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Zbigniew PAUL, Wojciech RYŁKO, Adam TOMAŚ

Geological structure of the western part of the Polish Carpathians

The study area is located between Cieszyn and meridian of Sucha Beskidzka. The Precambrian and its cover — Palaeozoic platform deposits — occurring here, are strongly deformed and capped by the Neogene molasse. The major part of the area is occupied by the Flysch Carpathians. In the Carpathians, units of the Middle Group (Skole, Sub-Silesian, Klippen, Silesian, Dukla and Grybów) as well as the Magura unit have been distinguished and described.

Geological structure of the lower structural stages have only been outlined while the flysch, its stratigraphy and tectonics, has been discussed in details. The Skole unit occurs in the marginal part of the Carpathians, in the region of Andrychów and in tectonic windows within the Sub-Silesian and Silesian units. Deposits of the Sub-Silesian unit are found at the surface as two or three discontinuous bands. During the Neogene the unit had been truncated and developed as doubled or even tripled scales (imbricated folds). The most external part of the Sub-Silesian unit occurs at the front of the Carpathian overthrust as a band extending from Cieszyn to the region of Andrychów. The more internal part of the unit is recorded in the Dzięgielów and Ustroń windows, and the innermost, southern part is found at the front of the Dukla, Grybów and Magura units. The middle element of the Sub-Silesian unit might be associated with the extension of the Lanckorona–Żegocina zone towards the west. The Silesian unit is divided into tectonic sub-units: the lower one — Cieszyn sub-unit (nappe), and the upper — Godula sub-unit (nappe). Detachment which lead to separation of the Godula sub-unit as a separate entity took place within the Upper Cieszyn Shales or slightly higher. The Dukla unit *sensu lato* has been distinguished between Ślemień and Istebna. In the eastern part, between Ślemień and Żywiec, the Dukla unit is thrust over the deposits of the Silesian unit of the Little Beskid block. In the southern part of the Żywiec Basin the discussed unit together with the deposits of the upper Grybów unit is thrust over the deposits of the Cieszyn Silesian sub-unit. South of Barania Góra Mt., the Dukla unit is thrust over the deposits of the Silesian Beskid.

The authors distinguish the deposits of the Grybów unit between Gilowice and Istebna region. The unit is mainly formed by clayey-marly deposits of the Lower Cretaceous-Palaeogene age. This unit was strongly compressed, scaled and crushed between the Dukla and Magura units. In exposures, the Grybów unit takes a form of isolated scales and tectonic caps. It has also been identified in numerous tectonic windows within the Magura unit. The Magura unit is the highest unit in the discussed region. It is subdivided into three sub-units. The northern one is the Siary sub-unit and its deposits are thrust over the units of the Middle Group. The middle one is Racza sub-unit over which the southern one — Bystrica sub-unit — is thrust.

INTRODUCTION

The study area is located between Cieszyn and the meridian of Sucha Beskidzka. Its western and southern borders coincide with Poland's state boundary. From geomorphological point of view the majority of the area belongs to the Outer Carpathians but the northern and northwestern parts belong to the fore-Carpathian basins. In the discussed region, the Carpathians are divided into the Beskids and the Carpathian Foothills.

The Precambrian and its cover — Palaeozoic platform deposits, occurring here, are strongly deformed and capped by the Neogene molasse. The major part of the area is occupied by the Flysch Carpathians. In the Carpathians, units of the Middle Group (Skole, Sub-Silesian, Klippen, Silesian, Dukla and Grybów) have been distinguished and described. Moreover, the Magura unit has been distinguished. There, the Siary, Racza and Bystrica sub-units have been singled out and characterized. The discussion of the Quaternary deposits occurring in the study area are beyond the scope of this paper.

REVIEW OF PREVIOUS STUDIES

First information about geological studies in this region originated from 160 years ago and can be found in papers by Austrian authors.

First cartographic maps were printed at the end of the last century by W. Szajnocha (1985) and included the following sheets of the *Atlas Geologiczny Galicyi* (Geological Atlas of Galicia) 1:75 000: Żywiec–Ujsoły, Bielsko-Biała and Maków.

In 1934–1935 the *Mapa Geologiczna Karpat Śląskich* (Geological Map of the Silesian Carpathians) was prepared under the initiative of the Silesia Publishing Commission, Polish Academy of Arts and Letters (J. Burtanówna *et al.*, 1937).

A dynamic development of investigations in the study area and in the neighbouring terrains went on in the post-war years. Works by A. Tokarski (1947) and M. Książkiewicz (1951) are particularly important. In the 1950s the studies on the structure of Żywiec part of the High Beskid Mts. were carried out by W. Sikora and K. Żytko (1956, 1960) and by J. Burtan, S. Sokołowski (1956). In the successive years various geological maps of the area in question were published. The authors of these maps were: K. Żytko (1966*a*, *b*), J. Golonka *et al.* (1979) and W. Ryłko, Z. Paul (1994). Besides the quoted works of a cartographic character and geological maps, the discussed area was the subject to other studies including: stratigraphic, tectonic and lithologic ones that resulted in numerous publications, i.a.: J. Burtan (1936, 1968*a*, *b*), J. Burtan, S. Sokołowski (1956), J. Burtan *et al.* (1959), J. Golonka, A. Wójcik (1978), L. Koszarski (1985), L. Koszarski, A. Ślączka (1973), M. Książkiewicz, J. Liszkowa (1972), J. Liszkowa, W. Nowak (1964), W. Nowak (1959), B. Olszewska (1981), N. Oszczypko, A. Tomaś (1985), W. Ryłko (1992, 1994), W. Ryłko *et al.* (1992, 1993) and S. Sokołowski (1958).

Moreover, a great many papers dealing with the basement of the Flysch Carpathians were put out, among others by: W. Heflik, K. Konior (1970, 1974), K. Konior (1965), T. Kuciński, F. Mitura (1958), W. Moryc (1970, 1989), W. Nowak (1975), W. Ryłko, A. Tomaś (1995), A. Ślączka (1976*a*, *b*), A. Tokarski (1947) and K. Żytko (1978).

