 6000 m in the Kielce, and about 10 000 m in the Łysogóry zones. As a consequence, most of the longitudinal faults dissecting the Paleozoic and Mesozoic rocks are developed as flexure-faults. These commonly display along-the-strike variation. In particular, the reverse faults which are most commonly developed in areas of strongest uplift, are laterally replaced by vertical or normal faults.

The unilateral and bilateral boxfolds of the Holy Cross Mts are relatively densely spaced, so that some of the intervening depressed tectonic zones are developed as distinct synclines. From this it can be inferred that the crystalline substratum of the Holy Cross Mts is dissected by sets of relatively numerous fractures.

The Laramide and pre-Laramide tectonic structures do not differ in trends in the Holy Cross area. This suggests that some of the faults or fault zones that were active during the Laramide tectogenesis, date from earlier diastrophic cycles. In some cases, this can be confirmed by direct evidence (*e.g.* the Łysogóry fault zone).

Conclusions

The Paleozoic core of the Holy Cross Mts did not act as a stable block during the Laramide tectogenesis, nor were the Laramide folds superimposed on passive Paleozoic structures. The Paleozoic and Mesozoic rocks were subjected to strong Laramide disturbances in the whole area. The Laramide structures follow the trend of pre-existing deep-seated fractures. Thus, they trend WNW-ESE in the zone of the Holy Cross lineament, whereas they strike NW-SE in the border zones of the Middle-Polish anticlinorium.

The sedimentation in the Holy Cross area was largely controlled by the Holy Cross lineament. Several deep-seated fractures, displaying the trend of the Middle-Polish anticlinorium, also acted in a similar way (Pożaryski 1957, 1964, 1971; Pietrenko 1961, Dadlez & Marek 1969, Marek & Znosko 1972). Thus deep-seated fractures can be regarded as the principal factors controlling both the sedimentary and the tectonic development of the Holy Cross area.

The zone of the Middle-Polish anticlinorium in the Alpine and the Variscan cycles

In the Alpine cycle, marked subsidence as well as strong uplift and strong structural disturbances were confined to the zone of the Danish-Polish trough and the Middle-Polish anticlinorium. In general, the markedly thinner Permo-Mesozoic deposits of the Szczecin-Łódź-Miechów synclinorium and the Border synclinorium are but slightly tilted. In the Variscan cycle, however, at least the southeastern part of the zone concerned did not differ conspicuously in its tectonic development from the adjoining areas farther northeast and southwest.

