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The contact between the Pieniny Klippen Belt and Magura Unit (the Małe Pieniny Mts.)

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The fold-and-thrust tectonic stage in the Pieniny Klippen Belt commenced at the Cretaceous–Tertiary boundary (late sub-Hercynian phase) and resulted in the formation of a series of tectonic units. In the Jaworki region these are: the Branisko and Niedzica Nappes, Czertezik and Czorsztyn Units (the last-mentioned unit is considered to be autochthonous). According to previous views, the tectonic stage associated with the Laramian phase (Palaeocene) which followed later, resulted in folding of the peri-klippen parts of the Magura Basin, their "retro-arc thrusting" over the Pieniny Klippen Belt and formation of the Grajcarek Unit. However, during the present studies, no evidence of a rearrangement of tectonic pattern which could be related to retro-arc thrusting, has been recorded. Instead, a possibility of progressive thrusting of the klippen units over the Magura forefield and the Czorsztyn Unit which already lost its autochthonous position, is considered. Consequently: (1) the thrust-nappe folding should be prolonged in time from Maastrichtian until Middle Palaeocene times, (2) the position of the Grajcarek Unit within the Pieniny Klippen Belt should be recognized as tectonic windows of the Magura Unit (but not as tectonic caps of the Magura Unit, back-thrusted and chocked in tectonic grabens) and, (3) the Grajcarek Unit in the peri-klippen part should be included into the Magura Unit, distinguishing, at most, a near-contact deformation zone. The result is that the boundary of the Pieniny Klippen Belt has been shifted southwards, i.e. from the contact between the Grajcarek and Magura Units to the contact between the klippen units and the Grajcarek Unit. In the Jaworki region, the Homole and Biała Woda Blocks must be considered a tectonic cap of the klippen units resting upon the Magura Unit. The Repowa Fault has been described as a new structural element related to the Carpathian arc-like bending.

INTRODUCTION

Tectonic position of the Grajcarek Unit has been determined by K. Birkenmajer (1965). A discussion on the age and affiliation of the deposits included into the Grajcarek Unit is given in K. Birkenmajer, O. Pazdro (1968). A thorough description of lithostratigraphic formations is presented in K. Birkenmajer's (1977). Completely different views on the age of folding and of some deposits is given in W. Sikora (1962*a*, *b*, 1971) and J. Morgiel, W. Sikora (1972, 1973).

According to K. Birkenmajer (1965, 1970, 1979, 1985), the Grajcarek Unit is the near-Pieniny part of the Magura Basin (Aalenian–Middle Palaeocene). Its lithology is similar to that of the Branisko and Pieniny series of the Klippen Basin. During the Laramian folding phase (Palaeocene) it was back-thrusted over the Pieniny Klippen Belt which was formed as early as during the late sub-Hercynian thrust-nappe folding. So, it is facially related to the Magura Basin, and tectonically — to the Pieniny Klippen Belt. The assumption of backward thrusting of the Grajcarek Unit in order to elucidate the existence of deposits originated from the Magura Basin, was a consequence of considering the Czorsztyn Unit, resting upon an older, maybe crystalline basement, to be autochthonous at the thrust-nappe folding stage (K. Birkenmajer, 1979, 1985).

The youngest deposits in the Grajcarek Unit are called the Jarmuta Formation. In the peri-klippen zone it is of a molasse character (cliff breccia). It passes northwards into flysch deposits (K. Birkenmajer, 1970, 1979). This formation evidences folding processes leading to a nappe structure of the Pieniny Klippen Belt. The initially assumed age of the Jarmuta Formation (Upper Campanian–Maastrichtian — K. Birkenmajer, 1970; K. Birkenmajer, O. Pazdro, 1968) has been extended in recent papers as late as the Middle Palaeocene, inclusive (K. Birkenmajer *et al.*, 1987*b*). This, together with mesostructural studies in the Jaworki region, permit to assume

