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FIELD – GUIDE

of the GEOLOGICAL EXCURSION to POLAND

Edited
by

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1991

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F I E L D - G U I D E

of the geological excursion

to P O L A N D

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MENTE ET MALLEO

21th May - 3rd June 1985

I N T R O D U C T I O N

This geological excursion to Poland has realized as a result of the scientific cooperation and exchange between INSTITUTE OF GEOLOGY AND PALEONTOLOGY, UNIVERSITY OF TÜBINGEN, and INSTITUTE OF GEOLOGY, UNIVERSITY OF WARSAW. The program of the excursion includes presentation of the structures strictly comparable in our two countries, as exemplified by some Paleozoic and Mesozoic sequences of the Holy Cross Mountains, as well as of the structures different in their type of development, as exemplified by the Neogene sequence of the Fore-Carpathian Depression. To make better opportunities for studying the selected sections, this very FIELD-GUIDE is presented to our best colleagues and friends.

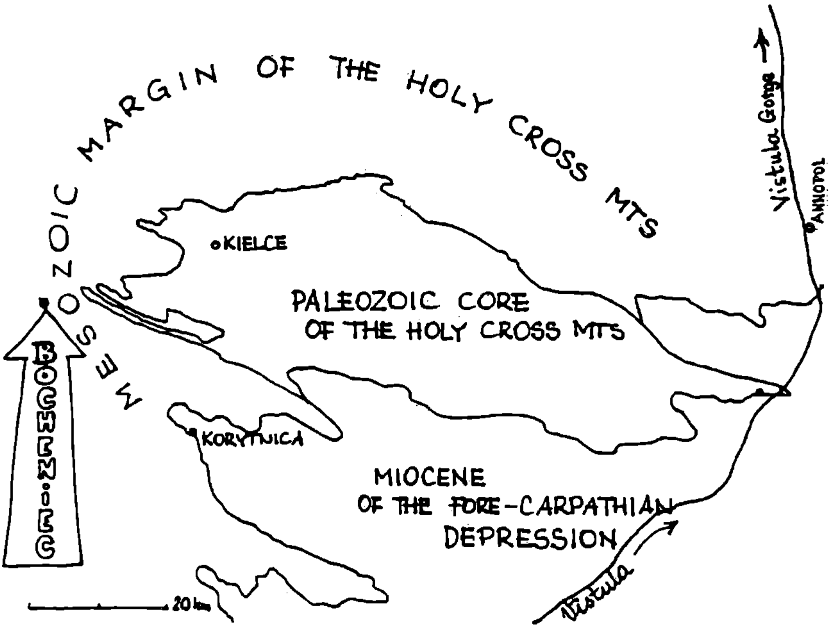


Fig. 1 General location-sketch of the camping place BOCHENIEC in the western part of the Holy Cross Mountains; for detailed geological map see Fig. 11.

C O N T E N T S

AN OUTLINE OF GENERAL GEOLOGY OF POLAND

A. Radwanski

The territory of Poland has undergone a long and differentiated history. The pre-Quaternary is exposed only in the southern part of Central Poland and in the belt of mountain ranges bordering Poland to the south (Sudetes and Carpathians). In Central Poland the exposures are arranged in a zone of uplands (Central Polish Uplands) which embrace from west to east successively: Upper Silesia; Polish Jura (with its southernmost part - Cracow Upland); Miechow Upland; Holy Cross Mts ; and finally the Lublin Upland with its southernmost part being named Roztocze. This zone of uplands repeats the extent of the Carpathian belt, being separated from the latter by the Fore-Carpathian Depression which is filled with marine Tertiary (Neogene) and glacial or alluvial Quaternary deposits.

The Carpathian belt may be subdivided into two large units, *viz.* the External Carpathians consisting of the Mesozoic flysch deposits, strongly folded and overthrust in a series of nappes, and the Internal Carpathians made up of a dozen Variscan granitoid massifs (*cf.* Dewey & *al.*, 1973, Fig. 4) of which only the Tatra Mts are situated in Poland, and which are lined or covered by a full post-Variscan sequence composed of the continental Permian (Verrucano facies) and marine Mesozoic (Lower Triassic through Upper Cretaceous) deposits. This sequence is also folded, and in parts napped, as a result of the Laramide orogenic movements. In some areas the epigeosynclinal furrows were formed in the Internal Carpathians during the Paleogene, as exemplified by the Podhale basin, the sedimentation in which started with the Middle Eocene transgression onto the folded range of the Tatra Mts, and lasted till the Oligocene. This resulted in a 2 km thick flysch series, slightly folded in a synclinorial style. The structure separating the external and internal parts of the Carpathians is the Pieniny Klippen Belt.

The south-western part of Poland is occupied by the Sudetic block which is divided, by a Tertiary (Miocene) fault, into the uplifted part of the Sudetes Mts, and their depressed foreland (Sudetic Foreland).

The Polish Lowland is almost completely covered by Pleistocene glacial deposits, and by Holocene alluvia developed mostly in wide glacial valleys. The pre-Quaternary substrate is exposed here when disturbed by glacitectonic pressure or transport (Tertiary deposits: marine Oligocene of the German type, Miocene brown-coal formation, and terrestrial clays of Pliocene age). Mesozoic deposits occur only in a few places where the substrate has been elevated, and in glacially transported masses ("floes") of which the most famous is that of Lukow which bears Callovian clays containing sideritic nodules with hundreds of extraordinarily preserved and showy ammonites monographed by Makowski (1952, 1962). Another greater floe is that of the Senonian (Upper Campanian/Lower Maestrichtian) chalk at Mielnik-on-Bug (cf. Fig. 3).

From the geotectonic standpoint of the last orogenic movements which belong to the Laramide-Alpine phase, the discussed regions of Poland belong to various units (Fig. 2): Carpathians - to the orthogeosynclinal zone with the Fore-

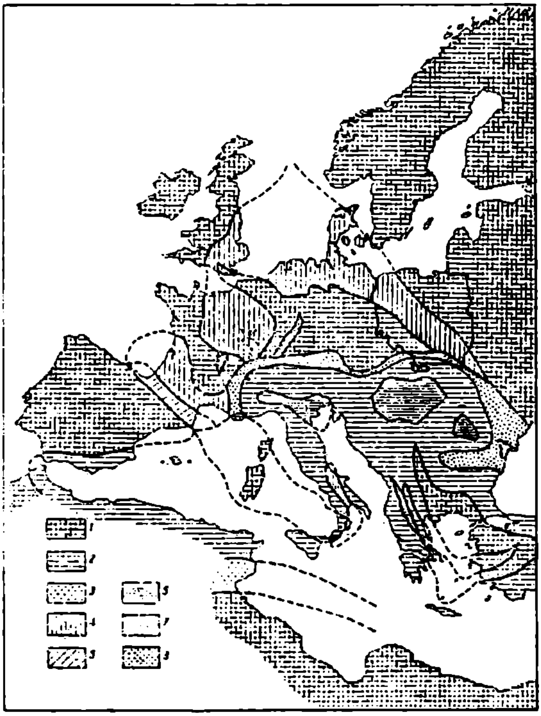


Fig. 2 Geotectonic subdivision of Europe.
1. Stable cratons; 2. Orthogeosynclines (eu- and mio-). 3-8: Parageosynclines.
3. Exogeosynclines; 4. Autogeosynclines;
5. Zeugogeosynclines; 6. Epieugeosynclines;
7. Epimiogeosynclines; 8. Taphrogeosynclines.
(After Kay, 1947)

Carpathian Depression as its exogeosyncline; Sudetic block and NE part of Polish Lowland - to stable cratons, whereas the Lowland pertains to the autogeosynclinal zone that has long been known as the Danish-Polish Trough (cf. Fig. 3).

The two aforementioned Alpine cratons are of different ages.

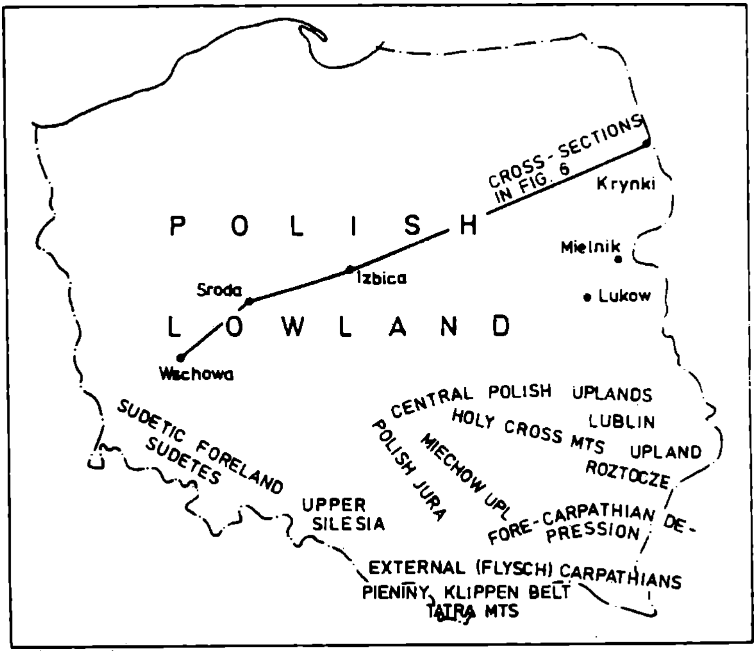


Fig. 3 Division of Poland into geological regions.

although both of them contain the oldest formations in Poland. The north-eastern part of Poland belongs to the Precambrian Fenno-Sarmatian Shield and, during further geotectonic epochs, it was covered only by platformal (unfolded) Paleozoic and Mesozoic deposits, usually very thin, with considerable stratigraphic gaps, and developed mostly in either terrestrial or shallow-marine but strongly land-influenced facies.

In the Sudetic block (Fig. 4), a fragment of the Precambrian Shield, certainly a part of the Bohemian (Moldanubian) one, is exposed in the Owl Mts (German: Eulengebirge) . The mesozonally metamorphosed rocks (paragneisses, migmatites) represent supracrustal series which in parts were also depressed into the katazone (eclogites, granulites). The Precambrian massif was intensively eroded and supplied clastic material to the **Variscan** geosynclines bordering it, as well as to the epi-Variscan depressions. It was strongly eroded at that time, and locally covered by the platformal Lower Carboniferous (Culm facies). Small patches of the latter deposits have occasionally been preserved in local depressions, whereas the more elevated parts supplied clastic material until the Upper Cretaceous. Further erosion took place only in the uplifted part of the Sudetes; the foreland part was, after a Miocene faulting, covered by various Neogene and Quaternary deposits.

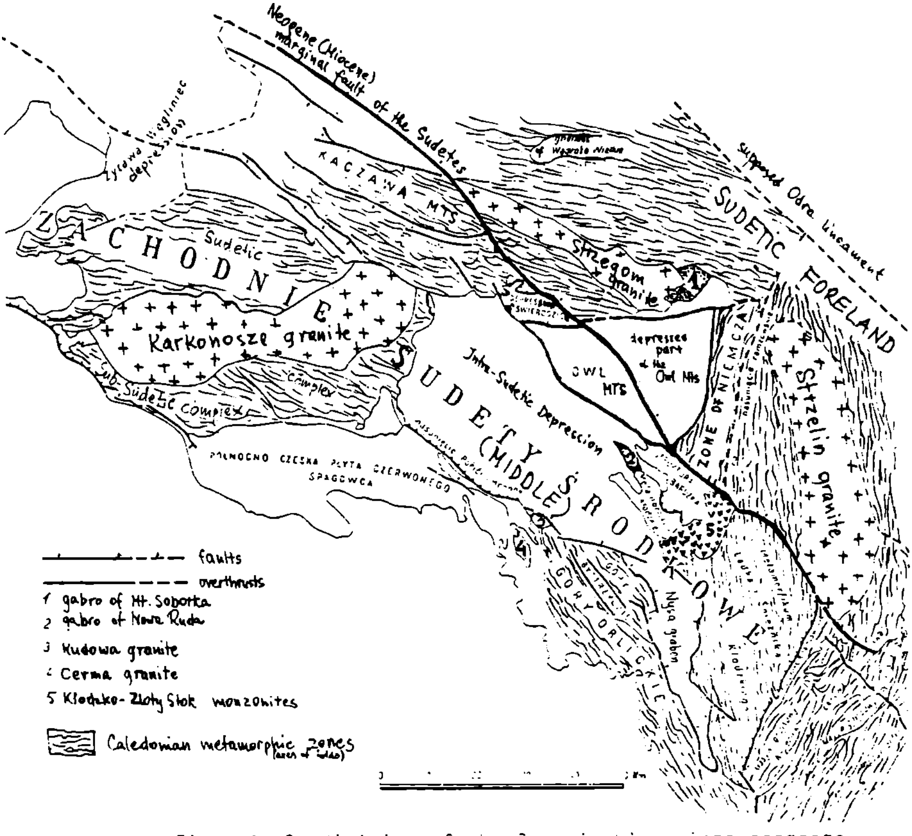


Fig. 4 Subdivision of the Sudetic block into geotectonic units (also recognizable in present-day morphology).

The massif of the Owl Mts itself is regarded as the backbone of the Sudetes, around which Variscan geosynclines developed and yielded more or less complicated folds that line and border the massif. These series (Lower Cambrian through Lower Carboniferous) are epimetamorphosed and exposed at present mostly in the Kaczawa Mts (German: Bober-Katzbach Gebirge). Over some parts of these geosynclinal zones the taphrogeosynclines originated, viz. the Swiebodzice Depression and the very deep Intra-Sudetic Depression. The latter was filled with a few km thick series of Culm, limnic coal-bearing Upper Carboniferous deposits of considerable thickness (Walbrzych and Nowa Ruda coal basins), and finally - by a 1.5 km thick series of Lower Permian effusives (melaphyres and porphyries), agglomerates, tuffs and other pyroclastics, partly intercalated by terrestrial material. These series are faintly inclined in a synclinal style, and covered by platformal Quader sandstones of Cenomanian-Turonian age, and of Saxonian type of development and morphology as to be seen in the Stolowe Mts (German: Heuscheuergebirge).

During the early stages of the Variscan orogeny, the geosynclinal range was strongly invaded by plutonic intrusives, viz. gabbro of the Nowa Ruda and Sobotka massifs (the former with transition to hypabyssal and subvolcanic diabases), monzonites of the Klodzko - Zloty Stok massif, and finally various granitoids as the post-orogenic batholits. The latter are exposed in the following massifs: 1) Karkonosze Mts (German: Riesengebirge - therefore in some English translations Giant Mts), 2) Strzegom-Sobotka with famous drusy pegmatites at Strzegom (German: Striegau) containing more than 50 pneumatolytic and hydrothermal minerals described previously by Schwantke (1896) and Gürich (1915), and more recently by Michell (1941), 3) Strzelin, and 4) two small intrusions at Kudowa and Cerma. The regional setting of all these intrusives around the Intra-Sudetic Depression (cf. Fig. 4) supports a new interpretation, offered by Krebs & Wachendorf (1973), of the Paleozoic central European basement and its development as resulting from vertical rises of buoyant magmas produced by differentiation in the upper mantle, while these upward movements were compensated isostatically by the subsidence of adjacent sedimentary troughs. This is however not the place to discuss the position of the Sudetes and their particular subregions within the so-far distinguished zones of Variscan orogenic belt, as the recent opinions on this subject are much diversified (cf. Dorn, 1960; Aubouin, 1965; Zwart, 1967; Dvorak, 1973; Oberc, 1972, 1973; Krebs & Wachendorf, 1973).

The Sudetic block, inactive during the Mesozoic, was strongly disturbed again during the Alpine movements recorded by faulting, followed by volcanic (mostly basaltic) activity that developed particularly in the Sudetic Foreland. This zone of extrusions continues to the west, along a far Alpine-forebelt, through Lusatia and northern Bohemia, Vogelsberg and Rhineland (Siebengebirge, Eifel, Kaiserstuhl), as far as Auvergne in the Massif Central (cf. Aubouin, 1965, pp. 98-99).

In the Sudetic region, the largest post-Variscan depression developed off the eastern part of the Sudetes. It is the Upper Silesian exogeosyncline (or Subvariscan Foredeep sensu Krebs & Wachendorf, 1973), filled with a 7-8 km thick series of Culm and Upper Carboniferous (to Westphalian) deposits; the latter consist of a paralleltype coal-bearing sequence (Upper Silesian coal basin with 447 coal measures in the west, and 105 in the east, of which the Reden Measure up to 28 m is the thickest). This Carboniferous sequence is slightly synclinally inclined (more disturbed at the Sudetic margin) and covered by platformal deposits of the uppermost Carboniferous (Stephanian), almost an entire Mesozoic succession (but with stratigraphic gaps), and Tertiary (Neogene) marine deposits of the same sea which invaded the Fore-Carpathian Depression from the Vienna Basin. The Alpine tectonics resulted, in Upper Silesia and the neighbouring Cracow Upland, in the Germanotype faulting which also introduced the ore-bearing hydrothermal solutions. They produced zinc-lead ores, usually screened by the Middle Triassic (Muschelkalk) carbonates, as seen in the Bytom and Olkusz mining regions (*cf.* Gorecka, 1972, 1973).

All the remaining parts of Poland may be regarded as belonging to the Danish-Polish Trough (*cf.* Fig. 2), the development of which began in post-Variscan time. Little is known of the Variscan substrate which has been deeply subsided and covered by a 6-8 km thick series of deposits, and therefore it is rarely reached by boreholes. The Trough itself is filled with a full sequence of Permian (mostly Zechstein) up to the uppermost Cretaceous deposits. Their remarkable thickness is greatest along a rather narrow zone which signifies the axis of the Trough (*vide* Fig. 5 - *A*, *B*, *C*, *D*, *E*, but not *F*).

The discussed axis of the Trough evidently parallels the SW margin of the Fenno-Sarmatian Shield (*cf.* Figs. 5 and 2), and it supposedly reflects the zone of deeper fractures, maybe of rift character, both in the Earth crust and upper mantle (Guterch, 1968, 1970). A tectonic uplift along this axis took place in the Maastrichtian, resulting in the formation of the Middle Polish Anticlinorium (Fig. 6) which had divided the Trough into the Szczecin-Lodz-Miechow Synclinorium, and the Danish-Polish (Gdansk-Warszawa-Lublin) Synclinorium, the latter being recently called the Border Synclinorium (Kutek & Glazek, 1972), as it borders the Fenno-Sarmation Shield in the west. In this synclinorial zone, comprising the Danish Embayment area sensu Larsen (1966), the recessive sea continued as late as the Upper Danian (*cf.* Hansen, 1970), the stage being represented by marine deposits in this zone both in Denmark and in Poland (the only exposure in Poland at Kazimierz-on-Vistula). The elevated zone of the Middle Polish Anticlinorium corresponds in Denmark to the Ringkøbing-Fyn-High (*cf.* Larsen, 1966, Fig. 1).

It is noteworthy that the direction of the discussed axis that parallels the Fenno-Sarmatian border, determines only the zone of maximum subsidence of the basin (Fig. 5), where-

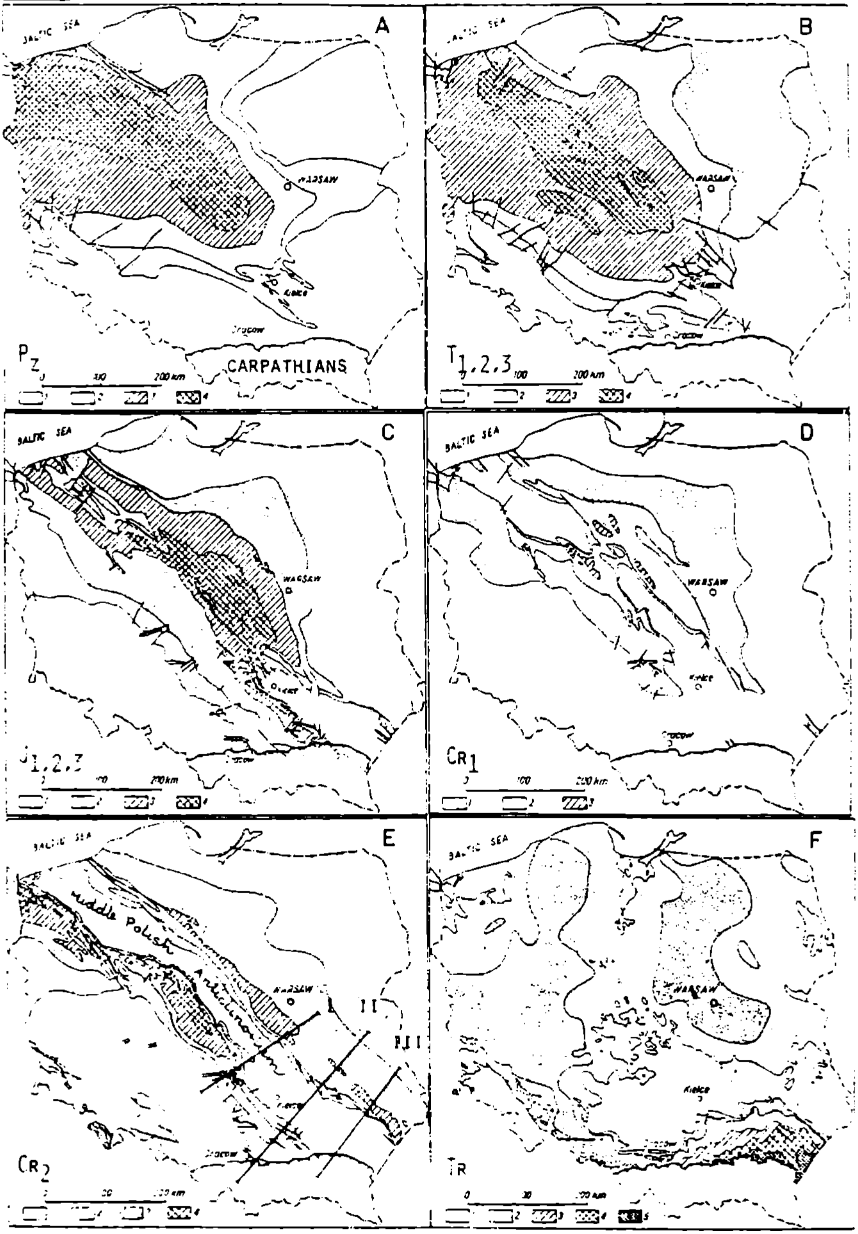

A
BALTIC SEA
WARSAW
Kielce
Cracow
Pz
0 100 200 km
CARPATHIANS
B
BALTIC SEA
WARSAW
Cracow
T1,2,3
100 200 km
C
BALTIC SEA
WARSAW
J1,2,3
200 km
D
BALTIC SEA
WARSAW
Kielce
Cracow
CR1
0 100 200 km
E
BALTIC SEA
Middle Polish Anticline
WARSAW
Cracow
CR2
F
BALTIC SEA
WARSAW
Kielce
Cracow
TR

Fig. 5 Thickness of particular members of the Post-Variscan cover in Poland.

A. Zechstein: 1.0-200m, 2.200-500m, 3.500-1000m, 4.over 1000m.

B. Triassic: 1.0-500m, 2.500-1000m, 3.1000-2000m, 4.over 2000m.

C. Jurassic: 1.0-500m, 2.500-1000m, 3.1000-2000m, 4.over 2000m.

D. Lower Cretaceous: 1.0-200m, 2.200-500m, 3.over 500m.

E. Upper Cretaceous: 1.0-500m, 2.500-1000m, 3.1000-2000m, 4.over 2000m.

F. Tertiary: 1.0-100m, 2.100-500m, 3.500-1000m, 4.1000-2000m, 5.over 2000m.

I,*II*,*III* in Fig. 5 *E*: Lines of cross-sections presented in Fig. 7. (Adopted from Kutek & Glazek, 1972)

as the facies distribution and the paleogeographic trends during marine invasions were controlled by a latitudinal direction of the German-Polish Basin (Central European Basin sensu Kölbel, 1968), as is clearly shown by successive, eastwardly extending transgressions of the Zechstein, Triassic (Röt-Muschelkalk), Lower Jurassic (Pliensbachian and Lower Toarcian only), Middle & Upper Jurassic, Neocomian (Valanginian and Hauterivian), Albian-Cenomanian till the Danian, and finally of the Oligocene. The southward extent of some deposits is visible to have been controlled by that very direction e.g. in Liassic lacustral or floodplain series, Neocomian transgression, and in first stages of the Albian transgression (*cf.* Fig. 8).

The last of the discussed transgressions (Oligocene) took place after folding of the Danish-Polish Trough (*cf.* Fig. 5 *F*), i.e. after the formation of the Middle Polish Anticlinorium, and therefore it is evidence of further crustal mobility along the direction of the Central European Basin; the mobility was not interrupted during uplift of the Trough. In places of intersection of these two directions, i.e. along the zones of greatest flexibility, the Zechstein

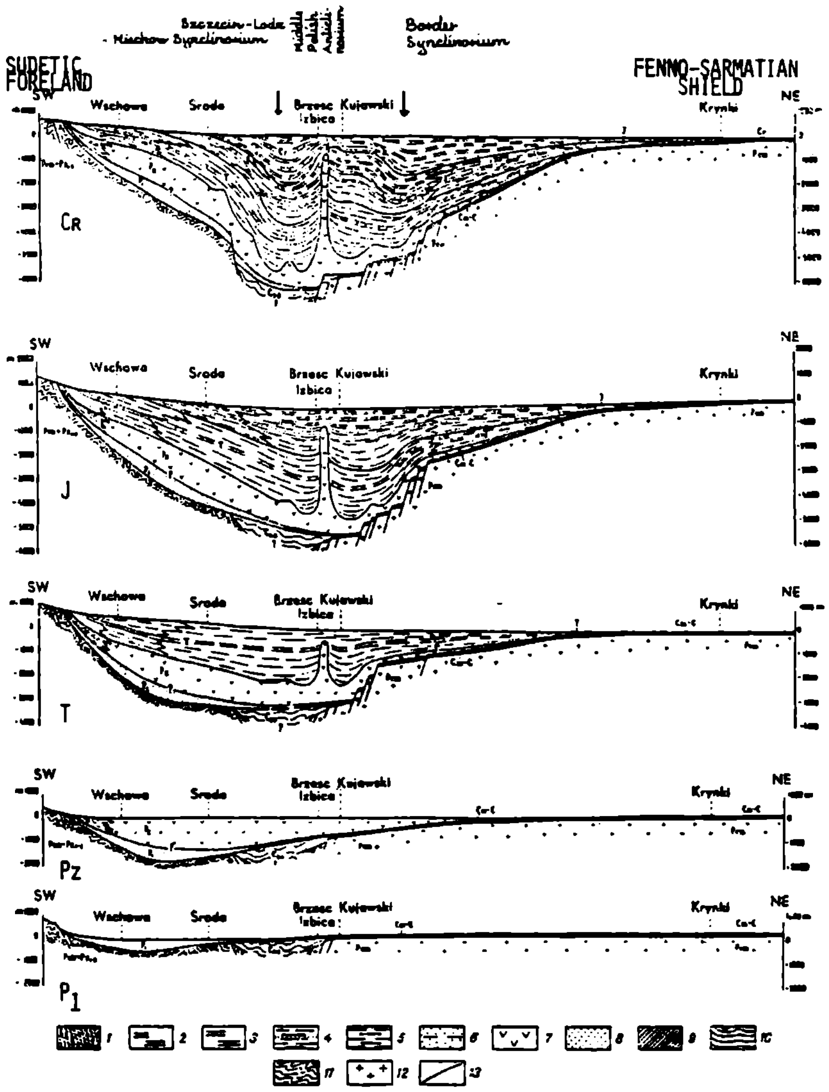

Szczecin-Lodz
Miechow Synclinorium
Border Synclinorium
SUDETIC FORELAND
FENNO-SARMATIAN SHIELD
SW
NE
Wschowa
Sroda
Brzesc Kujawski
Izbica
Krynki
CR
J
T
Pz
P1

Fig. 6 Successive developmental phases of the Danish-Polish Trough and Middle Polish Anticlinorium.
P_1. Lower Permian; P_z. Upper Permian (Zechstein); T. Triassic; J. Jurassic; Cr. Cretaceous.
1. Sand and sandy clay; 2. Limestone; 3. Marl; 4. Fine-grained clastic deposits (clay, shale, siltstone); 5. Claystone; 6. Sandstone intercalated by claystone; 7. Evaporites; 8. Coarse-grained clastics; 9. Platformal deposits of the Fenno-Sarmatian Shield; 10. Variscan exogeosyncline; 11. Sudetic block; 12. Crystalline substrate of the Fenno-Sarmatian Shield; 13. Deep faults. (Adopted from Pietrenko, 1961)

evaporite deposits, mostly halite, were able to move upwards in shape of more or less individualized diapirs. The sedimentological data show that the diapirs started to penetrate the overlying deposits as early as in the Upper Triassic (cf. Fig. 6), thus also confirming permanent active lines of the Central European Basin.

To the axial zone of the Danish-Polish Trough also the Holy Cross Mts belong (cf. Figs. 3 and 5). Their miogeosynclinal Variscan deposits are exposed by erosion which followed their maximal uplift. This latter has however been caused not only by the uplift of the Middle Polish Anticlinorium, which was insufficient to expose the Variscan series (cf. the thickness of Mesozoic deposits being removed - Fig. 7), but also by another uplift, viz. the circum-Carpathian one. The intersection of the two uplift zones resulted in successive processes of elevation and degradation that have directly led to the denudation of Paleozoic series ("core" of the Holy Mts). The restored cross-sections through the Holy Cross region during Mesozoic time (Figs. 7 and 8) evidently show that neither a land nor a submarine ridge existed at that time: the Variscan orogeny of the Holy Cross Mts had strongly been subducted along the Danish-Polish Trough.

The uplift of the circum-Carpathian zone at the northern

HOLY CROSS MTS

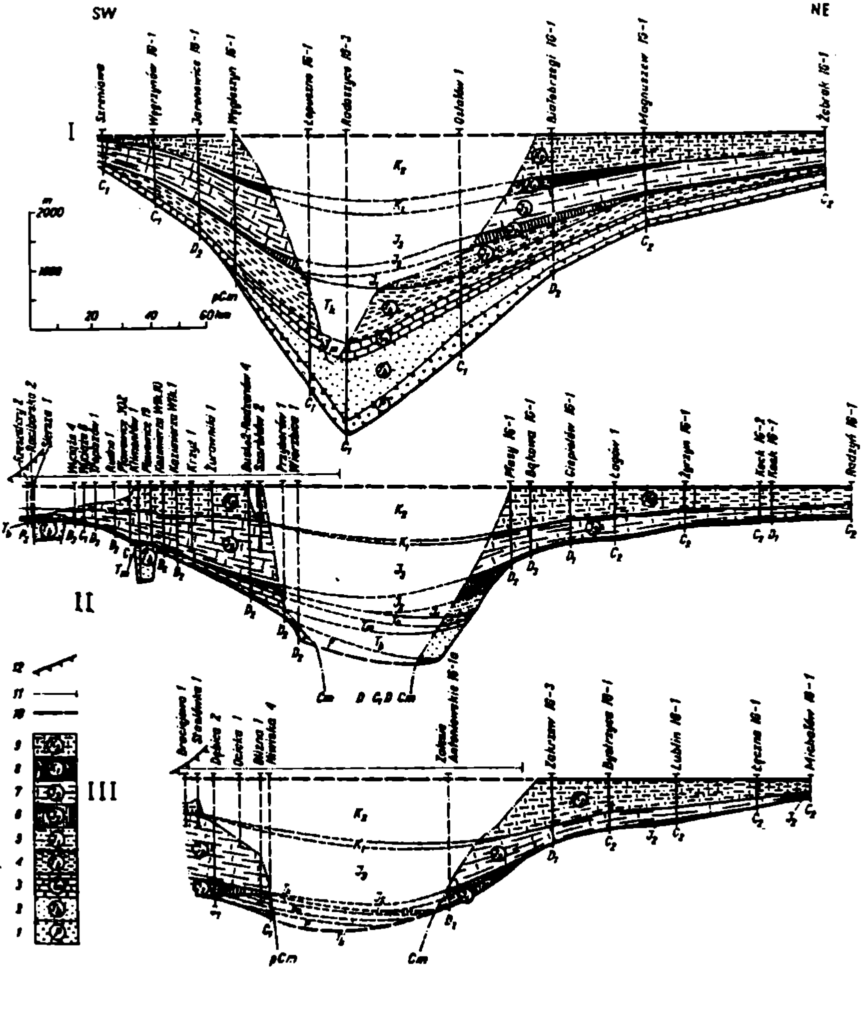


Fig. 7 Restored cross-section southwest and northwest of the axial part of the Holy Cross Mts. (Section lines indicated in Fig. 5 E).
Pre-Permian substrate: pCm. Precambrian (Late Proterozoic); Pz. Paleozoic; Cm. Cambrian; S. Silurian; D. Devonian (D_1. Lower, D_2. Middle, D_3. Upper); C. Carboniferous (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. (From Kutek & Glazek, 1972)

margin of the Fore-Carpathian Depression may be regarded as isostatically corresponding to the subsidence of the Depression. This uplift is responsible for the formation of the Central Polish Uplands which are arranged in a curved belt that repeats the outline of the Carpathian front and foredeep (cf. Fig. 3).

The detailed history of the Holy Cross Mts and their neighbouring uplands (from eastern part of Upper Silesia through Lublin Upland and Roztocze) which all belong in their geotectonic heritage to the Danish-Polish Trough, will be presented in separate chapters of this Volume. The same goes for the history of the marine Neogene (Miocene - only Tortonian stage) transgression that extented into the Fore-Carpathian Depression, and also for the history of the Carpathians.

Concerning the Carpathians, it may be stressed here that nappe zone of the External (flysch) Carpathians, at present about 60 km wide, represents a zone of at least 100-150 km within its sedimentary basin (cf. Swidzinski, 1971). The Pieniny Klippen Belt, few km wide and comprising a series of separate nappe units, must represent a few dozens of km respectively (100 km according to Sikora, 1971). If we also take into account the overthrust of both facially and tec-

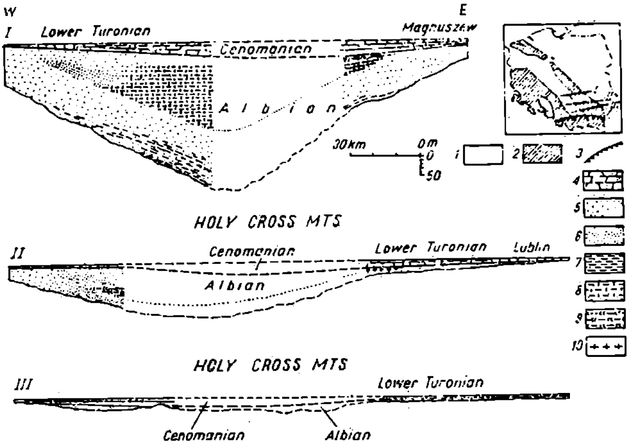


Fig. 8 Restored cross-section through the Albian and Cenomanian deposits preserved along both sides of the Middle-Polish Anticlinorium; visible is the extent of first transgressive deposits of the Albian to have been controlled by the latitudinal direction of the Central European Basin.
1. Epicontinental Cretaceous deposits; 2. Older deposits and Carpathian flysch; 3. Northern margin of the Carpathian nappes; 4. Marls; 5. Sands; 6. Sandstones; 7. Clays; 8. Gaizes; 9. Spongiolites; 10. Phosphorites. (From Kutek & Glazek, 1972)

tonically differentiated sedimentary series of the Internal Carpathians, the Tatra Mts including, the total value of the horizontal shortening of the Earth crust must be evaluated in this part of Europe as not less than about 300-350 km. Such a distance matches with the southernmost part of the Carpathian geosyncline to the centre of the Pannonian Depression, Neogene in age (at present the Hungarian Plain), and filled with a series of lacustral or brackish clays that attain the thickness of 7-8 km. This is a typical internid depression within the orogenic belt, and it may be inter-

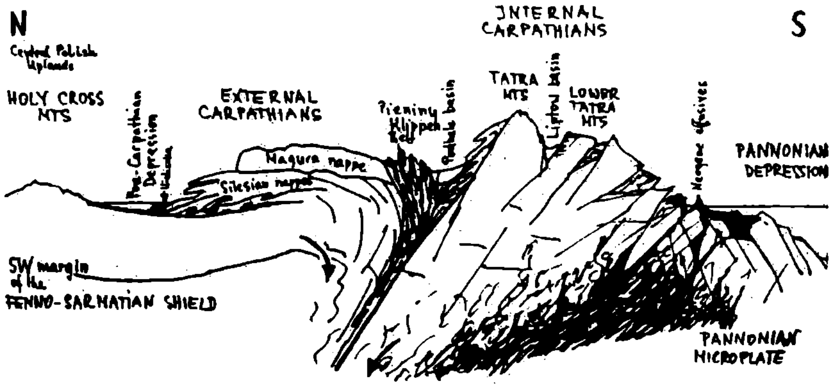
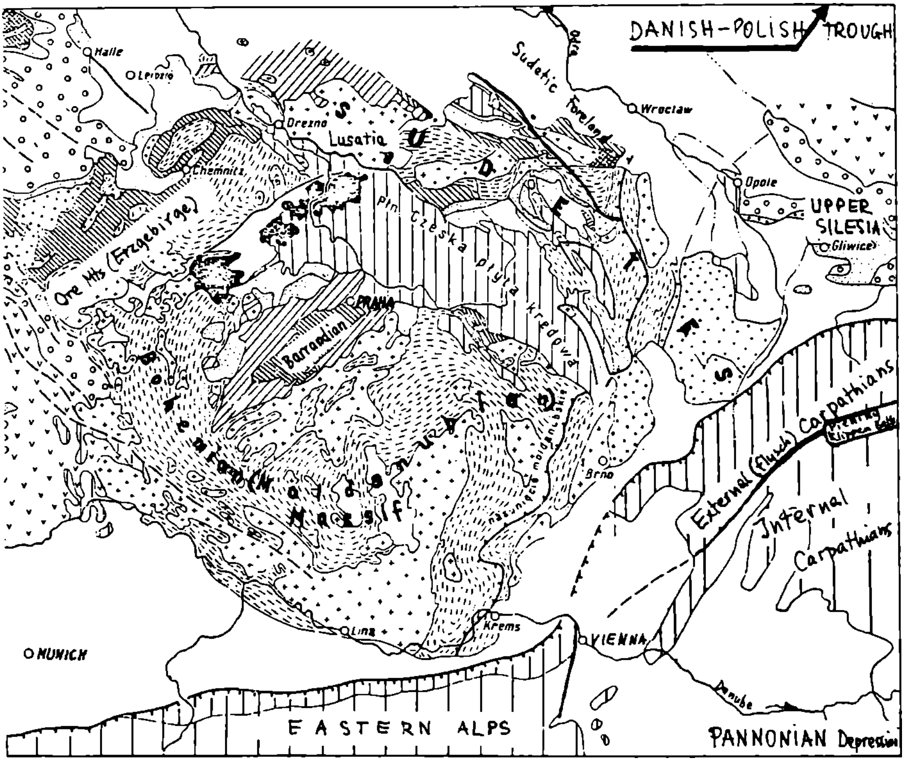


Fig. 9 Idealized sketch of the discussed regions being under conditions of the collision of continental plates.

preted as an area of a strong fracturing, dissemination and depressing of the Earth crust. All these processes were accompanied by strong volcanism at the margins of the depressed basin which was still active in the Quaternary (Tihany upon the Balaton Lake). The dissemination of the crust which resulted in a separation of the Variscan granitoid massifs (one of them being the "core" of the Tatra Mts) previously united, may be regarded as an effect of plate tectonics. In such a case, a nappe overthrust of the Carpathians is the result of collision of the two continental plates, *viz.* the Fenno-Sarmatian Shield and the Pannonian microplate that moved northwardly during the Alpine orogenic movements (*cf.* general idea in Dewey & *al.*, 1973). The margin of the Fenno-Sarmatian Shield is recognizable as far as the axial zone of the Danish-Polish Trough (*cf.* Figs. 6 and 9), the inversion of which into the Middle Polish Anticlinorium may supposedly be a distal effect of the discussed collision. The dissemination of the Pannonian microplate and the following plate collision simply explains an abrupt fracturing and eastward truncation



Regional units:

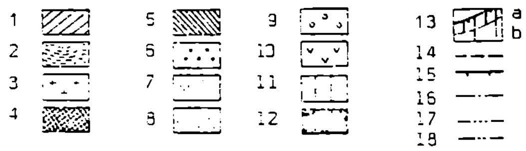


Fig. 10 Tectonic sketch of a part of Central Europe, demonstrating a mutual relationship of the Alpine-Carpathian belt, Bohemian (Moldanubian) Shield and Danish-Polish Trough.

1. Precambrian in the Barrandian; 2. Precambrian and strongly metaphosed older Paleozoic; 3. Granitoids; 4. Gabbro and serpentinites; 5. Older Paleozoic; 6. Lower Carboniferous (partly also Upper Devonian); 7. Upper Carboniferous; 8. Permian; 9. Triassic; 10. Jurassic; 11. Upper Cretaceous; 12. Tertiary basalts; 13. Flysch (a) and internal (b) zones of the Alpine-Carpatian belt; 14. Faults; 15. Overthrusts; 16. Limit of Culm deposits in the Eastern Sudetes; 17. Limit of Jurassic deposits of the Polish Jura; 18. Limit of Cretaceous deposits in the Opole area.

both of the Austrian Alps and Bohemian Massif, a northward displacement ("push") of the Carpathian range in relation to the Alps (cf. Fig. 10), as well as enormously strong folding, diapiric squeezing and brecciation of the Pieniny Klippen Belt confined to the contact zone of the plates being under the collision. Under such circumstances the role of the Pieniny Klippen Belt as the scar healing a deep lithospheric fracture between the Internal and External Carpathians is fully understandable (Fig. 9).

The regional pattern of all the discussed structures situated in the territory of Poland is presented in Fig. 10 that comprises a fragment of Central Europe from the Pannonian Depression in the south as far to the north as the southern margins of the Danish-Polish Trough.

H O L Y   C R O S S   M O U N T A I N S

B. A. Matyja and A. Radwanski

The Holy Cross structure is composed of:

(1) the Paleozoic core,

(2) the Mesozoic margins.

Within the Paleozoic core exposed are both the Variscan folds and their post-orogenic cover of Permian (Zechstein) age. The latter continues, with a presumed stratigraphic gap, into the Lower Triassic (Buntsandstone) series which begins the Laramide sedimentary cycle, recognizable fully within the Mesozoic margins on the northern and southern slopes of the Holy Cross Mountains.