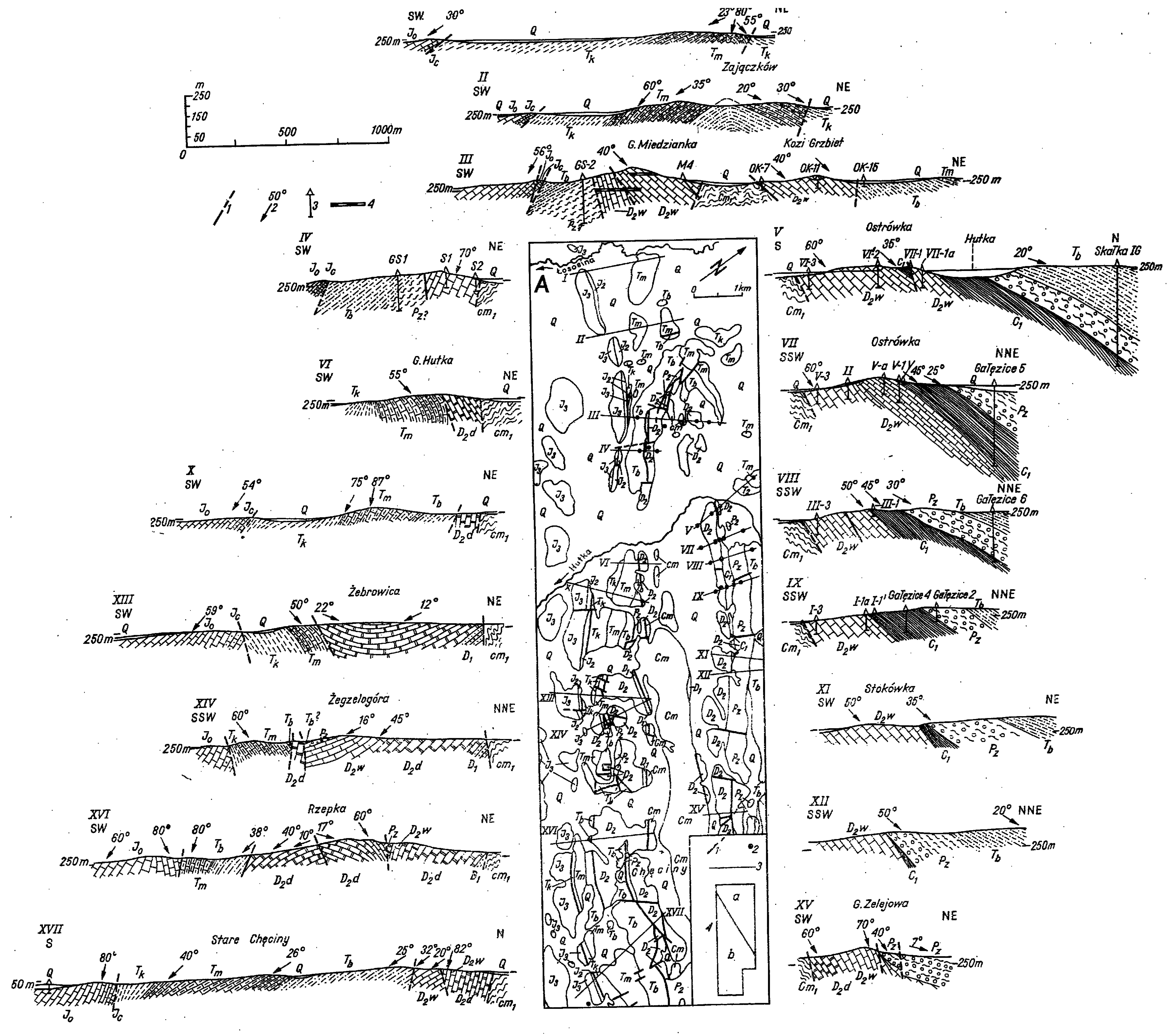
In the whole area extending from the Lublin Upper Carboniferous trough to the Upper Silesian Coal Basin, distinct germanotype structures of Variscan age have been recognized. Moreover, the Devonian and Lower Carboniferous deposits of the Lublin region, and the substratum of the Miechów synclinorium are not conspicuously thinner than those in the Holy Cross Mts (Pajchlowa & Miłaczewski and Żakowa, *in* Osika 1970). This suggests that the whole area between the Upper Silesian Coal Basin (the foredeep of the Moravo-Silesian Variscan foldbelt) and the Lublin Upper Carboniferous trough (the latter connected with the Tornquist-Teisseyre line), behaved as a rather uniform mobile platform in the Variscan cycle.

Geotectonic evaluation of the Holy Cross lineament

As far as the tectonic and sedimentary history of the Holy Cross area in Phanerozoic time is concerned, the Holy Cross lineament must be considered as a geotectonic structure of utmost importance. On the other hand, however, it seems to be a structure of a second order in the general tectonic framework of Central Europe.

The Holy Cross lineament does not appear to extend west of the Radomsko region, beyond the Poznań-Rzeszów lineament. Accordingly, it is most probable that the WNW trending tectonic structures of the Holy Cross area do not continue WNW of the Radomsko region. So far, not much is known about the Paleozoic structures farther west, but it can be supposed that they display an offset, or a different trend, with respect to those in the Holy Cross area. In any event, the WNW trending Paleozoic structures in the latter area should not be regarded as an extention of any of the Paleozoic structural belts, existing west of the Elbe line.

It can also be suggested that the Baikalian, Caledonian and Variscan structural zones, existing southwest of the Tornquist-Teisseyre line, display a predominant northwesterly trend northwest and southeast of the Holy Cross area. In the latter, a WNW trend was imposed to the



Tectonics of the western part of the Chęciny anticline

A — Geological sketch map: *Cm* Lower Cambrian, D_1 Lower Devonian, D_2 Middle and Upper Devonian, C_1 Lower Carboniferous, *Pz* Zechstein, *Tb* Bunter, *Tm* Röt and Muschelkalk, *Tk* Keuper and Rhaetian, J_2 Callovian, J_3 Oxfordian and Kimmeridgian; *1* faults and flexures observable at the surface, *2* boreholes, *3* section lines, *4* map compiled after: *a* unpublished material of J. Głazek, *b* Hakenberg 1972

B — Cross-sections; Cm_1 Lower Cambrian (shales, siltstones and sandstones), D_1 Lower Devonian (sandstones), D_2d Eifelian-Givetian (dolomites), D_2w Givetian-Famennian (limestones), C_1 Lower Carboniferous (shales and limestones), *Pz* Zechstein (conglomerates, limestones and marls), *Tb* Bunter (sandstones and shales), *Tm* Röt and Muschelkalk (limestones and marls), *Tk* Keuper and Rhaetian (shales and sandstones), *Jc* Callovian (calcareous gaizes), *Jo* Oxfordian (limestones), *Q* Quaternary (sands, clays and loams); *1* faults, *2* dips, *3* boreholes, *4* galleries

Paleozoic structures by the Holy Cross lineament. It is noteworthy that no WNW trending structures have been recognized in the San anticlinorium (except for that part of its northeastern margin which is an extention of the Holy Cross lineament).