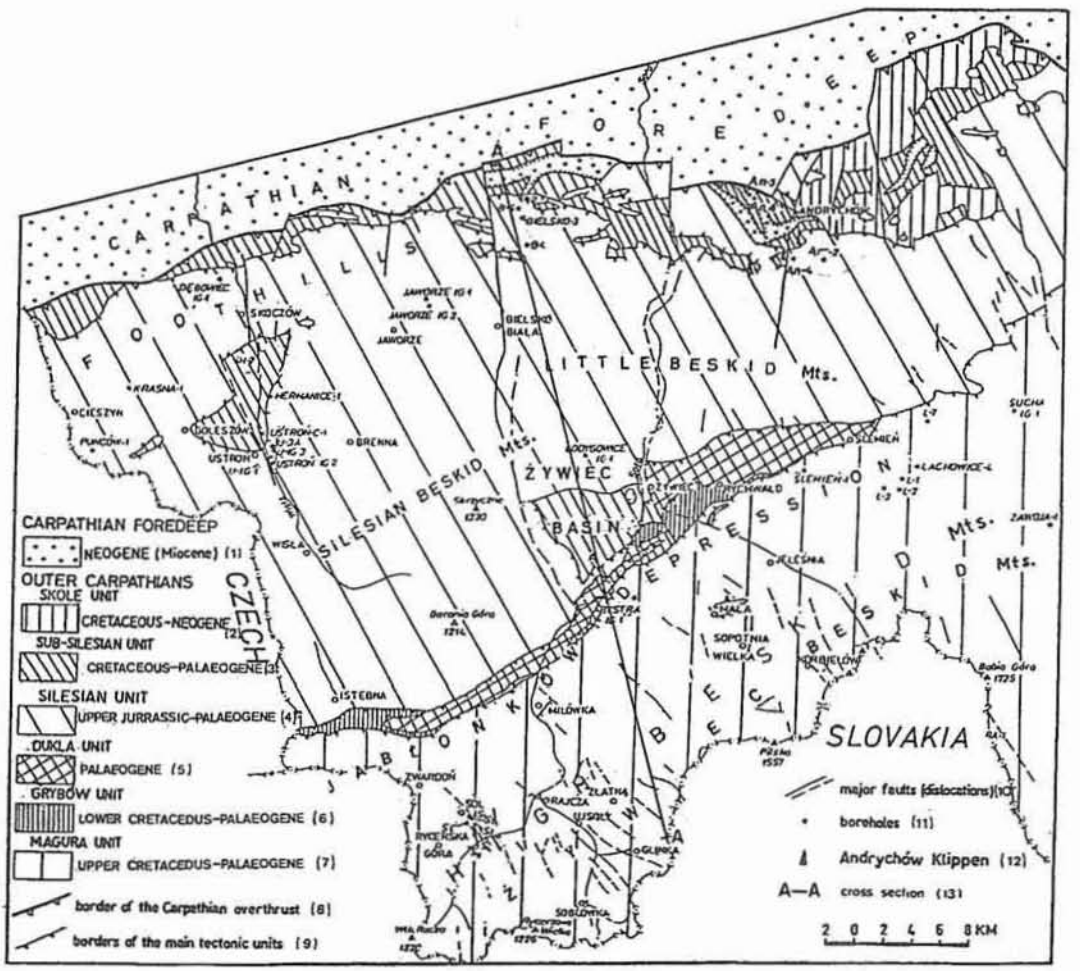


Fig. 1. Geological sketch of the Polish part of the Western Carpathians between Cieszyn and Sucha Beskidzka
Szkic geologiczny polskiej części Karpat Zachodnich między Cieszynem a Suchą Beskidzką
Zapadlisko przedkarpackie: 1 — neogen (miocen); Karpaty zewnętrzne: 2 — jednostka skolska — kreda-neogen, 3 — jednostka podśląska — kreda-paleogen, 4 — jednostka śląska — górna jura-paleogen, 5 — jednostka dukielska — paleogen, 6 — jednostka grybowska — dolna kreda-paleogen, 7 — jednostka magurska — górna kreda-paleogen; 8 — granica nasunięcia karpackiego; 9 — granica głównych jednostek tektonicznych; 10 — ważniejsze uskoki, 11 — otwory wiertnicze; 12 — skałki andrychowskie; 13 — linia przekroju geologicznego

A possible discovery of hydrocarbon deposits in the Polish and Czech Western Carpathians has aroused much interest for many years. Moreover, Polish Geological Institute made several deep, study boreholes (Fig. 1) in the 1970s. The first borehole was Łodygowice IG 1 (S. Geroch, W. Nowak, 1974), and the next one — Bystra IG 1 (K. Żytko, 1978). In 1974–1976 borehole Sucha IG 1 (A. Ślączka, 1976*b*), located in the eastern part of the study area, was made. In the 1980s Petroleum Drilling Co. continued exploration of the

discussed region. In the vicinity of Lachowice several boreholes resulted in interesting (oil- or gas-bearing) outcomes associated with the basement of the Flysch Carpathians. Investigations in this region are going on. A deep borehole Zawoja-1 has provided interesting data on stratigraphy of the Carpathians and their basement. Exploration drilling in the region of Sól that had been stopped in the 1950s was resumed in the 1980s and borehole Sól-8 was made.

GENERAL GEOLOGICAL CHARACTERISTICS OF THE STUDY AREA

The Precambrian-Palaeozoic platform deposits occur in the basement of the western part of the Polish Carpathians. They are capped by the Neogene molasse. Above these two structural stages there lies a third one — the Flysch Carpathians. The highest position is occupied by the Quaternary cover.

PRECAMBRIAN BASEMENT

In the triangle of Cieszyn–Andrychów–Żywiec, the oldest Precambrian deposits have been identified by boreholes: Puńców-1, Ustroń IG 3, Bielsko-4 and -5, Andrychów-3 and -4, Łodygowice IG 1, Bystra IG 1 and Lachowice-2. In these boreholes, metamorphic rocks belonging to the lower part of the epi-zone and to the meso-zone have been identified. The only exception is borehole Andrychów-3 where igneous rocks represented by diallage-olivine gabros have been recorded.

PALAEOZOIC DEPOSITS

The oldest Palaeozoic deposits are the Cambrian rocks that have been pierced in vicinity of Kęty, Andrychów and probably occur near Lachowice.

The Devonian and Carboniferous deposits have been identified by drilling in the northern part of the study area between Bielsko-Biała and Andrychów as well as in southeastern part, in the region of Lachowice.

NEOGENE DEPOSITS

The Precambrian-Palaeozoic basement is capped by the Miocene molasses. Sometimes, the Miocene sea, as shallow embayments, entered the Carpathians. There, the Neogene sediments were deposited. They are known as the Neogene deposits overlying the Carpathians. Based on the papers by Z. Buła, D. Jura (1983) and W. Moryc (1989) it can be assumed that between Cieszyn and the meridian of Sucha Beskidzka there occurs a complex of the Miocene molasse of the maximum thickness over 2600 m. These are the Lower Miocene and Badenian deposits. In Cieszynian Silesia, in the molasse deposits Z. Buła and D. Jura (1983) have distinguished the Zebrzydowice Formation, Dębowiec Formation with Zamar Member and the Skawina Formation. In the region between Bielsko-Biała and the meridian of Sucha Beskidzka, in the Lower Miocene deposits W. Moryc (1989) has

distinguished three lithostratigraphic units: Zawoja, Sus and Stryszawa Formations. In the latter the Stachorówka Conglomerate Member (A. Ślączka, 1976*b*) and Bielsko-Biała Member occur. The Badenian deposits occurring here are limited only to the Lower Badenian. In a lithostratigraphic column of the Lower Badenian, W. Moryc has distinguished (from below): the Jachówka Formation, the Dębowiec Formation and the Skawina Formation.