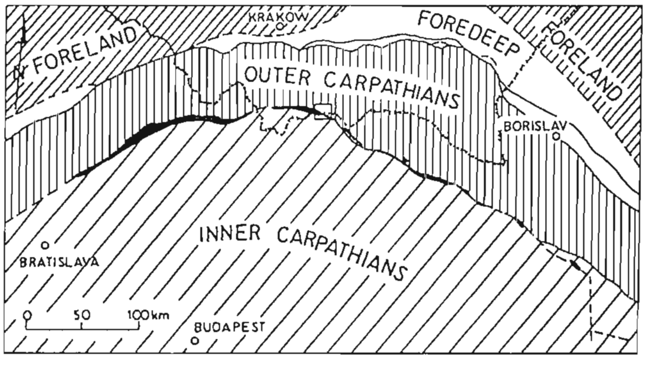


Fig. 1. Geological position of the investigated area (rectangle) in the Pieniny Klippen Belt (black), Western Carpathians

Położenie badanego obszaru (prostokąt) w obrębie pienińskiego pasa skałkowego (czarne), Karpaty Zachodnie

that the Laramian folding was a continuation of the Upper Cretaceous one, showing the same tectonic setting.

The area studied is situated in the Jaworki region in the eastern part of the Polish sector of the Pieniny Klippen Belt (Fig. 1). It comprises northern slopes of the Małe Pieniny Mts. and southern slopes of the Radziejowa Range. In this area, the Grajcarek Unit forms an eastward narrowing series of outcrops located between the klippen units and the Magura Unit (Figs. 1, 2) with flysch deposits being predominant and belonging in the north to the Jarmuta Formation and in the south to the Szlachtowa Formation. In the western part, between Szlachtowa and Jaworki villages, the Grajcarek Unit adjoins from the south the Czorsztyn Unit, between Jaworki village and the outlet of the Biała Woda Gorge — the Niedzica Unit, and in the Biała Woda Gorge — the Czorsztyn Unit again. East of Brysztan, the Grajcarek Unit adjoins, from both the north and south, the Magura Palaeogene (K. Birkenmajer, 1979).

In this part of the Pieniny Klippen Belt, there are also a few patches of the Grajcarek Unit located within the klippen units. These patches are even about 2 km away from the northern boundary of these units (K. Birkenmajer, 1970, 1979). Within the Klippen Belt the Grajcarek Unit is exposed mainly in stream floors of, among others, Krupianka, Koniowski and Skalski streams, left tributary of the Biała Woda stream at Repowa as well as at the Biała Woda spring at Brysztan (Fig. 2).

MESOSTRUCTURAL FEATURES OF THE GRAJCAREK UNIT

Tectonic style of the Grajcarek Unit slightly differs from that of the klippen units. It largely results from different lithologies (400–800 m of shaly flysch deposits in relation to 25–35 m of limestones and cherts — K. Birkenmajer, 1977). Within the Grajcarek Unit, there is a differentiation in character and intensity of tectonic deformations depending on locality. The area located north of the klippen units differs from the sites situated within the Pieniny Klippen Belt.

THE AREA LOCATED NORTH OF THE KLIPPEN UNITS

Predominance of shale-flysch deposits caused the area to have been more liable to folding and more poorly exposed compared with the klippen units. Strata show steep, frequently vertical dips (Fig. 3a,). They strike similarly to that observed in the Niedzica Unit (see Fig. 3a, k). Slightly higher scatter of strike measurements in vertical strata is associated with sigmoidal fault drags induced by numerous transversal faults interpreted by K. Birkenmajer (1985) to have originated during the Styrian phase. Most of the stream valley exposures are located along these faults. Folds are rare in the outcrops (Fig. 4A, B) but they are well legible in maps (K. Birkenmajer, 1956, 1957).

Fractures display a certain regularity in the Szlachtowa Formation flysch and Jarmuta Formation sandstones, whereas in conglomeratic members of the latter they are non-measurable. Non-systematic fractures, like in other units of the Pieniny Klippen Belt, are predominant (E. Jurewicz, 1994). Best visible, in both the field and diagram (Fig. 3b) — owing to fracture width and calcite mineralization — of transversal-extensional fractures is a series.

Fault deformations are common (Figs. 3c and 4C, D, E). Faults are usually steep. Their surfaces are flat and smooth, indicating a nonductile deformation character. Strike-slip and oblique slip faults are predominant. Their features and orientation show that they originated in younger tectonic phases (one of the sets of the Styrian phase transversal faults — K. Birkenmajer, 1985).