THE ORIGIN OF THE HOLY CROSS MTS

Uplift of the Middle-Polish anticlinorium

The Permian and Mesozoic sediments, which had accumulated in various parts of the Danish-Polish trough prior to the formation of the anticlinorium, differed strongly in thickness. They attained 11,000 m in the Kujawy region and about 6,000 m in Pomerania, but only about 3,000 m in the southern part of the Holy Cross area (Figs 2—6). Consequently, as the result of subequal uplift and subsequent erosion, various rocks were exposed along the axis of the Middle-Polish anticlinorium, and so, Precambrian in the San anticlinorium [4], Paleozoic in the southern part of the Holy Cross area, and Triassic, Jurassic or Lower Cretaceous in those parts of the Middle-Polish anticlinorium which are situated farther north (Fig. 1).

The following data suggest a subequal uplift along the axis of the Middle-Polish anticlinorium. In Kujawy and Pomerania, the amplitude has been estimated by Pożaryski (1964) and Dadlez (*in* Dadlez & Dembowska 1965) at about 3,000 m. The same figure is suggested for the southern part of the Holy Cross Mts. Another line of evidence is supplied by the striking relationship between the thicknesses and occurrences of the Permian and the Mesozoic in the particular parts of the Middle-Polish anticlinorium. Thus, for instance, much thicker and more complete Mesozoic deposits have accumulated in the northern part of the Holy Cross area than in its southern part. In consequence, Paleozoic rocks were exposed in the latter region, whereas in the northern part only Triassic and Lower Jurassic rocks crop out along the axis of the Middle-Polish anticlinorium (Figs 1—4). Still farther north, in the Kujawy region, very thick Permian and Mesozoic deposits have accumulated in the Danish-Polish trough prior to the formation of Middle-Polish anticlinorium; in the neighbouring Łódź synclinorium the Cretaceous deposits attain a maximum thickness of about 3,500 m (Pożaryski 1964). Accordingly, Upper Jurassic and even Lower Cretaceous deposits are preserved, in Kujawy, in the axial part of the Middle-Polish anticlinorium. In Pomerania,

[4] The absence of Paleozoic rocks in the axial part of the San anticlinorium is largely due to erosion subsequent to the Variscan uplift of this region.

where Mesozoic subsidence had been weaker than in the Kujawy region, Lower Jurassic and Upper Triassic rocks were exposed at the surface along the Middle-Polish anticlinorium, as a result of Laramide uplift and subsequent erosion.

This uplift must have been complicated by various factors, especially by pre-existing oblique faults. In the Łysogóry zone, for example, the uplift seems to have been more than 3,000 m.

In any event, the amplitude of the uplift along the Middle-Polish anticlinorium was much more uniform than the Permo-Mesozoic subsidence in the preceding Danish-Polish trough. Within the boundaries of Poland, the net subsidence in this trough ranged from about 3,000 m to about 11,000 m, whereas the variation in the amplitude of uplift along the Middle-Polish anticlinorium seems to have been, in most cases, less than 1,000 m.

The age of the Middle-Polish anticlinorium

Most authors (*e.g.* Pożaryski 1964, Znosko 1969) seem to assent that a strong Laramide tectogenesis took place in Poland during Maestrichtian and Paleocene (Danian included) time, but they differ in opinions concerning the exact date of the beginning of the uplift of the Middle-Polish anticlinorium. According to Znosko (1969) and Dadlez (1970), the general rise of this anticlinorium was restricted to the Maestrichtian and Paleocene, and had been preceded in earlier Cretaceous time only by minor block movements (Znosko 1969). On the other hand, Pożaryski (1964) considered that the southern part of the anticlinorium (the San anticlinorium and a part of the Holy Cross area) began to rise in the Santonian, whereas its middle part in the Campanian and its northern — in Pomerania — during the Maestrichtian. The problem of the age of the Middle--Polish anticlinorium can be discussed on the basis of the following data.