FLYSCH DEPOSITS OF THE CARPATHIANS

The Flysch Carpathians are made up of deposits of the Skole, Sub-Silesian, Andrychów Klippen, Dukla, Grybów and Magura units.

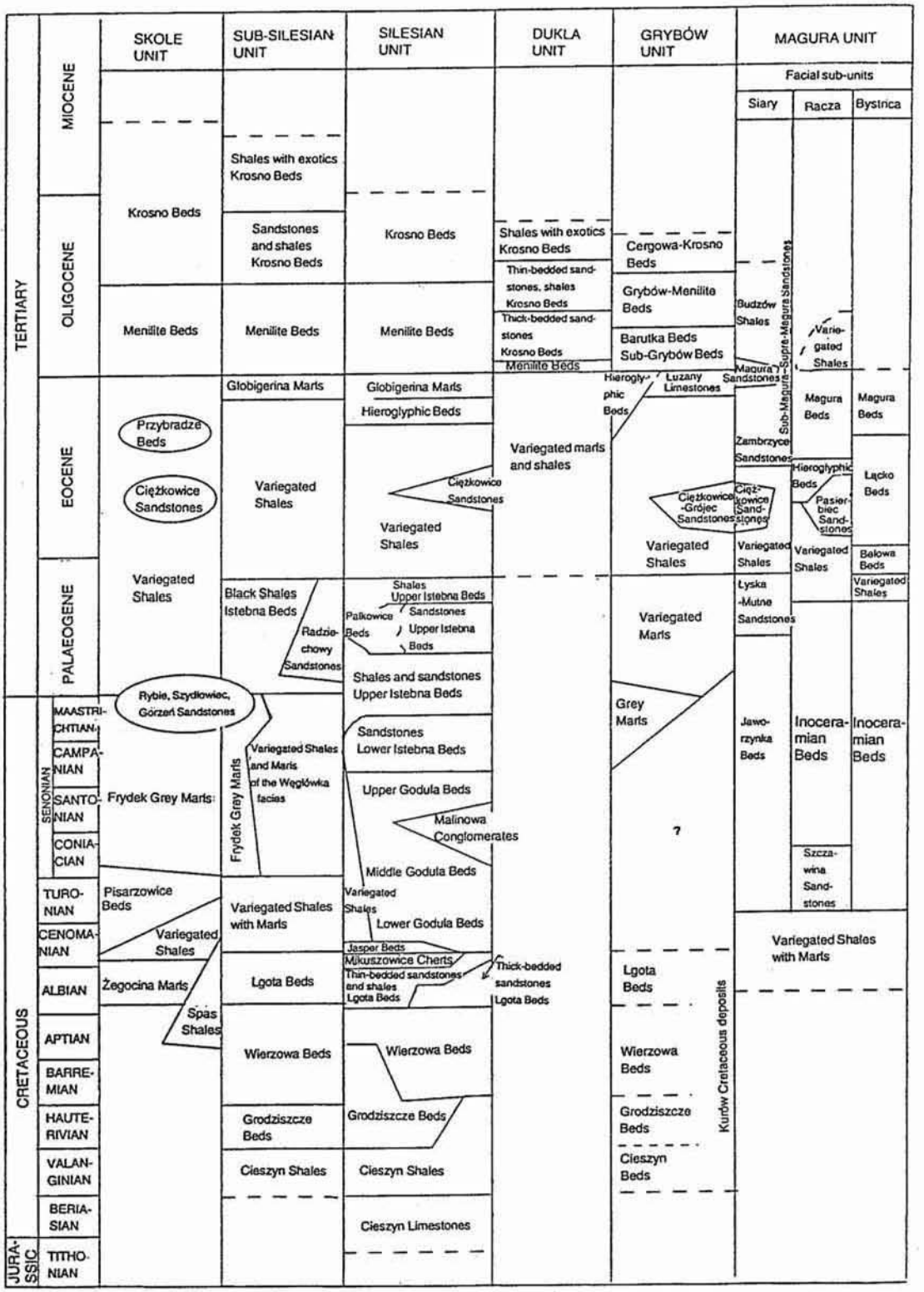
SKOLE UNIT

Deposits of the Skole unit occur in the northwestern part of the study area, north of Andrychów (Fig. 1). To this unit L. Koszarski (1985), K. Żytko (1985) and K. Żytko *et al.* (1988, 1989) include the Palaeogene-Neogene and Cretaceous(?) deposits of so-called outer flysch that have been described by M. Książkiewicz (1932, 1951). Opinions were expressed (M. Książkiewicz, 1972; J. Golonka *et al.*, 1979) that the deposits of this area represent the Sub-Silesian unit. Here, there are (Tab. 1) dark flinty Spas Shales; hard, white Żegocina Marls, Variegated Shales, grey sandstones and shales of the Inoceramian Beds (Pisarzowice Beds); dark marls and marly shales of the Frydek type with intercalations of Szydłowiec, Rybie and Gorzeń Sandstones etc. Above these sandstones occur thick Variegated Shales alternated with thick-bedded Ciężkowice Sandstones and the Przybradze Beds developed as grey clayey shales with inserts of thin- and medium-bedded limy sandstones with glauconite. The overlying Menilite Beds are made up of marls and cherts as well as of brown, almost black, shales with inserts of thin- and thick-bedded glauconitic sandstones. The youngest are the Krosno Beds which comprise mainly thin-bedded sandstones, often crustal ones, alternated with marly grey shales.