The Variscan orogenic belt of the Holy Cross Mountains is composed of the series of folds (Figs 11 and 12), the anticlinal parts of which display the Cambrian deposits at the present-day surface, and are the best pronounced in morphology (see Fig. 12).

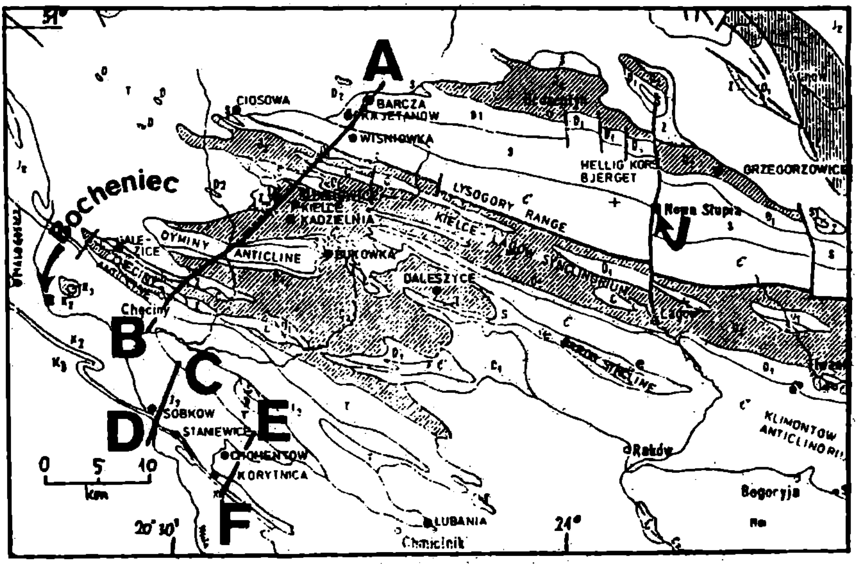


Fig. 11 Geological sketch-map of the western Holy Cross Mts.

A - B denotes the section presented in Fig. 12
C - D denotes the section presented in Fig. 34
E - F denotes the section presented in Fig. 57

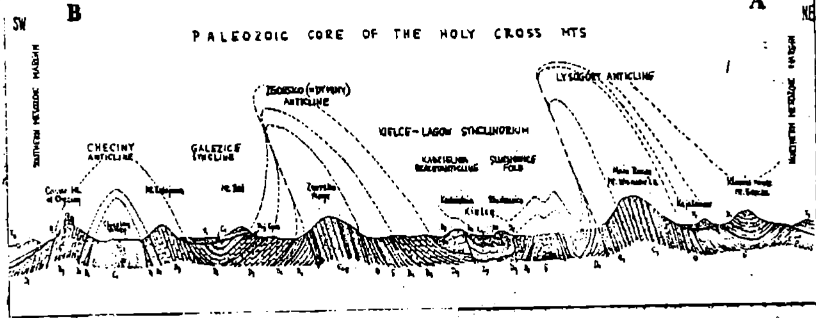


Fig. 12 Geological section through the Holy Cross Mts (for the section line A - B see Fig. 11).

CAMBRIAN

The Cambrian sequence of the Holy Cross Mts is developed as a thick(slightly over 2000 m), continuous series of fine-grained clastic deposits (Fig. 13 A; references in Orlowski, Bednarski & Radwanski, 1970). Finer-grained clastics, mostly shales and siltstones predominate in the Lower Cambrian; these are unresistant to weathering (see Checiny Valley along the axis of the Checiny anticline - Fig. 12). In the Middle and Upper Cambrian, the series with thick layers of quartzites are the most resistant, and they make up the most elevated parts of the Holy Cross Mts, namely the Main(=Lysogory)Range(cf. Figs 11 and 12). These quartzites form also the "block screes" along the Main Range, and they resulted from periglacial weathering during the Riss and/or(?) Würm glaciation. The quartzite-bearing series is the best exposed at the locality Wielka Wisniowka in the western part of the Main Range.

Fig. 13 B

"Block screes"(Blockmeer) along the northern slopes of the Lysogory Range.

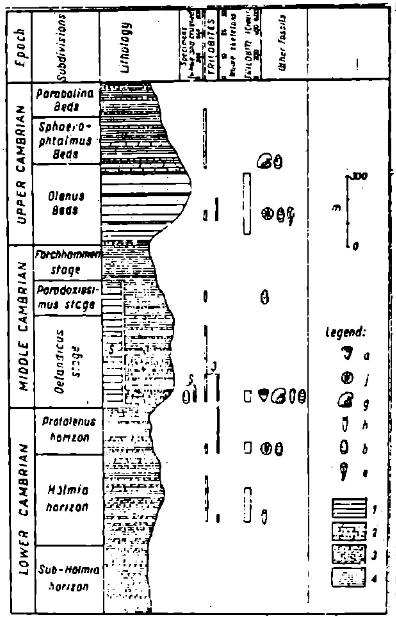


Fig. 13 A

Cambrian sequence of the Holy Cross Mts, including the frequency of trilobites, and of the trilobite traces(ichnia).

Associated fossils: a archaeocyathids, j jellyfish, g gastropods, h hyolithids, b brachiopods, e eocrinoids

Lithology: 1 quartzitic sandstones, 2 sandstones, 3 siltstones, 4 shales.

Fig. 13 C

General view of the quarry wall at Wielka Wisniowka to show the topsides of the layers featured by diverse types of ripplemarks.

Locality: Wielka Wisniowka

This is the name of a large quarry situated on the toppart of Mt. Wisniowka, in which Upper Cambrian quartzite series is exposed. The series belong to the Olenus Beds of the lower part of the Upper Cambrian (cf. Fig. 13 A), and it is the most thick-bedded and resistent part of the Cambrian sequence (cf. Fig. 13 A, and section in Fig. 12).

In the quarry visible is a c.350 m thick part of of the series, composed of quartzite layers intercalated with more of less distinct sets of silt- and claystones, the majority of which display their topside featured by various sedimentary structures formed by current and/or wave action. Especially well developed are diverse ripplemarks (Fig. 13 C, D, E) indicative of sedimentary conditions typical of the shallow subtidal zone (cf. references in: Orlowski, Radwanski & Roniewicz, 1970).

The locality is world-famous due to abundant biogenic structures produced by the trilobites, and briefly announced in the following subchapter.

Fig. 13 D

Megaripples, locally transformed into linguoid ripplemarks at Wielka Wisniowka.

Fig. 13 E

Symmetrical oscillation ripplemarks at Wielka Wisniowka.

THE TRILOBITE TRACE-FOSSILS AT WIELKA WISNIOWKA

A. Radwanski

In the Wielka Wisniowka sequence, a great profusion of trilobite traces makes this locality one of the best known and most famous for workers in paleoecology and palichnology. Various tribolite traces which were reported and described from this locality in the last decade (Radwanski & Roniewicz, 1963, 1972; Orlowski, Radwanski & Roniewicz, 1970, 1971) have recently been discussed in a set of papers (Crimes, 1970 a, b; Seilacher, 1970; Osgood, 1970; Birkenmajer & Bruton, 1971; Bergström, 1973b), and it is clear that this occurrence has a bearing on the general knowledge of trilobite mode of life and their behaviour.

The assemblage of traces, i.e. the ichnocoenose, from the Wielka Wisniowka sequence comprises, besides of forms left by trilobites, also traces of life activity of sea anemones - *Bergaueria perata*, polychaetes - *Diplocraterion*, and aglaspid merostomes - *Aglaspidichnus sanctacrucensis* (cf. Radwanski & Roniewicz, 1963, 1967; Alpert, 1973), all of which indicate the general composition of the organic community that inhabited the sea floor in the Wielka Wisniowka environment.

In the discussed trilobite ichnocoenose, four main types (ichnogenera) of trilobite traces may be distinguished (cf. Figs. 15-17), as follows:

1) *Rusophycus* - traces of resting,
2) *Cruziana* - traces of furrowing,
3) *Diplichnites* - traces of walking or striding,
4) *Monomorphichnus* and *Dimorphichnus* - traces of grazing during a sideway motion (similar to that of present-day shore crabs).

All these trace fossils are preserved as hyporeliefs on the underside of quartzitic sandstone layers (Figs. 15 and 16) overlying a clay layer. The original grooves, situated on the topsides of the layers, may be occasionally preserved in finer grained sandstones or siltstones (1 a in Fig. 15), whereas in clay layers these are fully obliterated. The most common trace fossils are the first two of the aforementioned ichnogenera, and they are represented by the ichnospecies *Rusophycus polonicus* Orl., Radw. & Ron., and *Cruziana semiplicata* Salter respectively. All these traces are attributable (cf. Orlowski, Radwanski & Roniewicz, 1970, 1971) to the trilobite species *Olenus rarus* which recently has been suggested (Bergström, 1973b) to belong to a ptychopariid genus.

Morphology of the traces of resting (i.e. *Rusophycus*) corresponds exactly to the morphology of trilobite undersides -

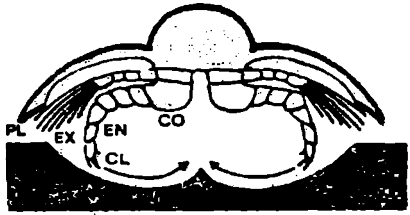


Fig. 14 Section through the trilobite body to show the digging possibility of particular appendages.

CO. Coxa; EN. Endopodite; CL. Claws; EX. Exopodite; PL. Pleural and genal spines. (Adopted from Seilacher, 1970) the imprints of coxae, endo- and exopodites, pleural or genal spines, as well as of claws and of the hypostome, are to be commonly found in most of the specimens (cf. Fig. 14 and explanations for 2 and 4 in Fig. 15). Cephalon imprints are absent and it may therefore be concluded that the trilobites were resting here and quietly shuffling the bottom in a tail-down (opisthocline) position (cf. Fig. 17 a), and thus stretching their heads up, supposedly watching care-

Fig. 15 Various specimens of *Rusophycus polonicus* Orl., Radw.&Ron.;.
1a. An original groove on the sea bottom; 1b. Its infilling, i.e. *Rusophycus* on the underside of overlying layer; 2-5. *Rusophycus* forms of greater dimensions.

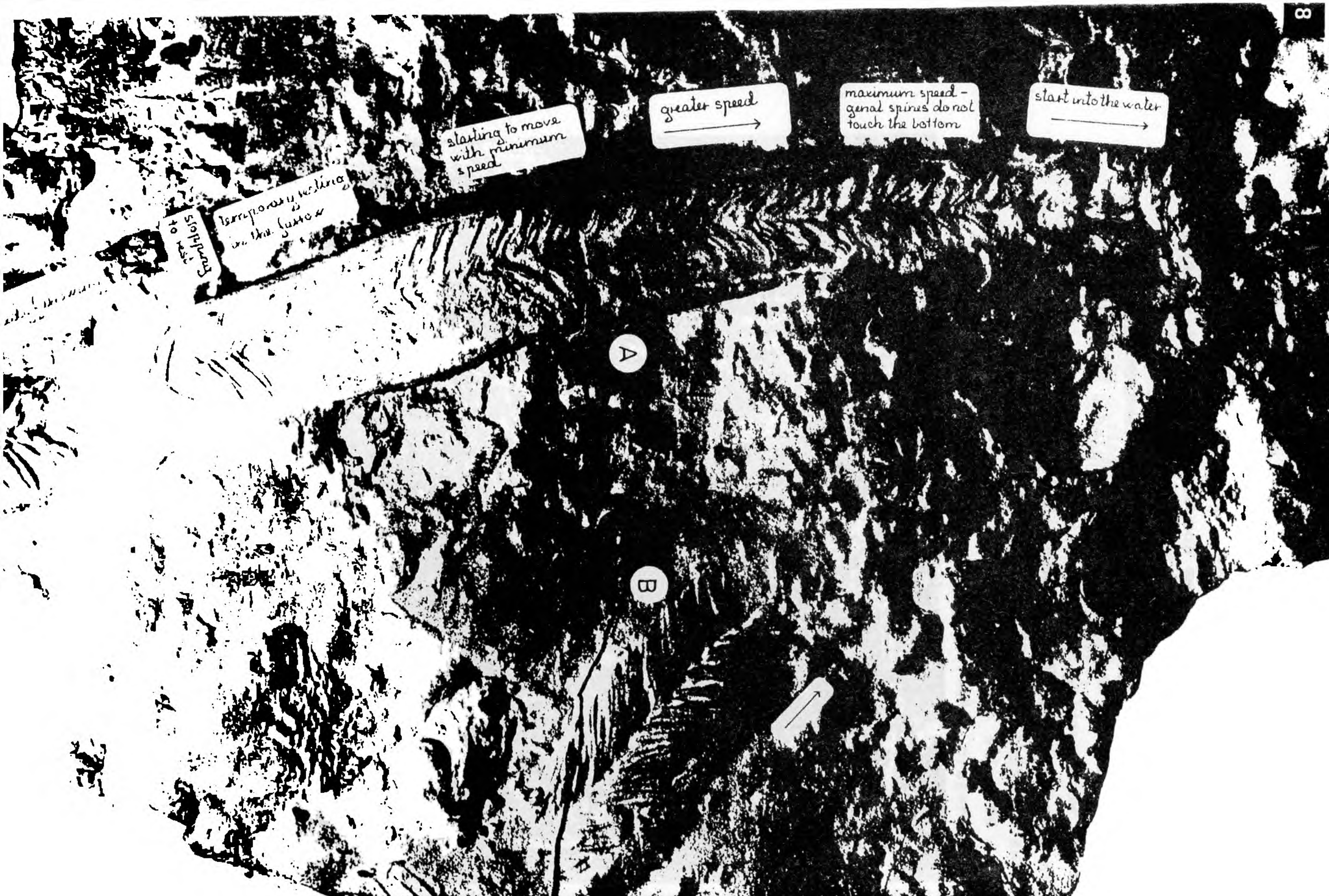

8
start into the water
maximum speed - genal spines do not touch the bottom
greater speed
starting to move with minimum speed
temporary resting in the furrow
stopping to rest
A
B

Fig. 16 Two trackways *Cruziana semiplicata* Salter. Along the longer trackway, an analysis is made of trilobite motion as revealed by traces of their legs (cf. Fig. 17). Double or triple ridges on leg traces correspond to the claws scratching the grooves.

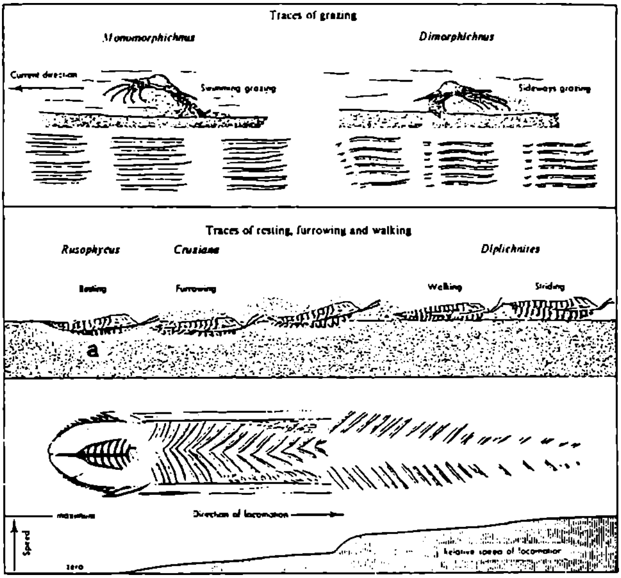


Fig. 17 Methods of trilobite locomotion revealed by various traces (cf. Figs. 15 and 16).
a. Trilobite resting in a tail-down (opistholine) position as explained in the text. (Modified from Crimes, 1970 a)

fully and greedily for a prey.

When moving along the bottom, the trilobites usually furrowed the sediment, and they left the grooves, the infilling of which became the *Cruziana* forms. In these trackways, the zones corresponding to particular parts of the trilobite body may also be recognized (Figs. 44 and 46). In the presented trackways the endopodites and genal spines were mainly responsible for the digging action which resulted from the mode of locomotion of the trilobites (cf. Fig. 47).

As recently shown on various traces (Crimes, 1970 a; Seilacher, 1970; Radwanski & Roniewicz, 1972), the angle at which the legs (endopodites) touched backwardly the midline of the trackway depended on the speed of trilobite locomotion: at a lower speed the angle is broader, and at a greater one it is more acute (Fig. 47). A record of such locomotion by a trilobite is visible in one of the presented trackways (Fig. 46 A) which, regarding its considerable length, corresponds to a few successive actions of the trilobite (cf. explanations along the trackway in (Fig. 46 A). Another, much smaller trackway (Fig. 46 B) represents a short-lived landing of a trilobite on the sea floor and starting up again into the water; along the trackway a gradual lowering of the trilobite speed is apparent when it furrowed the bottom after it had landed (cf. Fig. 47). This trilobite was then furrowing superficially, not imprinting its genal spines, but at a speed sufficient for the next movement into the water.

When comparing the size of traces of resting *(Rusophycus)* and of furrowing *(Cruziana)*, it clearly appears that the *Rusophycus* forms reveal a full set of dimensions from small (but not the smallest) specimens of width less than 1.0 cm, to large ones (presented in Fig. 45), whereas the *Cruziana* forms are only of greater width (average 2.5 - 3.5 cm,(smallest 1.5 cm) and they correspond to trilobites of the largest body size. On the other hand, the *Rusophycus* forms are much more frequent than *Cruziana*. A similar phenomenon is also noted in the Upper Cambrian strata of North Wales where it was interpreted (Crimes, 1970 b) as a result of the changing of trilobite behaviour at different stages of its life: planktic or pelagic after hatching; afterwards swimming and accompanied successively be resting on the sea floor; later walking; and finally furrowing (Fig. 18). Such a chain of ecological requirements explains the structure of the Wielka Wisniowka ichocoenose: no traces of juvenile trilobites; afterwards an appearance of *Rusophycus* attaining greater and greater dimensions; finally, appearance of the *Cruziana* forms attributable to the adults, presumably after their last moulting.

As a whole, the trilobite ichnocoenose from Wielka Wisniowka is very close in its composition to those from other shallow marine, usually strongly water-agitated Cambrian environments (cf. Seilacher, 1970; Crimes, 1970 a, b).

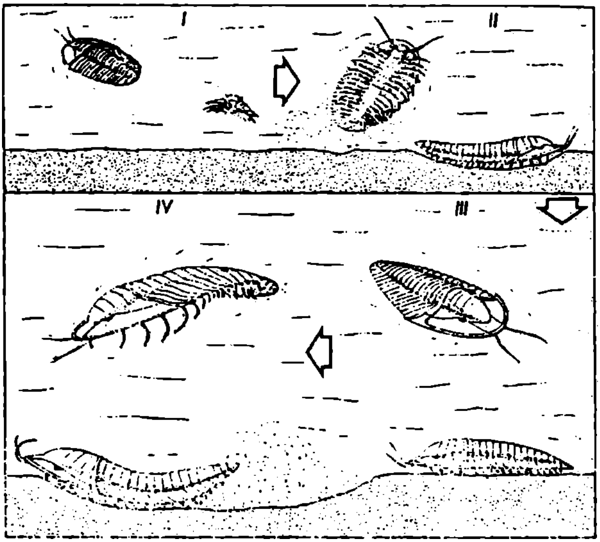
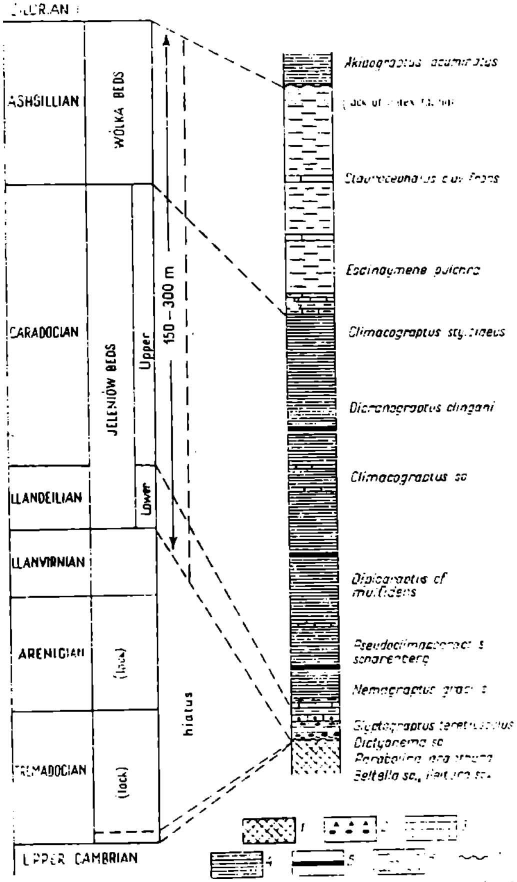


Fig. 19 Main trilobite activities during their life cycle.

I. Swimming stage; II. Resting and swimming; III. Walking and swimming; IV. Adult furrowing and swimming stage. (From Crimes, 1970 b)

ORDOVICIAN

The Ordovician facies in the Holy Cross Mts are diversified in the three areas. In the Lysogory region on the north, and in the Zbrza-Brzeziny area on the south, the argillaceous facies with graptolites dominated. In the central region (Kielce area and Bardo syncline - cf. Fig. 11), littoral facies appeared, and these are represented by sandy and carbonate deposits well exposed near village Mojcza.

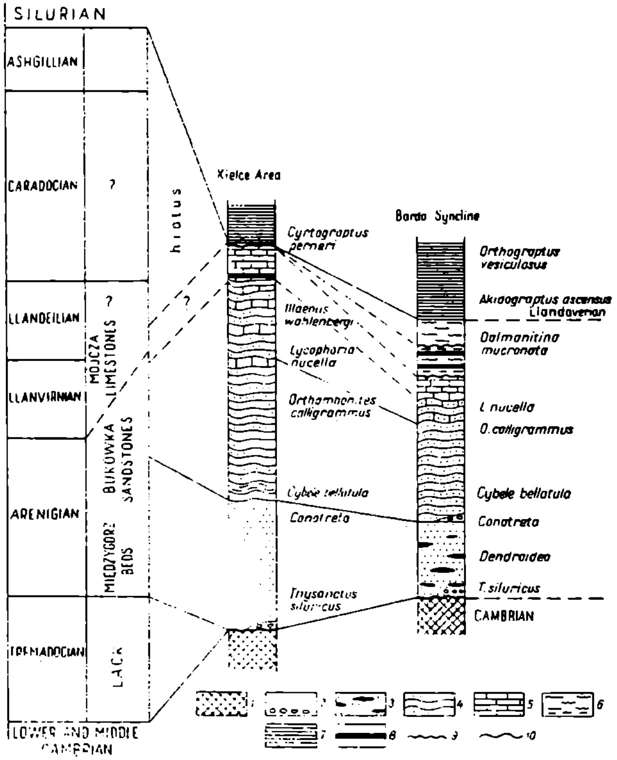


1 — claystones, 2 — oolite and pisolite limestones with chamosite and siderite, 3 — limestones and dolomites, 4 — graptolite shales, 5 — benthonites, 6 — siltstones and marls, 7 — hiatuses

Fig. 19

Ordovician sequence in the northern(Lysogory) region. (After:Tomczyk & Tomczyk)

In the Lysogory region, Upper Cambrian sedimentation continued till the lowest Tremadocian when claystones with Dictyonema sp. were formed (cf. Fig. 19). In the Upper Tremadocian there was a break in sedimentation, resulting from the so-called Sandomierz tectonic phase. Both the central and southern areas probably underwent emersion at that time, and continental erosion reached even as deeply as the Lower Cambrian deposits (cf. Fig. 20 and section of the Checiny anticline in Fig. 12). The Ordovician sedimentation returned at different times in particular regions (cf. Figs 19 - 20) and lasted, with the above-mentioned facies diversity, till the Taconian break appeared and resulted in stratigraphic gaps at the Ordovivian/Silurian boundary.



1 — Lower and Middle Cambrian rocks, 2 — glauconite sandstones and conglomerates, 3 — glauconite sandstones and chalcedonites in places, 4 — Orthis Sandstones, 5 — limestones, 6 — claystones and siltstones, 7 — graptolite shales, 8 — bentonites, 9 — unconformity, 10 — hiatuses

Fig. 20

Ordovician sequence in the central part of the Holy Cross Mts.
(After: Tomczyk & Tomczyk)

Locality: Mt.Skala near Mojcza

At the top part of the hill named Mt.Skala there appear small quarries kept in quartz sandstones belonging to the Upper Arenigian so-called *Orthis* Sandstones, or Bukowka Sandstones(*cf*. Fig. 20, and Bednarczyk 1971, Dzik 1978). Poorly preserved, as limonitized external casts, are diverse brachiopods - *Orthambonites calligrammus*, *Lycophoria nucella*, *Productorthis obtusa*, *Progonambonites inflexus*, and trilobite *Cybele bellatula*.

On the north-eastern slope of the hill, some other small quarries display a condensed sequence of organodetrital limestones(*c*. 8 m thick) which overlie the *Orthis* Sandstones. These sandy limestones contain chamosite ooids, glauconite, and blue-greenalgal onkolites indicative of shallow sublittoral conditions. A thin (*c*. 5 cm) layer of benthonite is visible in the middle part of that condensed sequence. Diverse fauna comprises brachiopods, trilobites, nautiloids, cystoids, and conodonts(*cf*. Bednarczyk 1971, Dzik 1978).

The beginning of calcareous sedimentation falls to the Lower Llanvirian (*cf*. Fig. 20), while its end probably represents the uppermost Caradocian, although the presence of some Ashgillian sediments is not unlikely.

SILURIAN

The Lower and Middle Silurian in the Holy Cross Mts is developed in a monotonous facies of graptolite shales, while the Upper Silurian comprises a thick (up to 2000 m thick) series of greywackes, commonly being regarded as flysch-like deposits connected with the Caledonian disturbances. The total thickness of the Silurian deposits is about 3 km in the Lysogory area, while in central and southern parts of the Holy Cross region it is much reduced (cf. Fig. 21). In that latter region the sequence is well exposed near village Bardo in the Bardo syncline (cf. Fig. 11), especially along the Pragowiec Ravine.

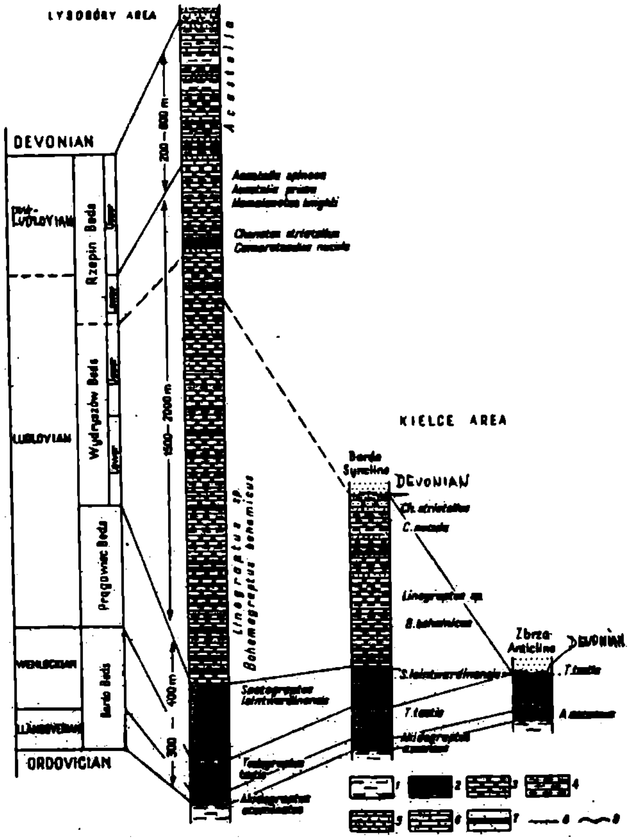


Fig. 21

1 — siltstones and marls, 2 — graptolite shales, 3 — greywackes, 4 — claystones, 5 — sandstones, 6 — limestones, 7 — bentonites, 8 — unconformity, 9 — hiatuses

Silurian sequence in the Holy Cross Mts. (After: H. Tomczyk)

Locality: Pragowiec Ravine

The Pragowiec Ravine is situated north of village Bardo. This is the only place in the Holy Cross Mts where the graptolite shales are well exposed. The graptolite shales contain limy concretions with undeformed graptolites, while in the shales themselves the graptolites are flattened.

Along the edges of the ravine successive parts of the profile are exposed (Fig. 22), and the shales contain rich assemblages of graptolites which indicate the time interval from the Testograptus testis through the Saetograptus leintwardinensis Zone, i.e. from the uppermost Wenlockian up to the Lower Ludlovian (cf. Fig. 21).

At the mouth of the ravine, there appears a diabase cliff exposed from a Variscan sill that reaches the thickness of about 18 m (cf. Fig. 22).

The famous fauna of the graptolite shales contains such diversified fossils as pelecypods Cardiola interrupta, cephalopods (nautiloids), tentakuloids, and various trilobites of which Odontopleura ovata is especially abundant at the Odontopleura Bed (cf. Fig. 22). Except the free-swimming groups, the presence of the named pelecypod Cardiola interrupta and trilobite Odontopleura ovata is ecologically important here. These two species presumably lived as epiplankton, being attached to floating colonies of graptolites.

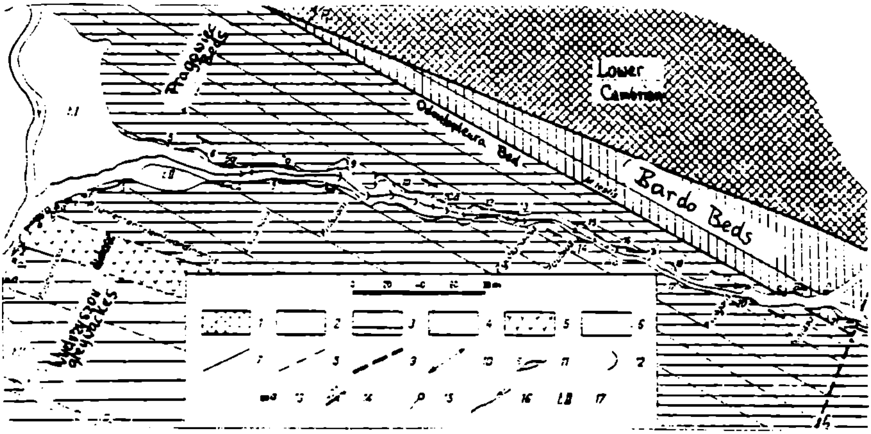


Fig. 22 Sketch map of Pragowiec Ravine. (After: H. Tomczyk)

DEVONIAN

An almost continuous, but with a presumed hiatus, Upper Silurian sedimentation lasted only in the Lysogory region, while in the southern region the stratigraphic gap is quite evident (cf. Fig. 22).

In the Lysogory region, the Lower Devonian is developed as a thick (probably about 1000 m) series of red, fine-grained clastics corresponding to the Old Red facies. Through the white colored, similarly grained clastics of lagoonal or brackish origin, the sequence passes into marine sandstones with brachiopods and trilobites of Upper Emsian age. At that time brackish-water sedimentation begins also in the central region, and it is marked by the Placodermi-bearing sandstones, the small thickness of which varies from place to place. Such brackish-water sandstone series with Placodermi may be studied in some quarries both in the Lysogory region (locality Mt. Beroza) and in the central region (locality Mt. Swinia near Daleszyce).

The Middle Devonian carbonate sequence begins with dolomites, a part of which is believed to be synsedimentary, either of an oligo-, or contrary, hypersaline origin. Overlying are diversified facies, generally deeper-water in the northern region, and shallower to the south. At their bottom, usually hydrozoan limestones altered into epigenetic dolomites appear that gradually pass into coral-bearing limestones. In the northern region, there also appear marly shales replete with brachiopods (famous locality Grzegorzowice) and various organodetrital and clastic sediments. This Middle Devonian sequence may be studied in plenty of localities as these carbonates are well exposed throughout the whole Holy Cross area (cf. Fig. 11). In the northern area it will be demonstrated along the section between Grzegorzowice and Skaly, and in the southern region - along the limbs of the Galezice syncline and Checiny anticline (cf. Figs 11 and 12).

The Upper Devonian facies pattern is controlled by the development of a huge bioherm and synsedimentary block-faulting, the both of which were also responsible for local condensation and/or non-deposition and erosion, especially in the Upper Frasnian and Famennian, which is detaily documented by the conodont dating (Szulczewski 1971, 1973, 1978). All these facies will be demonstrated in many localities, a few of which (Kadzielnia, Kowala, Lagow, Gorno, Galezice) are classical for the recognition of Upper Devonian environmental conditions in Europe.

Locality: Grzegorzowice

At this locality there is a section along the Dobruchna stream between villages Grzegorzowice and Skaly, where the Lower and Middle Devonian deposits are well exposed, being world-famous for their plentiful fossils. Higher parts of the profile are covered, with an angular unconformity, by the Buntsandstone (see Fig. 11).

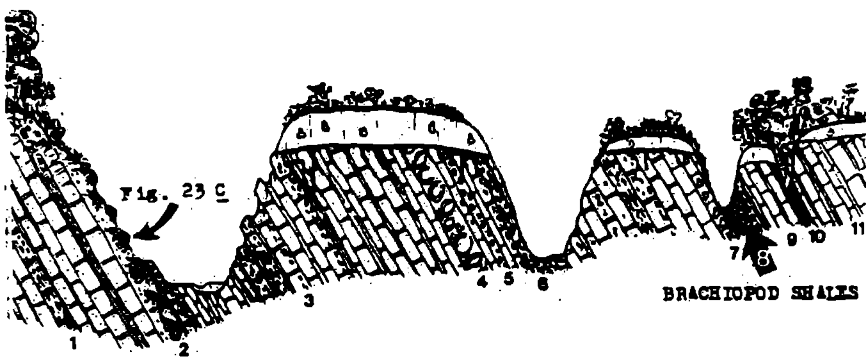


Fig. 23 A
Section along the Dobruchna stream at Grzegorzowice, to show the fossiliferous Middle Devonian carbonate sequence

1 - Saccharoid and pelitic dolomites, bearing Amphipora layers;
2 - Marly dolomites with huge colonies of Stromatopora preserved in their life position (see Fig. 23 C);
3 - Saccharoid, pelitic, and Amphipora-bearing dolomites;
4 - Limestone layer with Bornhardtina skalensis;
5 - Limestone layers with Emanuella sanctacrucensis;
6 - Saccharoid, Amphipora-bearing dolomites;
7 - Limestones with Calceola sandalina;
8 - BRACHIOPOD SHALES, replete with diversified fossils (some of them presented in Fig. 23 D);
9 - Marly limestones and marls;
10 - Shales with Microcyclus eifeliensis;
11 - Limestones intercalated by marly shales, with abundant corals and brachiopods, associated with trilobites.
(Overlying is Pleistocene loess with ubiquitous loess-babies)

The most fossiliferous carbonates and shales will be demonstrated in a part of the section which is of Eifelian through Lower-Middle Givetian age.

The oldest of the demonstrated deposits (Fig. 23 B) are several meters thick epigenetic dolomites containing hydrozoan banks composed of <u>Amphipora</u> and <u>Stromatopora</u> colonies. The latter, usually spherical in their shape, attain over half-a-meter in diameter, and are preserved in their life position (Fig. 23 C).

Fig. 23 B General view of one of the ravines along the Dobruchna valley, to show the picturesque landscape developed in the fossiliferous Middle Devonian carbonates : exposed are early dolomites with huge colonies of <u>Stromatopora</u> (see 2 in Fig. 23 A).

In the middle part of the dolomite series there occurs a bed of the brachiopod limestone replete with shells of Bornhardtina skalensis Biernat, most of which are also preserved in life position, and in assemblages containing both juvenile, adult, and gerontic forms, presumably being rapidly buried during their life. Another bed is composed of the shells of Emanuella sanctacrucensis Biernat and E.parva Biernat. The dolomite series is covered with coral-bearing limestones in which Calceola sandalina is commonly collected.

Overlying are the brachiopod shales, the ubuquitous species in which may be listed as follows: Spirifer diluvianoides Biernat, Schellwienella umbraculum(Schlotheim), Aulacella eifeliensis(Verneuil), Desquamatia subzonata(Biernat), Atrypa subtrigonalis Biernat, Spinatrypa aspera(Schlotheim), Productella varians Biernat, Eodevonaria zeuschneri(Sobolev), Schizophoria

Fig. 23 C Huge colonies of the hydrozoans Stromatopora sp. in their life position(some of them arrowed) within the Middle Devonian(Eifelian or Lower Givetian) marly dolomites at Grzegorzowice.

striatula (Schlotheim), *Chonetes supragibbosa* Sobolev, *Parastrophonella anaglypha* (Kayser), *Leptaena analogaeformis* Biernat, *Phragmophora schnuri* Cooper, *Uncinulus primipilaris* (v.Buch), *Cyrtina heteroclita* (Defrance), *Isorthis canalicula* (Schnur), *Douvillina interstrialis* (Phillips), *Leptodontella caudata* (Schnur), *Eoreticularia aviceps* (Kayser) and many others. Most of these species occur in many individuals, and can easily be collected. Their taxonomic position is well documented by excellent monographs presented by Biernat (1959, 1966).

Abundant associated fauna comprises diverse hydrozoans, corals, bryozoans, ostracodes, and crinoid ossicles. Less common are gastropods and pelecypods. Of the solitary corals such species as *Calceola sandalina*, *Microcyclus eifeliensis* and *Blothrophyllum irregulare* should be mentioned, as they are easily recognizable.

Very rare fossils are represented by such trilobites as *Phacops schlotheimi skalensis* and *Ph. latifrons grzegorzowicensis* monographed by Kielan (1954); some of these specimens may be found enrolled. Similarly enrolled are peculiar, aberrant crinoids of the genus *Ammonicrinus* (see Fig. 32 D).

BRACHIOPODS:

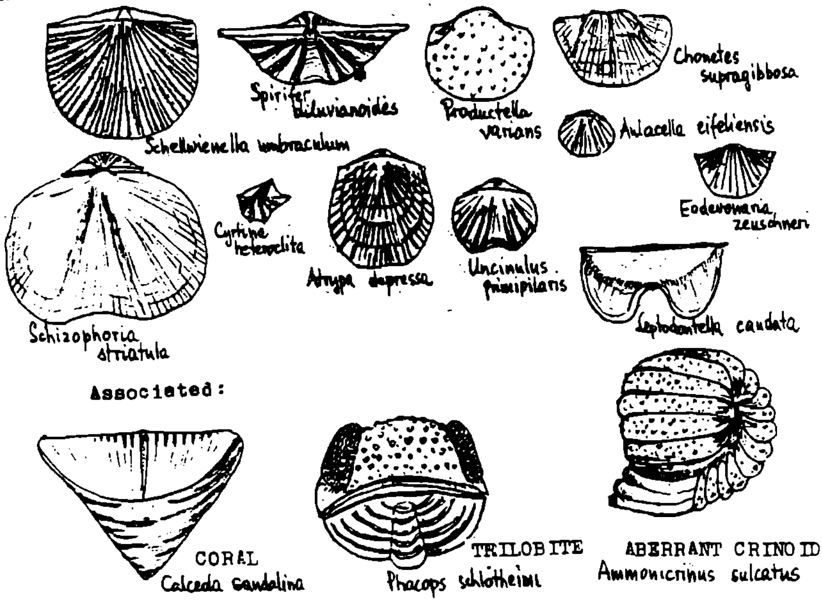


Fig. 23 D The commonest fossils of the BRACHIOPOD SHALES at Grzegorzowice (layer B in Fig. 23 A).

Locality: Kadzielnia

A large, abandoned quarry at the outskirts of the town Kielce displays an Upper Devonian biohermal structure and its cover. This bioherm and its diverse fauna has been studied since the middle of last century, either at this very quarry or in the others, situated along the southern limb of the Kielce syncline(Fig.24; cf. also Fig. 12).

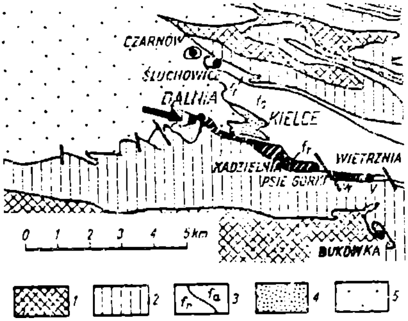


Fig. 24

Sketch-map to show the extent of the biohermal limestones (hachured and arrowed) around Kielce

1 Older Paleozoic, 2 Lower and Middle Devonian, 3 Upper Devonian(fr Frasnian, fa Famennian), 4 Lower Carboniferous, 5 post-Variscan cover.

This bioherm is commonly called the Kadzielnia reef, and its composition, fauna, stratigraphy and environmental conditions were recently studied by Szulczewski(1971). Generally, we may distinguish within the Kadzielnia reef: the reef core, the talus, both of which are Frasnian in age, and Famennian marly shales and marls with intercalations of thin limestones making up the reef cover (Fig. 25).

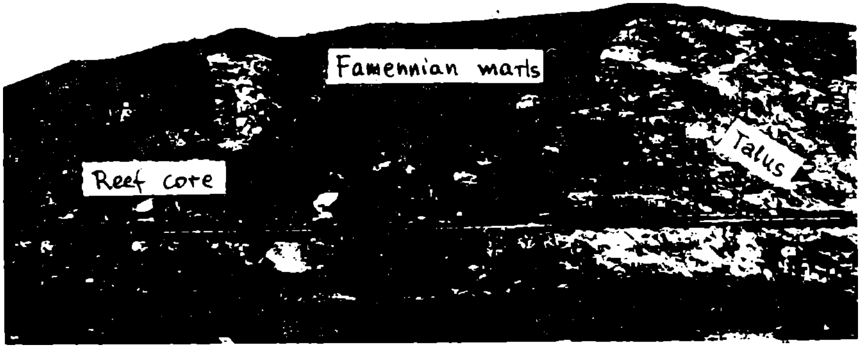


Fig. 25 General view of the bioherm exposed at Kadzielnia quarry.

The studying of the composition of particular facies, both in respect to their structure, paleontological content, taphonomy and spatial distribution enabled to reconstruct the sedimentary environment during formation of the reef (Fig. 26). The reef core, composed mostly of the lime mud which was stabilized by lamellar hydrozoans Actinostroma sp., represents an accumulation model comparable to Recent mud banks from the Florida offshores. The bank was rimmed by marginal reefs supplying detritus to the talus and neighboring basin deeps (cf. Fig. 27). In lagoonal conditions, at the top of the bank, in an area protected by the rimming marginal reefs, quiet water sedimentation commenced, subsequently followed by local oolitic facies.

The abundant and diversified fauna of the Kadzielnia bioherm is distrubuted patchy, and preserved either in their life position, or redeposited and accumulated in local pockets. The most famous are the brachiopod nests, composed of various species, the large Warrenella euryglossus (Schnur) including, which are the brachiopod colonies buried during their life (cf. Fig. 26 and Biernat 1971).