At present, Lower Maestrichtian deposits are preserved in the whole Szczecin-Łódź-Miechów synclinorium. Upper Maestrichtian and Paleocene deposits, however, have not been recorded from the Miechów and the Łódź synclinoria. In the Szczecin synclinorium, marine Upper Maestrichtian, and continental Upper Paleocene sediments, have been encountered (for details *see* Pożaryski 1960, 1962a; Błaszkiewicz, Cieśliński, Jaskowiak & Krassowska, Ciuk, *in* Osika 1970).

Northeast of the Middle-Polish anticlinorium, towards the East European platform, there persisted a marine basin in which Upper Maestrichtian and Paleocene deposits, 450 m thick were accumulated (Pożaryski 1960, 1962a, 1964; Ciuk, *in* Osika 1970; Pożaryska 1968, 1971; Liszkowski 1970). Since this basin can be regarded as a foredeep of the Middle-Polish anticlinorium, it is reasonable to believe that these deposits are contemporaneous with the rise of the anticlinorium. Finally, Upper Eocene deposits (and some possibly Early Eocene in age) are known to overlie unconformably the axial parts of the Middle-Polish anticlinorium (Ciuk, *in* Osika 1970).

From all this it can be inferred that the Middle-Polish anticlinorium was being formed during Late Maestrichtian and Paleocene time. It probably did not continue to rise in the Early Eocene.

On the other hand, available evidence suggests that it was not yet in existence until the end of the Campanian. As shown in several very suggestive cross-sections (Cieśliński 1959b; Marek & Raczyńska, *in* Osika 1970), the Neocomian (Berriasian to Hauterivian) and the Middle Cretaceous (Albian and Cenomanian) deposits conspicuously increase in thickness towards the axis of the Middle-Polish anticlinorium. As for the Turonian to Campanian deposits, they also, generally, increase in thickness towards this anticlinorium (Figs 4*A*, 6; Pożaryski 1962b, Table 42) [5]. Whether the Middle-Polish anticlinorium began to rise as early as Early Maestrichtian, it is an open question.

Except for the Lower Maestrichtian, the Upper Cretaceous occurring in the Łódź-Mogilno synclinorium is thicker than that encountered on the other side of the Middle-Polish anticlinorium, *i.e.* in the Border synclinorium (Znosko 1969). The Lower Maestrichtian, in turn, is conspicuously thinner in the Łódź-Mogilno synclinorium, than in the Border synclinorium, where marine sedimentation continued in the Late Maestrichtian and Paleocene. This may suggest that the foredeep northeast of the Middle-Polish anticlinorium and, consequently, also the anticlinorium itself, began to be formed as early as in Early Maestrichtian time.

In the Kujawy region and farther southeast near Radom, within Upper Cretaceous marine formations occurring at the northeastern border of the Middle-Polish aniticlinorium, arenaceous sediments (glauconitic-quartz sands and gaizes), Campanian and locally also Santonian in age, have been encountered. From this some authors stated (Pożaryski 1960, 1962a, 1964; Cieśliński & Pożaryski 1970) that some parts of the Middle-Polish anticlinorium had emerged as early as in the Santonian or the Campanian. However, the thickness pattern in Upper Cretaceous deposits does not favour this paleogeographic interpretation. Moreover, no similar extensive intercalations of terrigenous material are known to occur within Upper Cretaceous deposits at the southwestern border of the anticlinorium. Thus, minor synsedimentary tectonic disturbances, as suggested by Znosko (1969), best account for the occurrence of detrital material in the discussed pre-Maestrichtian sediments. It seems probable that these tectonic disturbances were, at least partly, of halokinetic origin. In areas adjoining the middle part of the Middle-Polish anticlinorium, stratigraphic gaps and signs of intermittent emersion are commonly encountered within Upper Creta-

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[5] This concerns only deposits of the same stratigraphic range. At present, the thickness of the Upper Cretaceous decreases at the margins of the Middle-Polish anticlinorium, because more and more early Cretaceous deposits come to the surface towards the axis of the anticlinorium, as a result of Laramide uplift and subsequent erosion. It should be also mentioned that the apparent decrease in thickness towards the anticlinorium, as displayed by the Cretaceous deposits depicted in some cross sections (Pożaryski 1960, 1962b), is due to the exaggerated vertical scale in these sections.

ceous deposits involved in halokinetic structures (Sokołowski 1966). Most probably similar halokinetic movements, resulting in emersion of restricted areas, occurred also within the zone which was to be transformed later on into the Middle-Polish anticlinorium.