SITES LOCATED WITHIN THE PIENINY KLIPPEN BELT

Compared with the previously described area, the intensity of tectonic deformations is much stronger here. They are also of a more ductile character. Strata are strongly folded, and continuous deformations are always accompanied by small faults and thrusts giving a boudinage character to the rocks (Fig. 4G). Southward dipping strata are the most common (Fig. 3d). Their strike does not differ from that measured in both the klippen units (see Fig. 3d, g and k) and Grajcarek Unit in the area located north of the Pieniny Klippen Belt (Fig. 3a).

In this area, fractures are of a non-systematic character showing traces of secondary deformations. These are related to a ductile character of deformations at a thrust-nappe folding stage (E. Jurewicz, 1994). Fractures of smooth and flat surfaces have been measured in the field. The attitude of fractures shown in the diagram (Fig. 3e) proves neither a cathetal relationship to strata nor their vertical positions. This may

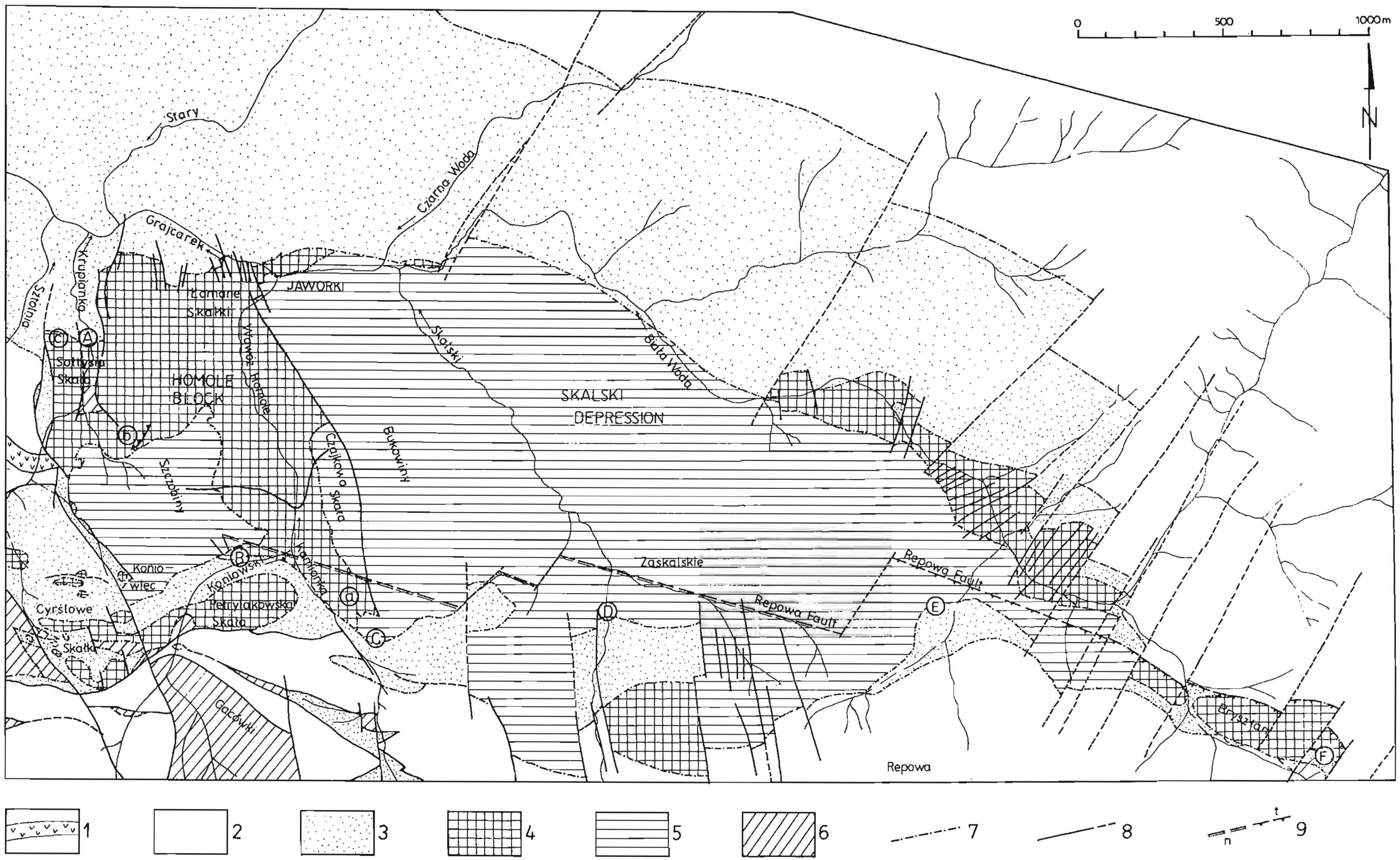
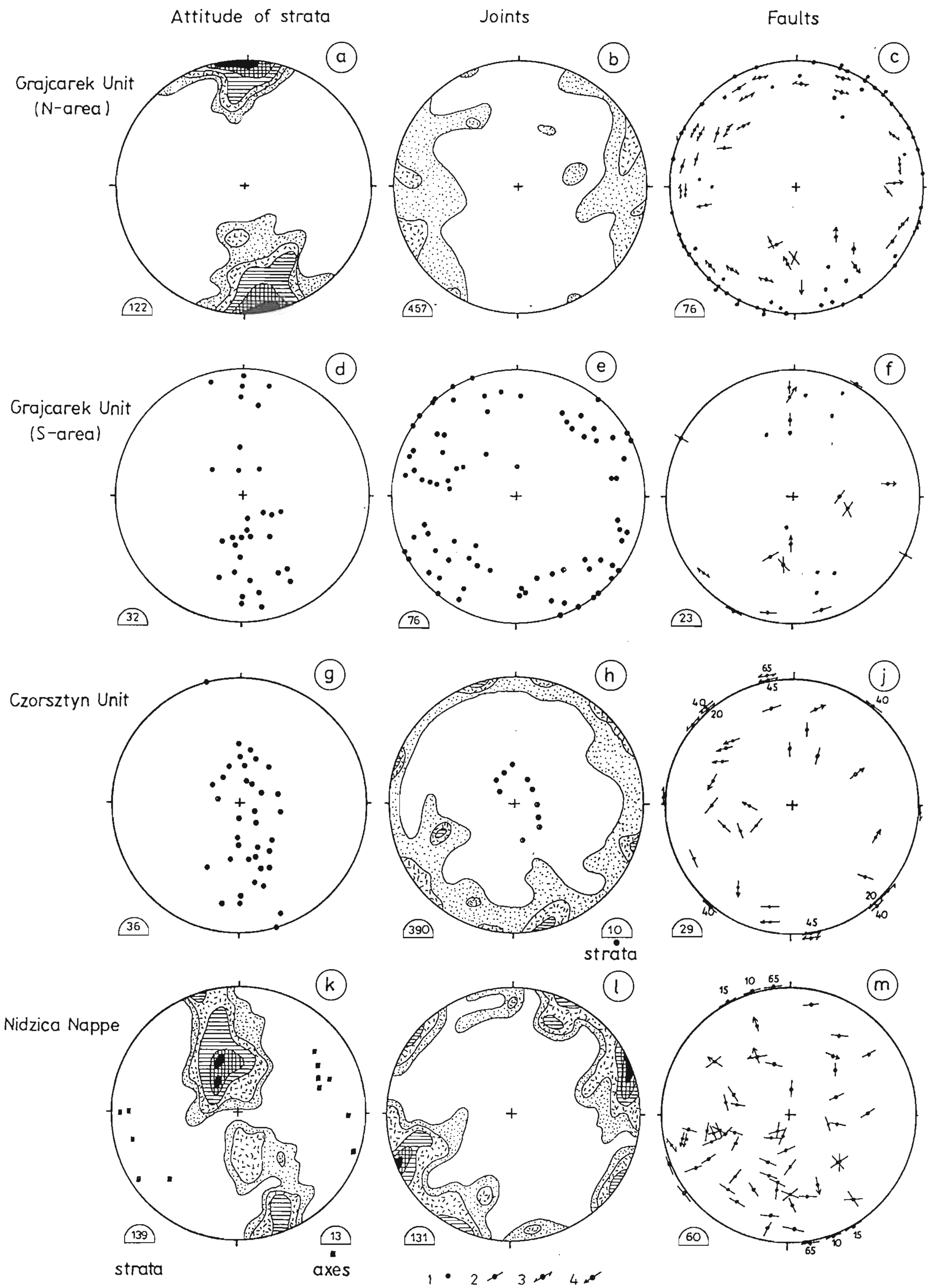