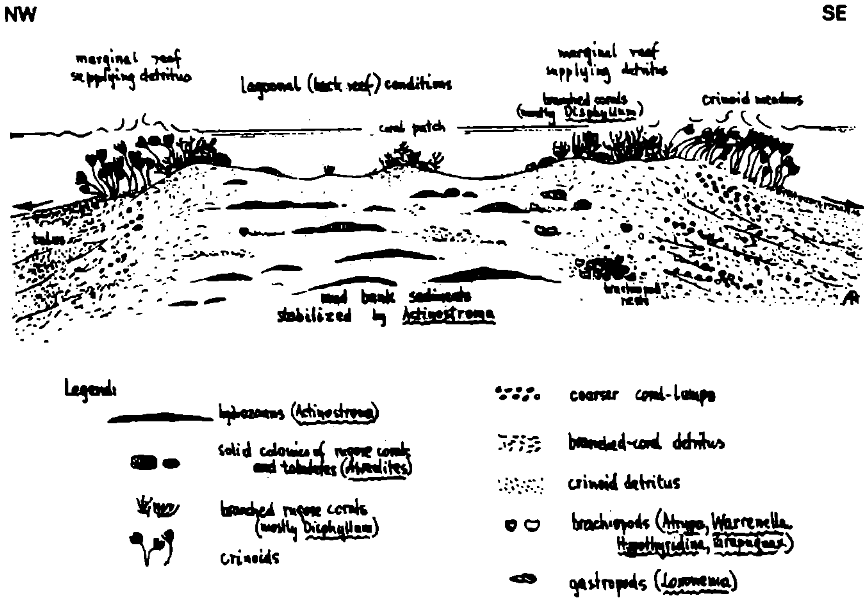


Fig. 26 Facies pattern in the Kadzielnia-reef environment. (After: Radwanski, 1974)

A detailed analysis of all the facies neighboring the Kadzielnia reef, and their precise stratigraphic dating by conodonts (Szulczewski 1971) allowed to recognize the successive stages of the reef development, from the tabular reef of larger extent to elevated seamounts reaching the water surface (Fig. 27). Synsedimentary block-faulting began in the Lower Famennian, and it became responsible for local gaps, facies diversity, and formation of the neptunian dykes within the reef core, exposed

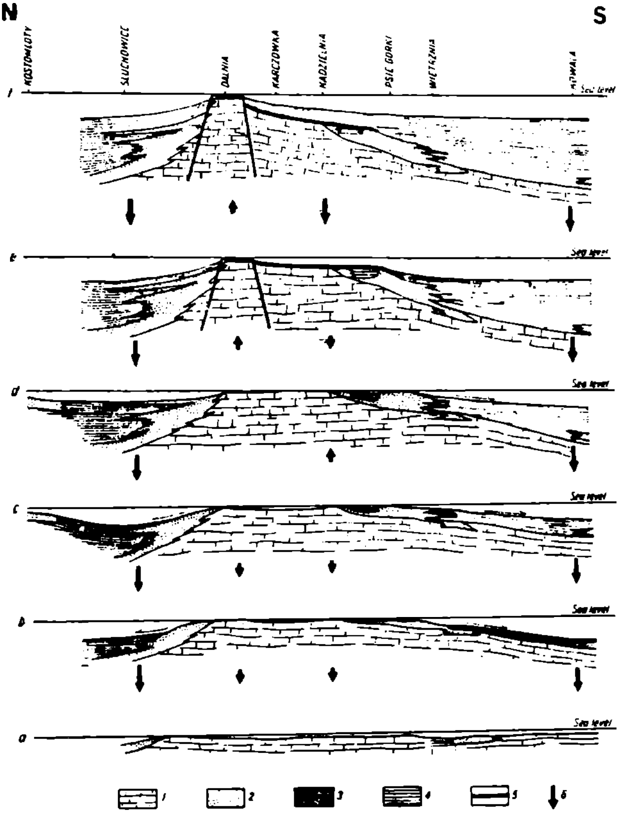


Fig. 27

Facies development of the Upper Devonian in the western part of the Holy Cross Mts; successive stages of the development are shown for the time of:

- a Middle Polygnathus asymmetricus Zone (to *Iα*)
- b Upper Polygnathus asymmetricus Zone (to *Iβ*)
- c Lower Palmatolepis gigas Zone (to *Iγ*)

} Frasnian

- d Middle Palmatolepis triangularis Zone (to *Iδ?*)
- e Upper Palmatolepis crepida Zone (to *IIα*)
- f Lower Palmatolepis quadrantinodosa (to *IIβ*)

} Famennian

1 stromatoporoid-coral limestones, 2 detrital limestones, 3 basin deposits, 4 Manticoceras limestones, 5 Cheiloceras limestones, 6 subsidence or uplift (length of the arrow corresponds to relative rate of vertical displacement)

(Szulczewski, 1971)

at Kadzielnia and Dalnia (see Figs 27 and 29; cf. also Sulczewski 1971, 1973).

The regional facies pattern around the Kadzielnia reef will be demonstrated by the profiles at Kowala and Sluchowice (for their position see Fig. 27).

At Kowala, along the railway cut, a section is exposed which displays the biohermal facies at the bottom, the transitional, detrital facies, and finally the basin facies with calcareous turbidites.

At Sluchowice, within a large, abandoned quarry, only transitional, detrital facies within the typical basin facies are exposed. These deposits are strongly folded, what is an exceptional situation within the Devonian sequence of the Holy Cross Mts. Hence, a part of the quarry where the axial part of the fold is present (Fig. 28) became the protected spot as a natural monument. The detrital facies is here developed as layers of intrastratal breccias or conglomerates. In the basin facies, abundant calcareous turbidites are typical feature of the sequence.

The strong folding of the Sluchowice area may be explained by different competency of (1) basin-facies deposits, and (2) neighboring massive block of the Kadzielnia reef during the Variscan orogeny. The Kadzielnia reef served as a rigid block at that time, against which the southward tectonic movement has been stopped (see Fig. 29A and Szulczewski 1973).

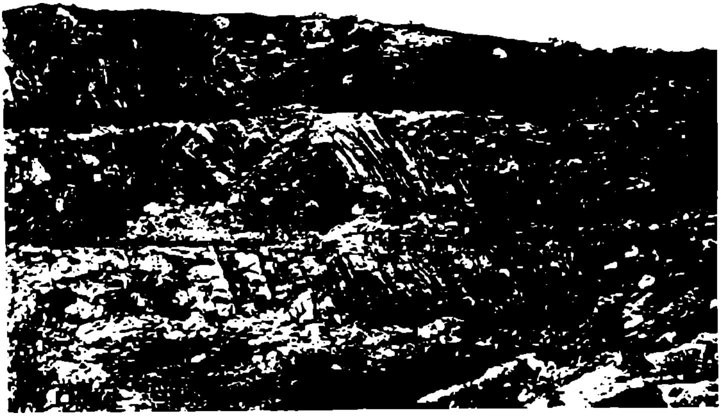


Fig. 28 Axial part of the Sluchowice fold (cf. Fig. 12).

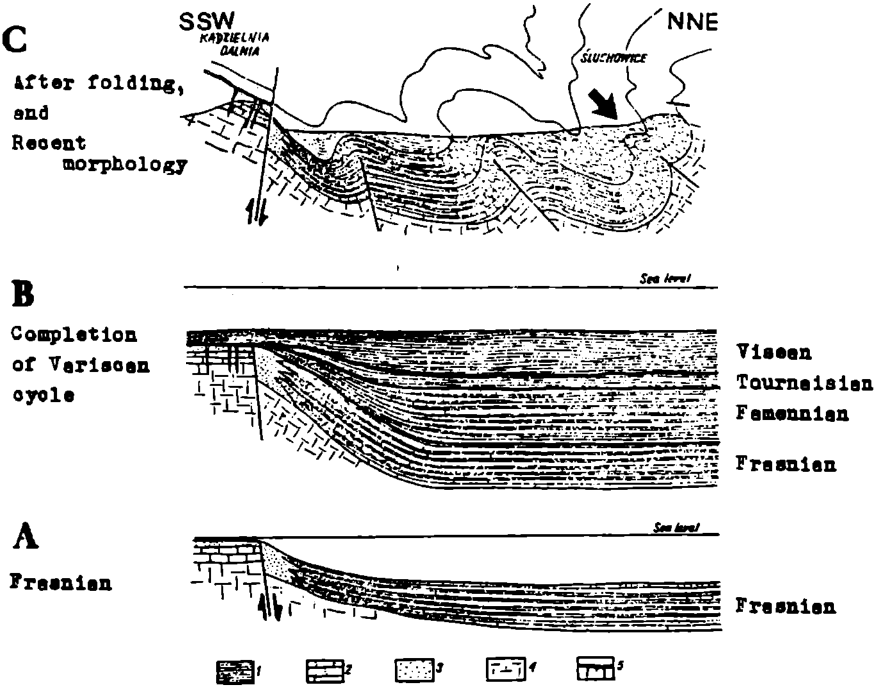


Fig. 29 A Upper Devonian and Lower Carboniferous-facies development, and its consequences in the Variscan tectonic movements between Dalnia (Kadzielnia reef) and Sluchowice; the development is shown for the three successive stages (A, B, C)

1 shales, 2 pelitic and marly limestones, 3 detrital limestones, 4 biohermal limestones, 5 condensed sequence with neptunian dykes

(Modified from: Szulczewski, 1973)

LOWER CARBONIFEROUS

The Lower Carboniferous deposits terminate the Variscan sequence of the Holy Cross Mts but owing to the post-Variscan erosion they are preserved only, locally in axial parts of synclines. In the Lysogory region the total thickness of the Lower Carboniferous reaches over 600 meters, while in the Kielce region it is predominantly about 200 m thick. In both areas, however, the Lower Carboniferous sequence is composed of basinal deposits. During the Tournaisian and the Viséan the facies contrast between Lysogory and Kielce regions was not so great as it was before /see Fig. 29 A/. The differences of thickness appear to have resulted from higher rate of subsidence in the northern part of the Holy Cross area.

Kielce region. The Lower Carboniferous sequence starts with pelagic condensed deposits which originated on the drowned Devonian carbonate platform. These deposits are usually developed as cherrish clayey shales intercalated with bands of nodular limestones. Moreover, there occur intercalations of volcanogenic deposits /see Kozłowski 1981/, the number and thickness of which gradually increase eastwards. Sometimes, the limestone interbeds yield scarse fossils: goniatites, trilobites, tabulates, and solitary rugose corals, and crinoids. The condensed sequence, ranging 3-18 m in thickness, comprises the Middle and/or Upper Tournaisian and it overlies the uppermost Famennian. The stratigraphic gap that occurs between the Devonian carbonates and the overlying Tournaisian rocks is interpreted to be a result of submarine nondeposition /Szulczewski 1978/.

The Tournaisian condensed sequence is followed by black radiolarian shales and cherts /lydites of German usage/ that occasionally contain phosphatic nodules. The fossil content except radiolarians includes sponge spicules and conodonts . These sediments represent the typical starved-basin facies developed in the Kielce region as a consequence of the permanent subsidence of sea-floor during the Lower Viséan. Analogous Lower Carboniferous deposits are widely distributed in many sections throughout the world, the Kieselschiefer formation in the Rheinisches Schiefergebirge including.

A thick /usually about 200 m/ series of clastic deposits forms the upper part of the Viséan sequence. Lithologically, this series is dominated by shales and siltstones, but some units composed of sandstone, greywackes, and volcanogenic rocks are also observed. The relatively abundant fauna, primarily goniatites, nautiloids, hyolithids, and epiplanktic bivalves of the Posidonia type occur in the lower part of this series, whereas in its upper portion plant remains are recorded.

Only in the Gałęzice area, the Viséan section contains, between radiolarian shales and clastic series, extremely fossiliferous limestones /as in locality Ostrówka - Figs 29 B and C/. The fauna is primarily composed of the unusually abundant corals, crinoids, and brachiopods, as well as rich assemblages of microfossils. The Upper Viséan age is indicated by conodonts and goniatites. These bioclastic limestones, up to 35 m thick, represent a mass flow deposits forming two distinct submarine fans. All

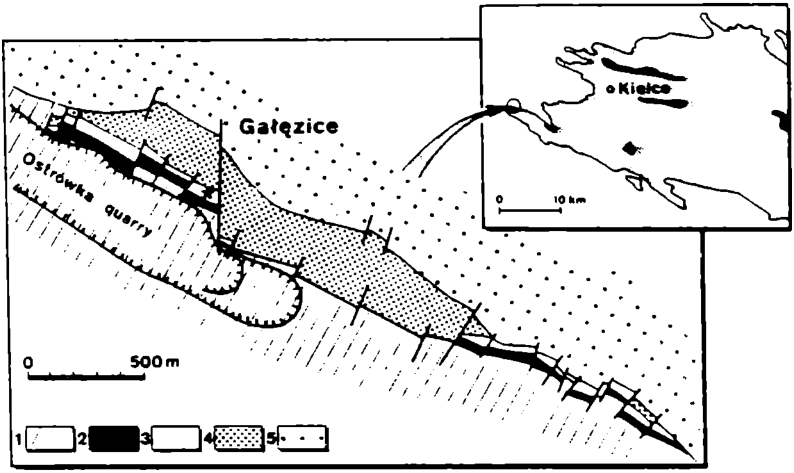


Fig. 29 B

Outcrops of Lower Carboniferous deposits /black spots/ within the Paleozoic core of the Holy Cross Mts, and simplified geological map of the Gałęzice area /slightly modified after Żakowa 1974/; asterisked is the location of Todowa Hill

1. Lower Frasnian/?/ Amphiporoid Limestone, 2. Famennian-Tournaisian condensed sequence and/or L.-M. Viséan radiolarian shales, 3. Upper Viséan bioclastic limestones, 4. uppermost Viséan clastic series, 5. Permian

fossils and clasts were transported from an adjacent, at the present time non-extant platform. The particles orientation indicates the northward transport. Thus, the carbonate platform were situated south of the Gałęzice area.

Lysogory region. In lithology and facies succession, the Lower Carboniferous is here similar to that of the Kielce region. The lower part of the sequence is developed as black radiolarian shales and cherts. Overlying are fine-grained clastic deposits that include interbeds of greywackes and volcanogenic rocks. Because of poor fossil content and a limited number of outcrops the stratigraphic recognition of this sequence is uncertain; on the other hand the contact to the Devonian substrate is here tectonic.

Locality: Ostrówka

A huge quarry at the Ostrówka Hill, within the northern limb of the Chęciny Anticline, offers at the present time a good insight into the problems of the Upper Devonian and Lower Carboniferous stratigraphy and facies development. The demonstrated section is exposed on the northern wall of the quarry and it continues across the Todowa Hill /Fig. 29 C/. It consists of the following units:

A - Amphiporoid Limestone: light colored, thick-bedded limestones quarried here. The topmost part of the unit exibits micritic limestones with some interbedded layers containing fine calcarenites and algal-mat sediments with cryptalgal fabric. Impoverished and sparse amphiporoid fauna is present.

The postulated sedimentary environment is shallow subtidal to intertidal.

The stratigraphic assignation of the Amphiporoid Limestone is somewhat uncertain. According to Kaźmierczak /1971/ stromatoporoids appear to be characteristic of the lowermost Frasnian, in contrast to the earlier opinions placing these carbonates in the Givetian. Unfortunately, the value of stromatoporoids for determination of any of the recently proposed positions of the Givetian/Frasnian boundary appears limited.

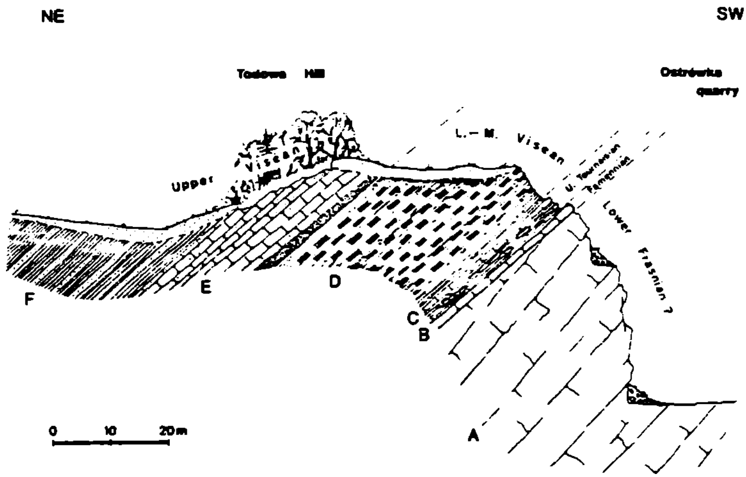


Fig. 29 C

Cross section through the Ostrówka quarry and Todowa Hill, to show the Upper Devonian-Lower Carboniferous sequence of the Gałęzice area /lithological complexes as in the text/

B - Famennian cephalopod limestone: made up of dark-grey remarkably fossiliferous limestone /about 1 m thick/, typical of the "Cephalopoden-Kalk", containing crinoid debris and clymenids. It is extremely condensed, and it ranges the time-span since the Upper *marginifera* Zone to the Middle *costatus* Zone, and it shows internal diastem caused by a marine nondeposition. Fossils from the very recently exposed section have not been described yet but diversified biota have been reported from the nearby hills. Cephalopods, crinoids, trilobites, gastropods, bivalves, ostracodes, and fishes are abundant. Rugose and heterocoralloid corals are also numerous.

The sedimentary environment is submarine rise situated within the photic zone /Szulczewski 1978/.

C - Uppermost Tournaisian shaly sequence: developed as greenish and cherrish clayey shales intercalated with thin bands of nodular limestone. Some of these intercalations contain goniatites, trilobites, small tabulates, and solitary rugose corals, as well as nonabraded crinoid ossicles and fragmented stems. The thickness of the sequence attains about 4 meters.

Pelagic environment below the effective wave-base and depth approaching CCD is indicated by the lithology, biota and position within the sequence.

The conodont fauna is characteristic of the anchoralis Zone /Szulczewski 1978/.

D - Lower-Middle Viséan radiolarian shales and cherts: developed as black monotonous deposits /at least 20 m thick/ which locally contain spherical phosphatic nodules, up to 10 cm in diameter. The fossil content consists only of abundant radiolarians accompanied by sponge spicules and rare conodonts. The calcareous fossils are totally absent.

The unit represents the typical basinal deposits originated below CCD, presumably in anoxic conditions.

Up to now, the age of this unit has not precisely been determined, but the position within the sequence indicates the Lower-Middle Viséan.

E - Upper Viséan bioclastic limestone: the most fossiliferous rock in the whole Paleozoic sedimentary sequence of the Holy Cross Mts. In the presented outcrop it is 12 m thick, but sections where the thickness attains 35 m are also observed. This carbonate unit starts with a breccia bed that comprises clasts of various Devonian and Carboniferous limestones along with large colonies of Syringopora and Lithostrotion / 1 m in diameter/ floating in coarse-grained skeletal debris. The underlying radiolarian shales containing phosphatic nodules were squeezed upwards, into the lower portion of this bed, and they amalgamate with carbonate skeletal detritus between large clasts. The thickness of breccia ranging from 0.5 to 5 m reflects probably the shape of the channel filling. The interval above breccia is developed as medium- and thick-bedded coarse-grained bioclastic limestones. Only at the top of the unit there are a few thin intercalations of micritic limestones. Some of medium-bedded layers yield gradation, whereas all other ones are non-graded and display very poor sorting and random clasts orientation. Allochems include bioclasts, a great amount of relatively well-preserved skeletons, and lithoclasts of various limestones, both Devonian and Lower Carboniferous in age. In fact, all beds contain extremely abundant shallow water benthic fauna dominated by corals, crinoids, and brachiopods. Gastropods and trilobites are also numerous. Associated are the high-diversity microfossil assemblages consisting of foraminifera, ostracodes, calcareous algae, and conodonts. The nektic elements such as nautiloids and goniatites occur relatively rarely. Both goniatites and conodonts are indicative of Upper Viseán age. Although only the small part of the fossil assemblage has been investigated in detail the introductory identification showed, for instance, that the total number of rugose coral species reaches 120-130, and of brachiopods several hundreds species. The shallow water benthic organisms that represent different ecological niches were here mixed together to produce unusually rich fossil assemblages.

The unit is interpreted as mass-flow deposits forming a submarine deep-water fan deposited on the basin floor.

F - Uppermost Viséan clastic series: at present not exposed in the Gałęzice area.The 150 m thick series consists of shales and siltstones with intercalations of sandstones, greywackes, and volcanogenic deposits. Pelagic fauna represented by goniatites, nautiloids, hyolithids, and epiplanktic bivalves occur in great amount.

Both lithology and fauna indicate the deposition of these sediments in basinal conditions.

Goniatites date the uppermost Viséan age, precisely the granosus ammonoid Zone /Żakowa 1971/.

A considerable gap exists between the Amphiporoid Limestone and the Famennian. The nature of the contact is sedimentary and it is marked by a disconformity resulted from an uplift of the carbonate platform and subsequent emersion before the Famennian.

In contrast to that, the sedimentation of the Famennian cephalopod limestone displaying condensation and internal diastem exemplifies the drowning of the pre-Famennian carbonate platform and its transformation into a submarine rise. The succeeding stratigraphic gap between the Famennian and the overlying Tournaisian is attributed to submarine nondeposition /Szulczewski 1978/. The lithology succession noted to occur in the Lower Carboniferous sequence reflects continuing subsidence which generated the lowering of the bottom below the compensation level. The problem, however, is a reason responsible for short-persistent but mass resedimentation of shallow-water carbonate material into the basin to form a deep-water fan. The most probable hypothesis is the sudden, tectonic uplift of the source area that might have produced significant bathymetric gradients and might have enable to remove carbonate material from the platform. The orientation of crinoid stems and solitary rugose corals, measured on the bottom surfaces of layers, indicates the transport direction toward the north, from an adjacent, non-extant carbonate platform which is inferred to have been located south of the Gałęzice area.

Variscan folding

The Variscan tectonic movements are generally attributed to the Sudetic phase which appeared by the end of the Viséan. The tangential pressure was acting from north-east, and thereby the folds are leaned to south-west /see Fig. 12/.
The whole Variscan sedimentary sequence which underwent the folding may generally be regarded as miogeosynclinal. The northern /Lysogory/ region was featured by deeper bathymetric conditions and almost continuous sedimentation, while the remaining areas characterized by shallower waters, as well as by local condensation and even stratigraphic gaps.
Taking into account all these differences, the total thicknesses of particular systems in the Holy Cross Mts are as follows:

	Lysogory region	Kielce region
Lower Carboniferous	max. 625	200 - 350 meters
Devonian	2000	700
Silurian	1000-1500	450
Ordovician	350	100 - 150
Cambrian	2500-3000	1700

Permo-Mesozoic cover

PERMIAN

During the late Permian the Holy Cross area represented a peripherial part of the Central European Zechstein Basin /Fig. 30/. The transition from continental into tidal and more open shallow marine environments took place in this area, so the typical cyclic Zechstein succession does not occur here.

The first deposits which overlie, with an angular unconformity, the Variscan substrate are pre-Zechstein conglomerates of the fanglomerate type /cf. Radwański & Roniewicz 1972/. Their thickness varies, being dependent on the substrate morphology, from zero /Besówecska profile at Gałęzice/ to over 100 meters /Mt. Red near Chęciny - cf. Fig. 12/. The continental origin of the conglomerates was confined to tectonic uplift and erosion of the Variscan folds /see Fig. 31/. Coarse detrital material is variable in composition, clearly depending on lithological character of rocks forming the pre-Permian

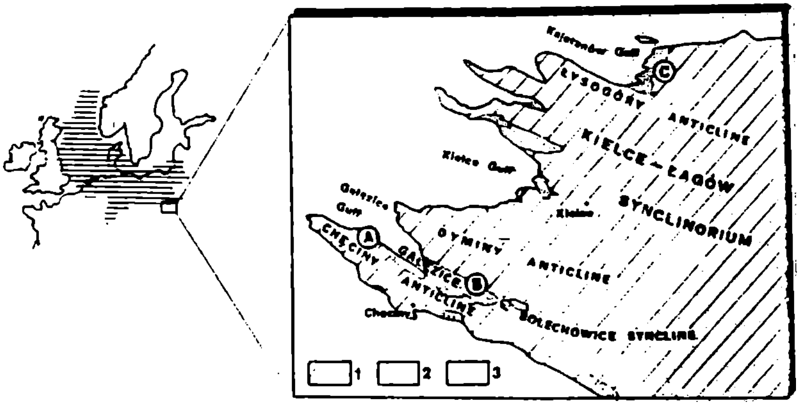


Fig. 30

Outline map of the south-western part of the Holy Cross Mts and its location in the Central European Zechstein Basin. The demonstrated profiles are marked: A - Gałęzice, B - Bolechowice, C - Kajetanów.

1. pre-Permian substrate, 2. Permian, 3. Mesozoic cover

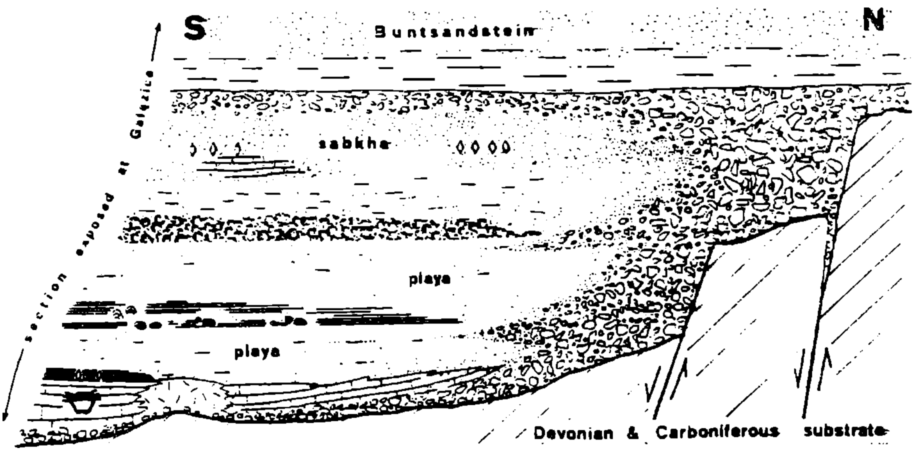


Fig. 31

Diagramatic cross section through the western part of the Gałęzice -Bolechowice syncline, to show the transition from continental to shallow marine sedimentary environment of the Permian sequence

basement. Besides conglomerates composed of pebbles of Devonian limestones which are the most common, there also occur those composed of pebbles of quartzites, sandstones and dolomites, from the Cambrian to the Lower Carboniferous in age. Pebbles are usually badly sorted, angular to rounded and in size up to 1m. Red matrix is of the clay--ferruginous-calcareous type and it contains large admixture of angular fine detritus. Most of massive conglomerates accumulated on the slopes of anticlinal elevations are clast-supported, but some covered the bottom of synclinal depressions are characterized by matrix-support /cf. Fig. 31/. Fabrics and structures in the conglomerates are consistent with debris flow process and occasionally also with alluvial transport.

The Zechstein sea entered the Paleozoic core with distinct post-Variscan relief marked by a very differentiated shoreline /cf. Fig.30/. The transgression easily penetrated along the longitudinal depressions open to the west. This gave origin to a system of small and relatively narrow embayments separated by equally narrow elevations providing terrigenous material for conglomerates and redbeds. The whole Zechstein sequence in the western margin of the Holy Cross Mts belongs to the Werra /Z1/ cyclotheme.

The transgression started throughout the whole area with sedimentatiom of organodetrital limestones. After that short event, an open marine sedimentation was stopped as a consequence of shallowing of the sea. The following part of the profiles shows varied carbonate deposits intercalated with red clastic deposits, sometimes with evaporites /Fig. 31/. The limestone units, with several accompanying sedimentary structures, display a gradation from subtidal to high tidal flat sedimentation. Clastic deposits separating carbonate complexes represent sediments of a sabkha-like and/or playa environments which developed on the tidal flat. The contacts between the continental and marine complexes are usually sharp.

Reconstruction of depositional events reveals that tidal conditions formed the main factor controlling sedimentary processes, but the facies changes were mostly caused by eustatic fluctuations of sea level. The marine units occur alternating with those originated under continental conditions enable the distinction of 3 /or 4?/ upward-shallowing cycles.in the Zechstein succession of the Holy Cross Mts. This cyclicity resulted from a glacioeustatic mechanism . Similar upward-shallowing cycles, with a rapid return to open sea conditions, are reported in the Zechstein Limestone /Ca1/ from the peripherial parts as well as within some elevated areas in the central part of the Central European Basin /Smith 1980/. Most likely, the whole Zechstein sequence of the Holy Cross Mts corresponds to the carbonate deposits /Ca1/ of the Werra cyclotheme only.

The paleogeographical setting speaks against the existence of astronomic tides in this vast epicontinental basin; rather it seems that sea level oscillations responsible for origin of tidal sedimentation in that peripherial part of the Zechstein basin resulted from the action of wind or waves.

Locality: Gałęzice

The profile exposed along the road from the Chęciny Valley to Rykoszyn at Gałęzice village is the most complete of Permian sequences preserved in the Holy Cross Mts. However, some rocks and especially weakly diagenesed shales, marls and clays are covered by land waste and are known from boreholes only. The Zechstein se-

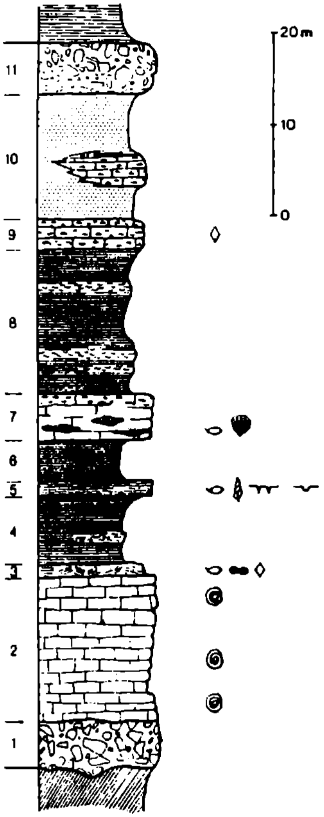


Fig. 32

Lithological profile of Permian deposits exposed at Gałęzice.
a. foraminifers, b. ostracodes, c. gastropods, d. algae - Solenoporaceae, e. chert pseudomorphs after anhydrite, f. calcite pseudomorphs after gypsum, g. mud cracks, h. erosional channels, /futher explanation in the text/

quence started with organodetrital limestones in the tectonic contact to the Upper Visean shales. Beneath these limestones, in the boreholes, pre-Zechstein conglomerates were found which overlie the Upper Visean substrate with angular disconformity of about 30°.

The whole Permian sequence is about 80m thick and comprises the following lithological units:

/1/ - Calcareous conglomerates with ferruginous-calcareous matrix. These are the so-called Lower Conglomerates, identical in their development to the famous Zygmuntówka Conglomerates from the Bolechowice area /exposed on the slopes and the summit of Mt. Red/.

/2/ - Thin-bedded organodetrital limestones, usually strongly bituminous and containing a very rich foraminifer fauna. The foraminifer assemblage comprises characteristic form Agathamina pusilla /Geinitz/ which is especially common in the top of this unit, and representatives of the genera Geinitzina, Spandelinoides, Glomospira, Dentalina, Nodosaria, and others.

/3/ - Laminated limestones with numerous calcite pseudomorphs after gypsum crystals. Gypsum was here diagenetic and a very fine lamination is often deformed or broken due to the crystal growth. Besides diagenetic deformation of single laminae, there are also common larger ones which effect the whole sets of laminae. The latter are represented by microfolds and overthrusts associated by chert pseudomorphs after anhydrite with concentrations of crystals of galena, barite and sometimes sphalerite and chalcopyrite.

/4/ - Thin-bedded marls and clay shales.

/5/ - Flat-laminated algal mat sediments with occasional intercalations of biomicrites yielding ostracodes and gastropods. Algae of the genus Girvanella are omnipresent. Mud cracks are common on large surfaces. There were also found small erosional channels 2-3cm deep and with characteristical flat bottom.

/6/ - Red clays with marls.

/7/ - Strongly silicified various carbonates. Micritic limestones with ostracodes form the lowermost part of this unit. They are overlain by calcirudite composed of fragments of Solenopora colonies and detritus of algal mat sediments. The contribution of silica clearly drops and limestones with cryptalgal fabric and very numerous irregular fenestrae appear towards the top of this set.

/8/ - Siltstones with intercalations of clays and marls.

/9/ - Cryptalgal limestones showing fenestral fabric and very numerous post-gypsum calcite pseudomorphs.

/10/ - Red siltstones composed of angular quartz grains, detritus of limestones and calcareous-ferruginous matrix. The siltstones are often cross-bedded. In the middle part of this unit there appear intercalations of cryptalgal limestones with fenestral fabric. Fenestrae are usually geopetally infilled and yield traces of dissolution.

/11/ - Conglomerates composed of pebbles of stromatoporoid Devonian limestones. These matrix-supported conglomerates contain also single fragments of Zechstein siltstones as well as a small admixture of quartz grains. The conglomerates are overlain by Buntsandstein deposits.

The demonstrated sequence occurring in the Gałęzice area is typical of the Permian profiles from the Gałęzice-Bolechowice syncline. Depositional environments range from continental to shallow marine. The shift of facies was due to the sea-level oscilations in the Zechstein basin along with persistent slow subsidence. Carbonate members evidence sedimentation in extremally shallow marine basin and often in the tidal flat area /cf. Bełka 1978a/. For instance, structures displayed by laminated limestones are the same as those recorded in recent sabkha deposits. Similar to that is the origin of complexes predominated in the upper part of the profile. While, redbeds separating carbonate units evidence sedimentation located above the tidal flat.

The development of conglomerates covering the Zechstein rocks which form the top of the profile was already connected with new phase of tectonic movements. The uplifted anticlinal elevations of the Variscan substrate were levelled by erosion to produce these so-called Upper Conglomerates.

Locality: Bolechowice

In a railway-cut reaching Bolechowice village from the east, exposed are Zechstein deposits including algal limestones /Fig. 33/. The lower part of the limestones is formed of thin /5 to 15 cm thick/ beds containing numerous rhodolites associated with single fragments of thalli of Solenopora and Ortonella, and ostracodes of the genus Carbonita, occurring in masses in some places, and some small gastropods. The majority of ostracod valves and gastropod shells are strongly crushed. The deposits are characterized by a high content of pelitic quartz dispersed in micritic matrix. Rhodolites are built of Solenopora tissue concentrically overgrowing bioclasts or small fragments of algal colonies. The Solenopora rhodolites resemble closely in structure the Cenozoic corallinacean rhodolites formed in shallow water environment /optimum depth ranges from low-tide to 10 meters/ under conditions of a continuous water movement.

The rhodolite-bearing layers are separated by thin intercalations of algal-mat sediments which always overlay the rhodolite-bearing horizons with certain discontinuity. The middle part of the algal limestones comprise algal-mat sediments showing cryptalgal fabric and associated with mud cracks, erosional channels, bioturbations,

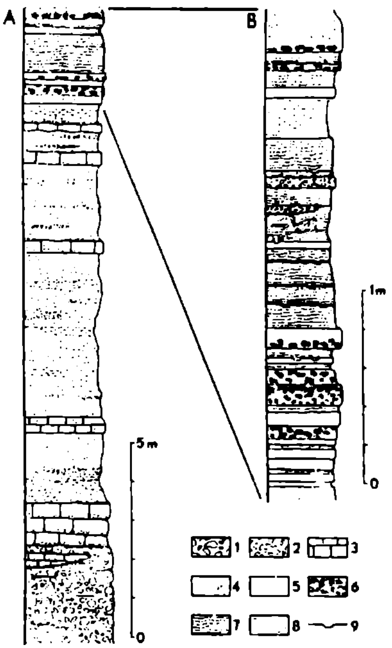


Fig. 33

Profile of Permian deposits cropping out east of Bolechowice /A/ and detailed lithological profile of algal limestones /B/.
1. conglomerates, 2. breccias, 3. sandy limestones and calcareous sandstones, 4. siltstones, 5. micritic limestones and biomicrites, 6. biomicrites with rhodolites, 7. algal-mat sediments, 8. clays, 9. erosional channels

and intraclastic-breccia lenses, all of them attributable to the intertidal deposition /Bełka 1978b/. The upper part of the sequence consists of red clays which are overlain by reappearing algal-mat sediments and a layer of limestones with rhodolites, with a large contribution of aleuritic quartz and iron-compounds. Single rhodolites appear once more in siltstone deposits higher up.

The demonstrated Solenopora rhodolites occur in limestones with a micritic matrix which developed as intercalations within intertidal deposits. The rhodolite orientation indicates clearly that these are redeposited elements. One may conclude that the Solenopora rhodolites developed in highly turbulent, subtidal environments close to the tidal flats. Due to a storm-wave action the rhodolites along with non-algal fossil detritus were repeatedly deposited on the algal-mat sediments of the intertidal zone.

Locality: Kajetanów

In a small, abandoned quarry exposed are bituminous limestones, marls and marly shales, about 10 m thick. The sequence comprises from the bottom:

/1/ - Greyish-black, highly bituminous limestones with common large brachiopods Horridonia horrida /Sowerby/ whose specimens are often preserved with long spines, used by the animal to protect itself against sinking into the quaggy bottom. Associated are other brachiopods, such as Strophalosia productoides and Lingula credneri Geinitz.

/2/ - Marly limestones with Strophalosia productoides.

/3/ - Marly shales with remains of primitive conifers /Voltzia and Ullmannia/ and of ferns /Sphenopteris/

In the sets /2/ and /3/ there also occur commonly large foraminifers Agathamina pusilla /Geinitz/ and bryozoans Acanthocladia, both of which are usually whitish in their tint, and are thereby easily recognizable on the surface of layers.

The demonstrated sequence developed in the central part of a larger bay which encroached upon the strongly eroded upper limb of the Łysogóry anticline /see Fig. 12/.

Mesozoic margins

The structure of the Mesozoic margins of the Holy Cross Mts will be demonstrated within the southern margin, south of Chęciny /cf. Figs 12 and 34/, although the first Triassic deposits - the Buntsandstein series - will be shown in the northern margin where that series is well exposed in large quarries at Tumlin and Ciosowa. In a nearby quarry at Zagnańsk—Zachełmie, an angular unconformity and erosional surface between the Middle Devonian carbonates and the overlying Buntsandstein series will also be demonstrated.

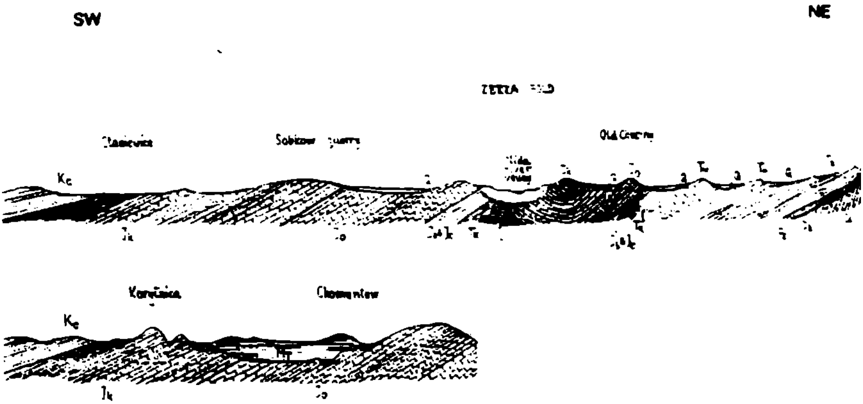


Fig. 34 Geological section through the southern Mesozoic margin of the Holy Cross Mts; it is a combined section, and it comprises a part of the section A-B in Fig.12, and two other parts indicated in Fig. 11, the last of which is taken to demonstrate the situation of the Miocene deposits at Korytnica and Chomentow(cf.Figs 45 and 47)

Legend: T_B Buntsandstone, T_r Roth, T_M Muschelkalk, T_K Keuper, J_b J_c Bathonian and Callovian, J_o Oxfordian, J_k Kimmeridgian, K_c Cenomanian; M_T Miocene(Tortonian); Q Quaternary

TRIASSIC

The Triassic sequence comprises the Buntsandstone, Muschelkalk and Keuper series(cf. Fig. 34) which are developed identically like in the whole German Basin.

The Buntsandstone contains mostly large-scale-cross-stratified sand bodies which are recently suggested to have been formed in terrestrial environment, presumably being deposited as the ergs, i.e. the fields of barchan-type dunes(Gradziński, Gągol & Ślączka 1979). Such sand bodies may be studied in large at Ciosowa (Fig. 35) and Tumlin (Fig. 36); all of them appear in the middle part of the series which beneath and above them is developed as red shales.

Fig. 35 General view of the Buntsandstone eolianites at Ciosowa.

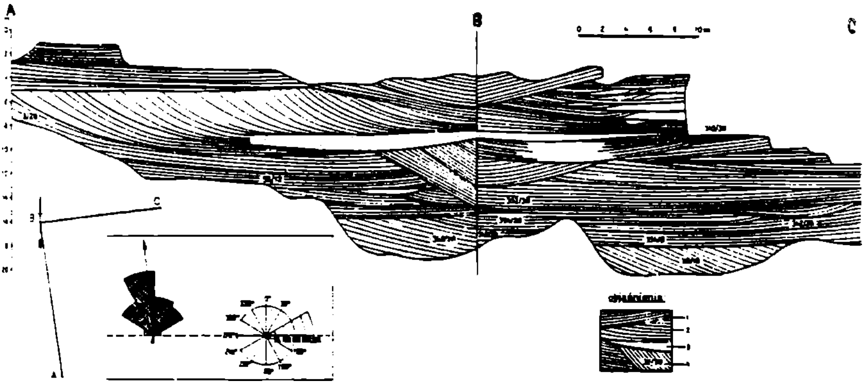


Fig. 36 Detailed view of the quarry walls at Tumlin, to show the structure of the eolianites

1 co-set boundaries, 2 individual laminae in the sets, 3 non-laminated sets, 4 measurements of inlination(the resulting diagram is presented at left).

(Taken from: Gradziński &al. 1979)

The Muschelkalk series comprises the Wellenkalk and a few local lithostratigraphic units which correspond to the Anisian and Lower Ladinian(Trammer 1975). The marine Lower and Upper Muschelkalk are separate by the Middle member which is hypersaliner. The Lower member is the best exposed at the quarry at Wolica (Fig.37), whereas the Upper one along the section south of Checiny, near the village of Old Checiny(cf. Fig. 34).