SUB-SILESIAN UNIT

Sediments of the Sub-Silesian unit deposited from the Lower Cretaceous (Valanginian) to the Lower Miocene (Tab. 1). The lithostratigraphic column of the unit starts with the Cieszyn Shales developed as grey marly shales alternated with thin-bedded sandstones overlain by the Grodziszcze Beds comprising conglomerates, shales and gaizes. Overlying are the Wierzowa Beds which differ from their normal development known from the Eastern Carpathians. They are black shales with conglomerates and large exotic boulders occurring in places. The Lgota Beds developed as gaizes or grey shales with radiolarites at the top (Jasper Beds) occur above the Wierzowa Beds. They are in turn overlain by Variegated Shales, usually green clayey shales alternated with hard, thin-bedded grey marls. Above the Variegated Shales with marls there are Węglówka Marls developed here as soft red marls alternated with Variegated Shales. Sometimes, the Węglówka Marls are replaced or

Stratigraphic chart of the western part of the Polish Carpathians



interlayered with grey or black marls of the Frydek type. Within the grey marls there is a lenticular sandstone horizon (Rybie, Szydłowiec, Gorzeń Sandstones). Grey and black muscovite shales, distinctly arenaceous, corresponding to the Upper Istebna Shales occur above the Węglówka Marls. Variegated Shales rest on the Istebna Shales. In the region of Żywiec, within these shales, there is a complex of thin-bedded glauconitic sandstones (Radziechowy Sandstones). Directly above the Istebna Shales there are the Eocene Variegated Shales with Globigerina Marls at the top. They are overtopped with the Menilite and Krosno Beds. The Menilite Beds are developed as clayey shales, sometimes flinty ones, with intercalations of thin-bedded sandstones or cherts, in places. The Krosno Beds are developed as thin-bedded sandstones passing to grey shales. Sometimes the sandstone horizon is sedimentary reduced, and, then, grey shales rest directly on the Menilite Beds. The Sub-Silesian unit comprises mainly shale-marly deposits with small amounts of thin-bedded sandstones. In the boreholes, they have been recognized under a large mass of the Silesian unit. In the northernmost part of the Carpathians they occur between Cieszyn and Andrychów while in the southern part they are found between Dzięgielów, Ustroń and Żywiec. Owing to lithology of the Sub-Silesian unit and its location, described above, its profile is discontinuous and truncated, and certain members have often been squeezed out or scoured.

KLIPPEN UNIT

Deposits of the Klippen unit occur in the region of Andrychów (Fig. 1) and are represented by mylonites, granitogneisses (locally), Oxfordian and Tithonian limestones and various marls from the Campanian to Maastrichtian as well as by limestones from the Upper Palaeocene to Middle Eocene. The deposits listed above have been described in details by, i.a. M. Książkiewicz (1935, 1951, 1965, 1968, 1972) and L. Koszarski (1985).

SILESIAN UNIT

Deposits of the Silesian unit occur in the northern part of the study area and stretch as a wide belt between Cieszyn and Andrychów region (Fig. 1). The series is represented by sedimentary rocks (Tab. 1) from the Upper Jurassic (Tithonian) to Palaeogene (Oligocene). In the study area, the Silesian unit has been subdivided into the Cieszyn sub-unit and Godula sub-unit. The differentiating feature between the both is the development of the Upper Cretaceous deposits. The deposits of the Lower Cretaceous and Palaeogene are developed alike and their differentiation is insignificant.

The lithostratigraphic column of both the Cieszyn and Godula sub-units starts with the Cieszyn Limestones. At the base, these are pelitic, pelitic-detrital limestones, and upwards — detrital limestones with graded bedding and limy sandstones. Higher up there lie the Cieszyn Shales, i.e. dark grey shales with thin-bedded limy sandstones. Above the latter occur extremely thick Grodziszcze Beds. They comprise sandstones which are thick-bedded and coarse-grained or conglomerates with limy cement. Above these beds occur Wierzowa Beds which are sometimes replaced by black shales with exotics. The overlying Lgota Beds are developed in the Cieszyn sub-unit as green and grey, spotty shales with thin-bedded sandstones while in the Godula sub-unit, they are tri-partite. The lower member is formed

by thick- and medium-bedded sandstones, the middle member comprises a shale-sandstone complex, and the upper member is represented by gaizes, the so-called Mikuszowice Cherts. In the Cieszyn sub-unit, Variegated Shales with small amounts of sandstones of the Godula type rest above the Lgota Beds, but the Godula sub-unit is developed as sandstones. The Godula Sandstones may be divided into three members: (1) thick-bedded sandstones, (2) medium- and thick-bedded sandstones, and (3) thin- and medium-bedded sandstones with intercalations of conglomerates, the so-called Malinowa Conglomerates. Unfortunately, the above division into members seems to be inadequate, particularly in the Little Beskid Mts. where fairly large complexes of grey shales and thin-bedded sandstones occur in the distinguished horizons. In the Cieszyn sub-unit the Variegated Shales are overlain by the Istebna Shales and by a rather thin complex of the Istebna Sandstones (known as the Pralkovice Beds in the Czech). In the Godula sub-unit, the Upper Godula Beds with the Malinowa Conglomerates gradually pass to the sandstone-conglomerates Lower Istebna Beds. On the latter rest thin-bedded sandstones with shales and conglomerate sandstones of the Upper Istebna Beds. These deposits are covered with the Upper Istebna Shales. In the Palaeogene part of the lithostratigraphic column, the deposits of both units become unified and comprise Variegated Shales with a packet of the thick-bedded coarse Ciężkowice Sandstones overlain by shales and thin-bedded sandstones of Hieroglyphic Beds, and above by the Menilite Beds with brown shales, thin-bedded glauconitic sandstones and cherts as well as by the Krosno Beds developed as thick- and thin-bedded sandstones gradually passing towards the top into thin-bedded sandstones and grey marly shales.

SUBVULCANITES

The Lower Cretaceous Cieszyn volcanic association is related to the Neocomian deposits of the Silesian unit. These are vein intrusions (sills), extrusions differing in thickness and inserts of pyroclastic rocks. Their petrographic composition is variable. Here occur cieszynits (rarely with tuff and tuffites), picrites, monchignites and basalts. Some of these rocks have been changed by secondary processes.

DUKLA UNIT *SENSU LATO*

Initially, the authors have distinguished deposits of the Dukla unit between Łękawica, Gilowice and Ślemień (Z. Paul, W. Ryłko, 1995). However, subsequent field studies allow to assume that these deposits occur also farther to the southwest, between Żywiec and Istebna, as well as in the region of Sopotnia (Fig. 1). In the lithostratigraphic column of the discussed unit, which used to be considered the Fore-Magura unit, the authors distinguish (at the surface) Variegated Marls and Shales developed as soft, red, lumpy marls alternated with green or red shales. In this horizon, the thin-bedded glauconitic sandstones occur sporadically. Above, there is a very thin (only a few metres thick) complex of black and brown shales with thin-bedded glauconitic sandstones, being an equivalent of the Menilite Beds in other units. The complex in question is overlain by a complex of thick-bedded muscovite sandstones of the Krosno Beds. A characteristic feature which differentiate them from the Krosno Beds of the Silesian unit is, for example, a higher diagenesis and thus a higher hardness and more diverse lamination patterns. Above the thick-bedded sandstone

complex there occur thin-bedded sandstones and grey shales of the Krosno Beds on which grey shales with exotics rest. The shales in question are marly with very fine muscovite and with a large variety of exotic rocks.