Fig. 2. Tectonic structure of the Pieniny Klippen Belt near Jaworki (after K. Birkenmajer, 1970, 1979, completed with Repowa Fault)
1 — Miocene andesite intrusion; 2 — autochthonous Magura Palaeogene; 3 — Grajcarek Unit; 4 — Czorsztyn Unit; 5 — Niedzica Nappe; 6 — Branisko Nappe; 7 — boundaries of tectonic units; 8 — faults; 9 — Repowa Fault (n — normal fault, t — overthrust); A–F — position of cross-sections in Fig. 6; a–c — position of lithostratigraphic columns in Fig. 7

Szkic tektoniczny okolic Jaworek (według K. Birkenmajera, 1970, 1979, uzupełniony o uskok Repowej)
1 — andezyty; 2 — autochtoniczny paleogen magurski; 3 — jednostka Grajcarka; 4 — jednostka czorsztyńska; 5 — płaszczowina niedzicka, 6 — płaszczowina braniska; 7 — granice jednostek tektonicznych; 8 — uskoki; 9 — uskok Repowej (n — uskok normalny, t — nasunięcie); A–F — lokalizacja przekrojów z fig. 6; a–c — lokalizacja profili z fig. 7



Attitude of strata
Joints
Faults
Grajcarek Unit (N-area)
Grajcarek Unit (S-area)
Czorsztyn Unit
Nidzica Nappe
a
b
c
d
e
f
g
h
j
k
l
m
122
457
76
32
76
23
36
390
10
strata
29
139
13
strata
axes
131
60
1
2
3
4

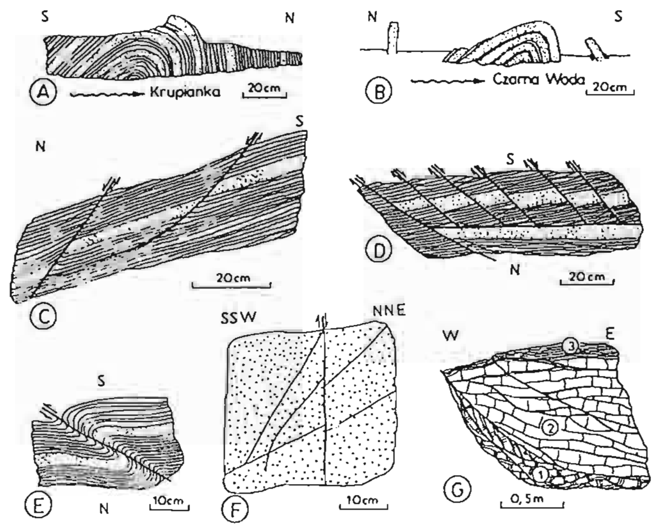


Fig. 4. Folds, fractures and faults in the Grajcarek Unit in the area located north of the klippen units (A–F) and in sites within the Pieniny Klippen Belt (G)

A, B — folds in the Szlachtowa Formation; C — homothetic faults, Szlachtowa Formation (Krupianka stream); D — small strike-slip faults associated with intrastratal fault, Szlachtowa Formation (view from above); E —fault-related deformations in vertical strata, Szlachtowa Formation (right side of the Grajcarek stream in Jaworki, view from above); F — fractures in sandstone, Jarmuta Formation; G — exposure of the Grajcarek Unit near Brysztan (formations: 1 — Czajakowa Radiolarite, 2 — Pieniny Limestone, 3 — Kapuśnica)

Deformacje fałdowe, spękania i uskoki w jednostce Grajcarka w obszarze położonym na północ od jednostek skałkowych (A–F) i wewnątrz pienińskiego pasa skałkowego (G)

A, B — fałdy, formacja szlachtowska; C — uskoki homotetyczne, formacja szlachtowska; D — drobne uskoki przesuwcze towarzyszące uskokowi międzyławicowemu, formacja szlachtowska (widok z góry); E — przyuskokowe deformacje w pionowo ustawionych ławicach, formacja szlachtowska (widok z góry); F — spękania na powierzchni ławicy piaskowca, formacja jarmucka; G — odsłonięcie jednostki Grajcarka pod Brysztanem (formacje: 1 — radiolarytów z Czajakowej, 2 — wapienia pienińskiego, 3 — z Kapuśnicy)

indicate that either they were formed under relatively high overburden pressure being loaded by the thrusting klippen units or they were deformed at later stages of tectonic deformations.