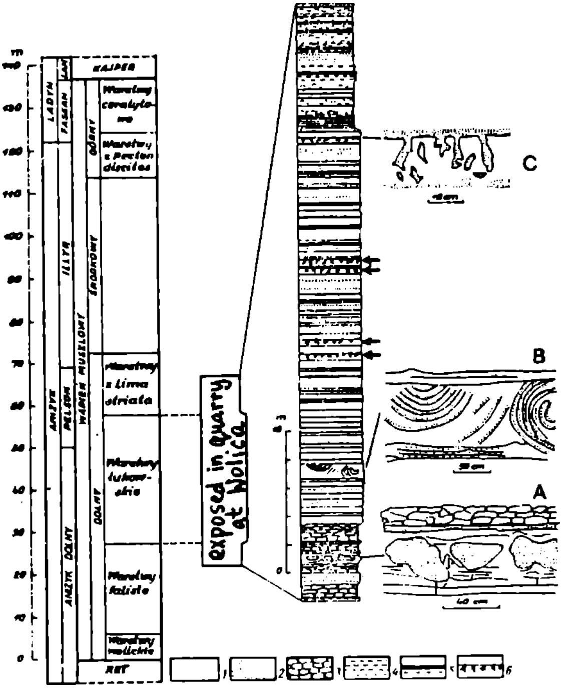


Fig.37

Lower Muschelkalk sequence exposed at Wolica; position of synsedimentary disturbances - deformations due to unstable density bedding (A), submarine slumping (B), and enteropneusten activity (C and other horizons arrowed) is indicated along the profile

1 micritic limestones, 2 detrital limestones, 3 knobby limestones, 4 lumachelles(shelly limestones), 5 flints, 6 enteropneusten burrows

(Adopted from: J. Trammer 1975 and other papers of that author)

The Lower Jurassic series composed of fine-grained sandstones with clay intercalations and local gravelous members originated in continental environment. It developed mostly in the northern part of the Holy Cross region /J_1 in Fig.11/, whereas in the southern sequence it is missing /cf. section in Fig.34/.

The Middle Jurassic black clays of Bathonian age /J_b in Fig.34/ begin the Middle/Upper Jurassic transgressive cycle. These clays, deposited in an euxinic bay are capped with stromatolites and a locally condensed sequence of the Lower Callovian /Szulczewski 1967, 1968/. Overlying and/or laterally passing are non-condensed nodular gaizes with cherts, and chert-bearing limestones, locally crinoidal at their top.

The Upper Jurassic sequence begins with the sponge facies /Matyja 1977/, closely related to the Upper Jurassic facies of the Swabian and Franconian Alb, and representing the open shelf environment /Fig. 38/. During the Middle Oxfordian, in the north-eastern part

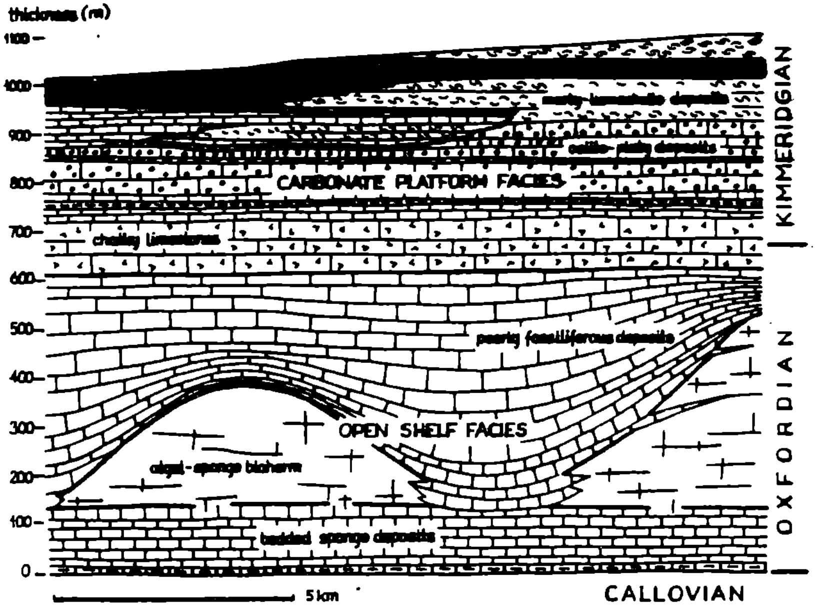


Fig. 38 Diagrammatic sketch of the facies relationships in the Upper Jurassic basin of the Holy Cross Mts

of the Holy Cross Mts, and during the Latest Oxfordian in the south-western part, established was sedimentation of carbonate-platform type, and variable shallow marine deposits have developed. The same type of sedimentation persisted in the Kimmeridgian, the sequence of which consists of deposits laid down in a high-energy environment /cross-bedde oolites, coquinas/ and those laid down in a low-energy environment /micritic limestones marls and marly shales/. In the both environments various non-depositional and early dissolution and/or lithification phenomena are extremely common /see Roniewicz & Roniewicz 1968; Kaźmierczak & Pszczółkowski 1968; Kutek 1968, 1969; Gruszczyński 1979/, as exemplified by the structures exposed at Żerniki /Fig.39 / and at Małogoszcz /Fig. 40/. The general distribution of these two energy-controlled groups of deposits indicates the prograding carbonate platform edge towards the west and south-west during the Oxfordian and Kimmeridgian /Kutek 1969/. The Upper Jurassic sequence is completed with black claystones of Upper Kimmeridgian and Lower Volgian age.

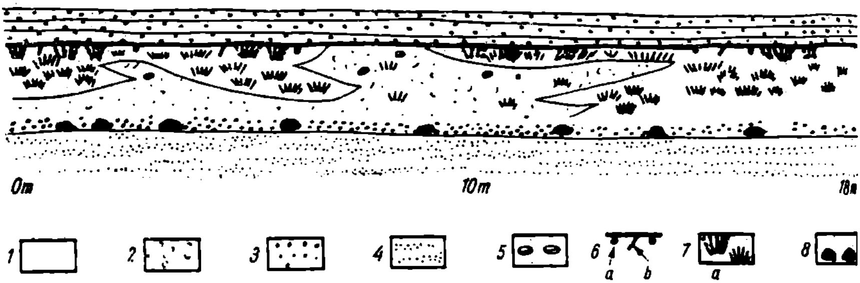


Fig.39 Coraliferous layer and associated sediments exposed at Zerniki

1 pelitic limestone, 2 pelitic limestone with admixture of organic detritus, 3 oolitic limestone, 4 banded limestone, 5 onkolites, 6 hard ground with borings of lithophags (a Lithophaga sp., b Potamilla sp.), 7 colonies of Calamophylliopsis stockesi (a colonies with partly dissolved branches), 8 colonies of Heliocoenia (Decaheliocoenia) variabilis

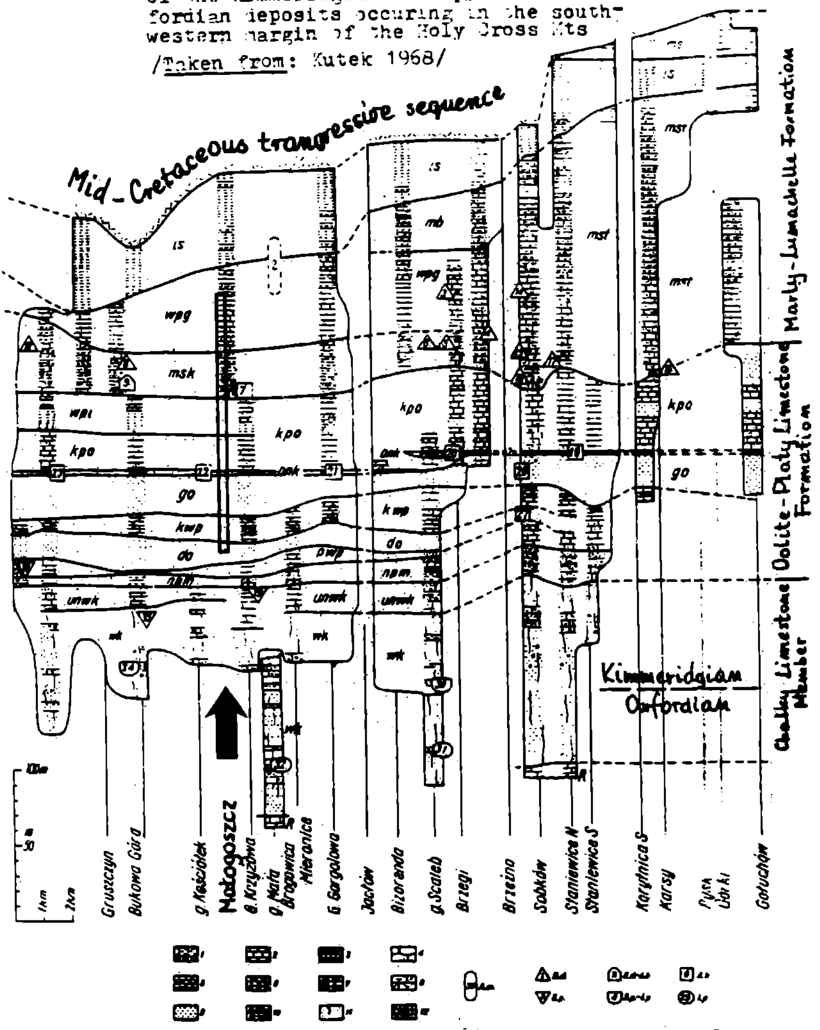
(Taken from: Roniewicz & Roniewicz 1968)

Locality: Małogoszcz

In a huge quarry located near the cement factory, exposed is the sequence of the Lower and lowermost Upper Kimmeridgian deposits, over 170 m thick. At the entrance to the quarry, the Oolite-Platy Limestone Formation is visible, as follows:

/1/ Lower Oolite Member /do/ - exposed 10 m,
/2/ Banded Limestone Member /kwp/ - 18 m thick,

Fig. 40 Lithological development and thickness of the Kimmeridgian and Uppermost Oxfordian deposits occuring in the southwestern margin of the Holy Cross Mts
/Taken from: Kutek 1968/



Lithology: *1* marly shales and marls, *2* platy limestones, *3* shaly limestones, *4* thick-bedded and indistinctly bedded pelitic limestones, *5* banded limestones (ripple-bedded limestones with flints), *6* *Exogyra* lumachelles, *7* *Alectryonia* lumachelles, *8* „grab" limestones, *9* oolites, *10* onkolites, *11* chalky limestones, *12* other, grained limestones. Mixed signature denotes intermittent lithological types. Ammonitiferous points in zones: *A.m.* Aulacostephanus mutabilis; *K.d.* Katroliceras divisum; *K.d.—A.h.* Katroliceras divisum or Ataxioceras hypselocyclum; *A.h.* Ataxioceras hypselocyclum; *S.p.* Sutneria platynota; *S.p.—I.p.* Sutneria platynota or Idoceras planula; *I.p.* Idoceras planula. Lithostratigraphic units: *ms* Top Lumachelle, *ls* Top Clays, *mst* Staniewice Lumachelle, *mb* Brzegi Lumachelle *wpg* Upper Platy Limestones, *msk* Skorków Lumachelle, *kpo* Oolite-Platy member, *wpi* Shaly Limestones and Underlying Clays, *onk* Onkolite horizon, *go* Upper Oolite, *kwp* Banded Limestone member, *do* Lower Oolite, *pwp* Underlying Pelitic Limestones, *npm* Lowermost Marly horizon, *unwk* Deposits Overlying Chalky Limestones, *wk* Chalky Limestone member, *R* deposits underlying Chalky Limestone member

/3/ Upper Oolite Member /go/ - 27 m thick,
/4/ Onkolite Horizon /onk/ - 0.1 m thick,
/5/ Oolite-Platy Member /kpo/- 18 m thick,
/6/ Shaly Limestone and Underlying Clays Member /wpi/ - 47 m thick.

The members /1/ and /3/ consist of cross-bedded and non cross-bedded oolites. The intervening deposits are assigned to the Banded Limestone Member /2/, in which there occur ripple-beded sediments with alternating bands of micritic and grained limestones. The members /1/-/3/ represent extremely shallow /sometimes subaerally exposed/ environment indicative of an edge of the carbonate platform. The deposits of the Banded Limestone Member are thought to have developed on submarine shoals sheltered by oolitic ridges /Fig. 41/.

The upper surface of the Upper Oolite Member is erosionally truncated and modified into an uneven surface of the hardground type. The Onkolite Horison which overlies the hardground, although is very thin, and it may be traced over a distance of several tens of kilometres /Kutek & Radwański 1965/. Micro- and pisoonkoids, less often also macroonkoids, are encountered in this onkolitic band which has a habitus of rewashed sediments deposited behind the areas where the oolites were formed.

The Oolite-Platy Member /5/ and Shaly Limestones and Underlying Clays Member /6/ are built of variable amounts of clays, marly limestones, and micritic limestones occasionally with onkoids and ooids. Several non-depositional surfaces and a few hardgrounds are recognizable in this part of the sequence, the uppermost part of which contains thick-bedded limestones with deep burrowing bivalves preserved in the life position.

In the middle part of the quarry, exposed are the Skorków Lumachelle Member /msk in Fig. 40/ and Upper Platy Limestone Member /wpg/belonging to the Marly-Lumachelle Formation /50 m thick/. The Skorków Lumachelle is composed of limestones, marly limestones and marls with various amounts of shell material of different bivalves, mostly Lopha gregarea /Sow./ in the lower part, and Nanogyra nana /Sow./ in the upper part. The limestones and marly limestones are composed of fine bivalve shell detritus /biomicrite and biopelmicrite/ partially with onkoids and/or ooids. Some intercalations of onkolites are also present. As a cor-

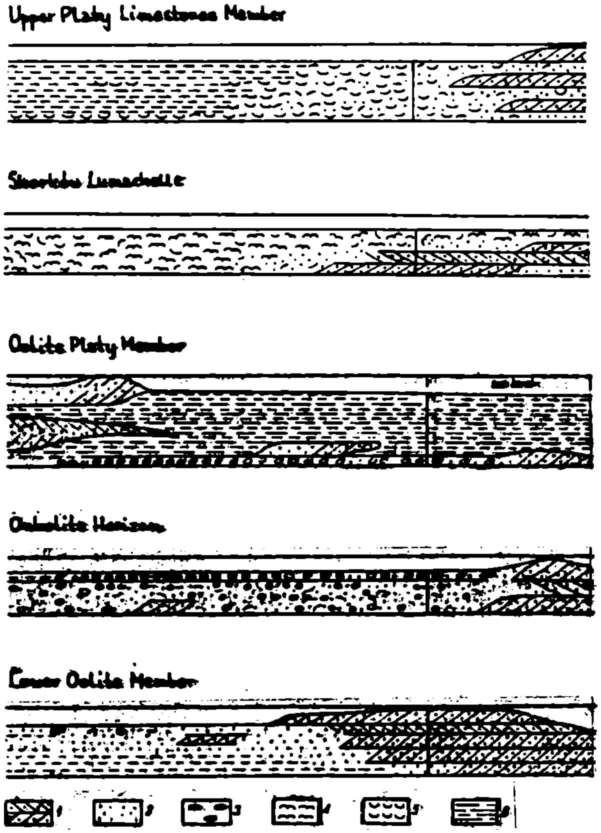


Fig. 41 Diagrams showing sedimentary environments and formation of deposits of the Lower Oolite Member, the Onkolite Horizon, the Oolite-Platy Member, the Skorków Lumachelle Member, and the Upper Platy Limestones Member
1 cross-bedded oolites, 2 non-cross-bedded oolites, 3 onkolites and onkoid-bearing limestones, 4 Lopha lumachelle, 5 Nanogyra lumachelle, 6 micritic limestones and marls

/Taken from: Kutek 1969/

relation marker, considered is the hardground occurring at the base of the member. The Skorków Lumachelle is aged as the Lower Kimmeridgian at the boundary of the Ataxioceras hypselocyclum and Katroliceras divisum zones, both in the western and in the north-eastern margin of the Holy Cross Mts. It may be indicated that the discussed lumachelle had covered the area of at least 10 000 sq km.

The *Lopha*-bearing strata are replete with ubiquitous fossils /"Fossil-Lagerstätte"/, the assemblage of which is dominated by diverse bivalves /*Mytilus*, *Modiolus*, *Gervilleia*, *Trichites*, *Pholadomya protei* /Brong./, and *Trigonia*/, associated with brachiopods /large specimens of *Epithyris subsella*/Leym./, *Septaliphoria pinguis* /Roem./, gastropods /large *Natica*, nerineids/, and crinoids /*Apiocrinites* - "Wurzeln" and stems/, as well as echinoids, both irregular /*Holectypus*, *Pygaster*, *Pygurus*/ and regular ones /*Cidaris*, *Rhabdocidaris*, *Hemicidaris*, *Acrosalenia*, *Hypodiadema*, *Trochotiara*/. Of these fossils, especially the bivalves appeared to be important for the rocognition of the organism/substrate relationship /Seilacher, Matyja & Wierzbowski 1985/.

The Upper Platy Limestones Member is composed of platy micritic limestones with marly and a few lumachelle intercalations. The lumachelles consist mostly of the *Nanogyra* shells. The single beds have sometimes a wide distribution, and may be traced over a distance of a few kilometres without any changes in their characteristic /*e.g.* lithology, thickness/.

Deposits of the Marly-Lumachelle Formation have been deposited on a drowned carbonate platform within the frames of slowly deepening sea, featured by an increasing supply of the terrigenous material.

Above the quarry, visible is a distinct step in morphology, covered by a pine forest, and built of Albian sandstones.

Fig. 42 Małogoszcz quarry: *Lopha* lumachelle bed /arrowed/ and a typical cluster of *Lopha* shells

The mid-Cretaceous transgressive sequence, resting with a low angular unconformity upon the Jurassic substrate (in the north-western part of the Holy Cross Mts also upon a Neocomian series of Berriasian through Hauterivian age), begins with the Albian quartzitic sandstones, usually unfossiliferous (as exposed over the quarry at Małogoszcz), or with the overlapping Cenomanian greensands and/or greensandstones (see Marcinowski & Radwański 1983). The latter are locally highly glauconitic, and then contain small phosphatic nodules and diversified faunal remains with Neohibolites ultimus (d'Orbigny) and abundant shark teeth (locality Staniewice in Fig. 34). These clastic deposits pass through the Turonian gaizes into siliceous chalks (so-called "opoka" in Polish literature) of Coniacian and Senonian age, and gradually more and more distant in their occurrence belts from the Holy Cross Mts (cf. Figs 1, 5B, 7, and 34).

A complete section of the mid- and Upper Cretaceous sequence is well exposed along the slopes of the Vistula Valley which makes a structural gorge through the Central Polish Uplands, north-east of the Holy Cross Mts (see Fig. 1). This world-famous section starts at Annopol-on-Vistula where the mid-Cretaceous condensed sequence begins with Middle Albian sands and sandstones overlain by a bipartite phosphorite bed replete with fossils and containing the ammonites indicative of low-Middle through Upper Albian age (see Samsonowicz 1925; Marcinowski & Radwański 1983, 1985; Marcinowski & Walaszczyk 1985; Marcinowski & Wiedmann 1985a,b); successive are Cenomanian glauconitic marls featured with two hardgrounds, and lowermost Turonian marls truncated by another hardground.

The higher parts of the Cretaceous sequence are exposed northwardly along the Vistula Valley (see Pożaryski 1938), where the topmost parts of the sequence make up a picturesque landscape around the medieval town of Kazimierz-on-Vistula.

The Vistula Gorge near Kazimierz-on-Vistula becomes extremely narrow, and the valley itself becomes confined to the river bed (Fig. 43). A series of natural exposures and larger quarries situated along the slopes of the Vistula Valley offer a good insight into the uppermost Maestrichtian and early Tertiary strata.

The Cretaceous/Tertiary boundary beds are featured with a hardground and associated greensand containing phosphatic nodules and a mass aggregation of fossils ("Fossillagerstätte"). These beds, formely better exposed at Bochotnice (see Putzer 1942), are at present easily available in a huge quarry at Nasiłów situated at the left flank of the Vistula River (see Figs 43–44).

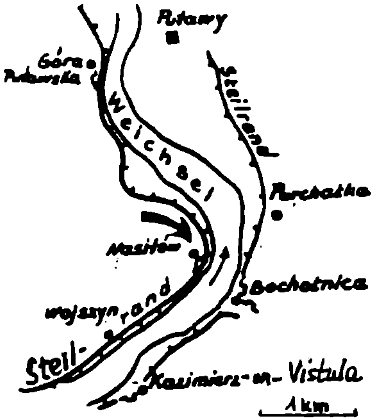


Fig. 43

Situation sketch-map, to show localities around Kazimierz-on-Vistula (arrowed is the quarry at Nasiłów)

(Adopted from: Putzer 1942)

Fig. 44 Landscape of the Vistula Gorge, as seen from Kazimierz-on-Vistula towards the Nasiłów quarry (cf. Fig. 43)

Note the artificially reinforced meanders disrupted by braided channels during a summer flood (a textbook case of the river braidening)

All the uppermost Maestrichtian deposits exposed near Kazimierz-on-Vistula yield abundant fossils (a paleontological bonanza), some of which having been established as new species. Such very species, named after the locality of Kazimierz (however, ethymologically more or less correctly: kasimiri, casimirovensis, kazimierzensis) have still remained endemic, whereas the others have soon been recognized as widely distributed in Europe (e.g. Belemnella casimirovensis of Skołozdrówna, 1932).

Locality: Nasiłów

The section begins (cf. Putzer 1942, pp. 364-365) with marly, but more or less siliceous chalks (= Opoka, or mergeliger Kreidekalk of Putzer, 1942) which are rather indistinctly stratified (see Fig. 47). Some parts of these deposits display lenticular microstratification and numerous bioturbations. The fossil content (see Pożaryski 1938, Putzer 1942) comprises diverse mollusks (scaphopods, abundant gastropods and bivalves, large nautiloids, some ammonites and belemnites) associated with numerous sponges, and scarce solitary corals, brachiopods, crinoids, echinoids, as well as shark and mosasaurid teeth.

Of the Nasiłów fossils, the most characteristic are numerous sponges, i.e. a curiously-shaped endemic species, Mastophorus kazimierzensis (Hurcewicz, 1968) [probably identical with Mastophorus arboreus of Schrammen, 1924)], which commonly occur in their life position (Fig. 45A), and such bivalves as Pholadomya kasimiri Pusch and Pecten acuteplicatus Alth (see Fig. 45 B). Noteworthy are also large-sized (over 30cm high) gastropods Voluta kasimiri Mazurek, and ammonites Scaphites constrictus (Sowerby) whose sexual dimorphs (Fig. 46) are encountered through the opoka sequence.

The present study of the gastropods (about 80 species) and bivalves (over 120 species), undertaken by Mr. Gouda Ismail Abdel-Gawad, indicate shallow-marine requirements of these mollusks, the biotope of which was featured by good photic conditions and local seagrass vegetation. This evidently indicates that former opinions on deep-water origin of these deposits are not justified.

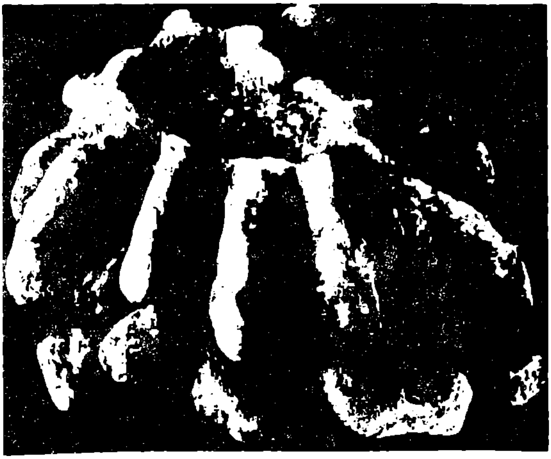


Fig. 45 A Endemic siliceous sponge, Mestophorus kazimierzensis (Hurcewicz), usually preserved in life position (as seen in the photo); nat. size

Fig. 45 B Endemic bivalve, Pholadomya kasimiri Pusch; nat. size

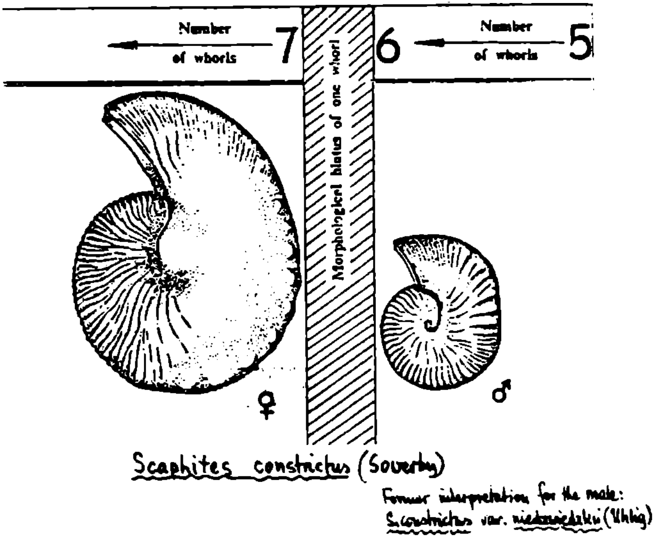


Fig. 46 Sexual dimorphs of Scaphites constrictus (Sowerby) collected from "opokas" at Nasiłów and Kazimierz-on-Vistule

(After: Makowski, 1962)

The top surface of opoka is featured by a hardground (see Figs 47–48), the morphology of which was formerly interpreted as a result of subaqueous dissolution. The present-day state of the exposure clearly shows the hardground topography to have formed due to biogenic activity, and all the "canals" are really the burrows, although some of them remain more or less eroded.

The most common are burrows of the Thalassinoides-type attributed to the shrimps, and J-shaped ones attributable to the ghost crab Ocypode. The latter burrows, usually more or less vertical, have their J-shaped parts preserved (Fig. 49) and identical with those produced by the present-day juveniles of diverse tropical species of Ocypode, for instance of Ocypode ceratophthalma from the Taiwan beaches (see Hayasaka 1935, Takahasi 1935) or Ocypode ryderi from the Somali beaches (see Vannini 1980). All these present-day analogs are typical of an intertidal, usually a backshore environment (cf. also Radwański 1977).

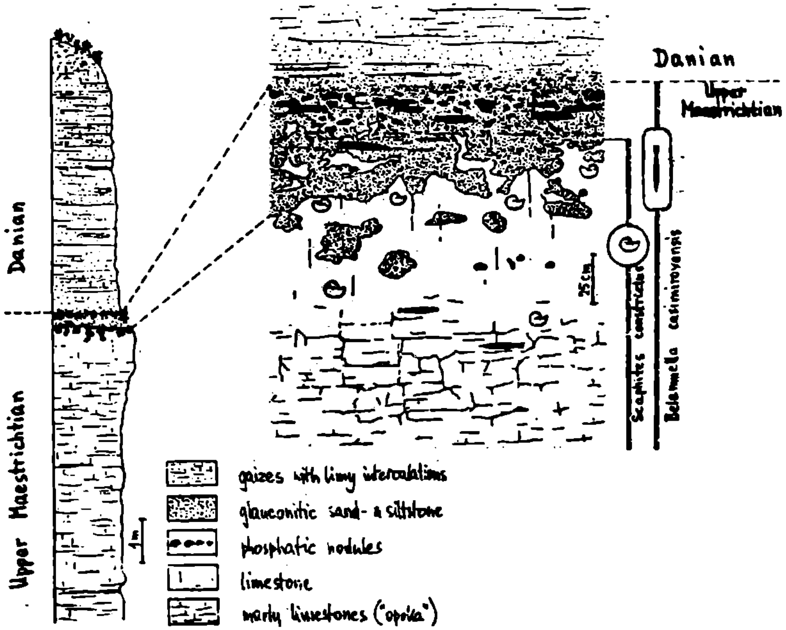


Fig. 47 Cretaceous/Tertiary boundary beds exposed near Kazimierz-on-Vistula

(Adopted from: Putzer 1942, Pożaryski 1956)

The Ocypode burrows evidence that the Nasiłów hardground has formed under extreme shallow-marine conditions, precisely within a temporarily emerged tidal flat. In the hardground horizon, a few generations of burrows are recognizable (see Fig. 48a-b), and the periods of biogenic activity have either been interrupted by progressing sedimentation (stage a in Fig. 48), or by erosion associated with the early lithification (stage b in Fig. 48).

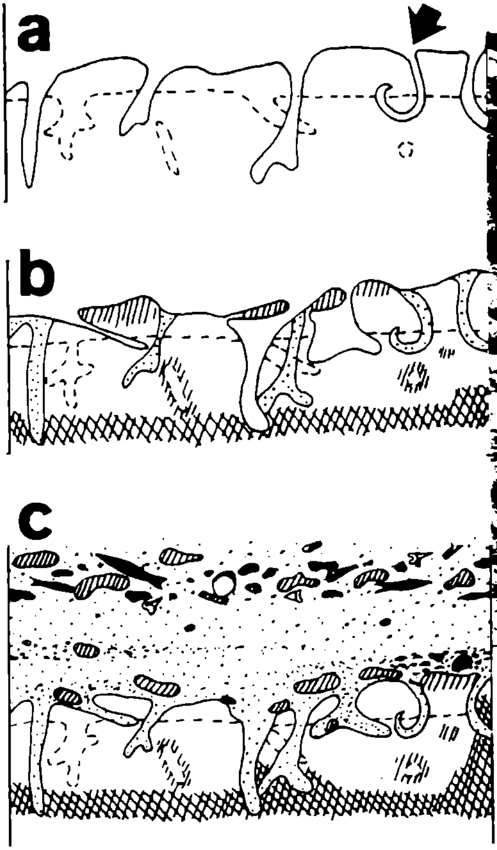


Fig. 49
J-shaped burrow of a juvenile ghost crab Ocypode, as taken from the hardground exposed at Nasiłów (arrowed in Fig. 48a)

Fig. 48 Successive developmental stages (a, b, c) of the hardground exposed at Nasiłów
(Adopted from: Jelinowska 1985)

All the above-presented features indicate a longer timespan for the formation of the Nasiłów hardground, and the changing depositional conditions which have also influenced the life conditions of diverse biota. This environmental heterogeneity, as well as diversified bottom morphology favored a settlement of many benthic biota which could not settle before, on the quaggy seafloor. Some of them have become the links of a trophic web, i.e. the food for higher invertebrates, as recently demonstrated by Jarvis (1980) for the belemnites. The mass occurrence of one belemnite species (see Fig. 47), Belemnella casimirovensis Skołozdrówna, is typical of some parts of the Nasiłów hardground (belemnite battlefiels, or Schlachtfelder). Noteworthy are occurrences of juvenile guards of this species (needle-like shaped, diametered less than 1mm), comparable to those noted by Jarvis (1980) for the chalk hardgrounds of England.

The greensand which fills up the burrows and overlies the hardground surface, contains all the fossils known from the underlying opoka, except of Scaphites constrictus (Sowerby) and other aragonite-shelled animals (see Fig. 47). The fauna is locally concentrated in lenticular streaks, usually containing small phosphatic nodules or phosphatized pieces derived from the top surface of opoka. All the fossils are fresh, not being worn, what indicates quiet and slow sedimentation, without reworking and redeposition (except of phosphatized opoka pieces).

The greatest amount of the fossil remains and phosphatic nodules occurs at a distance of about 30cm above the average surface of the hardground (see Fig. 47), and it is regarded as a residual lag formed during slow sedimentation and a winnowing action of the currents (stage c in Fig. 48). This very lag contains the latest Upper Cretaceous fossils, and is therefore thought to represent the topmost Maestrichtian horizon.

Above the topmost Maestrichtian lag horizon the Danian sedimentation begins. It is expressed by gaizes with limy intercalations (see Fig. 47), commonly known under a local name "siwak", and containing small amounts of glauconite at its bottom part.

The gaizes are assigned to the Upper Danian (cf. p. 11, and Hansen 1970, Marcinowski & Radwański 1983). Consequently, it is evident that the topmost Maestrichtian residual lag is associated with a stratigraphic gap lasting throughout the Lower Danian time.

List of the most common fossils from Nasiłów quarry

		Opoka	Greensand
Sponges:	Craticularia sp. div.	+	
	Mastophorus kazimierzensis (Hurcewicz,1968)	+	
Corals:	Trochocyathus sp.	+	+
Brachiopods:	Crania paucicostata Bosquet, 1859		+
	Cretirhynchia limbata (Schlotheim, 1813)	+	+
	Orbirhynchia parkinsoni Owen, 1959	+	+
	Carneithyris carnea (Sowerby, 1823)	+	+
	Carneithyris circularis Sahni, 1925	+	+
	Neoliothyrina obesa (Davidson, 1883)	+	+
Gastropods:	Turritella plana Binkhorst, 1861	+	
	Turritella quadricincta Goldfuss, 1844	+	
	Aporrhais pyriformis (Kner, 1850)	+	
	Tudicla carinata Münster, 1844	+	
	Tudicla althi Kner, 1852	+	
	Vermetus nodosus Kaunhowen, 1898	+	
	Trochus nilssoni (Münster, 1844)	+	
	Voluta kasimiri Mazurek, 1931	+	
	Pleurotomaria subgigantea d'Orbigny 1850	+	
Bivalves:	Hyotissa semiplana (Sowerby, 1825)	+	+
	Pycnodonte vesicularis (Lamarck, 1806)	+	+
	Pecten acutaplicatus Alth, 1850	+	+
	Neithea sexcostata (Woodward, 1833)	+	+
	Dimyodon nilssoni (von Hagenow, 1842)	+	+
	Gyropleura ciplyana de Ryckholt, 1853	+	+
	Pinna decussata Goldfuss, 1837	+	
	Pholadomya kasimiri Pusch, 1837	+	
	Pholadomya esmarki Nilsson, 1827	+	
Cephalopods:	Nautilus patens Kner, 1850	+	
	Nautilus althensis Schlüter, 1876	+	
	Nautilus intrasiphonatus Łopuski, 1911	+	
	Scaphites constrictus (Sowerby, 1818)	+	
	Acanthoscaphites varians (Łopuski, 1911)	+	
	Baculites anceps (Lamarck, 1801)	+	
	Pachydiscus sarsensis Atabekyan & Akopyan,1969		
	Sphenodiscus binkhorsti Böhm, 1898	+	
	Belemnella casimirovensis Skołozdrówna, 1932	+	+
Crinoids:	Bourgueticrinus sp.	+	+
Echinoids:	Salenidia bonissenti (Cotteau, 1866)	+	+
Sharks:	Notidanus agassizi Cappetta, 1976		+
	Squalicorax falcatus (Agassiz, 1843)	+	+
	Corax pristodontus Agassiz, 1843	+	+
	Scapanorhynchus striatellus Zaręczny, 1878	+	+
	Lamna serrata (Agassiz, 1843)	+	+
	Oxyrhina sp.	+	+
Teleosts:	Pycnodus cretaceus Agassiz, 1843	+	+
Reptiles:	Mosasaurus hoffmanni Mantell, 1828		+

FORE-CARPATHIAN DEPRESSION

A. Radwanski

The Fore-Carpathian Depression is situated at the northern margin of the Carpathian range and extends from Moravia in the west to the Ukraine in the east. It is bordered to the south by the Carpathian nappes, and to the north by the Central Polish Uplands. The latter consist, in a geotectonic sense, of the circum-Carpathian belt which was elevated as an isostatic response to Carpathian folding and formation of the foredeep. The evolution of this foredeep, viz. the Fore-Carpathian Depression, took place in a relatively short time in the Miocene, and is limited to the Tortonian stage. During that stage a marine invasion from the Vienna Basin entered this incorporating it into a system of circum- and intra-Alpino-Carpathian basins, commonly called the Paratethys (Fig. 50), as it originated from the Tethys Ocean of Mesozoic-Paleogene time.

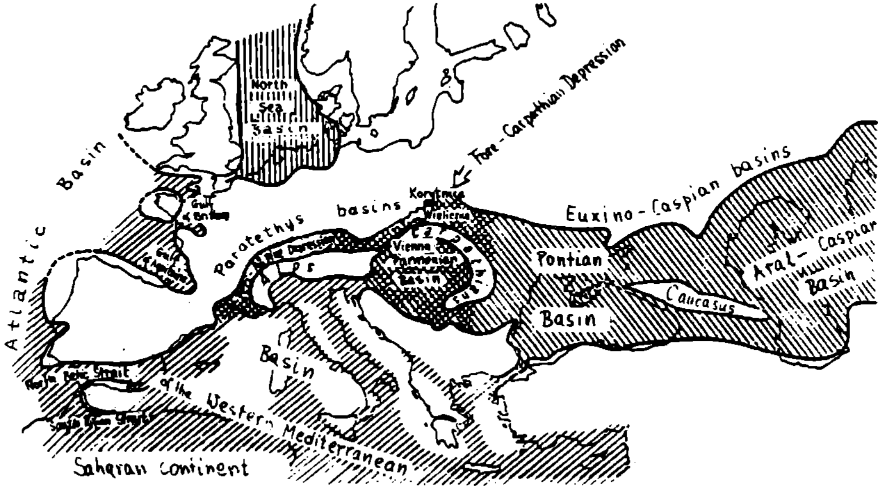


Fig. 50 Marine basins in the Miocene of Europe. (Compiled mostly from Gignoux, 1955, Papp, 1959 and Rasmussen, 1966).

During the Tortonian transgression the sea entered the slopes of the Central Poland Uplands along the valleys. The terrestrial erosion took here place in Paleogene after the Laramide folding of the Danish-Polish Trough and during successive uplift of the area (*cf.* Kutek & Glazek, 1972). Vadic erosion of surface waters was then accompanied by chemical corrosion of carbonate belts which readily underwent strong karstification in tropical or subtropical climate of the Eocene (*cf.* Glazek & *al.*, 1972). The valley network was transformed during the transgression into a diversified system of bays with differentiated shoreline, the extent of which is recognizable by occurences of borings left by various lithophags (sponges, polychaetes, pelecypods, cirripedes, echinoids) that bored any carbonate part of the shore (Radwanski, 1964, 1965a). In many

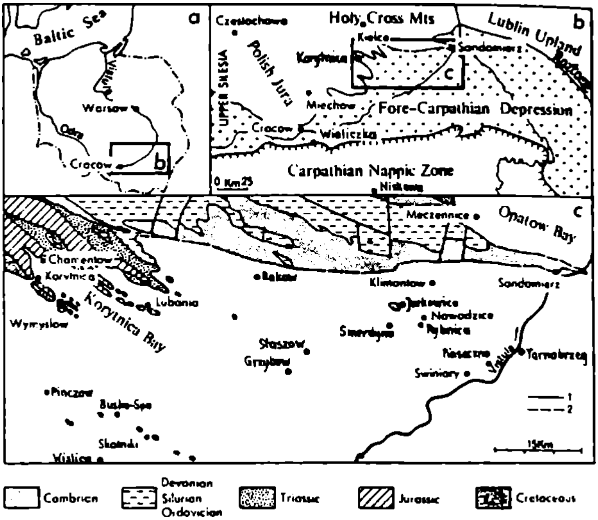


Fig. 51 *a.* General map of Poland depicting the area discussed; *b.* Extent of the Miocene (Tortonian) sea in Southern Poland; *c.* Tortonian deposits on the southern and eastern slopes of the Holy Cross Mts; in the Tortonian contours, the shoreline detected by littoral structures along the rocky seashores (*1*), and its probable extent (*2*) in the low lying eastern region are shown.

Fig.52 Types of littoral structures developed along the Tortonian seashores of the Central Poland Uplands:

a - cliff covered by rubble, b - cliff covered by finer clastics, c - abrasion surface, d - abrasion surface with rubble at the base, e - abrasion platform, f - littoral rubble, g - cliff-originated conglomerates, h - isolated boulders; borings produced by lithophags are indicated.