The particular parts of the Middle-Polish anticlinorium do not substantially differ in age. It should be expected, however, that there was some minor regional variation in the course of the uplift to which the anticlinorium was subjected. To some extent this is suggested by the variation in the distribution of detrital material which accumulated, during Late Maestrichtian and Paleogene time, in the marine basin bordering the Middle-Polish anticlinorium on the northeast (Pożaryski 1960, 1962a). However, the supply of detrital material from the rising anticlinorium depended not only on the rate of its uplift, but also on the variable lithic composition of the rocks removed from the particular parts of the anticlinorium. Thus, any conclusions concerning minor differences in progress of the uplift in the particular parts of the Middle-Polish anticlinorium, would be highly conjectural.

The rise of the Middle-Polish anticlinorium as a morphogenetic process

As a consequence of the Laramide uplift of the Middle-Polish anticlinorium, some 3,000 m of sedimentary rocks have been removed by erosion from its axial parts. Some of the detrital material supplied by the rising Middle-Polish anticlinorium, must have been trapped by the marine basin existing, during Late Maestrichtian and Paleocene time, on the northeastern side of the anticlinorium. The sediments laid down in this basin are developed as limestones, marls and various carbonate-siliceous rocks and as gaizes and glauconitic-quartz sands (Pożaryski 1962); the terrigenic material within these sediments may be regarded as partly derived from the area of the Middle-Polish anticlinorium. No conglomerates have, however, been found among the Upper Maestrichtian and Paleocene deposits.

The absence of conglomerates can be explained as a consequence of a very slow rise of the Middle-Polish anticlinorium, and of warm and humid climatic conditions prevailing at the turn of the Cretaceous and the Tertiary (*cf.* Cieśliński 1965). Thus, during the uplift of the anticlinorium, the formation and transport of detrital material must have been controlled to a large extent by profound chemical weathering, and by low geomorphological gradients. On the other hand, the absence of conglomerates suggests that no intermittent phases of short but rapid uplift were superimposed on the generally slow rise of the anticlinorium.

From the above it follows that the rising Middle-Polish anticlinorium was never much elevated topographically against the neighbouring areas, because its uplift was largely compensated by erosion. No lofty mountain chain stretched across the area of Poland during Early Tertiary time.

General problems concerning the Middle-Polish anticlinorium

The Middle-Polish anticlinorium and the preceding Danish-Polish trough can be classified as epiplatformal geotectonic units. The Danish--Polish trough can be termed an aulacogen (Khain & Slavin, *in* Sollogub & al. 1971).

The tectonic structures within the Middle-Polish anticlinorium, which are most commonly developed as unilateral or bilateral boxfolds, resulted from block movements in the substrate (Dadlez & Marek 1969, Znosko 1969, Kowalczewski 1971, Stupnicka 1971). They are a result of tectonic displacement on high-angle reverse and normal faults. This does not imply, however, that compressional conditions did not exist then in some deeper layer of the Earth. As argued by Pożaryski (1964), the Danish-Polish trough developed most probably under predominant tensional conditions, whereas the Middle-Polish anticlinorium under compressional ones.

In the zone of the Middle-Polish anticlinorium, the thickness of the earth crust is great (45—48.5 km), as compared to that (30—36 km) in the adjoining areas (Guterch 1968). A similarly thick crust underlies the Donbass area, which also underwent tectonic inversion, whereas farther northwest, within the noninverted Donets-Dnieper aulacogen, the crust is relatively thin (Subbotin, Sollogub, Chernook, Khain & Slavin, *in* Sollogub & al. 1971). This, and other facts discussed by the above authors substantiate the opinion that a relatively thin crust underyling the Danish -Polish trough (aulacogen), was considerably thickened during its tectonic inversion.

The whole Middle-Polish anticlinorium was formed at the same time as a result of the tectonic inversion of the Danish-Polish trough, the amplitude of uplift being similar in all parts of the anticlinorium. This suggests that the whole zone of the Middle-Polish anticlinorium, from the Baltic sea up to the Carpathians, was subjected to tectonic forces similar in intensity and character during the Laramide tectogenesis.

At present, some regional variation in the structural effects of the Laramide tectogenesis can be recognized along the Middle-Polish anticlinorium. For instance, the Mesozoic rocks seem to be tectonized more strongly in the Holy Cross Mts, than in the parts of the anticlinorium situated farther north. On the other hand, halokinetic disturbances are confined to the parts of the anticlinorium embraced within the German--Polish syneclise. Such differences can be regarded as being a result of the arrangement of pre-existing deep-seated fractures, the distribution of the Zechstein evaporates, the different thickness and lithic composition of the Permo-Mesozoic cover in the particular areas, and similar factors.