Ductile faults are predominant, i. e. faults of morphologically diversified surfaces and fading out by folds and flexures. Intrastratal glides and faults, oblique in relation to strata, are frequent causing the strata to be pinched out and resulting in boudinage (Fig. 4G). Tectonically brecciated zones, mineralized with calcite, rarely pyrite, are common. Calcite sometimes predominates by mass upon a parent rock, cementing its small pieces. In spite of considerable number of faults, most of them is non-measurable due to their irregular trends. Fault extents do not usually exceed 1 m and their throw amounts to centimetres. These faults are oriented (Fig. 3f) similarly to those occurring in the klippen units (Fig. 3j, m).

TECTONIC POSITION OF THE GRAJCAREK UNIT

The first folding of a thrust-nappe character commenced in the Pieniny Basin during the Late Cretaceous. In the Magura Basin, adjoining in the north, it induced the appearance of molasse deposits — the Jarmuta Formation (K. Birkenmajer, 1965, 1970, 1979, 1986). The Jarmuta Formation — the youngest deposits of the Grajcarek Unit — is composed of sediments originated from the eroded klippen units, thrusted one over another. Erosion undoubtedly preceded the thrusting of the Niedzica Nappe over the Czorsztyn Unit since, in the latter, there is lack of the youngest lithostratigraphic members (K. Birkenmajer, 1963, 1970, 1979) whereas in other regions of the Pieniny Klippen Belt, the Jarmuta Formation was deposited also upon the klippen units after a short sedimentary break, and shows a older mantle character (K. Birkenmajer, 1979, 1985, 1986). Such a situation can be observed about 8 km west of Jaworki along the Dunajec Fault in the vicinity of Krościenko (K. Birkenmajer, 1979).

In the southern part of the Magura Basin (in the peri-klippen zone), the Jarmuta Formation was deposited upon older stratigraphic members. It is of a molasse character there (cliff breccia with olistoliths, wild flysch), whereas to the north it passes into flysch deposits (Inoceramian Beds — Ropianka Formation) overlying in a sedimentary continuity older series — the Malinowa Shales Formation (K. Birkenmajer, O. Pazdro, 1968; S. W. Alexandrowicz, J. Kutyba, 1979; K. Birkenmajer, 1977; K. Birkenmajer, N. Oszczypko, 1989). Its thickness increases from the south toward the north from 10–50 m up to about 50–450 m (K. Birkenmajer, 1977). The sedimentation of the Jarmuta Formation came to the end in the Middle Palaeocene (Np-5 nannoplankton zone — K.

Fig. 3. Attitude of strata, joints and faults in the Niedzica Nappe, Czorsztyn Unit and Grajcarek Unit

Normals to surfaces, upper hemisphere; numbers in half-circles — number of observation; isolines: 1, 2, 3, 5, 7%; 1 — normal to tectonic mirror; 2 — azimuth of striations; 3 — sense of strike-slip movement; 4 — sense of upper limb movement

Diagramy położenia warstw, spękań i uskoków dla jednostki Grajcarka, jednostki czorsztyńskiej i płaszczowiny niedzickiej

Odwzorowanie biegunów płaszczyzn na górną półkulę; liczba w półokręgu — liczba pomiarów; izolinie: 1, 2, 3, 5, 7%; 1 — biegun lustra tektonicznego; 2 — azymut rys ślizgowych; 3 — zwrot ruchu przesuwczego; 4 — zwrot ruchu górnego skrzydła