Exemplified by the stuctures exposed at:

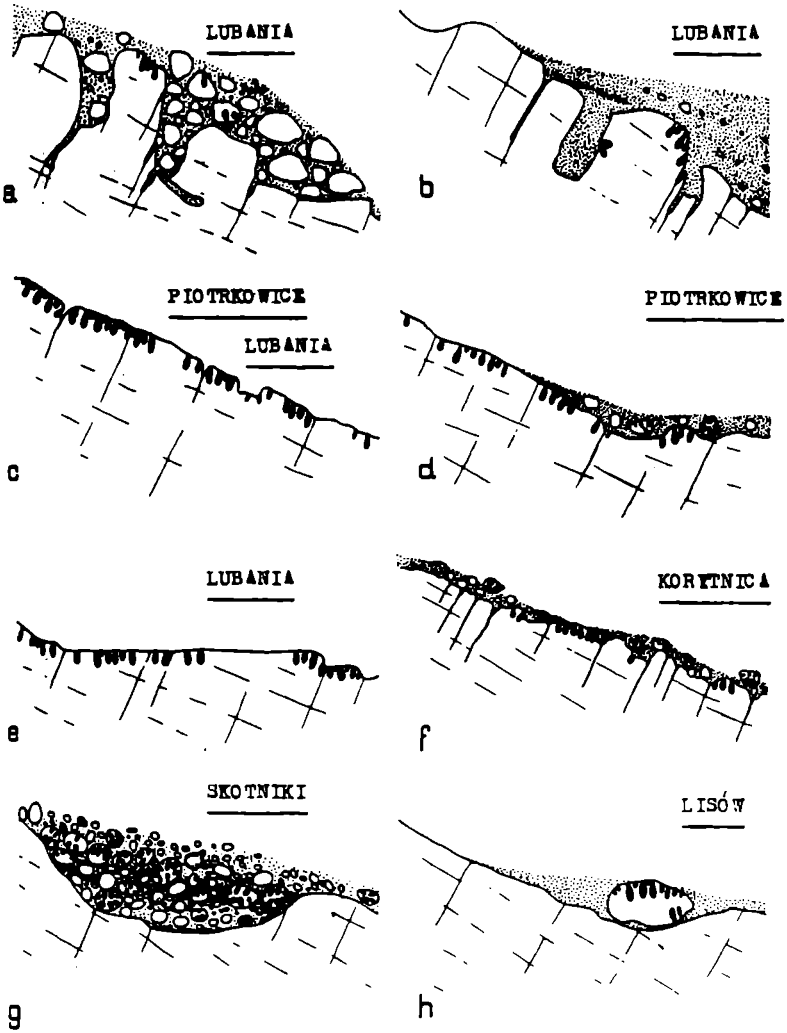
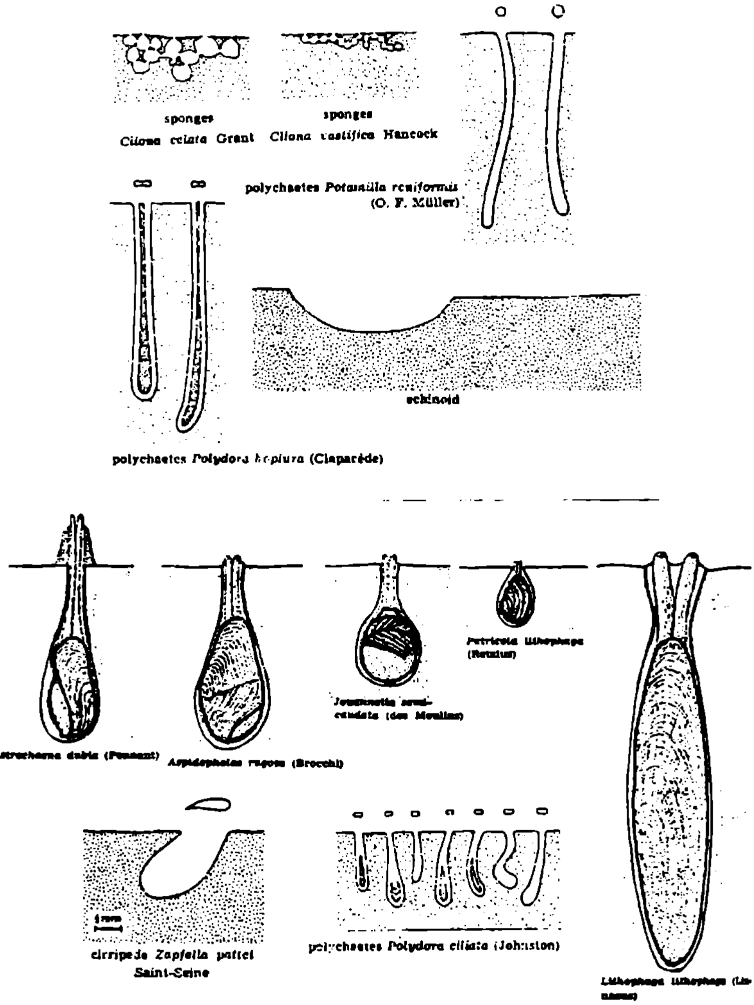


Fig. 53 Typical rock-borers (lithophags) domiciling the Tortonian seashores of the Central Poland Uplands:



All in natural size, except of <u>Zapfella pattei</u>

places the rock-borers occurrences stretch out to within a few kilometers of the maximum limits of the preserved Tortonian deposits and give therefore evidence of much greater extent of the shoreline into the regions where the marine deposits either were not formed or have not been preserved during subsequent erosion. Along the shoreline, the rock-borers usually settled within various littoral structures resulting from mechanical abrasion, such as cliffs, cliff rubble,

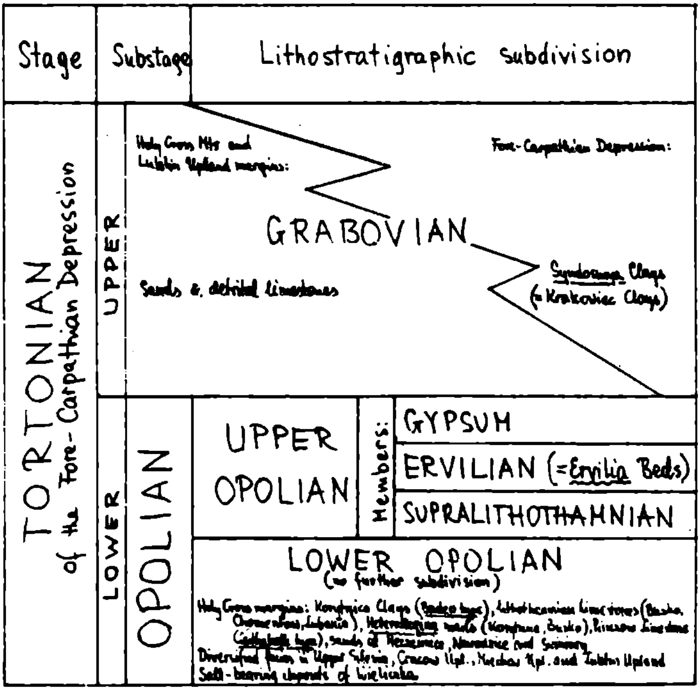


Fig. 54 Stratigrafic division of the Tortonian deposits of the Fore-Carpathian Depression.

abrasion walls (surfaces) or platforms, which allow the recognition not only of the regional paleogeography but also of the prevailing hydrodynamic conditions. The facies of the deposits that formed during the transgression give further evidence on both the life conditions in the sea basin and on the erosional processes on the adjacent land.

The Tortonian deposits in the Fore-Carpathian basin belong only to the Tortonian (Radwanski, 1969, 1973) and there is no evidence of previously postulated other stages. This Tortonian sequence is subdivided (Fig. 54) into the Lower Tortonian - Opolian (from the Opole country near Lwow in the Ukraine) and Upper Tortonian - Grabovian (after a village Grabowice at the Carpathian margin), the boundary of which is placed at the top of more or less continuous gypsum deposits (Gypsum Member). In the Upper Tortonian (Grabovian)the only facies that may be distinguished are those which were at the shores and the centre of the basin. In the Lower Tortonian (Opolian), further subdivision comprises Lower Opolian corresponding to open-sea conditions, and the Upper Opolian with its three successive members characterized by deposits formed during an increase of salinity in the basin (Supralithothamnian Member - as overlying lithothamnian facies of the Lower Opolian, Ervilian Member - with fauna of the *Ervilia* type), and its evaporation (Gypsum Member).

In the only open-sea portion of the sequence, i.e. in the Lower Opolian, all the deposits form a diversified pattern of facies, the development of which depended on bottom morphology, supplies of terrestrial material and life conditions in the basin. Even if a few facies are in succession in one place, their boundaries are diachronic with those of the same facies in other regions. Consequently,no detailed stratigraphic subdivision may be used here (cf. Fig. 54).

As there are no index fossils in the whole Tortonian sequence of the Fore-Carpathian Depression, all the units of the presented division (Fig. 44) are lithostratigraphic.

All the endo - and exogene processes which took place on the neighboring land more or less contemporaneously with the Fore-Carpathian Tortonian, the development of brown-coal formation (Polish Lowland, Sudetic Foreland) and volcanic activity (Sudetes, much weaker in the Pienines) including, may only be generally referred to the Miocene in its broadest meaning.

REGIONAL DEVELOPMENT

Along the Carpathian margin the Tortonian deposits are in part folded together with the flysch nappes which extended to the north over the oldest Tortonian substrate. The latter plunges therefore beneath the Carpathian nappes and stretches, as boreholes show, to a distance of a few tens of kilometers; in this part the Tortonian deposits are thin, and thus delimitate the southern, platformal margins of the Fore-Carpathian Depression, the zone of greatest subsidence of which was situated in the Carpathian Foreland. On the other hand, these Tortonian deposits are weakly folded; evidence that the thrusting did not disturb the substrate to a greater extent. The oldest Tortonian deposits are strongly folded only at the Carpathian margin, resulting from their lithology, which includes the salt deposits which certainly would easily have been squeezed. The salt formation, long known from the world famous medieval and still operating mine at Wieliczka (cf. Fig. 71), is of Lower Opolian age. In the mine sequence, the most remarkable are karst solutions in salts (cf. Glazek & al. , 1972) producing many fissures with dripstones, and caverns covered by great crystals of halite, as e.g. in the famous Crystal Cave. Younger Lower Tortonian (Upper Opolian) deposits are here not folded (Bogucice Sands with abundant mollusk fauna), the same as Upper Tortonian (Grabovian) part of the sequence.

The best opportunities for studying the Fore-Carpathian Tortonian are on the slopes of the Central Polish Uplands where well exposed profiles and long continuous exposures give a good insight into the sedimentary sequence and its successive members.

Along the southern slopes of the Holy Cross Mts during the Lower Tortonian transgression (cf. Radwanski, 1969, 1973), the differentiation of either bottom morphology and/or the resulting facies was the greatest. In the western part,

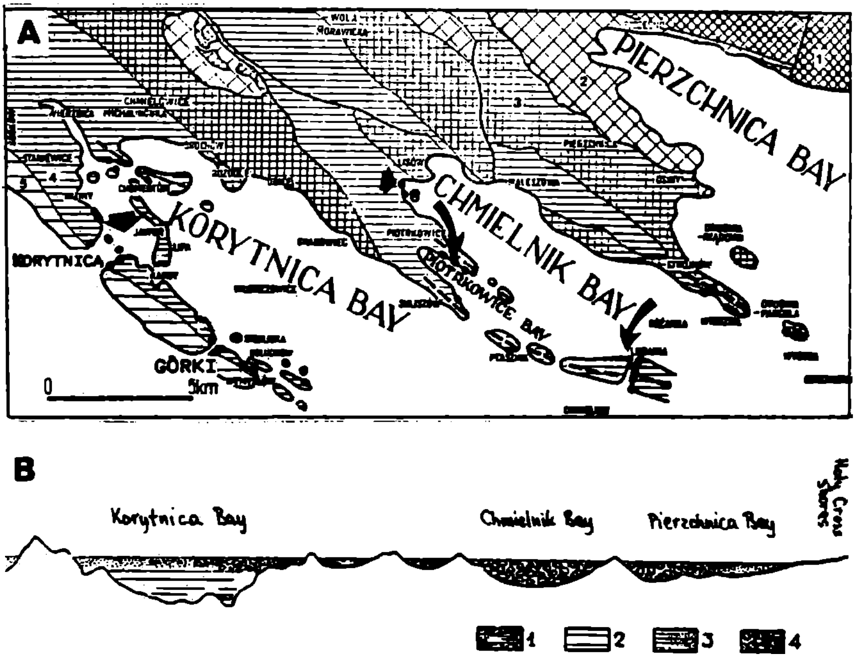


Fig. 55 A. General map of the Lower Tortonian bays on the southern slopes of the Holy Cross Mountains; preserved localities of littoral structures are marked with black spots along the shoreline; asterisked is the Korytnica basin (cf. Text-fig. [illegible]) situated in the terminal part of the Korytnica Bay (cf. Radwański 1969, Fig. 25; 1970, Fig. 1)

Within the inland areas distinguished are the occurrence zones of: 1 Cambrian (including locally Ordovician and Silurian), 2 Devonian, 3 Triassic, 4 Jurassic, 5 Cretaceous; marked with heavy dashes are the ridges in morphology that separate particular bays

B. Schematic section through the region of the Lower Tortonian bays. The section does not show a wing-like position of the bays and dividing ridges (cf. the map above): 1. Brown coal deposits; 2. Korytnica Clays; 3. Marly and fine-clastic deposits; 4. Lithothamnian limestones the transgression entered a set of more or less deep and extensive valleys, subsequently eroded in the Mesozoic substrate consisting mostly of Devonian and Mesozoic carbonates (cf. Fig. 55 A). As result a Dalmatian-type of the shore developed in which bays along previous valleys are the typical feature, and these are separated by more or less pronounced rocky ridges (Fig. 55B). In the eastern part, the morphology of the substrate was rather gentle as it was mostly built of Lower and Middle Cambrian fine clastic deposits, and in result uniformly smooth, sandy seashores orginated there. A similar situation took also place along the eastern slopes of the Holy Cross Mts in which the transgression entered only one wide valley and transformed it into a shallow extensive bay (Opatow Bay - Fig. 54 c). In all these regions various organic communities settled in, reflecting both the bathymetric and bottom conditions.

In the region of bays (Fig. 55; cf. Radwanski, 1969), in all the shallower parts and along the submerged or island ridges mostly red algae, *Lithothamnium*, thrived and supplied material to various local deposits, of which the most common are pure lithothamnian limestones or marls built of whole and uncrushed algal colonies (cf. Fig. 55 B). The Korytnica Bay was the deepest (Fig. 55 B) where sedimentation of a very fine clay material continued through almost the entire section. The resulting deposits, the Korytnica Clays, about 4o to 6o m thick at the deepest place, yield a remarkable abundance of various fossils and are world famous since the time of Murchison's travel to Russia during which he stopped in Poland to make a trip to Korytnica (cf. Murchison, 1845, pp. 292-293). Nearly all the systematic groups of invertebrates, as well as fishes, are represented here, the gastropods being the most abundant and striking. Of the latter the most common is *Clavatula*, previously attributed to *Pleurotoma* in a broad sense, and therefore the clays are often referred to as *Pleurotoma* clays. The total number of gastropod species is about 6oo, and only some of them have hitherto been monographed (Friedberg, 1911-1928, 1938; Baluk & Jakubowski, 1968; Ba-

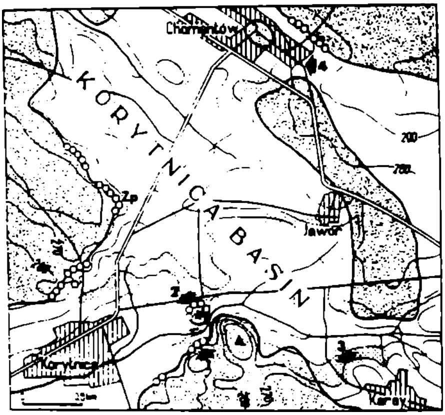


Fig. 56 Paleoenvironmental sketch of the Korytnica Basin

Indicated are: marine area of the Korytnica basin during the Middle Miocene (Badenian) transgression (*blank*) and present-day outcrops of the Korytnica Clays (*stippled*); preserved fragments of littoral structures (*circled*); land or island areas along the seashore (*hachured*)

Asterisked is the summit of Mt. Lysa; marked with black triangle is the summit of Mt. Grodzisko

Numbered are some more important localities discussed in the text:

1 — North-western slopes of Mt. Grodzisko: littoral rubble with borings domiciled by secondary dwellers (*Sphenia*, *Striarca*, *Crepidula* — see Fig. 9); clay facies with brackish gastropods. This is the area of conjectured mangrove swamps (*cf.* Text-fig. 5), discussed i.a. by Radwański (1969, 1974) and Hoffman (1977)

2 — Northern slopes of Mt. Lysa: littoral rubble covered by oyster shellbed (lumachelles) containing diverse fossils (*cf.* Text-fig. described by previous authors

3 — The only natural exposure of the Korytnica Clays, situated on the northern slope of the hill capped by the village Karsy; this is the locality often named by previous authors as Karsy

4 — Sand pit at Chomentów where the deposits overlying the Korytnica Clays are exposed: these are marly sands and red-algal (lithothamnian) limestones, both containing diverse fossils (*cf.* Radwański 1969, Text-fig. 23; 1970, Text-fig. 4; 1977 ; Jakubowski 1977)

Zp — Biotope of the acrothoracican barnacles, *Zapfella pattei* Saint-Seine, within the littoral rubble and fragmentary abrasion surface

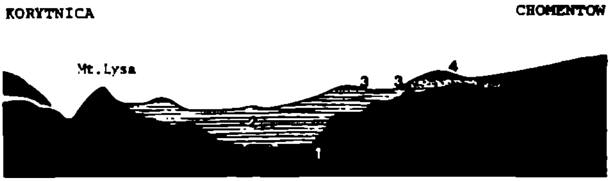


Fig. 57 Idealized section through the Korytnica Basin (not to vertical scale; *cf.* Text-fig. 56) to show the general sequence of the Middle Miocene (Badenian) deposits

1 brown-coal deposits, 2 KORYTNICA CLAYS, 3 marly sands, 4 red-algal (lithothamnian) limestones

luk, 1974). Other mollusks are represented by about loo species of pelecypods (cf. Friedberg, 1934-1936, 1938; Radwanski, 1964, 1969),over a dozen chitons (the richest assemblage in the European Miocene - Baluk, 1971) and scaphopods (Baluk, 1972), as well as a few cuttlefish (Baluk 1977). Associated are abundant foraminifers, bryozoans and serpulids, whereas corals, brochiopods, cirripedes, crabs and lobsters, various echinoderms (starfish, brittle stars,echinoids and comatulid crinoids) and fish (elasmobranchs represented by teeth, and teleosteans also by otoliths) are subordinate(see Hoffman, 1977; Baluk&Radwanski 1977).

In the Korytnica **Basin** the sedimentation started with a local accumulation of brown-coal material (cf. Fig. 55 B) derived supposedly from the neighbouring land or coastal swamps during the first stage of transgression. Soon thereafter clay sedimentation commenced, which however was limited to the zones situated off the rocky shores. These are usually bored by various rock-borers and in places covered with littoral rubbles. The oyster lumachelle was formed here from the material derived from banks inhabited by *Ostrea frondosa* de Serres, accompanied by various mollusks and by some corals (branched *Dendrophyllia* and coin-shaped *Discotrochus*) and cirripedes (stalked *Scalpellum*, and familiar acorn barnacles, *Balanus*). This lumachelle outlines the slope of the shore and at a distance of a few dozen of meters gradually changes into pure clays (Fig. 59).

A facies differentiation is also visible through the clay sequence. It is apparent in the successive changes in mollusk communities which lived there during the slowly progressive shallowing of the basin during filling by the deposits. This sequence reflects the original range of fauna along the shore slope (Fig. 59), which was inhabited by various communities depending on the water depth. The deepest community (I in Fig. 59) is characterized by a solitary coral *Flabellum*, great tusk shell *Dentalium (Antalis) badense* Partsch and gastropods *Turritella;* it may be compared to Recent communities typical of depths between 40 and 60 meters. In the overlying part of the clays various gastropods dominate (Fig.58), of which the most typical are various *Clavatula*, *Murex*, *Ancilla*, *Conus, Cypraea, Tudicla, Strombus, Turritella, Cassis, Triton, Fusus, Chenopus*, and diversified *Natica* and *Nassa*. Less common are *Ranella, Genota, Pyrula, Xenophora, Vermetus* and slipper limpets *Crepidula crepidula* (Linnaeus), the latter domiciling empty shells of other gastropods in which they adopt their shape to the colonized space which allowed the preservation in many cases of small dwarfish males on a female that is tightly matched into the whorl (cf. Bałuk & Radwański 1977). Associated here are colonial corals, mostly *Tarbellastraea*, and pelecypods, whereas numerous incisions in shells show the remarkable role played by various hermit crabs. Rock-borers, the same as in the littoral rubbles, also appear here. This community (II in Fig. 59) is comparable to Recent ones at depths between 40 and 20 meters. At such a depth there also lived very large individuals of a few gastropod species, viz. *Vermetus (Lemintina) arenarius* (Linnaeus), *Murex austriacus* Tournouër, *Triton nodiferum* Lamarck, *Galeodes cornutus* (Agassiz), *Rostellaria dentata* Grateloup, *Cypraea* and *Xenophora*, some of them attaining dimensions of 10-15 cm, which certainly inhabitated shallower parts of rocky shores amidst the oyster banks, and were swept away, usually broken, into the deeper parts.

The abundance of gastropods in this an the above interval, is of a special interest, as in the Recent examples is that in a given environment usually only a few species domicile , and it is especially true for a definite genus of which only one species usually settles in an ecologically uniform spot, i.e. one ecological niche. In the Korytnica Clays the gastropods must be regarded as representing various communities that lived non-contemporaneously . and were buried successively in bottom clays. Local transportation of shells should also be taken into account, both by hydrodynamic agents (waves, currents) and biological ones (scavangers, hermit crabs using the shells as "houses", etc.) which derived these from various ecological niches of living gastropods. The bottom conditions in the area of deposition were also differentiated, as evidenced by the shell preservation: most of them are fresh and supposedly buried just after the death of the host, some others are

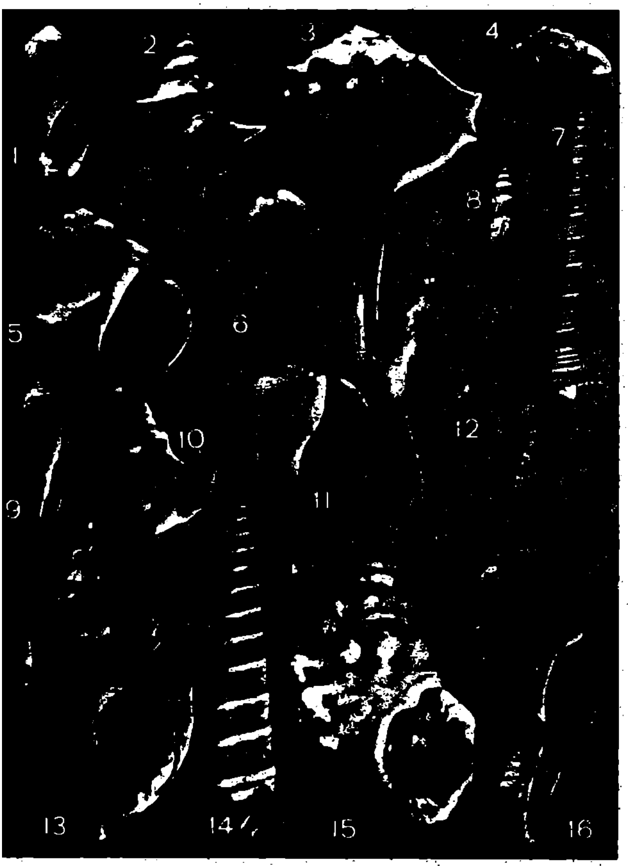


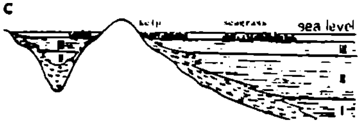
Fig. 58 Typical gastropods of the Korytnica Clays

1 — *Ancilla glandiformis* (Lamarck); 2 — *Murex friedbergi* Cossmann & Peyrot; 3 — *Tudicla rusticula* (Basterot); 4 — *Sigaretus striatus* de Serres; 5 — *Natica millepunctata* Lamarck; 6 — *Cypraea lanciae* Brusina; 7 — *Turritella badensis* Sacco; 8 — *Genota valeriae* (R. Hoernes & Auinger); 9 — *Conus ponderosus* Brocchi; 10 — *Aporrhais alatus* (Eichwald); 11 — *Pyrula geometra* Borson; 12 — *Fusus virgineus major* Hörnes, and sensu R. Hoernes & Auinger; 13 — *Triton nodiferum* Lamarck; 14 — *Terebra acuminata* Borson; 15 — *Ranella papillosa* Pusch, the shell contains a group of the slipper limpet *Crepidula crepidula* (Linnaeus): large female and two pygmy males, × 1.5; 16 — *Clavatula laevigata* (Eichwald)

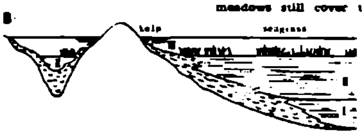
All figures in nat. size, except of Fig. 15

Fig. 59 Distribution of organic communities at rocky seashores of the Korytnica Bay and their succession in the clay sequence

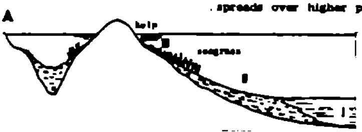
Succession of the organic communities (*I*, *II*, *III*) during formation of the Korytnica Clays



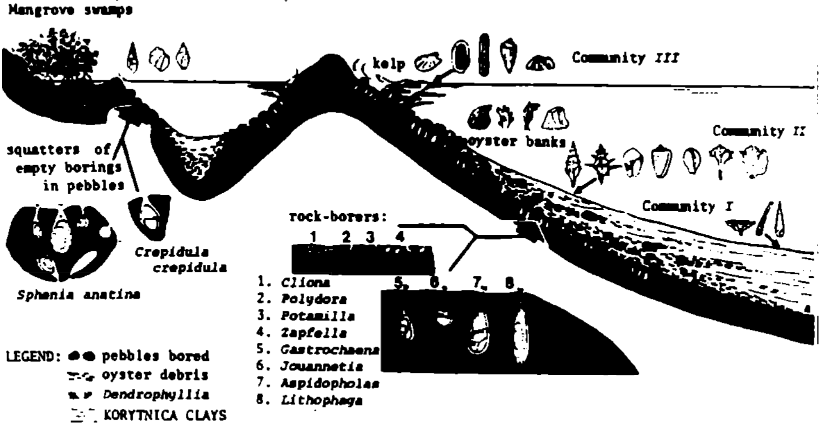
C — Time during depositon of the uppermost part of the Korytnica Clays (characterized by the community *III*) and a contemporaneous part of the oyster shellbed (os); the seagrass meadows still cover the bottom almost entirely, and locally stretch out of the sea level



B — Time after deposition of the middle part of the Korytnica Clays (characterized by the community *II*) and a contemporaneous part of the oyster shellbed (os); community *III* spreads over higher parts of the submerged slope; the seagrass meadows cover the bottom almost entirely



A — Time after depositi'on of the lowermost part of the Korytnica Clays (characterized by the community *I*) and a contemporaneous part of the oyster shellbed (os); communities *II* and *III* spread over higher parts of the submerged slope, the same as the seagrass and kelp



Idealized shorescape to show the distribution of organic communities at rocky seashores of the Korytnica basin

Community *I*: coral *Flabellum*, scaphopod *Dentalium badense*, gastropod *Turritella*

Community *II*: gastropods *Clavatula*, *Murex*, *Ancilla*, *Conus*, *Cypraea*, *Tudicla*, *Strombus*, the large-sized forms of *Triton*, *Conus*, *Cypraea*, *Strombus*, *Murex*, *Xenophora*, *Rostellaria*, and *Galeodes* including colonial corals *Tarbellastraea*; activity of various littoral rock-borers, and of hermit crabs

Community *III*: the same as *II*, but with participation of bivalved gastropods *Berthelinia*, chitons *Craspedochiton* and *Cryptoplax*, cirripedes *Creusia* (domiciled in corals *Tarbellastraea*), *Verruca* and *Chthamalus*, as well as of free-living bryozoans (*cf.* Baluk & Radwański 1977)

Oyster bank community: *Ostrea frondosa* associated with corals *Dendrophyllia*; cirripedes *Scalpellum*, *Balanus* and *Acasta*; gastropods *Lemintina arenaria* (Linnaeus) and *Tenagodus*

Community of brackish pools and mangrove swamps: gastropods *Terebralia*, *Neritina* and *Melanopsis*; secondary dwellers, pelecypods *Sphenia anatina* (Basterot) and *Striarca lactea* (Linnaeus), and gastropods *Crepidula crepidula* (Linnaeus), domiciled in empty borings within the littoral rubble corroded (usually on the side that streched out of the bottom deposit) and encrusted by various epizoans, bored by rock-borers or domiciled by slipper limpets. In other shells, usually also corroded numerous various tiny fossils, absent in the deposit nearby may be found, and these were centainly trapped when being swept by. All these facts show that the gastropod shells were lying on the bottom for a various span of time that reflected the sedimentation ratio: in some horizons the shells apparently represent a series of successive communities which dit not live contemporaneously.

The clay sequence gradually passes into a higher one in which thin marly intercalations appear and the gastropod community is enriched in species and some new associated animals which at first occur in thin current intercalations and afterwards are uniformly distrubited. The gastropod shells attain here the greatest dimensions and usually are the best preserved, very often with their natural colorations, which indicates both optimal life conditions and rapid post-mortem burial. The associated animals are represented by various extremely shallow-water forms of which the most attractive are the bivalved gastropods *Berthelinia* (the only locality in the European Miocene) various chitons with *Craspedochiton* and worm-shaped *Cryptoplax*, cirripedes *Verruca*, *Chthamalus*, *Balanus* and coral-inhabiting *Creusia*. All these forms live today along rocky coasts or in coral reefs near lower water level, sometimes spreading up into the intertidal zone. A comparable depth of a few meters may therefore be inferred for this community (III in Fig. 59) that settled during the deposition of the last portions of the Korytnica Clays (*cf.* Baluk, 1971; Baluk & Jakubowski, 1968; Baluk & Radwanski, 1977; Radwanski, 1969).

Another facies differentation is visible in the marginal zone of the basin, along small notches of the shoreline which were protected by rocky islands facing the open part of the bay (*cf.* Fig. 59). Water agitation was weaker here, and thus either the rock-boring pelecypods are preserved in their borings or, if the borings were emptied, the succeeding inhabitants were not removed. The latter forms that rapidly settled in and occupied any empty borings are represented (see Baluk & Radwanski 1979) both by pelecypods *Sphenia anatina* (Basterot) and by the slipper limpets, *Crepidula crepidula* (Linnaeus). The clay is contamined here by sand, and within the gastropod community such new forms appear as *Terebralia bidentata* (Grateloup) with other cerithids, *Neritina picta* Férussac, and *Melanopsis* which are of typical brackich character. It may be concluded that the fresh water supply from the adjacent land was greater than inflow from the bay, and the topographic situation resulted in stagnant water conditions and very restricted circulation. Such brackish pools were supposedly bordered by quaggy and swampy coasts, maybe of mangrove character as is commonly met with in Recent tropical reefs where the same brackich gastropods are also present (cf. Braithwaite & al., 1973).

The deposits capping the clay sequence are developed as marly sands with large pelecypods, acorn barnacles and decapod burrows evidencing near intertidal zone, and these are overlain by lithothamnian limestones with boulders derived from seashores and presumably hurled over the lithothamnian meadows by hurricanes at low water level, as happens in Recent coral reef (cf. Newell, 1955, pl. 2A). All these deposits (cf. Fig. 60 ; and Radwanski, 1969, 1977) correspond to a complete filling of the bay with deposits and its elimination from further sedimentation: the Tortonian marine conditions vanished here at the end of the Lower Opolian and did not return during the Tortonian sea expansion (cf. Fig. 55 B).

Fig. 60 Sequence of deposits capping the Korytnica Clays, and exposed in the sand-pit at Chomentow (cf. Fig. 55 B)

SECTION:

PALEOGEOGRAPHIC SETTING:

Legend:
- red-algal (lithothamnian) limestones
- marly sands
- KORYTNICA CLAYS
- brown-coal deposits

BURROWS ATTRIBUTABLE TO *OCYPODE:*

SECTION: The numbers denote the units (*1*—*4*):

1 marly sands with scarce fossils, mostly microfauna; *2* marly sands yielding large fossils:

a — burrows attributable to the ghost crab *Ocypode*; their position in the sediment and relation to the bedding plane (marked with a black bar, and arrowed) is also shown in the enlarged fragment;

b — segregated valves of the oyster, *Crassostrea gryphoides* (Schlotheim), commonly bored by various rock-borers, and encrusted by acorn barnacles (*cf.* Radwański 1969, Pl. 41, Figs 1—3);

c — complete shells of the pinnid, *Atrina radwanskii* Jakubowski, preserved in their life position (*cf.* Radwański 1969, Pl. 43; Jakubowski 1977, Pls 1—4);

3 marly, red-algal (lithothamnian) limestones; *4* red-algal (lithothamnian) limestones containing large pebbles and boulders (marked d) derived from the shore, and densely bored by various rock-borers, mostly pelecypods (*cf.* Radwański 1969, Pls 39—40)

PALEOGEOGRAPHIC SETTING: Idealised secuon through the Korytnica basin (*cf.* Bałuk & Radwański 1977, Text-fig. 4), being a part of the Korytnica Bay (*cf.* Bäluk & Radwański 1977, Text-figs 1—3), to show the position of the investigated section (marked by a vertical bar, and arrowed) in the sedimentary sequence of the basin

The pre-Tortonian morphology and the development of the Tortonian littoral structures in the marginal parts of the bays is well demonstrated by exposures at Lisow, Piotrkowice, and Lubania.

At Lisow (cf. Fig. 55 A and 52 h), isolated boulders, bored by lithophags are scattered along the rocky shoreline.

At Piotrkowice (cf. Fig. 55 A and 52 c-d), exposed are abrasion surfaces, locally with rubble at their base, which outline the shoreline along the present-day slopes of the Piotrkowice valley (Fig. 61).

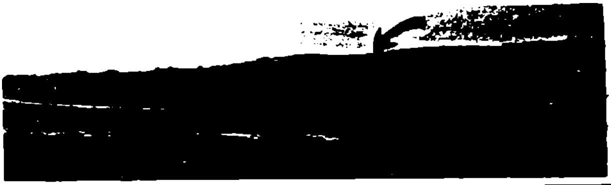
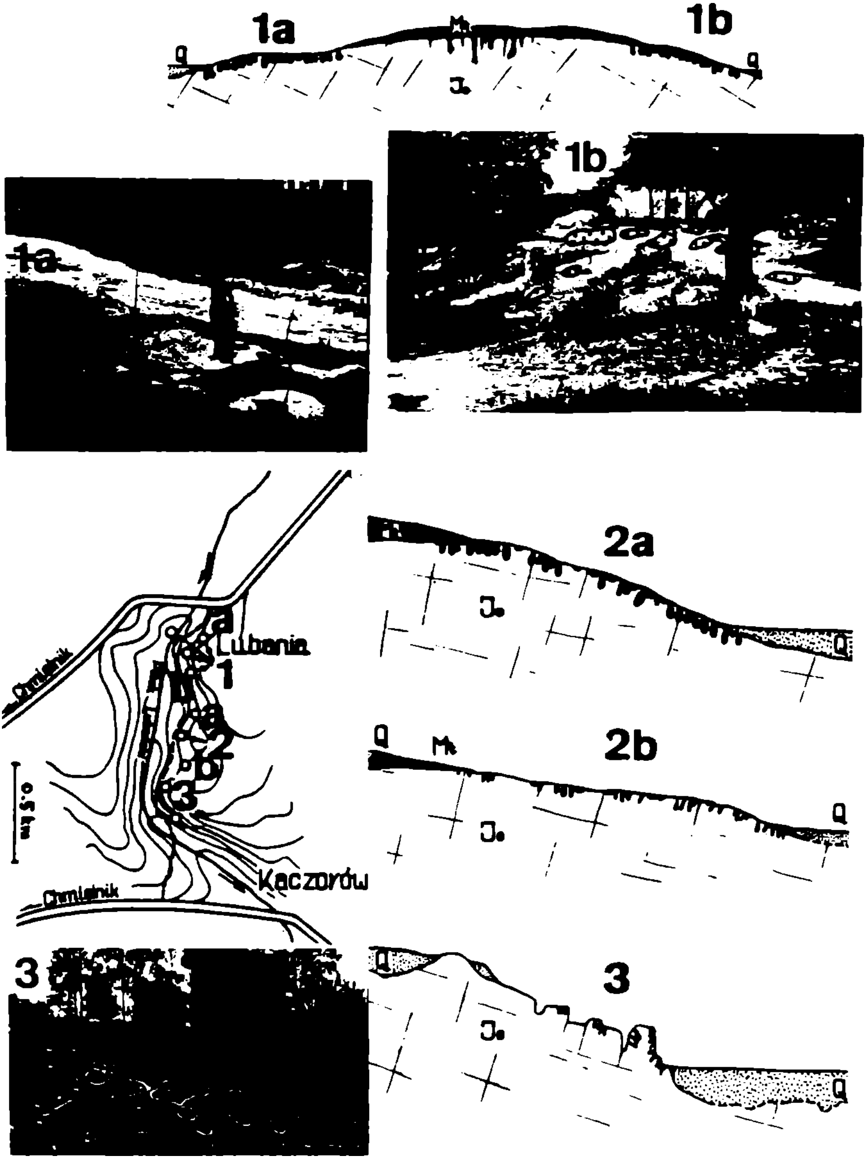


Fig. 61

Piortkowice valley: abrasion surfaces developed along the Tortonian shoreline. One of the surfaces (arrowed) shown in a close-up view.

At Lubania (cf. Fig. 55 A and 52 a-c, e), a larger fragment of the littoral zone is exhumed along the slopes of the Lubania stream (Fig. 62). Locally preserved the overlying red-algal (lithothamnian) limestones are composed of lithothamnian colonies ("nodules" or "rhodolites"), some of which developed with a thin cover of thallus over diverse gastropod shells ("lithothamnian mummies"). Lithothamnian colonies are embedded in a soft, marly matrix, in places replete with large foraminifers of the genus Amphistegina. The picturesque landscape of the locality reflects the pre-Tortonian morphology inundated during the transgression, and transformed into a narrow strait passing through the ridge between the Korytnica and Chmielnik bays (cf. Fig. 55 A).

Fig.62 Tortonian seashores exposed at Lubania, developed over the Oxfordian substrate (J_o), and covered either by red-algal (lithothamnian) limestones (M_t), or directly by Pleistocene sands (Q).



In the open-sea part of the Korytnica Bay sandy or lithothamnian deposits developed, the latter also supplying fine detrital material to deeper facies of the fore-bay region (Wymyslow, Pinczow, Busko-Spa, Skotniki - cf. Fig. 51 c). The resulting deposits there consist of fine-detrital lithothamnian limestones of the Leitha-kalk type and of various marls. The Leitha limestones exposed in a series of famous quarries at Pinczow yield rich and diversified fossils - besides very abundant large foraminifers *Amphistegina* and *Heterostegina*, various bryozoans and brachiopods, remarkable are large pelecypods (*Chlamys nodosiformis, Spondylus crassicosta, Cardium discrepans*), echinoids (*Clypeaster, Conoclypeus, Echinolampas*) and various remains of vertebrates. The latter are represented by dolphins (teeth and bones), sirenians and whales, as well as by crocodiles and diversified fish, including elasmobranchs with the largest shark that ever lived, *Carcharodon megalodon* Agassiz (cf. Radwanski, 1965 b). In these deeper parts of the fore-bay region local elevations of the substrate that formed a row of rocky islands during the transgression are also recognizable (Busko-Spa, Skotniki).

At Skotniki (cf. Fig. 51 c and 52 g), exposed is a series of conglomerates composed of large cobbles and boulders (up to 1m in diameter) derived from a nearby cliff. The series is preserved in an abrasional trough of the Mesozoic substrate, well exposed in a large quarry situated at the toppart of Mt. Zajecza (Fig. 63). All the cobbles and boulders within the conglomerate series are allochthonous, and the distribution of the lithophag borings over their surface (Fig. 64) indicates their supply from diverse parts of the fore-cliff shore developed around an island stretching out of the open sea, remarkably far off the Holy Cross shores (cf. Fig. 51 c). A peculiar feature of many cobbles and boulders is the development of pits which originated by the pressure-solution processes acting at the contacts of particular cobbles, regardless their previous sculpturing by the rock-borers. Some cobbles contain tens of pits at their surface, some others bear the deeply incised pits consuming a remarkable part of the "infected" elements (Radwanski 1965 c).

Fig.63 Schematic section through Mt. Zajecze at Skotniki

pre-Tortonian substrate: J_K - Kimmeridgian limestones; K_C - Cenomanian greensand, resting with a low angular unconformity; K_T - Turonian siliceous chalk with banded flints

Tortonian cliff-originated conglomerates and their cover: M-g - conglomerates, M-w - interfingering finer clastics, M-wg - lithothamnian limestones with gravels, M-al - detrital lithothamnian limestones of the Leitha type

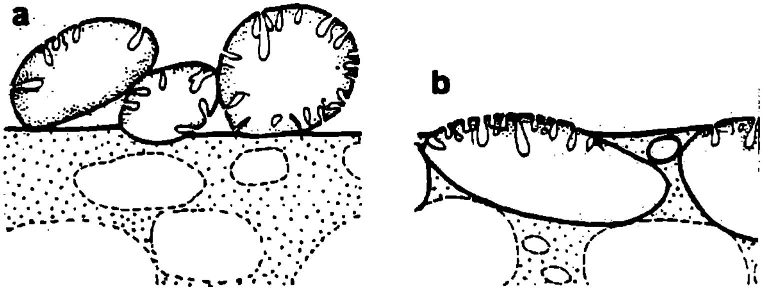


Fig.64 Distribution of lithophag borings in pebbles and cobbles within the cliff environment at Skotniki, before redeposition into a fore-cliff trough

a - pebbles constantly rolled over the bottom, b - pebbles buried partly in the sediment and partly exposed over its surface

In the vicinity of Skotniki and Busko-Spa exposed are also the stratigraphic members younger than the Lower Opolian (cf. Fig. 54). All the Lower Opolian members contain the faunas of the open-sea type, the same as those in the Vienna Basin and in the Mediterranean. The overlying member, the so-called Supralithothamnian Member (cf. Fig. 54) contains a poor fauna, at it is developed here as marls with "Pycnodonta cochlear(Poli)" [recte: Neopycnodonta navicularis(Brocchi)].

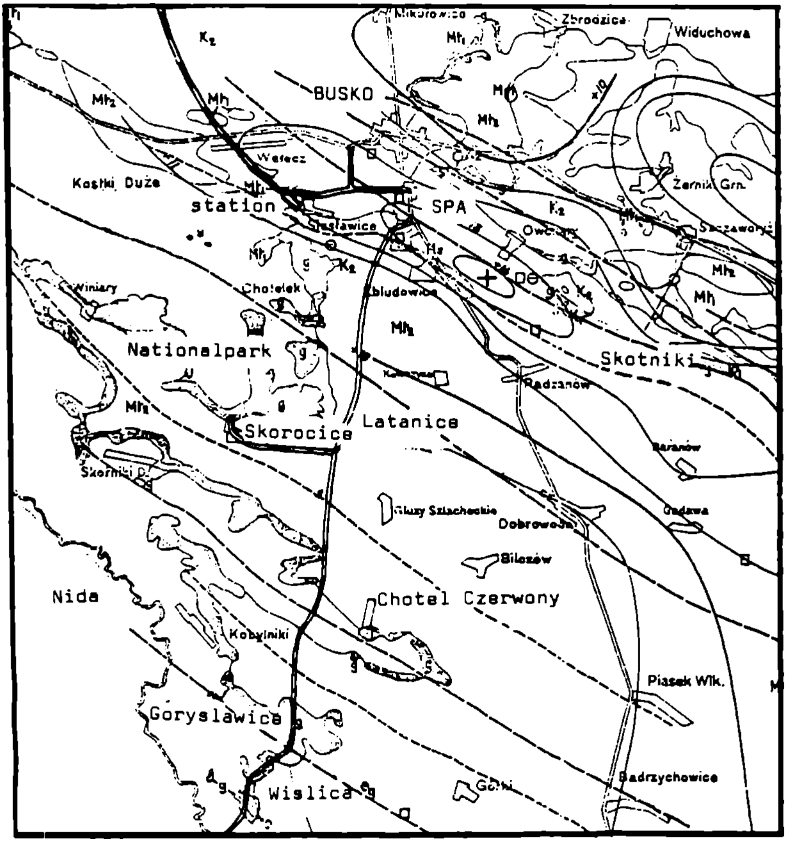


Fig. 65 Geological sketch-map of the vicinity of Skotniki and Busko-Spa ("Nida Gypsum Plateau")

K_2 - Senonian marls, Mt_1 - Lower Opolian, g - GYPSUM, Mt_2 - Upper Tortonian(Grabovian)

(Adopted from: Czarnocki, 1939)

Fig.66 Main gypsum horizon, built of large swallow-tail twins of gypsum crystals, exposed at Latenice

Fig.67 Sabre-like crystals of gypsum within the layers overlying the main gypsum horizon, exposed in the Skorocice National Park

[redacted]

Above these are marly lumachelles or clays loaded with shell detritus of only a few species of pelecypods such as *Ervilia* and some scallops (Ervilian Member, cf. Fig. **68**).
As the latter deposits underlie the Gypsum Member, it is reasonable to regard these pelecypods as confined to the environment of increasing salinity. These were certainly the few species which could adopt to hypersaline conditions whereas the remaining fauna was eliminated. The gypsum deposits completing the sequence (Fig. **68**) are at first marly either with clay or marl intercalations and thereafter coarse-crystalline. In this part of the sequence a remarkable feature is the so-called main gypsum horizon built of tightly welded elongated crystals of swallow-tail twins, up to 2-3 m high and all oriented with their longer axis and twin plane almost vertical (Fig. 66). The gypsum sedimentation in some places overlapped the substrate which up to that moment was not covered by deposits, and in others it finished before reaching the highest culminations (Fig. **68**). These were stretching out of the gypsum deposit and brine in the lagoon, and are observable in Recent morphology in the form of hills surrounded with a gypsum collar near their tops. It is however not common, as the Quaternary erosion of the gypsum formation leads often to initial sliding of the gypsum cover which creeps down to the valleys, due to overburden pressure and marginal bulging.
The origin of the gypsum bed of the main horizon, with such large and parallel-oriented crystals may be explained by successive growth of the swallow-tail twins on the bottom of brine lagoon, and their recrystallization from gypsum ooze. The topside truncation of the swallow—tail horizon probably results from corrosion by the brine when concentrated over 22.5% (cf. Gawel, 1955).