GRYBÓW UNIT *SENSU LATO*

The authors (Z. Paul, W. Ryłko, 1995) have distinguished and described the deposits of the Grybów unit in the region of Rychwałd–Rychwałdek, Kamesznica, Istebna and Koniaków (Fig. 1). In this region, the deposits of the Grybów unit used to be assigned to the Fore-Magura unit. However, the field studies allow to accept a hypothesis that the deposits of the Grybów unit, as in the former case, occur farther southwest, between Żywiec and Poland's western boundary in the region of Istebna and Sopotnia. Yet in contrary to the Dukla unit, the Grybów unit comprises mainly clayey-marly deposits. To the Grybów unit, the authors have also assigned the Lower Cretaceous Cieszyn Beds occurring at the surface in the Sopotnia Mała region.

The lithostratigraphic column of the Grybów unit starts with the Cieszyn Beds comprising grey, marly shales and thin-bedded sandstones. These beds are sedimentary strongly reduced as it is the case with all the deposits of the Lower Cretaceous age. They resemble the deposits occurring in this unit in the region of Nowy Sącz where they are called the Kurów Cretaceous deposits. The Godula Beds, normally occurring in the lithostratigraphic column above the deposits of the Lower Cretaceous, are here substituted by Variegated Shales with marls, biotite beds (Inoceramian Beds) and biotite-feldspar beds. Above, there are grey and Variegated Marls and Variegated Shales with thick-bedded and coarse sandstones of Ciężkowice type. A large diversity of grain sizes in these sandstones was the fundamental criterion to distinguish them as the Grójec Sandstones. These sandstones usually contain quartz grains differing in colours, fragments of magmatic and metamorphic rocks, and, in some beds, a very abundant fauna mainly including nummulites and discocyclines.

Above, there are the Hieroglyphic Beds, called in this series the Rdzawka Beds or Kleczna Beds, and zoogenic Koniaków Limestones (Łużany Limestones) which are also found in the overlying Variegated Shales up to the border with marls of the Barutka Beds. In the Variegated Shales, besides limestones, thin-bedded limy sandstones, are also found overcrowded with large foraminifera. Similar sandstone beds can also be observed in the Barutka Beds and in the Menilite Beds (Grybów Beds). Here, the Barutka Beds are developed as hard grey or beige marls and as marly shales. They are alternated with thin-bedded muscovite sandstones. In this horizon concretions or even beds of clay-ironstone often occur. The discussed sequence corresponds to the Sub-Grybów Marls.

The Grybów-Menilite Beds are represented by brown, almost black, shales sporadically alternated with muscovite-glauconitic sandstones and sometimes with conglomerates containing large foraminifera. These deposits are overlain by a complex of the Krosno Beds (Cergowa Beds) developed as grey marly shales, thin-bedded sandstones with singular

layers of medium-bedded muscovite sandstones with large amounts of hieroglyphs both organic and mechanic ones.

MAGURA UNIT

A characteristic feature of the Magura unit is its facial differentiation in meridional direction that is particularly well expressed in the Palaeogene deposits (Tab. 1).

The problem of facial changes in the Magura unit has been dealt with by numerous geologists including. Based on the studies of the authors mentioned above, four facial zones can be distinguished in the Magura unit. Starting from the north these are: Siary, Racza, Bystrica (Sącz) and Krynica sub-units.

The first three sub-units occur in the study area. The Ropianka Formation with local members occurs in the lower (Cretaceous-Paleocene) part of the profile in all these sub-units. The Eocene deposits in the Siary sub-unit (the Outer Racza unit according to W. Sikora, K. Żytko, 1960) are represented by Variegated Shales with intercalations of the Ciężkowice Sandstones (Lower Eocene-Middle Eocene), capped by marly-shale-sandstone deposits of the Upper Eocene-Oligocene. Here, one distinguishes a thick-bedded complex of glauconitic Magura Sandstones underlain by marly-shales of the Sub-Magura Beds (Zembrzyce Beds) and overlain by the Supra-Magura Beds (Budzów Beds). In the outermost regions of the Siary sub-unit the complex of thick-bedded sandstones often disappears.

The Racza sub-unit is typified by the Belowa Hieroglyphic Beds (the Middle Eocene), underlain by Variegated Shales and overlain by a thick complex of the thick-bedded muscovite Magura Sandstone.

In the Bystrica sub-unit, in the Middle and partially Upper Eocene, there is a member of the marly or the marly-sandy Łącko Beds underlain by the Lower Eocene Belowa Beds and by Variegated Shales. The overburden of the Łącko Beds consists of shales, marls, thin- and medium-bedded Sub-Magura Beds. The lithostratigraphic column ends with the thick-bedded, muscovite sandstones differing in thickness.

COMMENTS ON TECTONICS

Three structural stages can be distinguished in the study area. The lower stage consists of the Precambrian-Palaeozoic rocks of the subsided part of the platform which have been recognized in boreholes (i.a. Puńców-1, Ustroń IG 3, Andrychów-2, Łodygowice IG 1, Bystra IG 1, Sucha IG 1, Zawoja-1, Lachowice-1, -2, -3, -4, -7). The second stage comprises the Neogene molasses of the Alpine trough recognized in the surface exposures and in many borehole profiles. The third, allochthonous zone comprises the Flysch Carpathians represented by the deposits of the Skole, Sub-Silesian and Klippen (Andrychów Klippen), Silesian, Dukla, Grybów and Magura units (Fig. 2).

The platform deposits at the margin of the Carpathian overthrust (in the region of Cieszyn–Bielsko-Biała–Andrychów) are thick (often not pierced) Upper Carboniferous rocks of the southern slope of the Upper Silesian Coal Basin beneath which the older deposits gradually emerge southwards; these are the Lower Carboniferous (Bielsko-2), Upper Devonian (Bielsko-3), and middle Lower Devonian and presumably Cambrian