The age of the Laramide tectonic structures in the Holy Cross Mts

On the southern slope of the Holy Cross Mts and farther south, folded Mesozoic deposits, the youngest Early Maestrichtian in age, are unconformably overlain by Miocene (Tortonian) sediments. Accordingly, the tectonic movements, responsible for the folding of the Mesozoic strata, are often indiscriminately referred to as Early Tertiary or pre-Miocene. In the northern part of the Holy Cross Mts, however, remnants of Late Eocene or Early Oligocene deposits are known to overlie unconformably the Jurassic and Cretaceous strata (Karaszewski 1966; Ciuk, *in* Osika 1970). Moreover, the Middle-Polish anticlinorium as a whole, and all its subsidiary structures within, must be regarded as a result of the same tectonic movements. Since the anticlinorium was being formed during Maestrichtian and Paleocene (and Early Eocene?) time, the formation of the Laramide folds in the Holy Cross area must have been restricted to the same time span.

The Paleogene uplift of the meta-Carpathian zone

A marine basin stretching NW-SE persisted northeast of the rising Middle-Polish anticlinorium in the Maestrichtian and Paleocene. During Miocene and Pliocene time, the sedimentary basins of the Polish Lowland displayed a clearly different paleogeographic pattern; they stretched E-W, displaying an extension to the south in Western Poland (Fig. 1). Those existing in the Late Eocene and in the Oligocene showed, in this respect, intermediate features (Areń 1964; Różycki 1967; Ciuk, *in* Osika 1970). Furthermore, no Paleogene or pre-Tortonian Miocene marine sediments occur in Poland within the meta-Carpathian zone, except for some parts of the Lublin Upland.

The Lublin region, which had been embraced within the marine basin existing northeast of the Middle-Polish anticlinorium during Late Maestrichtian and Paleocene time, most probably remained a depressed area for some time after the end of the Paleocene. This region, however, was also subjected to the general uplift of the meta-Carpathian zone. As a consequence Paleocene and uppermost Maestrichtian deposits were removed by erosion from some parts of the Lublin region (*cf.* Pożaryski 1962a).

During post-Paleocene — pre-Tortonian time, the elevated meta-Carpathian zone included the southeastern part of the Middle-Polish anticlinorium (the San anticlinorium and part of the Holy Cross area). Most probably, however, the anticlinorium was not much elevated topographically against the neighboring regions of the meta-Carpathian zone. At the same time, the parts of the Middle-Polish anticlinorium situated farther north were being buried by Tertiary sediments.

Before the Late Miocene, the Precambrian and Paleozoic rocks were exposed at the surface in a belt, stretching from the area of the Paleozoic core of the Holy Cross Mts farther southeast, along the axis of the San anticlinorium (Fig. 1). Thus, the area of the outcrops of Precambrian and Paleozoic rocks considerably exceeded that of the present Paleozoic core.

During Mesozoic time, the intermittent uplifts of the meta--Carpathian zone were, in most cases, accompanied by subsidence in the German-Polish syneclise. The Early Tertiary movements followed the same pattern: when the meta-Carpathian zone was being uplifted, subsidence took place in the area farther north. However, the Polish Lowland was but slightly downwarped, as indicated by small thicknesses of the Eocene, Oligocene and Lower Miocene sediments (Areń 1964). This suggests that the contemporaneous uplift of the meta-Carpathian zone was rather slight, too. The occurrence of extensive Maestrichtian deposits in the Miechów synclinorium and in the Lublin Upland points in the same direction.

Miocene movements

In the Late Miocene, the southern part of the meta-Carpathian zone was downwarped, and covered by marine Miocene sediments and/or the Carpathian Flysch nappes. This part of the meta-Carpathian zone constitutes now the substrate of the Carpathian foredeep and the Flysch nappes. The San anticlinorium, which was also embraced within the downwarped part of this zone, was buried by thick Late Miocene sediments (Fig. 1).

The N part of the meta-Carpathian zone escaped downwarping, and during Late Miocene time it formed a barrier separating the marine basin of the Carpathian foredeep from the basin of the Polish Lowland. This part of the meta-Carpathian zone corresponds to the present belt of the Middle Polish Uplands; it is the meta-Carpathian arch as understood by Nowak (1927). The Holy Cross Mts are embraced within this belt. Thus, they comprise that part of the Middle-Polish anticlinorium which escaped downwarping and burial by Tertiary formations.