The remarkable sequence of the Gypsum Member, attaining up to about 4o m in thickness and everywhere with its main horizon of swallow-tail twins in the bottom part (see Figs 66-67), extends from the Miechow Upland toward the southernmost slopes of the Holy Mts, as far as Wislica and Busko-Spa (cf. Fig. **51c**). In this region, the gypsum formation which probably has never been covered by younger Tortonian deposits due

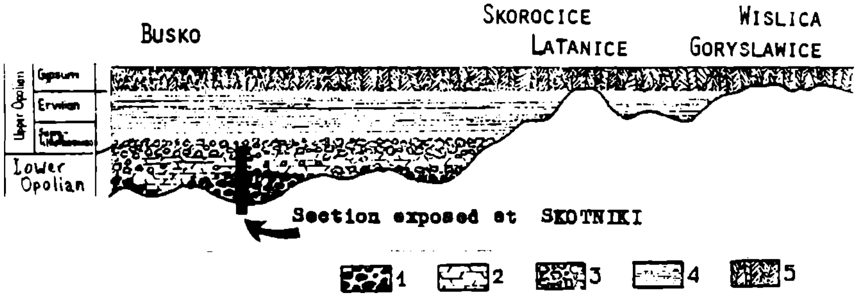


Fig.68 Diagrammatic section, to show the development of the Lower Tortonian sequence in the vicinity of Busko-Spa and Skotniki; the diagram does not illustrate the thickness of particular members

1 - littoral material abraded from the substrate (Upper Cretaceous, locally Upper Jurassic), 2 - marls with organodetrital material, 3 - red-algal(lithothamnian) limestones, 4 - clays and marls, 5 - GYPSUM

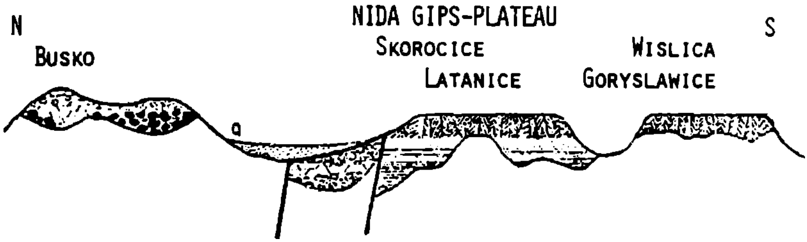


Fig.69 Present-day situation of the Nida Gypsum-Plateau, resulting from the post-sedimentary block-faulting (cf. Fig.71) and post-Tortonian erosion

to the synsedimentary tectonic uplift on both the Miechow Upland and Holy Cross shores (cf. Figs 71), is now exposed over a greater area and in many places it forms a continuous cover with its topmost part showing a flat morphology (Fig. 69). This is the Nida Gypsum Plateau, named after the river Nida. The post-Tortonian superficial erosion incised the plateau, whereas underground water circulation and dissolution along the intrastratal surfaces is responsible for the formation of extensive caves, uvalas, dolines and poljes giving the picturesque gypsum-karst morphology. Some forms as e.g. dome-shaped swells found over the caves developed during the Pleistocene as a result of a pushing-up of the cave ceiling by freezing water in the same manner as in arctic pingos (cf. Flis, 1954).

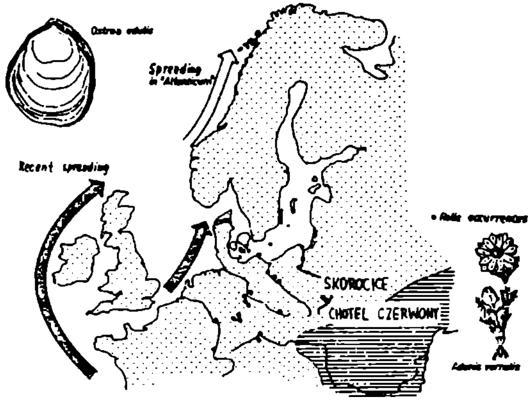


Fig. 70

Spreading of philothermic marine animals (exemplified by edible oyster) and terrestrial plants (exemplified by adonis) during the post-glacial climatic optimum ("Atlanticum"), and their Recent occurrences. New relic occurrences of adonis in disjunctive localities, Skorocice and Chotel Czerwony, on the Nida Gypsum Plateau are shown. (Adopted from Ziegler, 1972).

The most outstanding forms of the gypsum-karst morphology, usually bearing sections of the main horizon with swallow-tail twins (attaining here a remarkable hieght of 3-3.5 m), are now protected by law as national reserve areas (Skorocice, Chotel Czerwony). In these areas not only gypsum landscape is distinguishable but also the tshernozhem soil-cover with steppe-type vegetation. Of these steppe plants that have persisted here (cf. Fig. 70) since the post-glacial climatic optium ("Atlanticum" - cf. Ziegler, 1972) and that strike the visitors with their variegated blossom in spring and early summertime, the most spectacular are such herbs as adonis (*Adonis vernalis*) and hairy flax (*Linum hirsutum*), and a Mediterranean shrub, the burning bush or dittany (*Dictamnus albus*) the ethereal oils of which burn brightly during strong sunlight in June. All these philothermic plants may thrive here as a favourable Recent microclimate prevails in this part of the Fore-Carpathian Depression (the warmest spot in Poland) and the relic steppe-vegetation develops further on.

CONCLUSIONS

The Lower Tortonian transgression in southern Poland entered an area of a diversified morphology that had been shaped by continental weathering and erosion during the Paleogene. At the first stages of transgression all the valleys were transformed in the littoral zone into a system of bays that were pronounced along the shores of the circum-Carpathian belt of uplands (Cracow and Miechow Uplands, western Holy Cross region, Opatow Bay in the eastern slopes of the Holy Cross Mts). As the data from boreholes show, a similar system also existed in the central part of the Fore-Carpathian Depression. In this area both a general pattern of facies and thickness of particular members are similar and it may therefore be concluded that this area was not yet subsiding and certainly it was not a preferred route for the transgresion. The latter invaded the Fore-Carpathian region as a result of its general lowering below the sea level and thus opening a connection with the Vienna and Pannonian basins where the sea had persisted from Lower Miocene and Oligocene time. As it is shown by the same kind of facies and contained fossils, such a connection must have been very broad and not restricted by the Carpathin belt. It is therefore clear that this belt did not exist at that time as a mountain range and at most some parts of the rising nappes formed submarine swells or shoals. Amidst them the Lower Tortonian sea was penetrating by a chain of straits and more extensive basins in which diversified sedimentation began to develop. In most of these basins it is clastic or clayey, in places with brown coals at the bottom, as exemplified by the Niskowa basin (*cf.* Fig. 71 and 51b). In the zone of Wieliczka - Bochnia (*cf.* Fig. 71), after sedimentation of clays with abundant open-marine fossils (corals, bryozoans, mollusks of the Korytnica type, monographed by Reuss already in 1867), the basin became isolated and evaporated, resulting in a formation of salt deposits (*cf.* Fig. 71 *A*). The fossils, part of which are here embedded in salts, were either swept into the evaporating pool by temporary storms from the neighbouring shallow zone of normal salinity conditions, or were squeezed into the salt during subsequent tectonic folding.

The condition prevailing in the Lower Tortonian sea may be best recognized by analysis of the organic communities that developed in great profusion. The wealth of taxa and their diversity show that there were optimal biological conditions of an open sea character featured by a normal salinity, vast zoogeographic connections and the temperature typical of tropical or subtropical zones. This sea therefore, the deposits of which are now limited to a narrow zone of the Fore-Carpathian Depression never stretched along such an elongated channel and has never been an outside part of the Paratethys Ocean in the Miocene, as it may be referred to when seeing the present-day distribution of the deposits (*cf.* Fig. 51). The same is true for the aforementioned basins, the fragments of which have been preserved inside the Carpathian range and where, *e.g.* in the Niskowa basin, a diversified fauna of the Vienna type dominated and contained elements with more southern affinities than any other parts of the Southern Poland sea (cf. Baluk, 1966, 1970).

The most instructive hints on the climatic conditions prevailing in the Southern Poland sea are offered by an extensive group of fossils. Of those occurring in the Korytnica Clays the most stenotopic are the coral-inhabiting barnacles *Creusia* which at present live only in reef corals (cf. Baluk & Radwanski, 1967), bivalved gastropods *Berthelinia* which now browse on a seweed, *Caulerpa* in tropical littoral zones, inbetween the littoral rubbles in strongly agitated waters just below low water level (cf. Keen & Smith, 1961; Baluk & Jakubowski, 1968), and tropical chitons, both *Craspedochiton* and *Cryptoplax* (cf. Baluk, 1971). All these animals have been extinct in the Mediterranean Basin which at present has too low water temperature for the development of such philothermic invertebrates. The same is also obvious for gastropods *Parastrophia* and *Terebra* as well as for larger species of the genera *Conus, Cypraea, Cypraecassis, Strombus* and *Voluta (Volutilithes)*. Also a total assemblage of a definite group supports the same conclusions - for example in chitons the Recent, well-recognized community of the Mediterranean comprises only 13 species, whereas the Korytnica assemblage has as many as 17 and all of these have their counterparts in Recent species (cf. Baluk, 1971). Of the fossils occurring in the Pinczow Limestones the tropical character is revealed not only by the previously reported (Radwanski, 1965b) vagile sharks *Hemipristis*, skates *Aëtobatis* and bony-fish *Scorpaena*, but also by crocodiles. Of the fossils preserved in the sandy facies, some communities are closely comparable to Recent occurrences off the shores of Ceylon (cf. Herdman, 1906; Radwanski, 1973). It may generally be stated that at least some animal groups and their communities that lived in the Miocene sea of Southern Poland are very close to those of the Recent coral reefs and other littoral zones of the tropics. Gripp (1961) pointed that the climate in the Miocene of Europe was partly comparable to Recent Senegalian, and he drew this conclusion also for the Middle Miocene Hemmoor Stage of the North Sea Basin. When analysing the communities from Southern Poland, a warmer climate like the present Red Sea, and with Indo-Pacific connections should rather be considered (cf. Baluk & Radwanski, 1967, 1977; Radwanski, 1969; Baluk, 1971).

The discussed environmental and life conditions persisted through the period referred as to the Lower Opolian (cf. Fig. 54). Overlying deposits of the Upper Opolian contain very poor organic communities and soon thereafter very restricted to hypersaline conditions (*Ervilia* fauna) foreshadowing the progressing precipitation and formation of the Gypsum Member. For such a sharp and sudden change considerable displacements in paleogeography must be responsible. These are connected with the folding in the Carpathians, the nappic swells of which rose up and emerged separating the Southern Poland sea from the Paratethys Ocean. As an isostatic response, the zone of advanced subsidence occurred along the neighbouring foreland which became the Fore-Carpathian Depression. This subsidence also embraced the Cracow Upland and southern part of the Miechow Upland resulting in the spreading of the sedimentation onto the previously elevated or emerged ridges (*Pycnodonta* Clays) (cf. Fig. 71 B). A further isostatic response is also visible in the uplift of the Holy Cross shores (cf. Fig. 71 B) where the western bays became eliminated from further sedimentation, whereas the eastern part was even exposed to erosion (cf. Fig. 51 c). The receding sea persisted during the Upper Opolian only in the zone of greatest subsidence near the Carpathians, whereas along the uplifted northern margins gradual evaporation in widespread lagoons came into being (Fig. 71 C).

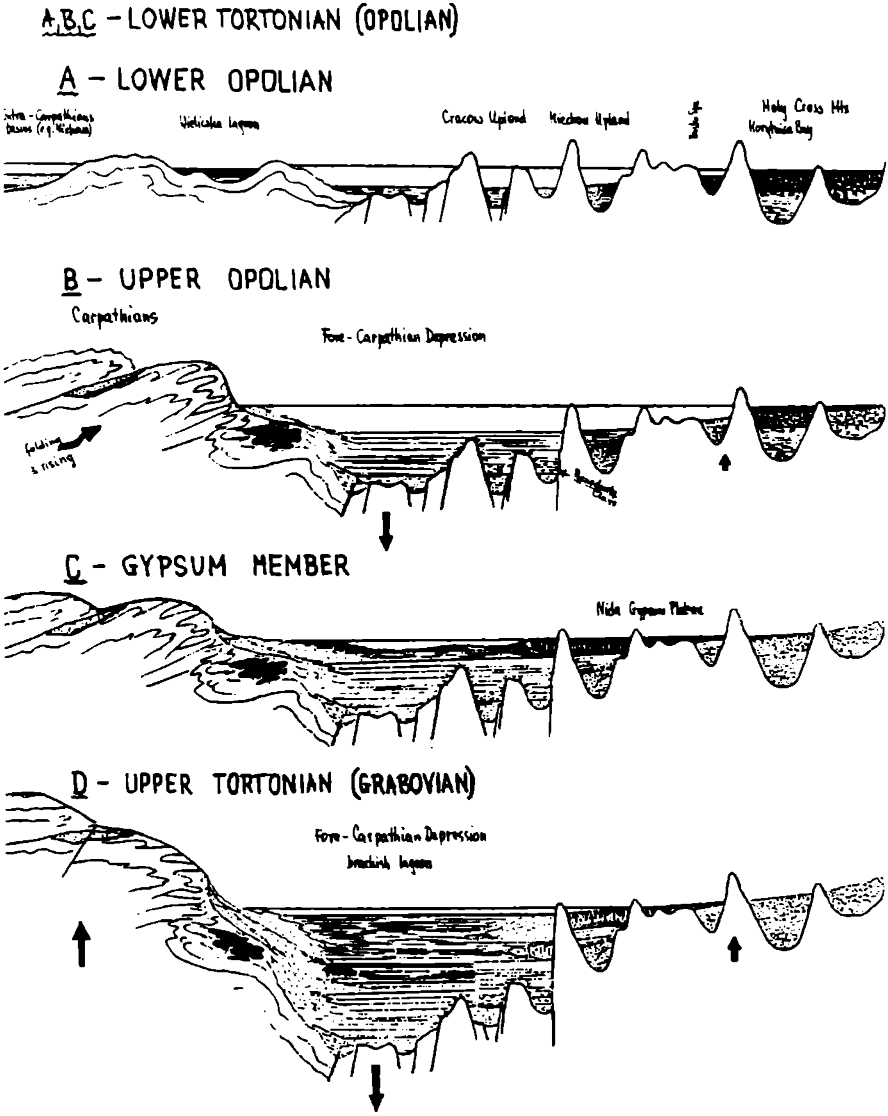


Fig. 71 Successive developmental stages of the Fore-Carpathian Depression (vertically strongly exaggerated).

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In the history of the European Tortonian, the Fore-Carpathian Depression was the only area in which an open-sea basin was so rapidly changed into an evaporating lagoon, and it happened here due to synsedimentary tectonics that elevated the Carpathian range by the end of Lower Opolian time.

The tectonic lull of the Gypsum Member was broken by the second phase of the Carpathian folding the rise which also found its isostatic response in a very strong subsidence of the foredeep and further uplift of the Holy Cross shores (Fig. 71 D) resulting there in abrasion of older sediments and their redeposition along the progradating shores (*cf.* Fig. 71 *C-D*). The Fore-Carpathian Depression was gradually filled with brackish clays originating from fine clastic supplies from the adjacent lands (Carpathians and circum-Carpathian belt of Central Polish Uplands). This period is referred to as Upper Tortonian (Grabovian) and it lasted till the final isostatic uplift of both the Carpathian belt and its foredeep basin.

During the Pliocene the area of the Fore-Carpathian Depression was partly covered by alluvial fans of the Carpathian gravels (*cf.* Kucia-Lubelska, 1966), and otherwise became exposed to terrestrial erosion which continued during the Pleistocene (*cf.* Dzulynski & *al.*, 1966).

GROWTH AND SEDIMENTARY ENVIRONMENT OF LARGE GYPSUM CRYSTALS OF THE NIDA GYPSUM-PLATEAU

M. Bąbel

The mode of growth of large gypsum crystals, especially those forming the main gypsum horizon in the Nida Gypsum-Plateau (see p.102 and Figs 66 and 68–69), has recently subjected to detailed crystallographical investigations. It has been intended to recognize the relation of these crystals both to the primarily deposited gypsum ooze, and to the sediment/brine interface. Simply, it was a question: did these crystals originate on, or in the bottom.

The discussed large crystals, called the glassy gypsum (not selenite, because of their dark-brown or greyish coloration) and usually growing in pairs (cf. Fig. 66 and 72), do not appear to be the true twins. The composition surface, along which the pairs easily split off, has no features of the twin-symmetry plane; moreover, orientation of the every two crystals, although constant indeed, is different than in the swallow-tail twins (see Fig. 72a and 72b). All the crystals display typical blocky structure, and particular blocks (=subcrystals) are well seen by their slightly different light reflection on the (010) planes of perfect cleavage.

The composition surfaces, formed when all the crystals have tightly grown upwards, acquired the nature of induction surfaces. Their shape was controlled by the growth of the neighboring crystals (or subcrystals). The clay inclusions, visible on the composition surfaces (when these are split-off, see Fig. 72d_1) allow to recognize the bunch-like shape of the tops of particular crystals (see Fig. 72d_2 and 72c).

All the crystals started to grow in pairs combined with the developping composition surface, and the growth realized more or less perpendicularly to the crystallographic axis c of the coupled crystals (see Fig. 72e). The growing crystals (or subcrystals) produced a pattern of rods lying one on the other, but the rods did not fill the space tightly. It was thus the skeletal growth, especially well displayed by the tops and margins of particular crystals (see Fig. 72f).

Fig. 72 Intergrowths of glassy gypsum (opposite page)

a - Orientation of crystallographic axes (a and c) in the intergrowths, to show the setting of the (010) planes near the composition surface;

b - Typical swallow-tail twin, to show the cleavage planes: (100) parallel to c, and (011) parallel to a, as well as the etch figures (natural, or easily produced in running water) on (010) and (010') faces;

c - Upper surface of crystals below the clay cover (arrowed is the composition surface): the faces of prism (120) are built of lenticular subcrystals (cf. Fig. 72d);

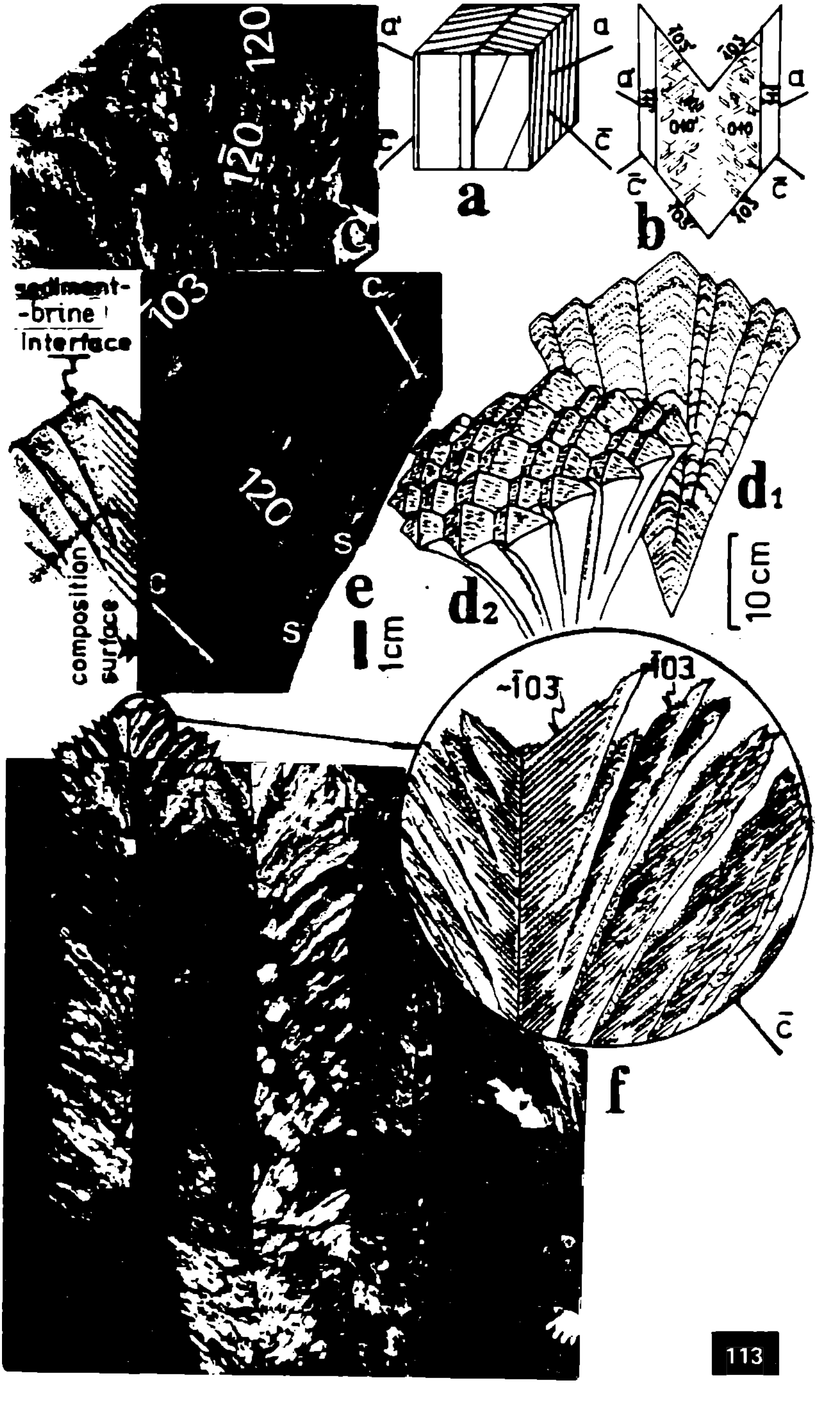
d - Upper surface of the intergrowth built of prism (120):

d_2 - general view, to show the bunch-like shape of the tops of the crystals,

d_1 - zonation of clay inclusions on the composition surface along which the crystals are split-off;

e - Growth structures on the (010) perfect cleavage planes: at left - a scheme of the crystal displaying non-skeletal growth; at right - induction surfaces (arrowed) between subcrystals or their aggregates; clay inclusions (black) deposited along the composition surface and, in the form of stripes or streaks (s), along the prism (120);

f - Large intergrowths from locality Marzęcin, to show their skeletal growth.



120
$\bar{1}20$
a'
a
c
$\bar{c}$
a
b
c
sediment-
-brine
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s
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s
composition
surface
e
1cm
d_1
d_2
10 cm
~$\bar{1}03$
$\bar{1}03$
$\bar{c}$
f

Consequently, the crystals growing in couples, i.e. the intergrowths, produced a lattice framework, through the pores and fissures of which the brine could migrate. Any free space was thus infilled either by clay or by secondary gypsum. The latter either gave overgrowths upon the primary skeletal parts of crystals, or crystallized in a drusy manner.

Several clay stripes, recognizable in all crystals of the main gypsum horizon (cf. Fig. 72e and 68), continue over a distance of 20 km. They indicate episodes in which clay supplies were greater, or the rate of the gypsum growth (i.e. salinity of the brine) was lower. A few horizontal surfaces of corrosion are interpreted (see p. 102) as formed due to inreasing salinity of the brine.

Fig. 73 Sedimentary structures in sabre-like gypsum (opposite page)

a - Sabre-like crystals growing by spreading of the faces of prism (120);

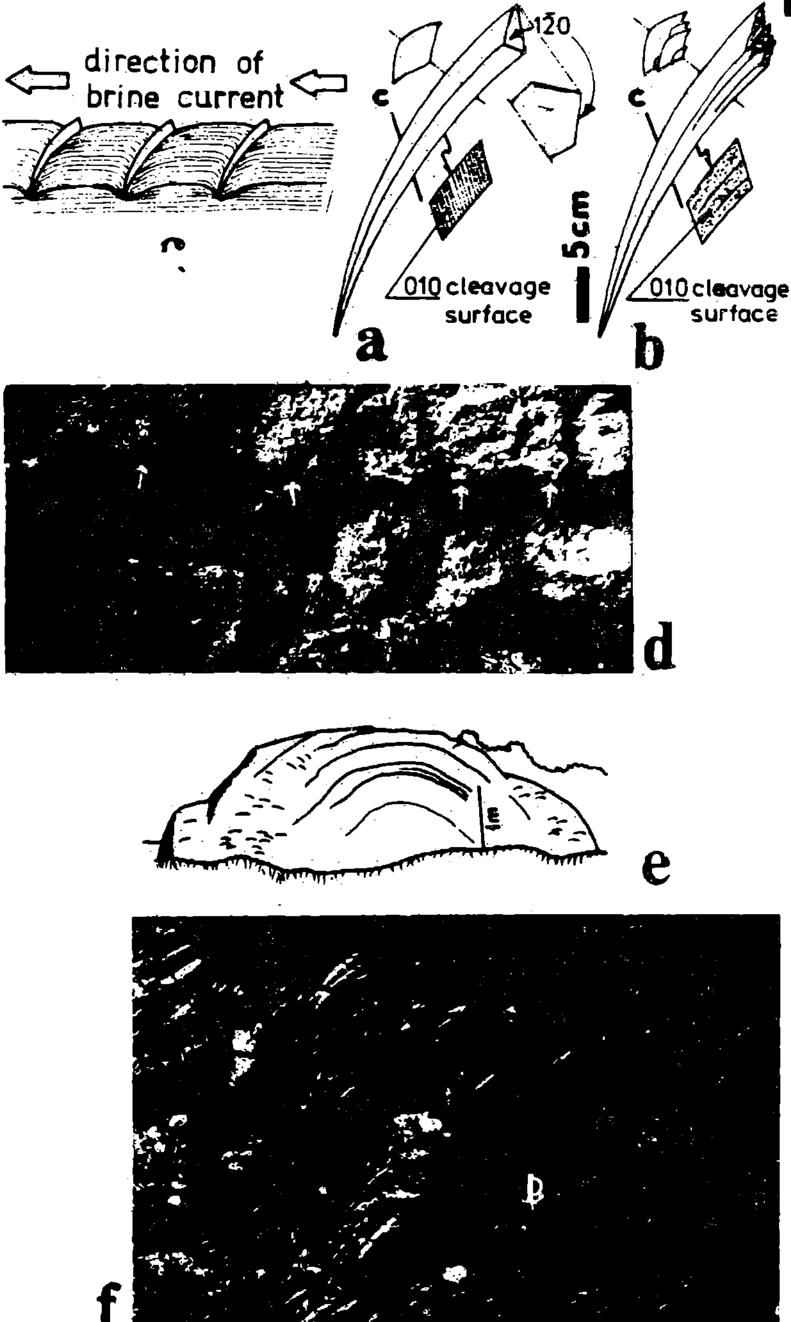
b - Sabre-like crystals growing by spreading of parallel, lens-shape subcrystals or their aggregates; note different growth structures visible on the (010) planes of perfect cleavage;

c - Interpreted growth of sabre-like crystals due to exposing to the brine current, and structures formed in the layered gypsum ooze due to the sinking (load-casting) of the growing crystals;

d - Knobby structure (arrowed) of the base of sabre-like gypsum layer, resulted from the sinking of larger crystals (cf. Fig. 73c) at locality Gacki;

e - Domal structure in gypsum from locality Zamczysko at Wislica (see Fig. 65 and 68-69): radial orientation of sabre-like crystals along the slopes of the dome is indicated (Former interpretation: periglacial pingo structure of Pleistocene age);

f - Well-oriented sabre-like crystals in successive gypsum layers at locality Sieslawice near Busko (see Fig. 65).


direction of brine current
c
120
010 cleavage surface
5cm
c
010 cleavage surface
a
b
d
1m
e
f

Another variety of large gypsum crystals is the sabre-like gypsum occurring in some layers overlying the main gypsum horizon (cf. Fig. 67). The sabre-like crystals, attaining the length even up to 90 cm, become locally the most striking element of such layers (see Figs 67 and 73f).

The sabre-like crystals grew upward by the spreading of the faces of prism (120), or of the lens-shape subcrystals or their aggregates (see Fig. 73a and 73b). The upper, convex surfaces of these crystals, corresponding to the faces intermediate between $(\bar{1}11)$, $(\bar{1}01)$, and $(\bar{1}03)$, were presumably formed when their growth was inhibited by the organic compounds which prefertially adsorb to the $(\bar{1}11)$ and $(\bar{1}03)$ faces. Some crystals are twisted lengthwise, and the c axis becomes more and more vertical near their tops. All these crystals are usually well oriented, and this is thought to have resulted from feeding the growing crystals by the brine current (see Fig. 73c).

The sabre-like crystals, associated with smaller ones which often nucleated on the former, grew in layers (15-40 cm thick) intercalated with fine-grained gypsum or clay. Some sabre-like crystals were growing singly scattered in laminated gypsum ooze. In such a case, they were commonly sinking into the still soft substrate (see Fig. 73c and 73d). On the other hand, the longer crystals are usually broken into smaller and larger pieces due to subsequent compaction.

In the discussed sequence of the sabre-like gypsum there occur relatively large domal structures, attaining the diameter of over a dozen meters or so, and the height of a few meters. Some of them are planated in the present-day morphology. In the best preserved domal structures (see Fig. 73e) the sabre-like crystals are oriented quaquaversally what evidences the primary nature of the domes. Contrary to the outer parts of the domes built of layered gypsum, the interiors of the domes are built of fine-grained gypsum, chaotically oriented, and containing a greater amount of clay material. These interiors are easily dissolved by karst waters, and thus specific bell-shaped caves develop under the layered gypsum roofs.

A. Radwanski

The Cracow Upland which is the southernmost part of the Polish Jura (cf. Fig. 51 b) represents a unique region for the geology of Poland. Its fame began two centuries ago when its first description by Jaśkiewicz (1787) appeared. The subsequent studies, especially of diversified fauna contained in Paleozoic, Mesozoic, and Tertiary strata, have efficiently resulted in a very good recognition of the fossil content. This made some of the fossiliferous localities world famous, e.g. the Middle Jurassic iron oolites of Balin, the fauna of which was monographed and/or discussed i.a. by Reuss, Laube, Neumayr, Suess, Waagen. Comprehensive regional studies of the stratigraphical, lithological (environmental), and tectonic settings of particular lithosomes, both sedimentary and igneous, undertaken a century ago by S. Zaręczny and continued until the present times by S. Dżułyński, R. Gradziński, and many younger investigators, have allowed to understand well a geological jigsaw of this small region sculptured by the morphology full of beauty (see Fig. 74).

The Paleozoic sequence of the Cracow Upland comprises the Middle and Upper Devonian carbonates which pass into the Lower Carboniferous Limestone developed along the eastern, epicontinental

Fig. 74 Picturesque landscape of the Cracow Upland: the Prednik Valley incised in Upper Jurassic (Middle Oxfordian) massive limestones (photo by Gunner Larsen)

margin of the Upper Silesia Basin (Bełka 1985). The Carboniferous Limestone facies is associated with the Kulm facies of Viséan age (Bełka 1982), overlain by the Coal Measures of Namurian-Westphalian age. The post-Variscan cover which rests with a distinct angular unconformity, begins with diverse terrestrial deposits and volcanogenic formations. The first are represented by loose arkoses and arkosic sandstones (Kwaczała Arkoses) as well as by lacustrine travertines (Karniowice Travertines), all usually assigned to the Stephanian or even to the lowermost Permian. The second are represented both by the intrusive subvolcanites (ryodacite laccolith of Zalas, diabase sill of Niedzwiedzia Gora) and both by acid (ryodacite) and basic (melaphyre) lavas associated with their tephras; the age of all these volcanites is regarded as Lower Permian. Overlying are terrestrial conglomerates of the fanglomerate or bajada type (Myslachowice Conglomerate) which laterally pass westwardly into gypsiferous red clays of the playa type.

The Mesozoic sequence rests upon the Paleozoic substrate almost horizontally, with a very low regional dip to NE, towards the Szczecin-Lodz-Miechow Synclinorium of the Danish-Polish Trough provenance (see Fig. 6).

The Triassic deposits are locally developed: in the central part of the Cracow Upland these are the Upper Bunter (Rhöt) marls which, to the west are covered by the Muschelkalk series.

The Jurassic sequence begins with locally developed kaolinitic clays of terrestrial origin and assigned generally to the Liassic (Mirow Clays). The Middle/Upper Jurassic transgression encroached the region at Bathonian time, and both the littoral sands and the elevated substrate (e.g. Zalas porphyries) are overlapped by Callovian sandy deposits of variable thickness and locally terminated with stromatolites. The Oxfordian limestone series contains diverse marly deposits at the bottom, and massive sponge-bearing limestones interfingering with platy limestones in the higher part of the sequence which locally continues through the Lower Kimmeridgian.

The mid-Cretaceous transgression entered the region featured by land erosion (Fig. 75). The Cracow Upland was then a marginal part of the Central European Basin (see Marcinowski 1970, 1974; Marcinowski & Radwanski 1983, 1985), and thus some of the transgressive deposits are very thin or locally missing.

By the Cenomanian decline the sedimentation began disturbed by synsedimentary block-faulting which resulted in the uplifting of some areas, especially those near the city of Cracow (locality Zabierzów including - see Fig. 75). In consequence, the transgressive sequence often begins here with thin Turonian sandy limestones which locally are overlain directly by the phosphate-bearing glauconitic marls of Santonian age. Soft chalky marls of Lower Campanian age complete the Mesozoic sequence of the Cracow Upland.

The Mesozoic platform of the Cracow Upland underwent a strong karstification under tropical or subtropical climatic conditions during the Eocene when the Jurassic massive limestones were exposed and shaped into the mogote-type of landscape. In the eastern

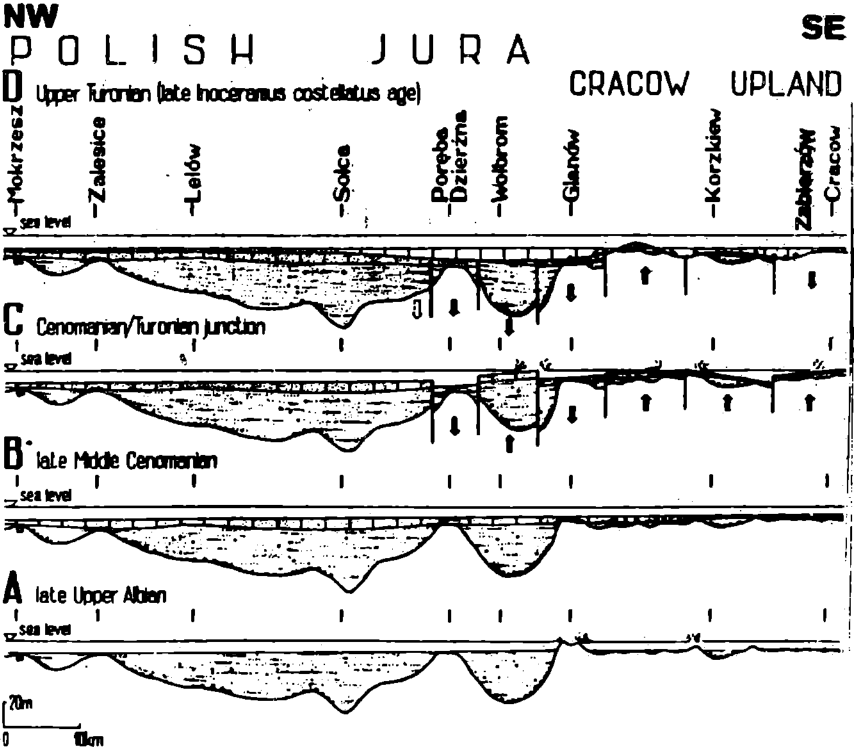


Fig. 75 Idealized successive stages (A-D) of the mid-Cretaceous transgression onto the Polish Jura and Cracow Upland (paleogeographic position of the locality Zabierzów is indicated) (Taken from: Marcinowski & Radwanski 1983)

and southern part of the Upland, near Cracow, this karstification phase is weakly recognizable, as this area certainly bore a thicker cover of Upper Cretaceous marls during the weathering, and consequently no mogotes developed here. This region was then situated off the karstifying part of the plateau, and a caliche type of weathering waste was formed there (so-called "fresh-water limestones" - cf. Fig. 78; and Gradziński 1963, Radwanski 1968). Another process which took place here and which was reflected by platformal setting of the region, was strong block-faulting that supposedly resulted from the first Carpathian movements (Dżułyński 1953). It sculptured here (?Oligocene - early Miocene) the morphology into a system of horsts and grabens (cf. Fig. 77 which subsequently were, to varying extents, eroded before the Lower Tortonian transgression, as is well shown by a narrow belt, a few kilometers long, of small grabens or depressed (thrown-down) tectonic wedges near Libiaz (Fig. 76) in

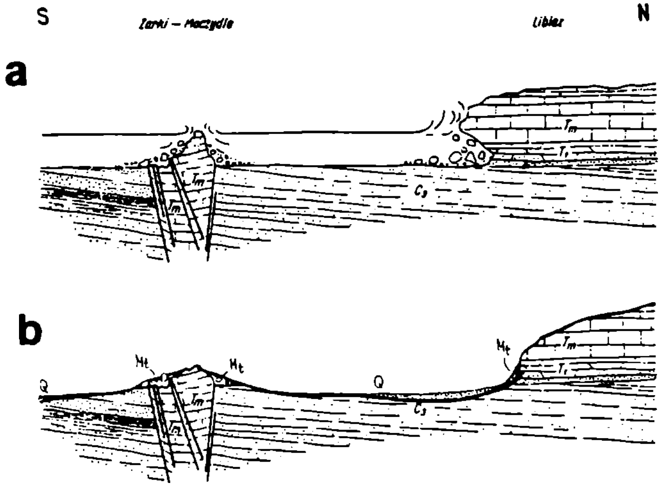


Fig.76 a. Schematic reconstruction of Lower Tortonian (Lower Opolian) seashores between Libiaz and Zarki; b. Recent morphology of the area: C_3. Upper Carboniferous (Stephanian arkoses); T_1. Röt; T_m. Muschelkalk; M_t. Tortonian; Q. Quaternary.

the western part of the Upland where erosion reached the Upper Carboniferous loose arkoses, and more resistant Middle Triassic carbonates within the grabens began to stretch out of the arkose neighbourhood (cf. Fig.76 a). Such a morphological inversion was met with here by the Lower Tortonian transgression that encroached onto that zone and changed the carbonate hills into a row of submarine ridges or islands, densely populated by littoral rock-borers (Fig. 76 a). Near Cracow, the slopes of the horsts became at that time rocky seahores, more or less steeply inclined, and also inhabitated by gregarious rockborers (Fig. 77).

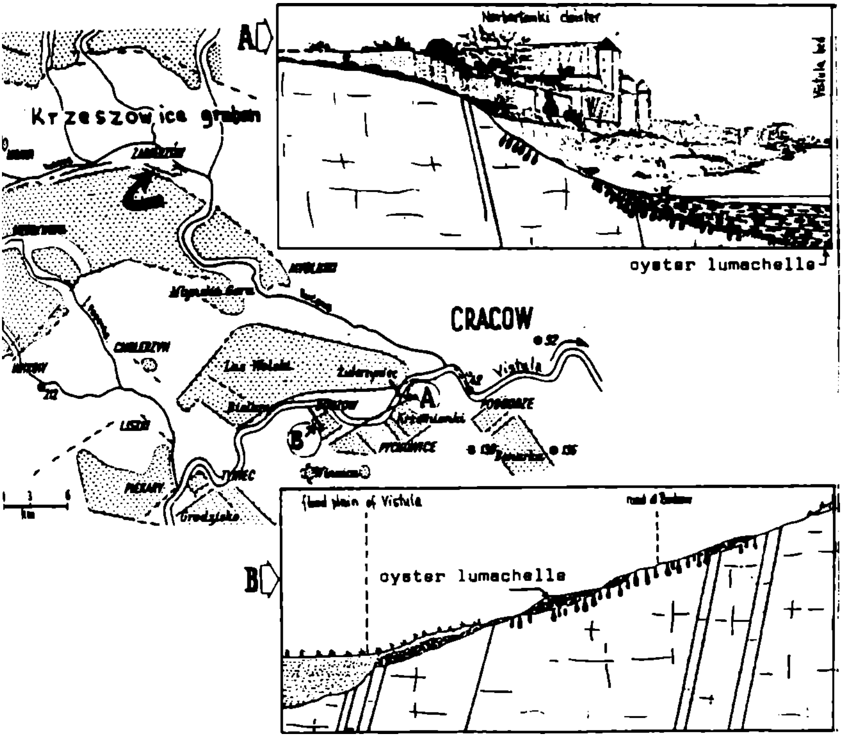


Fig.77 Relation of the Lower Tortonian littoral structures to the substrate in the Cracow Upland. General map showing the older block-faulting tectonics (After: Dżułyński 1953), and two sections at Cracow-Zwierzyniec nearby the Notbertanki cloister (A) and Bodzow (B);
arrow indicates the quarry at Zabierzów

The depositional sequence of the Tortonian (cf. Radwanski, 1968) begins in the Cracow Upland with oyster lumachelles, in places intercalated by acorn-barnacle lumachelles, that formed around rocky cliffs (Fig. 77 A-B), and with land-supplied clays deposited off shore (cf. Fig. 78). To the north, mophology of the substrate was more gentle and terrestrial supplies coarser-grained; as a result, loose sands with large foraminifers, *Heterostegina costata* (d'Orbigny) were formed there (*Heterostegina* Sands). All these deposits are rich in various open-sea fossils, and they are to be referred as the Lower Opolian (Fig. 78). Overlying these

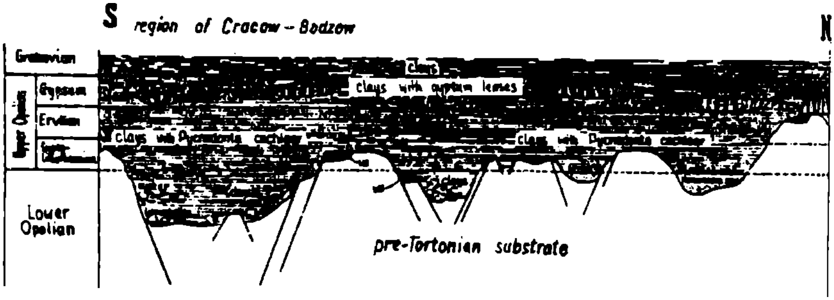


Fig.78 Diagram showing individual stratigrafic members of the Tortonian in relation to the substrate in the Cracow Upland; wa. fresh-water limestones of the caliche type (Older Tertiary).

are Upper Opolian clays with the oyster, *Pycnodonta oochlear* (Poli), whose shells are common mostly in lower part of the member while other fossils are very scarce. These clays rest in many places directly upon the substrate (Fig. 78) evidencing a greater extent of sedimentary areas over the previously non-depositional submarine ridges or islands. Clay sedimentation continued here through the lowermost Upper Tortonian, to some extent interrupted by a discontinuous gypsum precipitation which in the northern part of the Upland encroached onto the highest elevations of the basin bottom that had not been covered by deposits prior to evaporation (cf. Fig. 73).