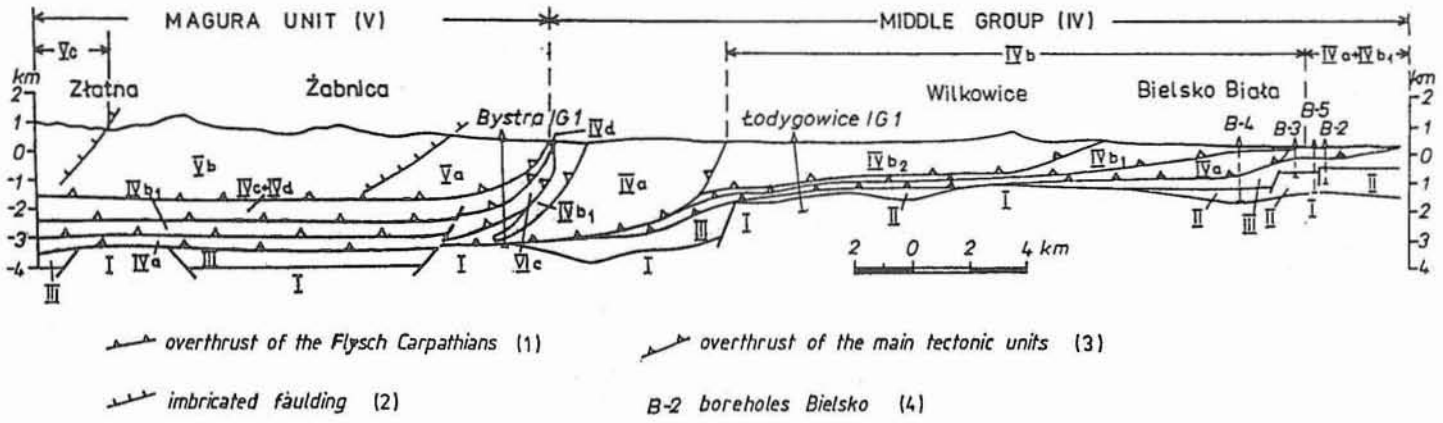


Fig. 2. Geological cross-section between Złatna and Bielsko-Biała
I — consolidated basement; II — platform basement; III — Neogene deposits; Flysch Carpathians: IV — Middle Group: IVa — Sub-Silesian unit, IVb — Silesian unit (IVb_1 — Cieszyn Silesian sub-unit, IVb_2 — Godula Silesian sub-unit), IVc — Dukla unit, IVd — Grybów unit; V — Magura unit: Va — Siary sub-unit, Vb — Racza sub-unit, Vc — Bystrica sub-unit
Przekrój geologiczny między Złatną a Bielskiem-Białą
I — podłoże skonsolidowane; II — podłoże platformowe; III — utwory neogenu; Karpaty fliszowe: IV — grupa średnia jednostek: IVa — jednostka podśląska, IVb — jednostka śląska (IVb_1 — podjednostka śląska cieszyńska, IVb_2 — podjednostka śląska godulska), IVc — jednostka grybowska, IVd — jednostka dukielska; V — jednostka magurka: Va — podjednostka Siar, Vb — podjednostka raczańska, Vc — podjednostka bystrzycka

(Bielsko-4) deposits. South of the Ustroń–Bielsko-Biała line crystalline basements represented by the so-called Cieszyn plate (A. Kotas, 1982; N. Oszczypko *et al.*, 1989; W. Pożaryski, P. Karnkowski, 1992) has been recognized by boreholes Łodygowice IG 1 and Bystra IG 1. Based on the results of seismic studies, borehole Bystra IG 1 and magnetotelluric studies (W. Ryłko, A. Tomaś, 1995) one can presume that farther southward the border line of the Palaeozoic deposits is a longitudinal fault or a system of faults of ENE–WSW direction. This fault is recorded ca. 11 km south of borehole Łodygowice IG 1, between Pietrzykowice and Lipowa. South of it the basement is downfaulted by ca. 1550 m.

The direct overburden of the Precambrian-Palaeozoic deposits is the molasse Miocene of the Carpathian Foredeep. The Miocene deposits at the Carpathian margin (Bielsko-Biała region, Andrychów region — borehole Kęty 8) were partially folded together with the Sub-Silesian unit (W. Nowak, 1959). In the remaining part of the Carpathian Foredeep (Cieszyn–Andrychów region), as well as deep beneath the Carpathians, the Miocene is undisturbed by folding, but, at most, cut by faults.

The Flysch Carpathians form a next structural element and comprise: the Skole, Sub-Silesian, Klippen, Silesian, Dukla, Grybów and Magura units. According to M. Książkiewicz (1972) the first six units form the so-called Middle Group of flysch nappes. Following the opinion of M. Książkiewicz the Middle Group might be considered a huge nappe from which stem secondary nappes (listed above).

SKOLE UNIT

Within the present-day framework (K. Żytko *et al.*, 1988, 1989), the Skole unit occurs in the marginal part of the Carpathians, in the region of Andrychów and in tectonic windows within the Sub-Silesian and Silesian units. In the region of Andrychów, to the Skole has been assigned, among others, the Palaeogene outer flysch. Following the opinions of K. Żytko (1985) and L. Koszarski (1985), the Frydek succession might also be included to the Skole unit in the discussed region. Here, the flysch deposits of the Upper Cretaceous and Palaeocene are developed locally (e.g. Szydłowiec, Rybie Beds etc.) and show a certain similarity to the Ropianka Beds.

SUB-SILESIAN UNIT

Deposits of the Sub-Silesian unit occur at the surface as two or three discontinuous bands. During the Neogene the unit had been truncated and developed as doubled or even tripled scales (imbricated folds). The most external part of the Sub-Silesian unit occurs at the front of the Carpathian overthrust as a band extending from Cieszyn to the region of Andrychów (Fig. 1). The more internal parts of the unit are recorded in the Dzięgielów and Ustroń windows, and the innermost, southern part is found at the front of the Dukla, Grybów and Magura units and appears at the surface in the Żywiec tectonic window. There, it is present as intensely folded NE scales. The middle element of the Sub-Silesian unit might be associated with the extension of the Lanckorona–Żegocina zone towards the west.

The southern band of the Sub-Silesian unit stretches in the southern part of the Silesian unit. The Sub-Silesian unit has been best recognized in the Żywiec tectonic window. There,

the Valanginian through Oligocene (J. Burtan, 1968*a*) deposits occur. They are intensely folded and arranged in scales trending north-south. In general, the Sub-Silesian unit is tectonically compressed and deformed very strongly owing to its lithology (mainly marly and shaly rocks).

KLIPPEN UNIT

One of the most interesting features in the Western Beskids is the occurrence of isolated klippen in the region of Andrychów. According to M. Książkiewicz (1972) the klippen occur up on the deposits of the Sub-Silesian unit, at the base of the Silesian unit. He claimed that such a position showed that the Silesian unit, while thrusting north towards, encountered a ridge built of crystalline and Jurassic rocks, covered with the Senonian and Palaeogene deposits. One should assume that the ridge could have been a fragment of a cordillera separating the Sub-Silesian basin from the Silesian one. L. Koszarski (1990) suggests that the klippen are olistostrome. The latter originated either from a cordillera separating the Sub-Silesian unit from the Skole unit or from the margin of the Carpathian geosyncline lying farther to the north.

SILESIAN UNIT

Owing to the development of the Godula Member and to disharmonic folding, the Silesian unit divided into two tectonic sub-units: the lower one — Cieszyn sub-unit (nappe), and the upper — Godula sub-unit (nappe) (*cf.* M. Książkiewicz, 1972). Detachment which lead to separation of the Godula unit as a separate entity took place within the upper Cieszyn Shales or slightly higher.