At the end of the Miocene, within the elevated Holy Cross area, the Paleozoic core and its Mesozoic margin displayed a diversified relief. The southern part of the area concerned was covered by Miocene sediments. Thus, at that time, all the substantial geologic and geomorphologic features of the Holy Cross Mts were already in existence.

In the Pliocene and Quaternary, relatively extensive Miocene sediments, and to some extent also Mesozoic rocks, must have been removed by erosion from some part of the Holy Cross Mts. Thus, the area of the present Paleozoic core exceeds that one in which the Paleozoic rocks were exposed at the end of the Miocene.

On the southern slopes of the Holy Cross Mts, subhorizontal or but slightly tilted Miocene deposits overlie folded Mesozoic and Paleozoic rocks. This indicates that the Laramide fold structures of the Holy Cross Mts were not significantly modified during Miocene and post-Miocene time.

The tectonic movements of epeirogenic type, to which the Holy Cross Mts were subjected in the Pliocene and Quaternary, will not be dealt with in this paper.

Problem of subsequent troughs

Apart from the Middle-Polish anticlinorium, there are many other structures, that were formed by inversion of preceding epiplatformal troughs. An excellent example is supplied by the "Mangyshlak dislocation system" (Shlezinger 1965). Similar but smaller structures occur in Western Europe (the Weald anticline and its extension in the Boullonais, the anticline of the Pays de Bray, the structures due to inversion of the sedimentary troughs in West Netherlands and Lower Saxony — Voigt 1963). In all those cases, more or less distinct subsequent troughs, bordering the uplifted stuctures, have developed after the inversion of earlier sedimentary basins.

Similar subsequent troughs did not develop on both sides of the Middle-Polish anticlinorium. As argued before, the Szczecin-Łódź-Miechów synclinorium and the Border synclinorium were formed as structural units simultaneously with the Middle-Polish anticlinorium during the Maestrichtian and Paleocene. Before the Maestrichtian, the Cretaceous deposits laid down in the zones of these synclinoria sloped towards the axis of the Danish-Polish trough. The Szczecin-Łódź-Miechów synclinorium was never transformed into an autonomous sedimentary basin. Only the Border synclinorium acted as a sedimentary basin during Late Maestrichtian and Paleocene, forming a shallow foredeep on the northeastern side of the Middle-Polish anticlinorium, towards the ancient East-European platform (or its elevated part).

During Tertiary (post-Paleocene) time, sedimentation in the area of central and northern Poland followed the pattern of the German-Polish syneclise (Fig. 1). As indicated by the thickness pattern of the Tertiary sediments (Fig. 4*B*), no sedimentary troughs, clearly connected with the anticlinorium with respect to their genesis and spatial arrangements, developed in this area after the Paleocene.

The Tertiary history of the Middle-Polish anticlinorium was rather complex. In parts of the Cenozoic, it was subjected to slight uplift, accompanied by halokinetic activity (*e.g.* in Pliocene and Quaternary time — Areń 1964, Znosko 1969). On the other hand, some data suggest that, in the Kujawy region, the Middle-Polish anticlinorium was being downwarped with respect to the Border synclinorium during the Middle Oligocene (*cf.* Areń 1964, Wilczyński & Krażewski 1970).

Northeast an southwest of the Holy Cross Mts and the San anticlinorium, no autonomous sedimentary troughs existed after the Paleocene (Figs 1, 4*B*). The San anticlinorium itself was strongly downwarped in the Late Miocene, during the generation of the Carpathian foredeep.

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OBSZAR ŚWIĘTOKRZYSKI W CYKLU ALPEJSKIM

(Streszczenie)

Góry Świętokrzyskie i antyklinorium dolnego Sanu wchodzą w skład antyklinorium śródpolskiego, stanowiąc zarazem część strefy metakarpackiej, w której utwory permu i mezozoiku posiadały znacznie mniejszą miąższość, aniżeli dalej na północ w obrębie syneklizy niemiecko-polskiej. W obrębie strefy metakarpackiej miąższość pokrywy permo-mezozoicznej wyraźnie wzrasta w stronę Gór Świętokrzyskich i antyklinorium dolnego Sanu (Fig. 5). Wynika stąd, że obszary te wchodziły do końca kredy w skład rowu duńsko-polskiego i następnie uległy inwersji tektonicznej podczas ruchów laramijskich.