The morphology of particular blocks originated due to the pre-Tortonian block-faulting tectonics, and either completely built of, or only capped by Upper Jurassic massive limestones, has intensively been sculptured by the post-Miocene erosion (Dżułyński & al. 1966). The picturesque valleys (cf. Fig. 74), some of which are closed by the so-called "gates" (Fig. 79), developed during the Pliocene and Pleistocene erosion which lasts until the present times.

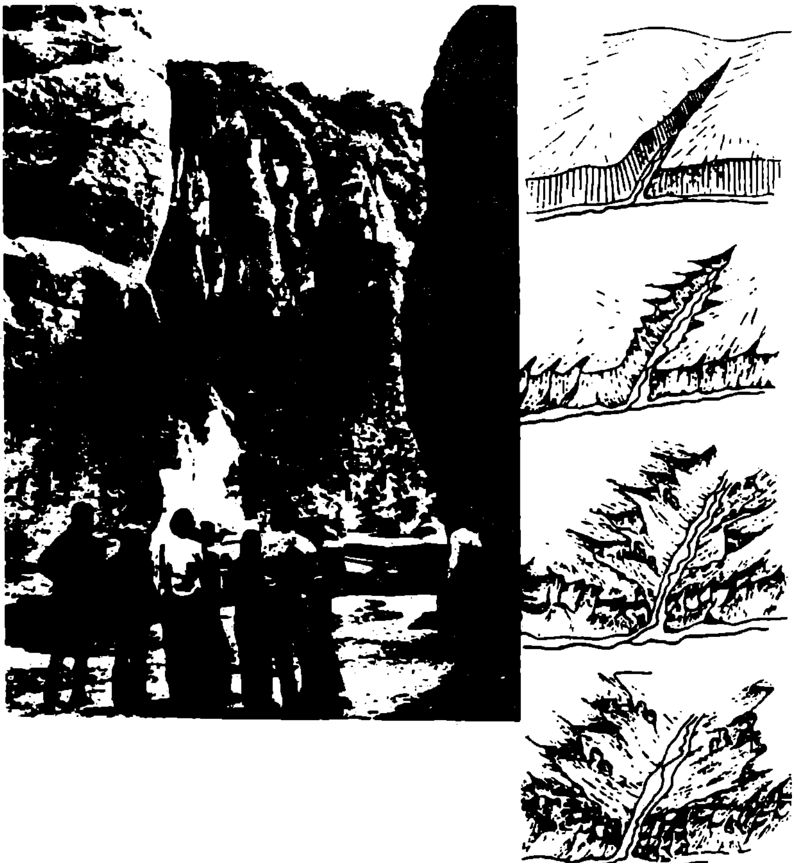


Fig. 79 One of the tributary valleys in the Prednik Valley (cf. Fig. 74), closed by a "gate"; the scheme shows four developmental stages of the gate (Photo by Gunnar Larsen; scheme after Dżułyński 1953)

Locality: Regulice

/written by Z. Bełka/

The late Variscan magmatic activity of the Cracow Upland was concentrated along the dislocations confining the Nieporaz-Brodła graben /see Fig. 80/. An abandoned quarry at Regulice exhibits a sequence of melaphyric rocks representing several lava flows of the aa type, associated with tephra, some layers of which yield evidences of redeposition by aquatic transport. Particular lava flows are usually compact in their lower portion, and they become vesicular and porous upwards. The vesicles are filled with zeolites, chlorites, calcite, and quartz. The amethyst geodes can sporadically also be found.
The melaphyres overlie arkosic sandstones and conglomerates of the fanglomerate type /Fig. 81/. The latter contain, except clasts of Lower Carboniferous carbonates, also fragments of melaphyres. This indicates the presence of at least two phases of eruptions of basic lavas in the Cracow Upland.

Fig. 80
Variscan magmatic rocks in the southern part of the Cracow Upland.
1. melaphyres and diabases, 2. porphyries, 3. depth contours of the top of the Upper Carboniferous Coal Measures, 4. marginal faults of the Nieporaz-Brodła graben /taken from: Siedlecki & Żabiński 1953/

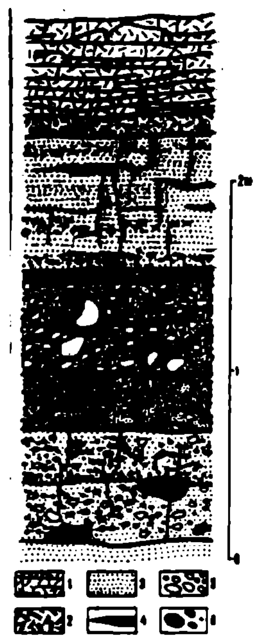


Fig. 81
Contact of melaphyres with substrate rocks at Regulice.
1. melaphyres, 2. altered melaphyres, 3. arkosic sandstones, 4. clay intercalations, 5. carbonate clasts, 6. melaphyre clasts /taken from: Siedlecki 1954/

Locality: Zalas

/written by B.A. Matyja/

In a huge quarry located 8 kms south of Krzeszowice /about 30 kms west of Cracow/, exploited are Lower Permian porphyries /ryodacites/ which are covered by Middle and Upper Jurassic deposits.

The porphyries intruded as a laccolith into the Lower and Upper Carboniferous clastic deposits /Fig.82/, the top of which was removed before Jurassic time.

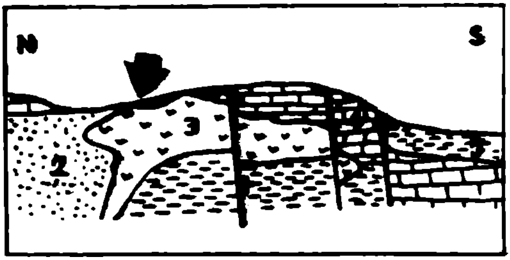


Fig. 82 Schematic cross-section through the Zalas laccolith /arrowed is the quarry/
1 Lower Carboniferous, 2 Upper Carboniferous, 3 porphyries /ryodacites/, 4 Jurassic, 5 Miocene
/Adopted from: Dżułyński 1955/

The Jurassic deposits overlie discordantly the eroded porphyries, the denivelations of which attain several metres. The Middle Jurassic transgression reached the Zalas porphyries in Early Callovian time; the eroded surface of the porphyries has been successively covered during Callovian and Early Oxfordian time.

As seen in the quarry, the porphyries are covered by white, uncemented quartz sands or by sandy crinoid limestones /Fig.85/. The sands sometimes yield nodules of calcareous sandstones usually rich in bivalves and brachiopods. In the upper part of the sands the bivalves /oysters and trigonids/ are accompanied by brachiopods, nautiloids and ammonites. In these sands, locally large blocks of porphyry occur, the same as along an ancient cliff exposed nearby at Sanka /Fig.83/.

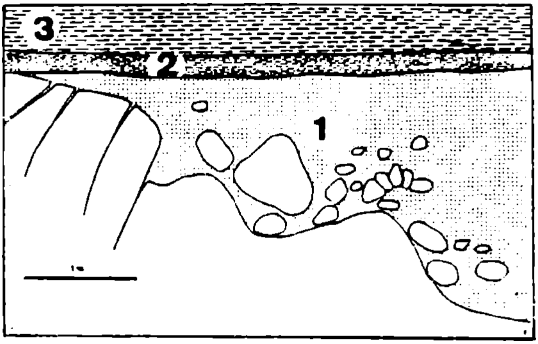


Fig. 83 Middle Jurassic cliff developed along the slopes of the Zalas porphyry, exposed at Sanka near Zalas

1 Sandy limestones /Macrocephalites macrocephalus and Sigaloceras calloviense zones/, 2 Glauconitic marls, 3 Marls /Cardioceras cordatum Zone/

/Adopted from: Dżułyński 1950/

Lower parts of sandy crinoid limestones display intercalations of conglomerates with quartz pebbles and shelly layers. The rich faunal assemblage of these layers comprises bivalves, brachiopods, corals, bryozoans, serpulids, nautiloids, ammonites, and calcareous sponges. This part of the deposits represents a shallow sublitoral environment. The upper part of crinoid limestones has nodular structure. The fossils /ammonites, bivalves, and gastropods/ display ferrugineous coatings and traces of both chemical corrosion and erosional truncation. Slow sedimentation was favorable for early lithification and chemical corrosion which are recognizable since the uppermost part of the Sigalloceras calloviense Zone. During the Kosmoceras jason and almost whole Erymnoceras coronatum time there was no deposition throughout the area /Giżejewska & Wieczorek 1977/.

A new sedimentary event began with the development of a stromatolitic layer. The stromatolites /cf. Fig. 84/ are built of calcareous ooze with an admixture of quartz grains. Black or red coloration of the lower part of the stromatolitic layer results from impregnation of stromatolite laminae with manganese and iron compounds. At the top of the stromatolitic layer there occur dome stromatolites and, in the overlying layer of pink marls, numerous onkolites with nuclei formed of crinoid limestone pebble with ferromanganese coatings. The structure of stromatolites is explained by hydrodynamic changes resulting from a deepening of the basin and passing of the area into a low-energy zone of the open shelf. The deepening of the basin and milder hydrodynamic conditions are evidenced by the succession of stromatolites /replacement of continuous stromatolites by dome stromatolites, and finally by onkolites/ as well as by the appearance of Lower Oxfordian deposits rich in pelagic fauna /Giżejewska & Wieczorek 1977/.

The age of the Oxfordian sequence is from the Quenstedtoceras mariae to the Perisphinctes plicatilis Zone /Matyja & Tarkowski 1981/. The Oxfordian strata overlie the nodular crinoid limestones or stromatolites and, outside the Zalas quarry, also the porphy-

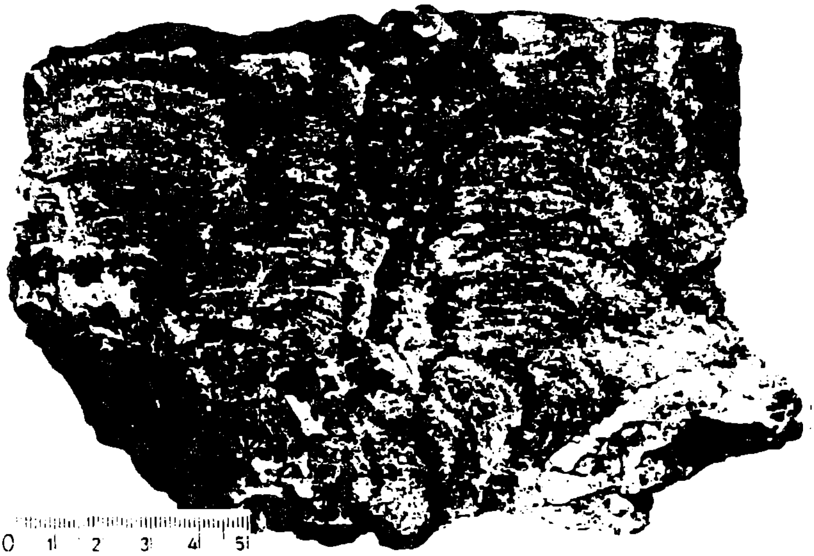


Fig.34 Typical Callovian stromatolitic layer from the Polish Jura

ries. They are represented by the interbedding micritic limestones, marly limestones, and marls with siliceous sponges. Besides the bedded deposits, there occurs a small sponge bioherm /cf.Fig.85/ built up of the bodily preserved siliceous sponges. The bioherm contains the same sponge species as the surrounding rocks do, but the sponges density is a few to a dozen or more times higher in the bioherm. The bioherm is dominated /cf. Trammer 1979,1981,1982/ by the species Reiswigia ramosa Trammer, Cnemidiastrum rimulosum /Goldfuss/, and Cnemidiastrum stellatum /Goldfüss/. The bioherm grades

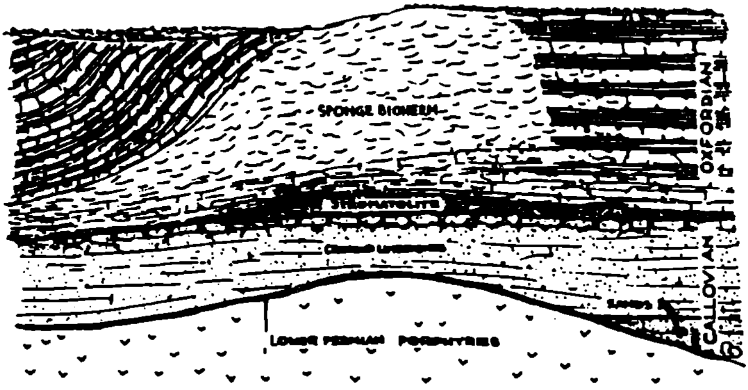


Fig.85 Succession and lateral relationship of the Jurassic deposits overlying the porphyries /ryodacites/ exposed at Zalas

to the east into bedded limestones including a few beds of calcarenites forming a kind of the talus. This talus consists of densely packed fragments of spongy mummies, derived from the bioherm.

The distribution of ammonites within the bioherm and the surrounding deposits worth special attention.In bioherm one can find plenty of ammonites, the assemblage of which is characterized by small-sized specimens of the genus Cardioceras, Neocampylites, Popanites, Lissoceratoides, and Perisphinctes. In the bedded sediments, one can find suprisingly few ammonites and even if so, only those having distinct bigger diameter. This is thought to have resulted from the sheltering of small-sized ammonites by the sponge mazes /Matyja 1984/.

Locality: Zabierzów

(written by A. Radwański)

In the Zabierzów quarry (arrowed in Fig. 77), situated along the southern margin of the Krzeszowice graben, exposed is a considerable part of the Upper Cretaceous succession typical of the Cracow Upland.

The Cretaceous deposits at Zabierzów are preserved in a small graben developed within the step faults bordering the Krzeszowice graben (Fig. 86). The sequence displays one to three abrasion platforms which originated during oscillation of the seashore caused by synsedimentary tectonics acting coevally with the mid-Cretaceous sedimentation (cf. Fig. 75).

The sequence begins with thin (half a meter or less) Lower Turonian sandy or gravelous limestones, locally replete with the echinoids Conulus ellipticus (Zaręczny), and truncated by another abrasion platform above which higher-Turonian limestones have been deposited. In some parts of the quarry, this abrasion platform truncates all the Lower Turonian deposits and reaches the Upper Jurassic substrate (Middle Oxfordian massive limestones - cf. Fig. 86).

Fig. 86 Schematic section through the southern margin of the Krzeszowice graben, to show location of the Upper Cretaceous deposits within a small step-faulted graben exposed in the Zabierzów quarry (cf. Fig. 77 - area indicated by an arrow)

The higher-Turonian limestones are truncated by the third abrasion platform which also locally reaches the Upper Jurassic substrate (Fig. 87).

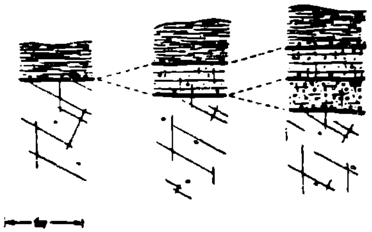


Fig. 87 Mid-Cretaceous abrasion platforms within the sedimentary sequence exposed at Zabierzów
(Adopted from: Alexandrowicz 1954)

The latter abrasion surface is covered by grey-greenish glauconitic marls with small phosphatic nodules and rich belemnite guards of Actinocamax verus Miller and Gonioteuthis granulata (Blainville), as well as shark teeth (i.e. Corax kaupi Agassiz) associated with isolated calycal plates of the crinoid Marsupites testudinarius (Schlotheim). This condensed deposit represents either the whole, or only the upper part of the Santonian. A small thickness (less than 1 meter) and continuity to higher deposits seem to indicate the uppermost Santonian.

Overlying are snowy white, soft chalky marls containing locally ubiquitous fossils, primarily calcareous sponges Porosphaera globularis Phillips and diverse echinoids, such as: Salenia obnupta Schlüter, Offaster pillula (Lamarck), O. pomeli Munier-Chalmas, Galeola senonensis (d'Orbigny), Micraster sp. div., and Echinocorys sp. div. Associated are belemnites Gonioteuthis quadrata (Blainville) and small crinoids (cf. Marta 1972) of the species Bourguetiorinus utriculatus (Valette), all indicative of Lower Campanian age.

C A R P A T H I A N S

A. Radwański

The Alpino-Carpathian orogenic belt in Poland comprises several units, the sequence of which is as follows /cf. Fig. 9/:

1/ The External /Outer/ Carpathians composed of a series of nappes featured by secondary folds /see Fig. 89/. Particular nappes reach the Carpathian margin discrepantly and, on the other hand, they reveal a compensation in their lateral extent: consequently, of the total number of 7 nappes, only two or three are well developed in particular transverse sections /see Fig. 89/. The discussed nappes are usually grouped into three larger units: the Skole unit developed to the east /see Fig. 88/, the Silesian unit composed of 5 nappes, and the Magura unit composed of one "blocky" nappe /cf. Figs 88 and 89/. All these nappes are built of typical flysch deposits, the investigation of which /by Kuenen, Książkiewicz, Dżułyński, Unrug, Sanders, Walton/ has resulted in the present-day knowledge of the turbidite sedimentation. The sedimentary sequence of the External Carpathians, begins in the Tithonian /only in the Cieszyn nappe/ and continues until the Lower Miocene /only in the Silesian nappe/; the total thickness of the flysch deposits is estimated as about 6 km.

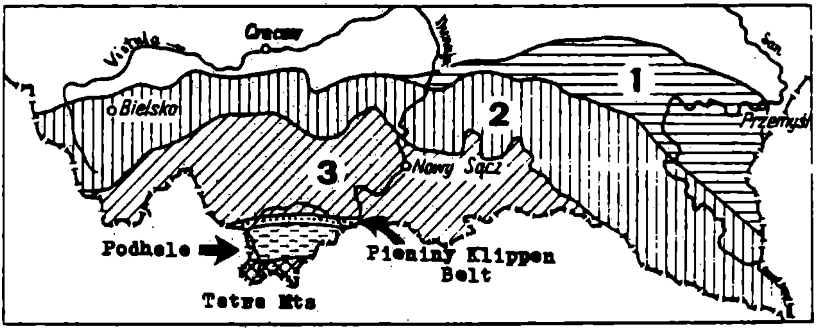


Fig. 88 The main geotectonic units of the Carpathians. Within the External /Outer/ Carpathians distinguished are: 1 - Skole unit, 2 - Silesian unit, 3 - Magura unit

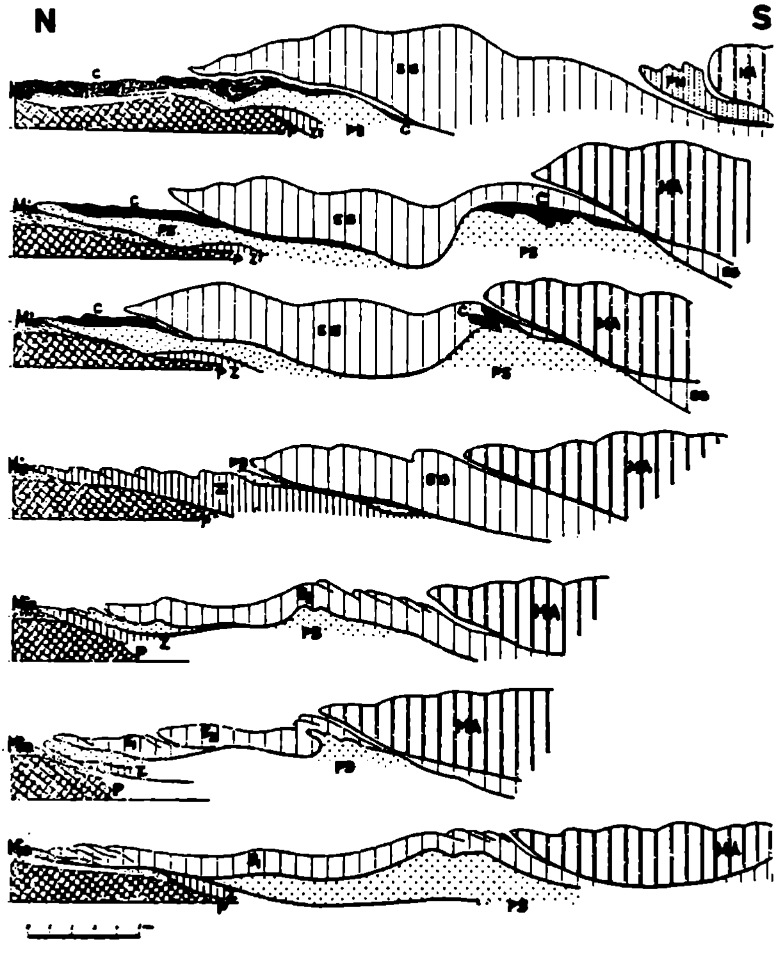


Fig. 89 Transverse sections through the Flysch Carpathians (successively from the west to the line of Cracow - Zakopane dual carriageway)

P - basement, Mio - Miocene of the Fore-Carpathian Depression (cf. Fig. 9), Z - External Flysch nappe, PS - Sub-Silesian nappe, C - Cieszyn nappe, SG - Godula nappe, S - Silesian nappe, PM - Sub-Magura nappe, MA - Magura nappe (Książkiewicz, 1953)

2/ The Pieniny Klippen Belt which is also composed of several tectonic units, all of which are more or less strongly compressed and squeezed into a narrow zone between the External and Internal Carpathians /cf. Fig. 9/ and continuing from Austria, through Czechoslovakia, Poland, further to the east.

3/ The Internal /Inner/ Carpathians are represented by the Tatra Mountains which are the highest range /about one-third of it lies in the territory of Poland/, situated northernmost of all the other massifs /e.g. the Lower Tatra, the Great and the Small Fatra, the Little Carpathians/ situated in the territory of Czechoslovakia. All these Variscan-cored massifs display their geotectonic structure similar to that of the Tatra Mountains /cf. Fig. 9/. Within the frames of the Internal Carpathians, the Tatra Mountains are bordered by Paleogene /Eocene/ flysch basins - the Podhale basin to the north /reaching the Pieniny Klippen Belt/, and the Liptow basin to the south /cf. Fig. 9/. The sedimentary sequence of the post-Variscan cover of all the Internal Carpathian massifs consists of the Verrucano series of Permian age, and more or less complete Triassic — mid-Cretaceous sequence which terminates about Cenomanian or Turonian time, being followed by the nappe folding. The Gosau event still remains unclear, and the first overlying series are of Eocene age at the border of the Podhale and Liptow basins.

PIENINY KLIPPEN BELT

A. Radwański & A. Wierzbowski

Within the Pieniny Klippen Belt, the most important units are the Czorsztyn Series /Succession/ and the Pieniny Series /Succession/, which together with the others /the Czertezik, the Niedzica, the Branisko, and the Haligowce series/ were folded at the same time as the sedimentary cover of the Tatra Mountains. These units are covered by the so-called Upper Cretaceous mantle /primarily, bricky-colored Globotruncana marls/, into which the Klippen series have been squeezed during the Laramide tectonic movements /cf. Figs 91 A and 94-95/. In many places the more resistant Jurassic sequence are, within the Upper Cretaceous mantle, tectonised in a boudinage-type manner /Fig. 94/. Due to subsequent erosion, particular boudins strech out from the surface as isola-

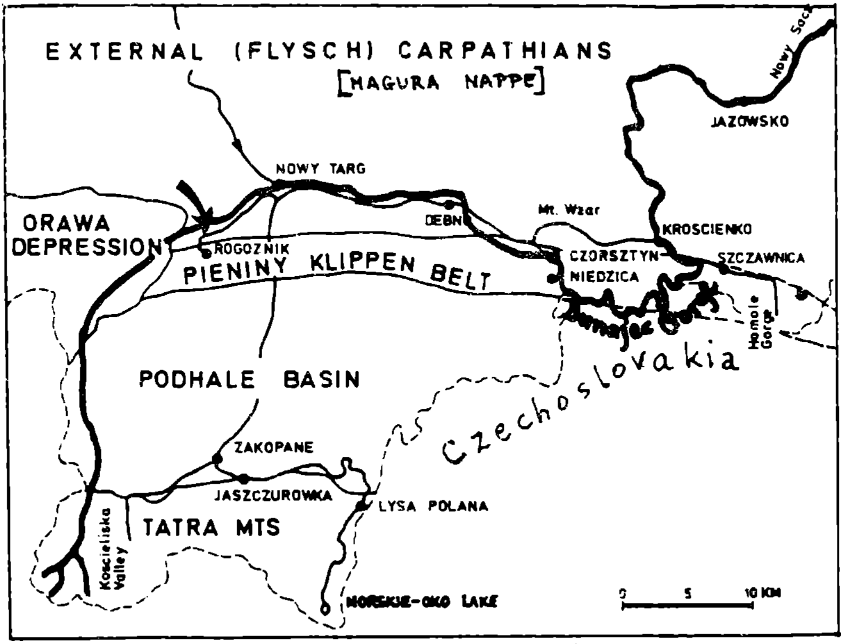


Fig. 90 Location of the most important exposures and other visiting sites in the Pieniny Klippen Belt, Podhale Basin, and the Tatra Mountains

ted klippes in the present-day morphology.

The development of the lithological sequence of the Pieniny Klippen Belt will be demonstrated in the classical locality Rogoźnik, and at the Czorsztyn Castle. Moreover, the younger-Tertiary /Middle Miocene/ subvolcanic andesites at Mt. Wżar, and the present-day morphology of the Dunajec River will also be shown /for location see Fig. 90/.

Locality: Rogoźnik

/written by A. Wierzbowski/

At Rogoźnik village, some 7 km SW of Nowy Targ /arrowed in Fig. 90/, exposed is a strongly tectonized part of the Czorsztyn Series /Succession/. At the Rogoża Klippes, there occur coquinas that yielded lots of Tithonian ammonites /and other fossils/

monographed by Zittel /1870/, and widely discussed by subsequent authors, e.g. Zeuschner, Neumayr, Zaręczny, Uhlig, Arkell, Birkenmajer. The coquinas have become world-famous due to their rich Middle Tithonian ammonites, and the concept of the Semiformiceras semiforme Zone considered as the Middle Tithonian equivalent. However, several ammonites of the Lower Tithonian, and a few Berriassian ones were also reported from Rogoźnik. Unfortunately, older ammonite collections were not derived from bed-by-bed collecting, and thus the more detailed stratigraphical works have been taken here as late as in the last decades.

The two ammonite coquinas were described by Birkenmajer /1963/, namely the Red Rogoźnik Coquina /distinguised recently as Rogoża Coquina Member/, and the White Rogoźnik Coquina /distinguished as Rogoźnik Coquina Member/. These units are exposed in the abandoned Rogoźnik quarry together with older and younger beds of Jurassic and Cretaceous age occurring in strongly tectonized situation /Fig. 91 A/.

The Red Rogoźnik Coquina is represented by hard, dense, red or red-brown micritic limestone with abundant, but mostly fragmentarily preserved ammonites. The observed sequence of the unit /about 10 m thick/ and its relation to the other rock-units is not clear due to tectonic disturbances. Of the fauna, there occur brachiopods /mostly diverse species of Pygope/ and ammonites: Physodoceras neoburgense /Oppel/, Glochiceras cf. carachtheis /Zeuschner/, Haploceras spp, Phylloceras spp, Lytoceras spp, some of which may eventually be treated as indicative of the Tithonian. However, few kilometers east to the Rogoźnik, at Stankowa Skala locality, deposits similar to the Red Rogoźnik Coquina contain ammonites indicative of the Oxfordian and Kimmeridgian. Hence, it is not excluded that at least part of this unit in the Rogoźnik section may be older than the Tithonian.

The best section of the White Rogoźnik Coquina /Rogoźnik Coquina Member/ is offered by two small klippes above the abandoned quarry /see Fig. 91 B/. These klippes /the Rogoża Klippes/ are under protection as the monument of inanimate nature.

Twenty three beds numbered consecutively downwards have been recognized in the section /Fig. 91 C/. They lie subvertically with the youngest one /number 1/ at the northwestern side of the klippes. The sequence is disrupted by a 1-2 m wide gap covered with coquina rubble. The bulk of the section of the southeastern part

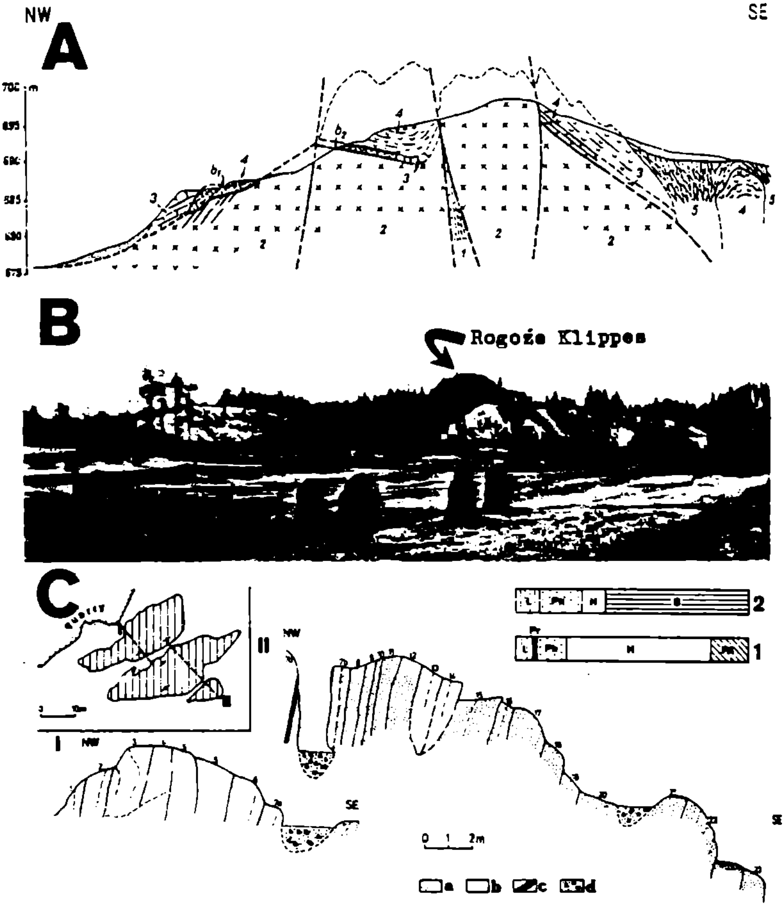


Fig. 91 A - Cross-section through the Rogoźnik Klippe: 1 - Murchisonae Beds (Aalenian to Middle Bajocian), 2 - White crinoidal limestones (Middle and Upper Bajocian), 3 - Red Rogoźnik Coquina, 4 - White Rogoźnik Coquina, 5 - *Globotruncana* marls (Turonian - Coniacian); tectonic breccias are indicated as b_1 and b_2
(**Taken from**: Birkenmajer 1963)

B - General view of the abandoned quarry at Rogoźnik, and the Rogoże Klippes above the quarry (cf. Fig. 91 C)

C - Sections through the two Rogoże Klippes, and ammonite spectra for the Lower-Middle Tithonian (1) and Berriasian (2) strata

a sparry coquinas (Lower-Middle Tithonian), *b* — micritic coquinas (Upper Tithonian-Berriasian), *c* crinoidal-detrital limestones filling the neptunian dykes (? Late Berriasian-Valanginian), *d* rubble
1 — Ammonite spectrum for the lower part of the section (beds *7b—12* and *15—23*, Lower — Middle Tithonian), 2— Ammonite spectrum for the upper part of the section (beds *1—5*, Berriasian): **L** — Lytoceratacese, **Pr** — Protancyloceratinae, **Ph** — Phylloceratacese, **H** — Haploceratacese, **B** — Berriasellidae, **PA** — Perisphinctidae and Aspidoceratidae

(**Taken from**: Kutek & Wierzbowski 1979) of the klippes /beds 23-15 and 12-7b with a total thickness of some 20 m/ consists of bedded, somewhat spotty, white or pinkish to red coquinas composed mostly of ammonite shells, and locally crinoid fragments. Ammonite aptychi, brachiopods and bivalves are common, whereas other fossils /gastropods, echinoids, sponges, solitary corals, and fish teeth/ are less frequent. The ammonite shells are often size-sorted. Sparry cement prevails in the coquinas, while sparse micritic matrix occurs locally. The ammonites yielded by the discussed part of the sequence enable to distinguish the hybonotum and darwini Zones of the Lower Tithonian, and of the semiforme and fallauxi Zones of the Middle Tithonian.

In the Lower Tithonian there occur: Hybonoticeras mundulum /Oppel/, Glochiceras lithographicum /Oppel/, G. carachtheis /Zeuschner/, Taramelliceras waageni /Zittel/, Streblites folgariacus /Oppel/, Aspidoceras rogoznicense /Zeuschner/, Physodoceras neoburgense /Oppel/, Protancyloceras spp, Haploceras spp, abundant phylloceratids and lytoceratids.

In the Middle Tithonian there occur: Semiformiceras semiforme /Oppel/, S. gemmellaroi /Zittel/, S. fallauxi /Oppel/, Pseudolissoceras spp, Physodoceras neoburgense /Oppel/, Aspidoceras zeuschneri Zittel, A. rogoznicense /Zeuschner/, Sutneria asema /Oppel/, Simocosmoceras simum /Oppel/, S. adversum /Oppel/, Richterella spp, Protancyloceras spp, Haploceras spp, abundant phylloceratids and lytoceratids.

In the northwestern part of the klippes exposed are poorly-bedded, whitish to creamy or pinkish coquinas /beds 1-7a/ composed of abundant micritic matrix containing fragmented ammonites /mostly Berriasellinae/, crinoids and brachiopods, as well as abundant calpionellids indicative of the Uppermost Tithonian-Berriasian. It is to note that within the discussed sequence of the Lower to Middle Tithonian from the southeastern part of the klippes there occur micritic limestones /beds 13-14/ containing calpionellids indicative of the Upper Tithonian. These deposits form a stratiform rock-body composed of internal sediments having possibly a character of the neptunian dyke. There also occur some other veins of crinoidal-detrital limestones cutting the Upper Tithonian coquinas of the Klippes, which are interpreted by Birkenmajer /1963/ as neptunian dykes of Valanginian /or Late Berriasian/ age.

Locality: Mt. Wżar

Along the slopes and top part of Mt. Wzar at Kluszkowce near Czorsztyn /cf. Fig. 90/ exposed are andesite dykes of Middle Miocene age. The dykes /Figs 92-93/ cut the flysch deposits mantling the Pieniny Klippes from the north, and partly also the flysch series of the Magura nappe /cf. 88-89/. Within the dykes two generations are recognizable: an older swarm of latudinal extent /Figs 92-93/, and few younger dykes of meridional extent. The largest of the younger dykes which cuts Mt. Wzar totally /cf. Fig. 92/, is well exposed in an abandoned quarry which offers a good insight both into the dyke body and its thermal--contact zone.

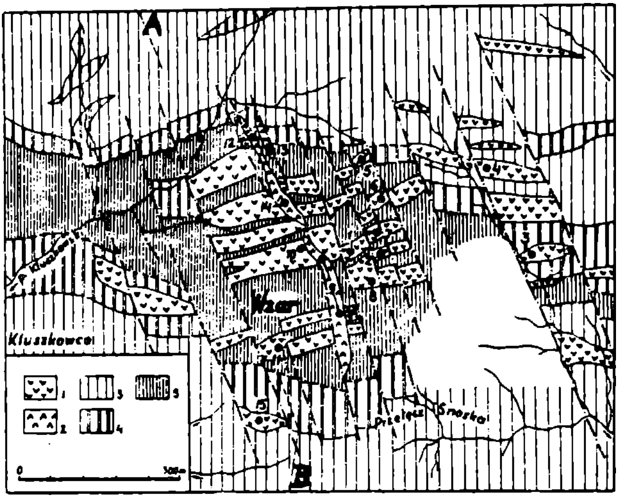


Fig. 92 Geological map of Mt. Wzar, to show the occurrence of the two generations of andesites: 1 - an older swarm of small dykes, and 2 - the younger, larger dykes of meridional extent; 3-5 - flysch deposits of the klippen mantle and of the Magura nappe /cf. Figs 89 and 94/.

/Birkenmajer, 1962/

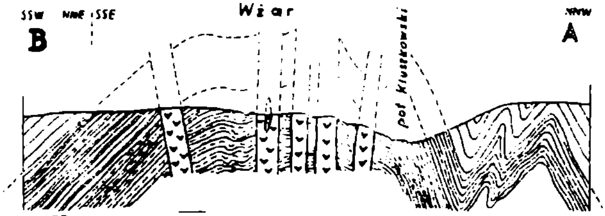


Fig. 93 Transverse section through Mt. Wżar, to show swarm dykes of older generation
(Birkenmajer, 1963)

Locality: Czorsztyn

Along the slopes of the Castle Mount at Czorsztyn exposed are both Jurassic deposits of the Czorsztyn-Castle Klippe and the mantling Globotruncana marls /see Figs 94-95/. Of the Jurassic sequence of the Klippe the most interesting are Upper Jurassic /Oxfordian - Kimmeridgian/ red nodular limestones /nodular Czorsztyn limestones in Fig. 95/ of typical "Ammonitico rosso" appearance /Fig. 96/; these limestones are also well exposed in a small klippe just at the Dunajec river-bed /arrowed in Fig. 94/.

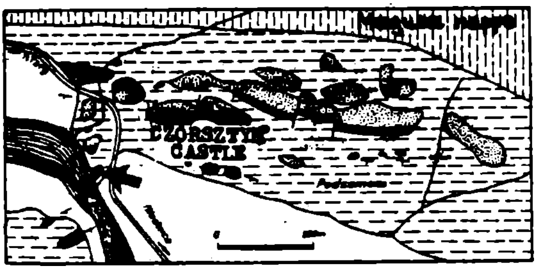


Fig. 94 Boudinage-type tectonic structure of the klippes near Czorsztyn
/After: Uhlig 1890, simplified by Birkenmajer 1953/

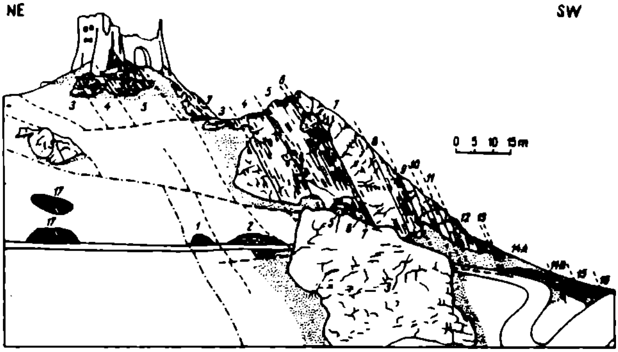


Fig. 95 Geological panorama of Jurassic and Cretaceous rocks [illegible] Czorsztyn

Czorsztyn succession: 1 — marls and spotty limestones (Opalinus Beds), 2 — sphaerosiderite clays and shales (Murchisonae Beds), 3 — white crinoid limestones, 4 — red crinoid limestones, 5 — nodular Czorsztyn limestones, 6 — red Calpionella Limestones, 7 — white Calpionella limestones, 8 — brachiopod limestones, 9 — lower crinoid-brachiopod limestones, 10 — main detrital limestones, 11 — upper crinoid-brachiopod limestones, 12 — crinoid Sputz Limestones, 13 — Chmielowa Beds, 14 — Pomiedznik Beds (A — lower, B — upper), 15 — green Globotruncana marls, 16 — variegated Globotruncana marls; Magura succession: 17 — flysch Aalenian

/Birkenmajer 1963/

Fig. 96 Red noduler limestone of the "ammonitico rosso" type from Czorsztyn (Oxfordian - Kimmeridgian)

The picturesque Dunajec Valley continues downstream, along the klippe topped by the ruins of the Niedzica Castle /Fig. 97/, into the world-famous antecedent gorge of the Dunajec River. The Dunajec Gorge, with many meanders, is incised primarily into the klippes of the Pieniny series, making up here a larger massif of the Three Crowns, built of pelagic Upper Jurassic - Neocomian cherty limestones of the biancone type.

An unforgetable route by rafts through the Dunajec Gorge, which lasts about 2 hours, terminates downstream at Krościenko /see Fig. 90/.