The Cieszyn Silesian sub-unit occurs mainly between the Olza and Soła rivers, and its smaller fragments have been found in the western, southern and southeastern margin of the Żywiec window. Moreover, the isolated tectonic caps resting on the Sub-Silesian unit, have been spotted in several locations in the Żywiec Basin (Fig. 1). The authors presume that in the western and southwestern part of the Żywiec window there are two partial Cieszyn sub-units: the lower Cieszyn sub-unit and the upper one. The lower unit (at the contact with the Sub-Silesian unit of the Żywiec window) is located more to the east, the upper unit rests on the lower one in the contact zone with the Godula Silesian sub-unit of the Silesian Beskid block. The discussed sub-units occur as intensely disturbed scales. The lower Cieszyn sub-unit is built of Lower and Upper Cretaceous deposits. In this sub-unit, within the Cieszyn–Grodziszcze Beds, the presence of the Lower Callovian olistolite of the detrital limestone (klippen from Leśna) has been stated. The upper Cieszyn sub-unit is built of the deposits ranging in age from the Upper (or Lower) Cretaceous to the Palaeogene.

Following the approach of M. Książkiewicz (1972), the Godula Silesian sub-unit is clearly delimited from its foreland. The transverse, NW–SE faults divide this sub-unit into three blocks: Jablonkovsky Beskid (in the Czech), Silesian Beskid and Little Beskid (Fig. 1). The Silesian Beskid block forms a four-sided body whose northern and eastern margins are uplifted. From the south the Dukla, Grybów and Magura units are thrust over the block. From the west the Jablonkovsky Beskid is thrust over the Silesian Beskid.

The Silesian Beskid block is dissected by several transverse faults with downthrown eastern sides. Along the eastern margin of the block there is a great NNW–SSE fault which separates the Silesian Beskid block from the Little Beskid block (Fig. 1). The blocks in question were displaced along the fault line and rotated. In the northern part of the fault the older members of the Silesian Beskid block are in contact with the Krosno Beds of the Little Beskid block (Fig. 1). Thus, the Little Beskid block is downthrown with respect to the Silesian Beskid block. Farther south, along the same fault, the Cretaceous members of the Silesian Beskid block are in contact with the deposits of the Cieszyn sub-unit and of the Sub-Silesian unit in the Żywiec window (Fig. 1). There, the arrangement is reverse, the block of the Silesian Beskid is downthrown and the area of the Żywiec tectonic window is uplifted. The discussed fault is then a pivotal fault (*cf.* M. Książkiewicz, 1972).

The Little Beskid block (Fig. 1) is a monocline dipping southward. In this direction, the younger and younger members of the Godula Series, including the Palaeogene members, appear at the surface. Within the discussed block there are also larger transverse N–S faults. Particularly important is the fault zone along the Soła river that, in the southern part, forms the eastern border of the Żywiec tectonic window.

DUKLA UNIT *SENSU LATO*

The Dukla unit has been distinguished by Z. Paul and W. Ryłko (1995) between Ślemień and Istebna. In the eastern part, between Ślemień and Żywiec, the Dukla unit is thrust over the deposits of the Silesian unit of the Little Beskid block. In the southern part of the Żywiec Basin the discussed unit together with the deposits of the upper, Grybów unit is thrust over the Cieszyn Silesian sub-unit. South of Barania Góra Mt., the Dukla unit is thrust over the deposits of the Silesian Beskid (Fig. 1).

The Dukla unit occurring at the surface is represented here by a thick complex of the Palaeogene deposits. Thick deposits of the Krosno Beds predominate. In borehole Bystra IG 1 (K. Żytko, 1978), at the depth of 2240–2890 m, there is a complex of the Krosno Beds classified by A. Tokarski (1947), K. Żytko (1978), as so-called Juraszów scale which, in turn, belongs to the Godula Silesian sub-unit. In our opinion, the discussed complex might represent the Dukla unit (Fig. 2) that is in agreement with the views of K. Żytko (1966*a*, *b*) and R. Unrug (1969) who have assigned the Juraszów scale to the Sub-Magura unit.

Deposits of the Dukla unit are likely to occur in the Sopotnia Mała tectonic window where the discussed unit is represented by the Krosno Beds. Farther to the south, the deposits of the Dukla unit detected in the logs of the boreholes in vicinity of Sól occur under the overthrust of the Grybów and Magura units.

GRYBÓW UNIT *SENSU LATO*

The authors of this paper distinguish the deposits of the Grybów unit between Gilowice and Istebna region. The unit is mainly formed by the clayey-marly deposits of the Lower Cretaceous-Palaeogene age. Owing to the character of the deposits, the unit was strongly compressed, scaled and crushed between the Dukla and the Magura units. In exposures, the Grybów unit takes a form of isolated scales and tectonic caps resting on the deposits of the

Dukla and Silesian units (Fig. 1). Moreover, it has been identified in numerous tectonic windows within in the Magura unit, e.g., in Rychwałd and Sopotnia Mała.

MAGURA UNIT

The Magura unit is the highest unit in the discussed region (Fig. 1). As it has been emphasized in the section on stratigraphy, three facial zones with defined stratigraphic profiles might be distinguished in Polish territories: Siary, Racza and Bystrica zones. As results from the detailed studies by J. Burtan, S. Sokołowski (1956), W. Sikora, K. Żytko (1960), J. Golonka, A. Wójcik (1978), W. Ryłko *et al.* (1992, 1993), W. Ryłko (1992, 1994) the contacts between the listed zones are tectonic. Following the approach of W. Sikora, K. Żytko (1960) and L. Koszarski *et al.* (1974), three sub-units might be distinguished.

The northernmost is Siary sub-unit (unit A according to W. Sikora, K. Żytko, 1960). The Magura unit, or speaking more precisely, the deposits of the Siary sub-unit are thrusted over the units of the Middle Group. An abruptly increasing width of the Siary sub-unit towards north-east is a striking feature. In the region of Milówka it reaches about 5 km while farther NE, in the region of Sopotnia Mała — ca. 6 km, and finally near Żywiec–Jeleśnia line — even 11 km.

The Racza sub-unit thrusting over the Siary sub-unit is located more to the south. Near Sól, the line of thrusting is latitudinal while farther to the east it takes a SW–NE direction and then near Sopotnia regions its primary orientation. East of Żywiec–Jeleśnia line the overthrust is again SW–NE oriented. The analysis of the width of the Siary sub-unit and of the geometrical pattern of the overthrust of the Racza sub-unit indicate that the thrusting of the latter on the Siary sub-unit is 4.5 km at Zwardoń–Milówka line, ca. 5.5 km at Milówka–Sopotnia line and ca. 10 km at Milówka–Jeleśnia line.