W obrębie strefy metakarpackiej, układ miąższości i facji utworów kredy i jury, a zwłaszcza triasu i permu, wykazuje pewne komplikacje w wyniku paleoreliefu oraz ruchów tektonicznych, działających m.in. w postaci ruchów synsedymentacyjnych, podczas permu i mezozoiku. Jeszcze silniej zaznaczyło się oddziaływanie stref rozłamowych, a mianowicie rozłamu świętokrzyskiego, poznańsko-rzeszowskiego (Pożaryski 1971) i strefy brudzowicko-kolbarskiej. Rozłam świętokrzyski, który w obrębie trzonu paleozoicznego Gór Świętokrzyskich stanowi granicę między strefą kielecką i łysogórską, biegnie dalej ku ESE wzdłuż północno-wschodniego brzegu antyklinorium dolnego Sanu, a ku WNW przedłuża się do obszaru Radomska. Strefa położona na północ od rozłamu świętokrzyskiego podlegała silniejszej subsydencji, aniżeli obszar leżący na południe od tego rozłamu, nie tylko w paleozoiku, lecz także w mezozoiku, a zwłaszcza w okresach tworzenia się formacji terrygenicznych (*np.* pstry piaskowiec, lias i środkowa kreda).

Z analizy paleogeograficznej obszaru świętokrzyskiego wypływa wniosek, że podczas górnego permu i mezozoiku nie zaznaczała się tu nigdy elewacja, która odpowiadałaby swym kształtem i wielkością obszarowi obecnych Gór Świętokrzyskich, albo ich trzonu paleozoicznego. W niektórych okresach obszar położony na południe od rozłamu świętokrzyskiego był jednakże wyniesiony w stosunku do położonego bardziej na północ.

Z aktualnych danych tektonicznych wynika, że obszar trzonu paleozoicznego Gór Świętokrzyskich nie stanowił sztywnego bloku podczas tektogenezy laramijskiej, a utwory paleozoiczne tu występujące doznały znacznych deformacji laramijskich. Na obszarze świętokrzyskim, struktury zarówno bajkalskie, kaledońskie, waryscyjskie jak i laramijskie wykazują w strefie rozłamu świętokrzyskiego kierunek WNW-ESE, podczas gdy w strefach rozłamów obrzeżających antyklinorium śródpolskie przeważa kierunek NW-SE. W ślad za Znoską (1962a, 1970), oraz Pożaryskim i Tomczykiem (1968b, 1969) wyrażony został pogląd, że obszar świętokrzyski nie rozwijał się w cyklu waryscyjskim w warunkach geosynklinalnych. Na obszarze tym waryscyjskie deformacje reprezentują typ germański, i były słabsze od młodszych laramijskich.

Podczas ruchów laramijskich, głównie w górnym mastrychcie i paleocenie, w wyniku tektonicznej inwersji rowu duńsko-polskiego powstało w strefie między Bałtykiem a Karpatami antyklinorium śródpolskie. Cała ta strefa uległa mniej więcej równomiernemu wypiętrzeniu rzędu 3 km (w miejscach jednakże, gdzie antyklinorium przecięte jest skośnymi rozłamami, np. w strefie łysogórskiej, wypiętrzenie było nieco większe). Ponieważ pokrywa permo-mezozoiczna miała mniejszą miąższość w strefie metakarpackiej, aniżeli dalej na północ, odsłonięte zostały w antyklinorium dolnego Sanu i w Górach Świętokrzyskich w wyniku erozji utwory prekambru lub paleozoiku, podczas gdy wzdłuż osi bardziej północnych części antyklinorium śródpolskiego jedynie utwory triasu, jury lub dolnej kredy. Brak zlepieńców wśród osadów górnego mastrychtu i paleocenu synklinorium brzeżnego sugeruje, że wypiętrzanie antyklinorium śródpolskiego było w znacznej mierze kompensowane przez erozję. Należy zatem przyjąć, że antyklinorium to nigdy nie tworzyło wyniosłego pasma górskiego. Po paleocenie a przed późnym miocenem, strefa metakarpacka wraz z antyklinorium dolnego Sanu i obszarem świętokrzyskim uległa nieznacznemu wypiętrzeniu, natomiast Niż Polski stał się obszarem subsydencji, która trwała również w późnym miocenie i pliocenie, doprowadzając do pokrycia środkowych i północnych części antyklinorium śródpolskiego utworami trzeciorzędu. W późnym miocenie południowa część strefy metakarpackiej, wraz z antyklinorium dolnego Sanu, została pogrążona i pokryta osadami miocenu rowu przedgórskiego Karpat, a częściowo także płaszczowinami fliszu karpackiego. Góry Świętokrzyskie odpowiadają zatem tej części antyklinorium śródpolskiego, która uniknęła pogrążenia w trzeciorzędzie.

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