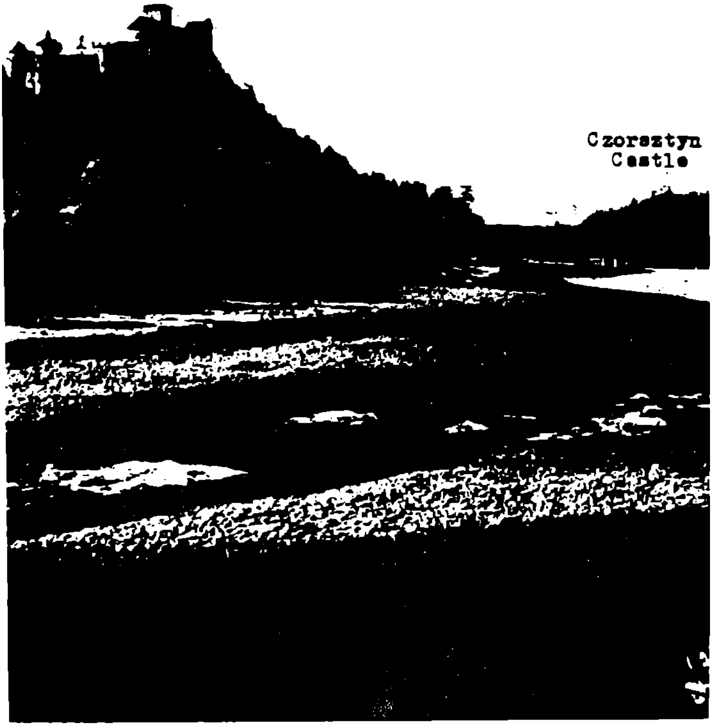


Fig. 97 The landscape of the Dunajec Valley between Niedzica and Czorsztyn /cf. Fig. 90/

/Photo by Gunnar Larsen/

P. Roniewicz

Within the Tatra Mountains one can distinguish /see geological map by Bac & al. 1979/ two main rock complexes differing in age:

crystalline core of Paleozoic age,
and sedimentary cover of Mesozoic age.

To the north, the Mesozoic rocks of the Tatra massif are bordered by Paleogene rocks - the carbonate Nummulite Eocene, and the Podhale Flysch /cf. Figs 88 and 102/.

Crystalline core

The crystalline core is built of granitoids and metamorphic rocks. The main granitic body is thought to be a late- or post--cinematic batholith intruding into metamorphosed Old Paleozoic sedimentary rocks. In the eastern part of the massif /Eastern or High Tatra/ the metamorphic cover had been completely removed, and the granitoids were overlain directly by unmetamorphosed Mesozoic sequence /locally, also Permian series of the Verrucano type/. The metamorphic cover is preserved in the Western Tatra where it consists of different gneisses, migmatites, amphibolites and minor bodies of varioud granitic rocks.

The granitoids of the High Tatra have a granodioritic or tonalitic composition. Due to the development of porphyroblastic microcline they approach the composition of true granites in some zones abundant in pegmatites and aplites. Most of these zones are often referred to as "marginal zone of pegmatitization".

White granites /alaskites/ occur mostly amidst metamorphic rocks of the Western Tatra and within the crystalline core of the Giewont nappe /the so-called "Goryczkowa crystalline island"/. The alaskites are fine-grained rocks, composed of albite, microcline, milkish-white quartz and fine muscowite flakes. Probably, they are an anatectic mobilizate originated from underlying metamorphic rocks.

The isotopic data of the crystalline Tatra rocks invariably point their Variscan age. The Rb/Sr determinations /Burchart 1968/ have yielded 290-315 m.y. for the granitoids as well as for the recrystallization of metamorphic rocks. Whole rock analyses of gneisses from the "Goryczkowa island" revealed some traces of previous isotopic homogenization which occurred about

420 m.y. ago /Burchart 1968/.

Mylonites and fault zones are very characteristic features of the crystalline core. Most of the major and minor passes have developed in such zones. Mylonites are of various age; some of them originated during the Variscan cycle, while the others are associated with the overthrust movements of the Alpine cycle.

Mesozoic sedimentary cover

The sedimentary cover of the Tatra Mts belongs to several tectonic units /see Bac & al. 1979/. Its part deposited directly on the crystalline core is called the High-Tatric zone. Others were tectonically transported to their present-day position from the southerly situated areas during the Alpine orogeny /Mediterranean phase/; these sequences are called the Sub-Tatric zone.

Within the High-Tatric zone the following tectonic units are recognized:

an autochtonous series cover resting directly on the crystalline core;

the overthrust High-Tatric nappes:

the Czerwone Wierchy nappe,
and the Giewont nappe.

The Sub-Tatric zone, located directly north of the High-Tatric, is composed of the three Sub-Tatric nappes:

the Lower Sub-Tatric nappe correlated with the Krizna nappe of Slovakia,

the Middle Sub-Tatric nappe correlated partly with the Choc, and partly with the Vepor nappes of Slovakia,

and the Upper Sub-Tatric nappe correlated with the Strazov nappe of Slovakia.

Of these Sub-Tatric nappes, only the lower one is wide-spread along the northern slopes of the Tatra Mts, and it is assumed that it has once covered the whole Tatra massif. The two remaining Sub-Tatric nappes are preserved in small fragments in the Western Tatra /cf. Fig. 100/, and they probably never covered the massif completely.

High-Tatric zone

The High-Tatric sequence /Fig. 98/ is of an intrageoanticlinal character, and a para-platform facies development of the Triassic formations is its most characteristic feature.

Lower Triassic red clastics /Seis/ of continental origin /Roniewicz 1966/ are the oldest ones in the Polish part of the Tatra Mts. Only in the Slovakian part of the massif, Permian red clastics /Verrucano/ are preserved /Passendorfer 1957/. Lower Triassic /Seis/ red-beds are composed /see Roniewicz 1966/ of conglomerates, quartzites and shales rest on strongly denuded surface /pre-Triassic peneplain/ of the crystalline rock. In these red-beds there is no material from the crystaline core. The clastic material was transported southward from the Pre-Car-

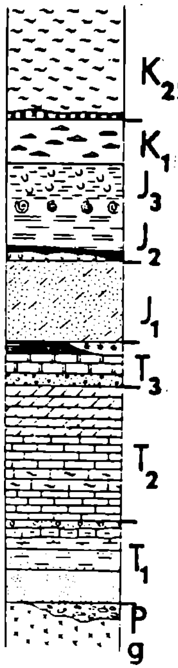


Fig. 98 Lithostratigraphic sequence of the High-Tatric zone

K_2 - Urgonian: crystalline limestones with Orbitolina; Albian: glauconite limestones with rich Ammonite fauna; Upper Albian-Cenomanian: marls, in upper part with Globotruncana

J_3-K_1 - Oxfordian: rose limestones; Kimmeridgian: grey limestones; Tithonian-Valanginian: limestones with Calpionella

J_2 - Bajocian: crinoid limestones; Bathonian: limestones with rich ammonites fauna; Callovian: grey limestones with ammonites fauna

J_1 - Lower Liassic: coarse-grained sandstones with pelecypods and belemnites; Middle Liassic: sandstones; Upper Liassic: sandstones and crinoid limestones

T_3 - Carnian: red and green shales; Norian: dolomites and limestones; Rhaetian: carbonaceous shales, quartzitic sandstones with flora

T_2 - Anisian: breccia or basal conglomerates, dolomites, vermicular limestones with Dadocrinus; Ladinian: dolomites and dolomitic limestones

T_1 - Lower Seisian: quartzitic sandstones, conglomerates; Upper Seisian: yellowish-weathering dolomites, black bituminous limestones, interformation-breccia with Costatoria costata

P - Permian conglomerates; g - granite

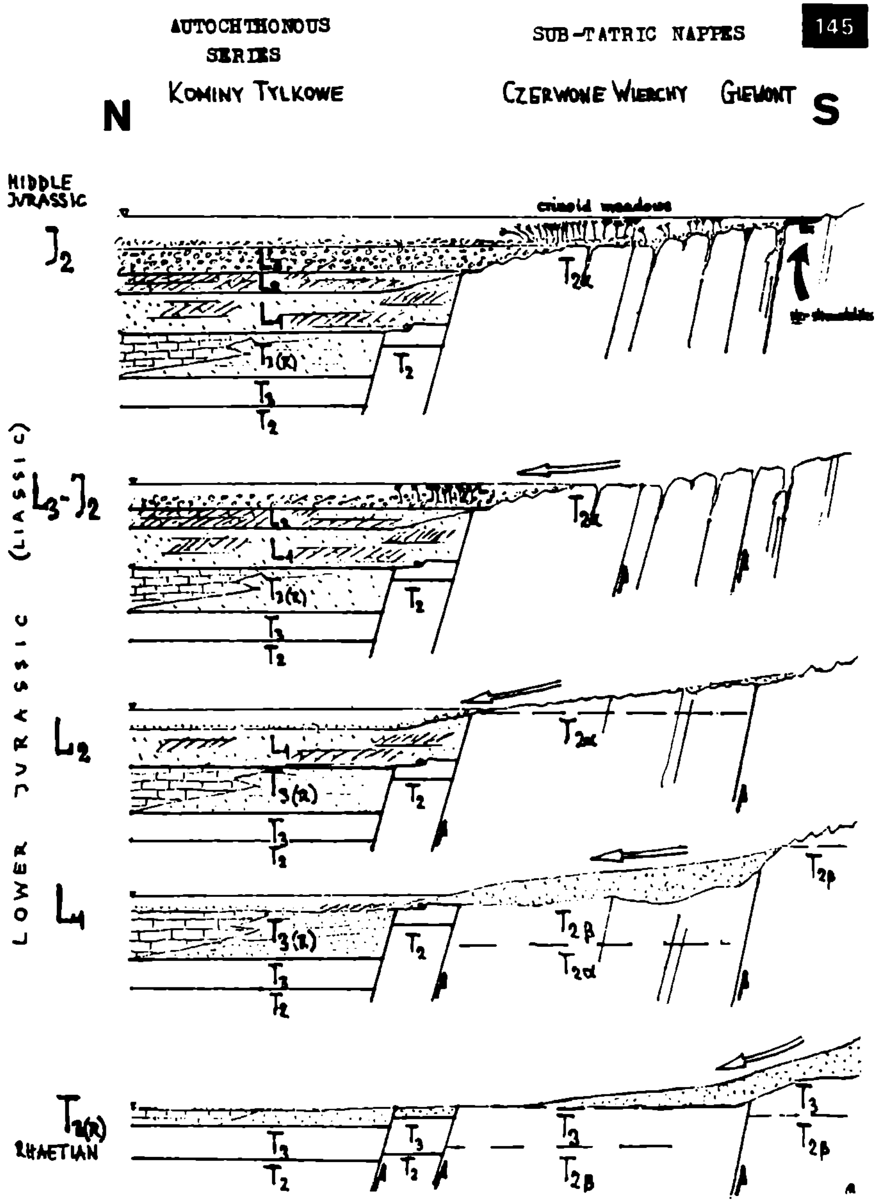


Fig. 99 Sedimentary models of the High-Tatric zone, taken at time interval Rhaetian - Bajocian/Bathonian, to show the facies pattern and the distribution of depositional and non-depositional areas

(Radwański, 1973)

pathian massif situated now under the Outer Carpathians. The red and brown quartzites are more resistant to weathering and they form distinct ridges in the present-day morphology /e.g. Żółta Turnia and those over the Kondratowa and Tomanowa Pass/. Nonresistant red shales crop out through the passes.

The higher Lower Triassic /Campilian/ rocks are the so-called cellular dolomites /Rauhwacken/, dark bituminous limestones, thin laminated dolomites and variegated shales. Yellow dolomites and vermicular limestones /Würmlikalk/ belong to Middle Triassic /Anisian/; locally they contain dasycladacean algae and /see Lefeld 1958/ completely preserved crinoids Dadocrinus grundeyi. Higher Middle Triassic /Ladinian/ deposits are preserved only in autochthonous series /Kominy Tylkowe massif/.

The Upper Triassic is developed as the facies of the so-called Carpathian Keuper, and it embraces variegated shales, sandstones and conglomerates and yellowish dolomites. Another Upper Triassic facies is the Tomanowa Beds, a continental formation consisting of coaly shales, ferruginous oolites and sandstones with flora remains /Raciborski 1890, Radwański 1968/, Rhaetian facies are represented by onkolitic, algal, and organogenic limestones /Radwański 1968/. The Upper Triassic and Lower Jurassic rocks are absent from the High-Tatric nappes /see Fig. 99/. Lower Jurassic clastic rocks are present in the autochthonous series, best exposed in the Kościeliska Valley /see Fig. 100*/; their clastic material was transported from the south /see Fig. 99/, and it was deposited in a near-shore environment /some layers represent tempestites/.

Middle Jurassic encrinites occur both in the autochthonous series and in the High-Tatric nappes /see Fig. 99/. These are crinoidal limestones of Bajocian and/or Bathonian age, locally deposited upon the eroded surface with neptunian dykes /Lefeld 1957/ and stromatolites /see Figs 99 and 100, and Szulczewski 1963/. The latter contain hematitic concretions and locally abundant ammonites /Passendorfer 1936, 1938/. Pinkish to greyish microonkolitic limestones /cf. Lefeld & Radwański 1960/ represent the Upper Jurassic, including the Callovian /best exposed

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*Fig. 100 is given as a separate fold-out at the back of the Guide *e.g.* at the crest of Giewont, and in the Kościeliska Valley, *see* Fig. 99/. Lower Cretaceous micritic and pseudo-oolitic and onkolitic limestones were continuously laid down above the Upper Jurassic carbonates. The shallowing sequence terminates with the reef breccias and reefal limestones of the Urgonian /*cf.* Lefeld 1968/. These rocks abound in various fossils, of which the orbitolinas, calcareous algae and corals are the most common. Urgonian limestones form picturesque crags in the Mała Łąka Valley, the Kościeliska Valley, and along the northern wall of Mt. Giewont.

Mid-Cretaceous /Albian-Cenomanian - Lower Turonian/ rocks represent a completely different type of sedimentation. These are glauconitic limestones rich in ammonites and other fossils /Passendorfer 1921, 1930; Marcinowski & Wiedmann 1985a, b/ and, higher up in the sequence, marls with sandstone interbeds of the distal flysch type. Mid-Cretaceous rocks rest upon eroded Urgonian limestones, and they are the youngest rocks preserved in the High-Tatric zone.

Sub-Tatric zone

Within the Sub-Tatric zone, the largest extent has the Lower Sub-Tatric nappe. The other two occur entirely in the westernmost part of the Tatra Mts.

The sedimentary sequence of the Lower Sub-Tatric nappe /Fig. 101/ begins with the Lower Triassic /Seis/ red quartzitic sandstones and shales very similar to the High-Tatric sequence of the same age. Campilian rocks developed as dolomites and shales. In the Middle Triassic, the dolomites and dolomitic limestones predominate. Steep crags built of Middle Triassic dolomites can be seen in vicinity of Zakopane, *i.a.* in the Strążyska Valley. The Upper Triassic is represented by variegated shales, conglomerates, sandstones and yellowish dolomites of the Carpathian Keuper facies. Many passes were eroded in these rocks /*e.g.* Czerwona, Grzybowiec/. In the eastern part of the Polish Tatra Mts, in the Filipka Valley, the Keuper sediments contain large proportion of black shales which make them similar to the Lunz Beds.

The Rhaetian beds are developed as limestones with megalodonts, shales and coral-bearing limestones with numerous fossils /Gaździcki 1974/; the best exposed profiles are in the Lejowa

Valley and at Mt. Mały Kopieniec near the Olczyska Valley.

Jurassic rocks of the Lower Sub-Tatric nappe represent, as a rule, much deeper facies than the coeval rocks of the High-Tatric zone. The Lower Jurassic rocks are a continuity of the Rhaetian sedimentation: these are sandstones of the Gresten facies, limestones or marlstones, frequently spotty /Fleckenmergel/, and spongiolites. The Toarcian is developed in two different facies. In the eastern Polish Tatra these are spotty marly limestones and dark marly shales with ammonites and pelecypodes. To the west, there occur red nodular limestones with iron and manganese ores.

The Middle Jurassic sequence is composed of greenish radiolarites and nodular limestones /Callovian/ representing the deepest facies in the Lower Sub-Tatric zone. Red, green and again red radiolarites were deposited also at Oxfordian time. Nodular lime-

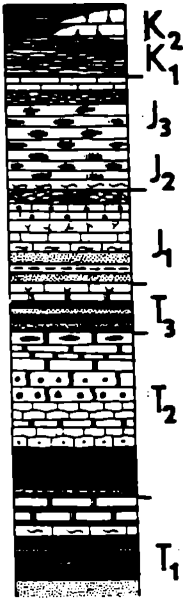


Fig. 101 Lithostratigraphic sequence of the Lower Sub-Tatric /Krížna/ zone

K_2 - Barremian-Aptian: marls; K_1 - Valanginian-Hauterivian: marls with ammonites fauna; J_3 - Oxfordian: radiolarites; Kimmeridgian: upper nodular limestones; Tithonian: limestones with Calpionella and ammonite fauna; J_2 - radiolarites, lower nodular limestones; J_1 - Hettangian: sandstones with hieroglyphs with Cardinia; Sinemurian: marly shales, limestones with Pentacrinus; Lotharingian: spotted limestones with Arietites; Pliensbachian: greyisch limestones, in upper part spongiolites; Toarcian: nodular limestones with ammonite fauna, manganous limestones, crinoid limestones with hornfels; Aalenian: grey limestones; T_3 - Carnian-Norian: conglomerates, sandstones, red and green shales; Rhaetian: limestones and shales with rich fauna of pelecypods, brachiopods /Rhaetina gregaria/ and corals; T_2 - Anisian: basal breccia, dolomites, limestones, vermicular limestones with Dadocrinus; Ladinian: dolomites with Encrinus and Diplopora annulata, dolomites with flints; T_1 - Lower Seisian: sandstones and conglomerates; Upper Seisian: sandstones interbedded with red shales; Lower Campilian: black limestones and shales, interformation breccia /Myophoria Beds/.

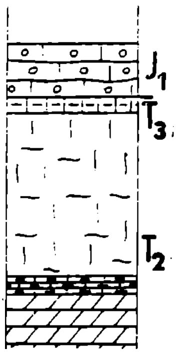


Fig. 102 Lithostratigraphic sequence of the Upper Sub-Tatric /Choc/ zone

J_1 - Lower Liassic: crystalline limestone, crinoid limestones with brachiopods fauna;
T_3 - Rhaetian: limestones and shales with brachiopods fauna;
T_3 - Anisian: platy dolomites /bearing some resemblance to Ramsau dolomites/ in lower part; limestones with hornfels /resembling Reifling limestones/, marls, limestones with ammonites, pelecypods, and brachiopod fauna /Partnach Beds/ in upper part.

stones of the Kimmeridgian-Lower Tithonian indicate probably a slightly shallower marine environment, although still fairly deep. Siliceous limestones of the Biancone type were deposited during the Tithonian and Berriasian. Lower Cretaceous marls, laid down all over the Sub-Tatric zone, locally contain intercalations od sandy and carbonate turbidites. In the east, the carbonate turbidites are thick /up to 100 m/, and are called the Muran Limestone Formation.

The sedimentary sequence of the Middle Sub-Tatric nappe /Fig. 102/ is preserved in the westernmost part of the Polish Tatra Mts only in fragments. Its sedimentary series were laid down within an intrageosyncline, the most deepened at Dogger and Malm time. The series is very analogous to the rocks of the lower East-Alpine nappes.

Tectonics of the Tatra Mts

The tectonics of the crystalline core of the Tatra Mts, contrary to the tectonics of the sedimentary cover, is not satisfactorily known. In some places, considerable displacements possibly of the nappe type were discerned. Some of them are Alpine in age, but the others are only the rejuvenated old Variscan dislocations. It is assumed that the granitoid complex was thrust over the metamorphic complex along a diaphtoritic-phyllonitic zone. Some parts of the crystalline core have been rotated in relation to other portions. Slickensided fault-planes, very common in the granitoid part of the core, are often coated with pale-greenish epidote.

The High-Tatric zone, intensively folded and overthrust, has its autochthonous series undulated and inclined toward the north. The High-Tatric nappes are preserved first of all in the transverse tectonic depressions of the crystalline core. The Czerwone Wierchy and Giewont nappes fill the Goryczkowa-Jawor depression in the west, and the Szeroka Jaworzyńska depression in the east.

The Czerwone Wierchy nappe is also intensively folded and subdivided into two separate blocks /Organy and Zdziary/. The Czerwone Wierchy nappe is best developed between the Kościeliska and Kondratowa Valleys /see Fig. 100/. Toward the east it is replaced by the Giewont nappe /tectonic compensation/, the best preserved in Mt. Kasprowy and Mt. Giewont. It fills the Goryczkowa-Jawor depression and, further on it disappears toward the Koszysta transverse elevation.

The crystalline core of the Giewont nappe is well discernible in Mt. Kasprowy, Mt. Czuby Goryczkowe, and Mt. Kopa Kondracka /it is easily noted on the geological maps that the overthrust crystalline rocks are surrounded by sedimentary rocks/. Some isolated tectonic caps of crystalline rocks belonging to the core of the Giewont nappe are preserved at the tops of Czerwone Wierchy--Kopa Kondracka ridge. The whole geological structure of the Giewont nappe is well visible when going on Kuźnice - Kasprowy Wierch cable car.

The Mesozoic rock complex of the autochthonous series are from 700 m /the Cicha Valley/ up to 2500 m thick /at the Kominy Tylkowe massif - see Fig. 100/. The rock complex of the High-Tatric nappes are thinner /550-800 m/ due to some stratigraphic gaps /cf. Fig. 99/. They have sedimented on the crystalline Tatra core, south of their present-day positions.

The Sub-Tatric nappes are composed of many smaller tectonic units of the scale type/Guzik & Kotański 1963/. They quickly replace one another, due to tectonic compensation. Usually, the particular strata of these units show normal positions and dip northward despite of their intensive folding. Root hinges are rare and can be observed only locally /e.g. at Mt. Nosal near Kuźnice/.

The rock complexes of Sub-Tatric nappes are derived from sedimentation areas situated far to the south of the Tatra Mts. To their present-day position, they were thrust over the Low Tatra and High Tatra massifs /cf. Fig. 9/.

NUMMULITE EOCENE and PODHALE FLYSCH

P. Roniewicz

The Tatra massif, tectonized during the Mediterranean orogenic phase, became a land and subjected to erosion and denudation through Upper Cretaceous and Lower Paleogene time. A transgression came from the Outer /Flysch/ Carpathians regions, and throughout the whole area of the Inner Carpathians a littoral, carbonate sedimentation of the "Nummulite Eocene" was established. It is regarded as of Lower and/or Middle Eocene age, and in the Upper Eocene it changed into clastic turbidites of the Inner Flysch of the Podhale region.

The Eocene deposits had certainly covered the whole Tatra massif, but they were denuded during Miocene time when the massif was uplifted.

The Nummulite Eocene dips steeply along the northern margin of the Tatra Mts, and the Podhale Flysch forms a vast synclinorium situated between the Tatra Mts and the Pieniny Klippen Belt /see Fig. 90/. The folding and faulting of the Eocene rocks took place during the Miocene, and their uniform cover subjected to erosion. The eroded material formed clastic sediments of the Neogene- Quaternary Orava depression, a part of which lies within the boundaries of Poland, near Czarny Dunajec /see Fig. 90/.

Within the Podhale Flysch distinct parallel zones can be recognized which differ in the character of tectonic deformations caused by the block movements of the Mesozoic substrate /Tatra nappes/. Additionally, the fault zones of meridional direction are superimposed on the older deformations.

The Nummulite Eocene rocks strech along the northern margin of the Tatra Mts and Choc massif on the west in the Slovakian territory. These littoral deposits /conglomerates and detrital dolomites/ originated from destruction of the Sub-Tatric rocks. Their thickness and lithological composition differ strongly from outcrop to outcrop /cf. Figs 103-107/, due to local paleomorphology during the transgression, and environmental conditions controlled by clastic material supply and local tectonic movements /Roniewicz 1966, 1969/.

The Tatra Mts as well as other Inner Carpathian massifs were elevated above the surrounding territory during the Eocene transgression and maintained the islands in the Eocene sea /Passendorfer & Roniewicz 1963/.

Basing on big-foram-stratigraphy, the Nummulite Eocene repre-

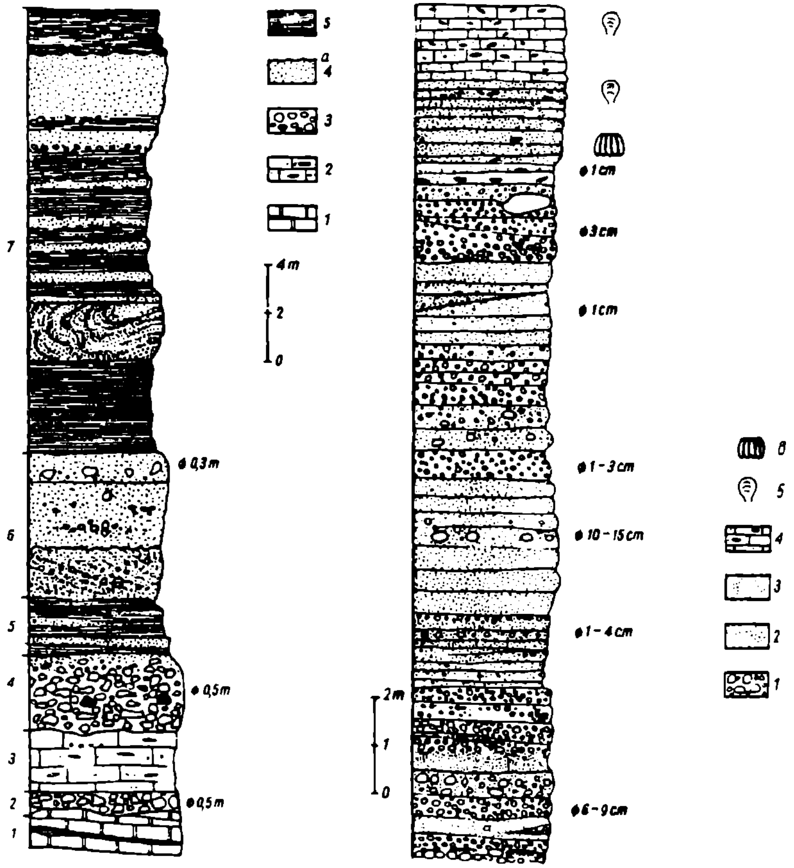


Fig. 103 A

Profile of the Nummulite Eocene in the bed of the B'elski stream:

1 substratum of the Eocene (yellow dolomites with intercalations of red shales — Upper Triassic), 2 limestones and detrital dolomites with large forams, 3 conglomerates (pebbles with large Eocene forams are marked in black), 4 sandstones (a ripples on the surface of beds), 5 shales of the Zakopane Beds type

B

Profile of the bottom conglomerates in the quarry in the Suchy Valley
1 conglomerates, 2 sandstones
3 cross-bedded sandstones
4 organogenic sandstone with nummulites, 5 calcareous algae
6 thick-shelled pelecypodes

sents the Upper Lutetian and Lower Bartonian. In many places the tests of big forams were redeposited, as a rule into flysch deposits, which affects the estimation of the age of sequences and which makes practically impossible fine correlation of the profiles /Roniewicz 1966/.

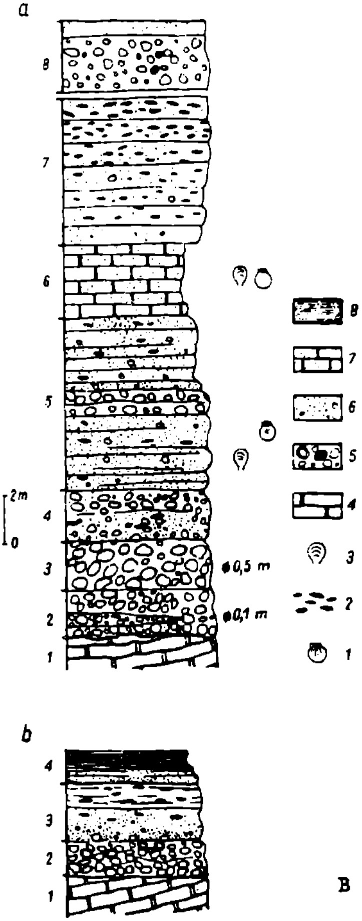
On account of their situation in profiles /cf. 103-104 and 107/, two types of conglomerates are distinguished: the lower /basal/, and the upper conglomerates. The lower conglomerates rest as a rule discordantly on diverse rocks of the Mesozoic substrate, and they are composed of the local material of the Sub--Tatric units /at Zakopane area, mostly Triassic dolomites/, and sometimes also of exotic pebbles /gneisses, ryolithes, black cherts/ derived from the Gemeridian massif in the south.

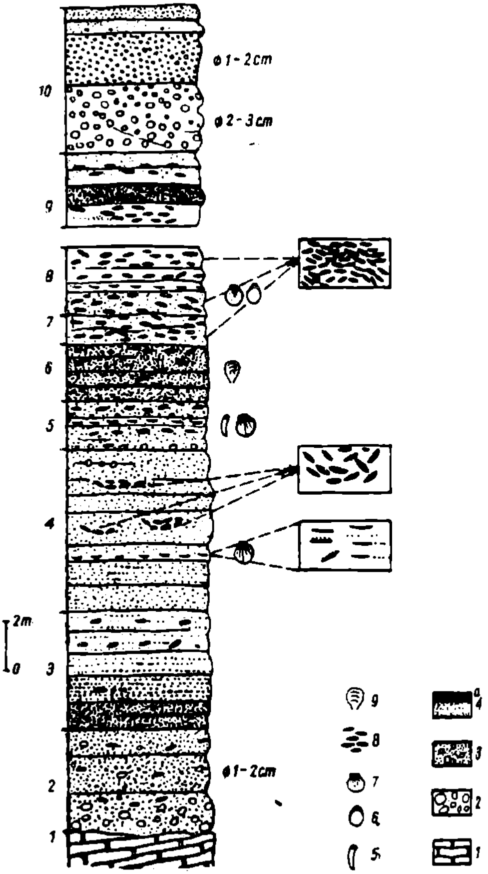
The lower conglomerates represent diverse sedimentary environments: red conglomerates or fanglomerates from Hruby Regiel were formed by cementation of weathered and partly mineralized with iron oxides Mesozoic rocks. The red conglomerate was changed by grey one composed mostly of Triassic dolomites; it represents a marine, near-shore environment in which gravels were transported from a synsedimentary fault zone, and accumulated as submarine fans /Roniewicz 1969/.

Another type of conglomerates is exposed in the Sucha Dolina quarry /Fig. 103 B/, and this consists of alternating beds of conglomerates and sandstones with lenses of mudstones containing remains of subtropic flora. It is probably a river or a small marine delta environment.

On Mt. Wysoki Regiel, the conglomerate forms an extensive flat lens and consists of the material of variable size and degree of rounding, with borings of lithofags in some pebbles. This conglomerate was formed during the cliff abrasion, and the abraded material was transported by waving and currents, and accumulated in form of a tongue-like bank.

The upper conglomerates occur above the deposits which contain large forams and other marine fossils /Figs 103 A and 104 A, B/. They consist of Sub-Tatric and exotic rocks, and of scarce pebbles of nummulite limestones. These deposits were formed as a result of rapid sedimentation controlled by a local tectonic shock or an earthquake: consequently, they are to be classified as seismites.





B

Profile of the Nummulite Eocene in the eastern part of the Pod Capkami quarry

1 substratum of the Eocene (Ladinian dolomites), 2 conglomerates and coarse-grained detrital dolomites with dolomite pebbles, 3 detrital dolomites with coarser grains, 4 detrital dolomite sandstones and siltstones (a siltstones with glauconite), 5 tubes of *Ditrupa* sp., 6 brachiopods, 7 thin-shelled pelecypods, 8 large forams, 9 calcareous algae

Fig. 104 A

Profiles of the Nummulite Eocene: *a* — in the Olczyska Valley, *b* — in the left slope of the Bystry Valley

1 thin-shelled pelecypods, 2 large forams, 3 calcareous algae, 4 substratum of the Eocene (in fig. 4a — Anisian dolomites, in fig. 4b — Ladinian dolomites), 5 conglomerates (thick line are the coatings of dark, algal limestone, black — pebbles of Eocene rocks), 6 coarse-grained detrital dolomites with gravels, 7 detrital dolomite sandstones and siltstones, 8 shales of the Zakopane Beds

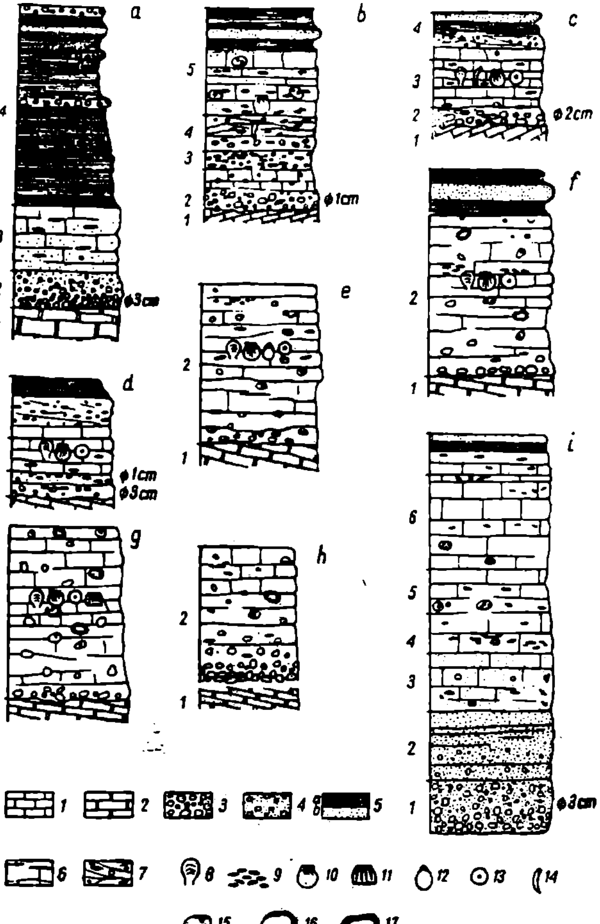


Fig. 105 Profiles of the Nummulite Eocene: *a* — Bialy Valley, *b* — Spadowiec, *c* — Ku Diurze Valley, *d* — Strążyska Valley, *e* — Suchy Żleb Valley, *f* — Za Bramka Valley, *g* — Maly Żleb Valley, *h* — Eocene patch on the eastern slope of the Mala Łąka Valley, *i* — quarry at the outlet of the Mala Łąka Valley

1—2 substratum of the Eocene (*1* Liassic marls and limestones, *2* Ladinian dolomites), *3* conglomerates, *4* conglomeratic sandstones; *5* — *a* shales of the Zakopane Beds, *b* quartz sandstone within shales; *6* organodetrital limestones, *7* sandstones and siltstones with cross-bedding, *8* calcareous algae, *9* large forams, *10* thin-shelled pelecypods, *11* thick-shelled pelecypods, *12* brachiopods, *13* echinoderm debris, *14* tubes of *Ditrupa* sp., *15* pebbles bored by lithophags, *16—17* algal coatings on pebbles (*16* asymmetric, *17* symmetric and concentric)

In some thicker profiles /Figs 106-107/, the conglomerates pass gradually into thick layers detrital dolomites, frequently cross-bedded with gravelous intercalations and concentrations of big forams. Detrital dolomites were deposited more distant from the shore than underlying conglomerates. Dolomitic sandy material, resulting from weathering of the Sub-Tatric dolomites, was transported by littoral currents and deposited in a tongue-like bank outside of the deposition zone of the gravels.

Where the sequence is generally thinner /Figs 105 a-i and 107 b/, the conglomeratic organodetrital limestones predominate. This rock consists of single dolomite pebbles, frequently bored by different lithophags, embedded in mass of big foram tests, fragments of calcareous algae, bryozoans, ori-

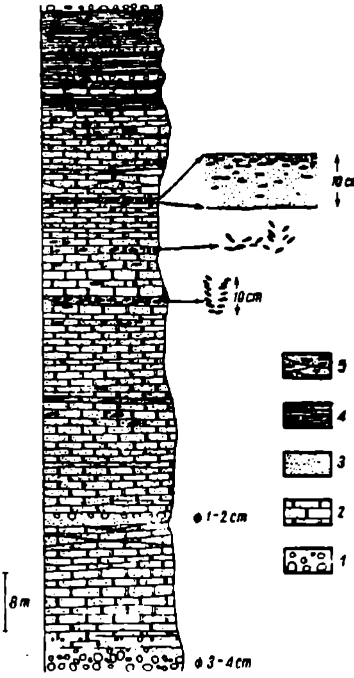


Fig. 106

Profile of the detrital dolomites in the Staników stream at Mt. Hruby Regiel

1 gray conglomerates, 2 dolomitic sandstones and siltstones, 3 quartz-dolomite sandstones, 4 shales, 5 detrital dolomites abundant in large forams, cross-bedded

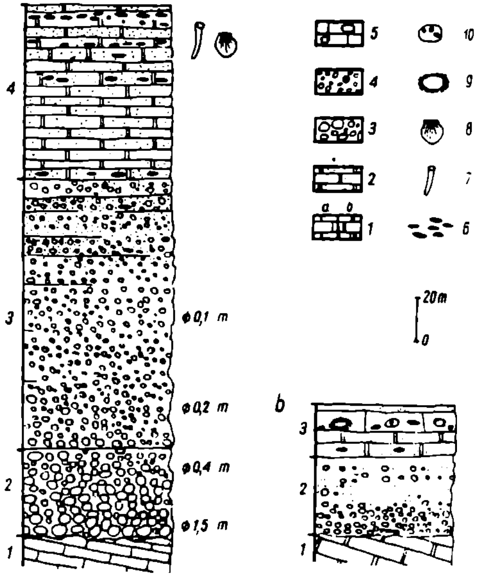


Fig. 107 Profiles of the Nummulite Eocene: a — Kościeliska Valley, b — Polana Molkówka

1 substratum of the Eocene (a limestones of the Choč Liassic, b Choč dolomites), 2 dolomitic sandstones and siltstones, 3 red conglomerates, 4 gray conglomerates, 5 organodetrital limestones and sandstones with dolomite pebbles, 6 large forams, 7 tubes of Ditrupa sp., 8 pelecypods, 9 pebbles with algal coatings, 10 pebbles bored by lithophags

noid ossicles, and pelecypod /frequently oyster/ shells. Some pebbles, also bored, are coated by calcareous algae. All these facts indicate that conglomeratic organodetrital limestones were formed in a relatively shallow littoral zone in which the supply of detrital material from nearby shorezone was low, and organodetrital type of sedimentation had to occur /Roniewicz 1966, 1969/.

To the north, the Nummulite Eocene pass into shales of the Zakopane Beds with siderite-ancerite concretions and few thin sandstone layers. In the northern part of the Podhale synclinorium /cf. Figs 108-109/ the profile begans with the Szaflary Beds with conglomerate intercalations and numerous graded sandstone layers. These are overlain by shaly deposits similar to the Zakopane Beds. The Zakopane Beds are overlain by the Chochołów Beds represented by typical flysch sequence, sandstone layers with graded bedding and the whole assemblage of features typical of turbidite sedimentation. These deposits are overlain by the sandstone-dominated Ostrysz Beds which represent the final phases of flysch sedimentation. In the whole profile, especially in the Chochołów Beds, numerous tuffites occur and can be used as marker horizons /Roniewicz & Westwalewicz-Mogilska 1974/.

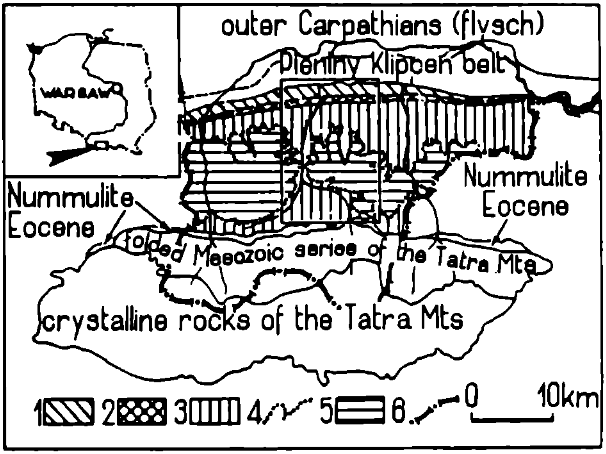


Fig. 108 Sketch map of the Podhale Flysch Basin with the ichnostratigraphic units. 1 beds without trace fossils; 2 *Planolites* beds; 3 beds with *Sabularia*, *Gordia* and *Helminthopsis*; 4 *Taphrhelminthopsis* beds; 5 beds with *Sabularia* and *Cochlichnus*; 6 state frontier.

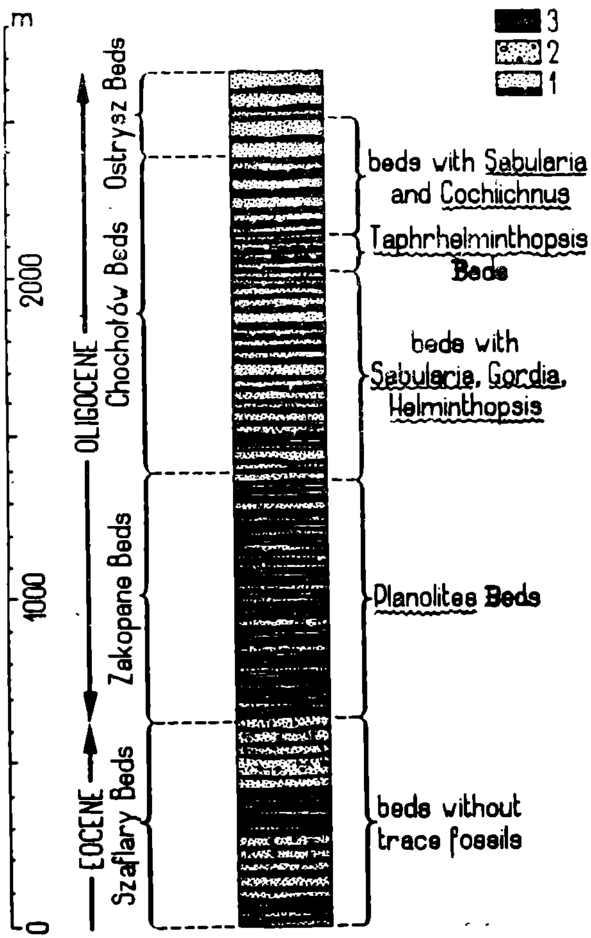


Fig. 109 Compound profile of the Podhale Flysch. 1 sandstones with trace fossils; 2 conglomeratic sandstones; 3 shales.

The thickness of the Podhale Flysch is estimated at about 3000 m. An analysis of paleocurrent direction showed that the source of the turbidity currents was situated west of the area. The Eocene-Oligocene ichnocoenose of the Podhale Flysch comprises mainly post-depositional trace fossils belonging to 15 ichnogenera and about 30 ichnospecies. An analysis of the distribution and frequency of the trace fossils allows to recognize some lithological units as local ichnostratigraphic zones, the Taphrhelminthopsis Beds and the Planolites Beds /cf. Fig. 109 and Roniewicz & Pieńkowski 1977/.

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