The Bystrica sub-unit thrusts over the Racza sub-unit. In the region of Wielka Racza–Rycerzowa Wielka, the Bystrica sub-unit is tectonically depressed when compared with its eastern part. From the region of Soblówka–Ujsoły, the sub-unit is tectonically uplifted. This uplift continues to the east towards the region of Mutne in Slovak Orava. In the discussed region, the northern border of the uplifted Bystrica sub-unit runs to the south of Pilsko Mt. Farther to the east, the Bystrica sub-unit appears (in Poland) near Glinne Pass and runs to the north (region of Korbielów). East of Korbielów the line of its overthrust follows latitudinally and between Beskid and Jaworzyna Mts. enters again Slovakia. On the eastern slopes of Jaworzyna Mt. the uplifted Bystrica sub-unit is cut off by a large transverse (NW–SW) fault along Jeleśnia–Głucha–Oravska Polhora line. In the NE side of this fault the deposits of the Bystrica sub-unit are displaced south-east by ca. 8 km, towards the region located north-east of Rabčice. Here the front of the Bystrica sub-unit is SW–NE oriented and the sub-unit runs towards the Polish boundary to the region located south of Babia Góra Mt.

Translated by Teresa Mrozek

Oddział Karpacki
Państwowego Instytutu Geologicznego
Kraków, ul. Skrzatów 1
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Zbigniew PAUL, Wojciech RYŁKO, Adam TOMAŚ

BUDOWA GEOLOGICZNA ZACHODNIEJ CZĘŚCI KARPAT POLSKICH

Streszczenie

Omawiany teren leży między Cieszynem a południkiem Suchej Beskidzkiej. Granicę zachodnią i południową stanowi granica państwa. Pod względem geomorfologicznym większość obszaru to Karpaty zewnętrzne. Północna i północno-zachodnia część terenu należy do kotlin podkarpackich. Karpaty w omawianym rejonie dzielą się na Beskidy i Pogórze.

Występują tu prekambryjsko-paleozoiczne utwory platformowe, silnie zaangażowane tektonicznie, przykryte molasowymi utworami neogeńskimi. Południową część terenu zajmują Karpaty fliszowe. W obrębie Karpat wyróżniono i opisano jednostki grupy średniej (skolską, podśląską, skałkową, śląską, dukielską i grybowską) oraz jednostkę magurską, w której wydzielono i scharakteryzowano podjednostki: Siar, raczańską i bystrzycką.

Budowa dolnych pięter przedstawiona została w ogólnym zarysie. Szerzej potraktowano stratygrafię i tektonikę piętra fliszowego. Karpaty fliszowe budują utwory jednostki skolskiej, podśląskiej, skałek andrychowskich, jednostki śląskiej, dukielskiej i grybowskiej *sensu lato* oraz magurskiej. Stratygrafię opisanych serii w skondensowanej formie przedstawia tab. 1.

Jednostka skolska występuje w brzeżnej części Karpat w rejonie Andrychowa oraz w oknach tektonicznych jednostki podśląskiej i śląskiej. W rejonie Andrychowa zaliczono do niej m.in. paleogeński flisz zewnętrzny.

Utwory **jednostki podśląskiej** występują na powierzchni w formie dwóch lub trzech nieciągłych pasów. W czasie neogeńskiej przebudowy tego obszaru nastąpiło jej zerwanie i podwojenie lub nawet potrojenie. Najbardziej zewnętrzna część jednostki podśląskiej znajduje się u czoła nasunięcia karpackiego w postaci pasa biegnącego od okolic Cieszyna po rejon Andrychowa. Bardziej wewnętrzna jej część jest rejestrowana w oknach Dzięgielowa i Ustronia, a najbardziej wewnętrzna, południowa, znalazła się u czoła jednostek dukielskiej, grybowskiej i magurskiej. Środkowy element jednostki podśląskiej można wiązać z przedłużeniem na zachód strefy lanckorońsko-żegocińskiej.

Jednostka śląska, dzięki rozwojowi ogniwa godulskiego i dysharmonijnemu sfałdowaniu się, zróżnicowała się na dwa elementy tektoniczne: dolny — podjednostkę (płaszczowinę) cieszyńską oraz górny — podjednostkę (płaszczowinę) godulską. Odkłucie, które doprowadziło do usamodzielnienia się jednostki godulskiej, odbyło się albo w obrębie górnych łupków cieszyńskich, albo nieco wyżej.

Jednostkę dukielską *sensu lato* wyróżniono między Ślemieniem a Istebną. W części wschodniej, między Ślemieniem a Żywcem jednostka ta nasuwa się na utwory jednostki śląskiej bloku Beskidu Małego, natomiast w południowej części Kotliny Żywieckiej, wraz z utworami wyższej jednostki — grybowskiej, na jednostkę śląską cieszyńską. Na południe od Baraniej Góry jednostka dukielska nasunięta jest na utwory bloku Beskidu Śląskiego. Jednostka dukielska, występująca na powierzchni, jest reprezentowana przez miąższy kompleks utworów paleogenu. Dominują w nim dużej miąższości utwory warstw krośnieńskich.

Utwory **jednostki grybowskiej** *sensu lato* wydzielono między Gilowicami a rejonem Istebnej. Zbudowana jest w przewadze z utworów ilasto-marglistych dolnokredowo-paleogeńskich. Ze względu na charakter osadów jednostka ta została silnie sprasowana, złuskowana i roztarta między jednostką dukielską i magurską. W odsłonięciach powierzniowych występuje ona w formie izolowanych łusek i czapek tektonicznych leżących na utworach

jednostki dukielskiej i śląskiej. Stwierdzono ją również w licznych oknach tektonicznych w obrębie jednostki magurskiej, np. w Rychwałdzie i w Sopotni Małej.

Jednostka magurska jest najwyższą jednostką omawianego rejonu. Rozdziela się ona na trzy podjednostki. Najbardziej północną jest podjednostka Siar, która nasuwa się na jednostki grupy średniej. W przebiegu podjednostki Siar uderza szybki wzrost szerokości tej strefy w kierunku SW i NE. Analiza szerokości podjednostki Siar i geometrycznego obrazu linii nasunięcia podjednostki raczańskiej wskazuje, że nasunięcie tej ostatniej na strefę Siar wynosi na linii Zwardoń–Milówka około 4,5 km, na linii Milówka–Sopotnia około 5,5 km, a na linii Milówka–Jeleśnia nawet około 10 km. Najbardziej południową podjednostką, ostatnią w granicach państwa, jest podjednostka bystrzycka nasuwająca się na podjednostkę raczańską. W rejonie Wielkiej Raczy–Rycerzowej Wielkiej podjednostka bystrzycka jest obniżona tektonicznie w stosunku do części wschodniej. Od rejonu Soblówki–Ujsołów rozpoczyna się jej tektoniczne wyniesienie, które kontynuuje się ku wschodowi po rejon Mutnego na Słowackiej Orawie.