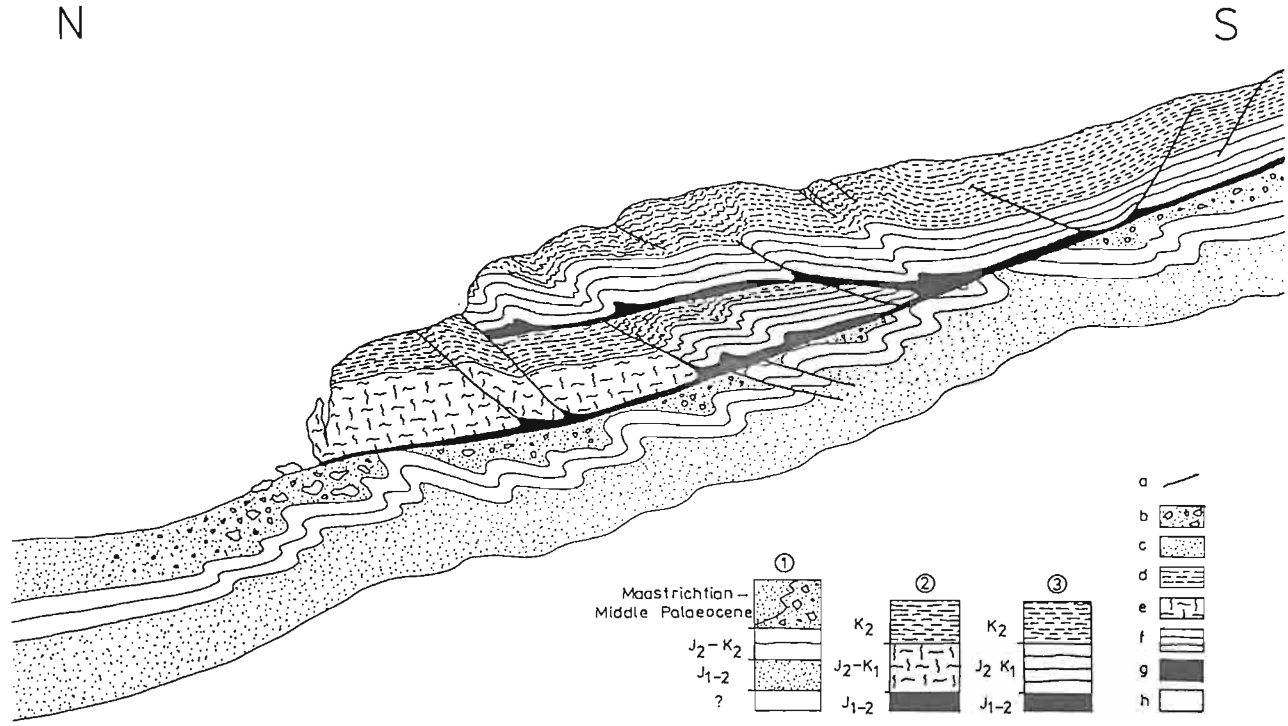


Fig. 5. Model of the last phase of Maastrichtian–Middle Paleocene nappe thrusting near Jaworki

1 — Magura Unit, 2 — Czorsztyn Unit, 3 — Niedzica Nappe; a — faults, b — conglomerates, c — sandstones, d — marls, e — massive limestones, f — bedded limestones and radiolarites, g — clay shales, h — older basement

Schemat nasunięć płaszczowinowych (mastrycht–paleocen środkowy) w rejonie Jaworek

1 — jednostka magurska, 2 — jednostka czorsztyńska, 3 — płaszczowina niedzicka; a — uskoki, b — zlepieńce, c — piaskowce, d — margle, e — wapienie masywne, f — wapienie ławicowe i radiolaryty, g — łupki, h — starsze podłoże

Birkenmajer *et al.*, 1987*b*), whereas the overlying Szczawnica Formation started to be deposited at the turn of the Middle and Upper Palaeocene (Np-7 nannoplankton zone — K. Birkenmajer, J. Dudziak, 1981). If the Grajcarek Unit had been thrusted from the north, so the timing of this event should have been related to that short sedimentary break at the boundary between the Jarmuta and Szczawnica Formations, i. e. between zones Np-5 and Np-7.

The Upper Cretaceous folding proceeded from the south toward the north embracing zones of younger and younger deposits: Coniacian–Lower Santonian — Klapska Unit, Santonian–Campanian — Pieniny and Branisko–Kýsuca Units, Campanian–Maastrichtian — Niedzica Nappe in the vicinity of Jaworki village (E. Schneibner, 1968; K. Birkenmajer, 1970, 1974). So, it is possible that in the Palaeocene, folding processes reached as far as the southern part of the Magura Basin, and the klippen units might have been gravity flowed northwards at that time, making the Magura deposits be folded at their base and in the forefield (Fig. 5; see fig. 95C in: K. Birkenmajer, 1979). This interpretation is supported by the following facts:

— similarity of tectonic pattern of the Grajcarek Unit to the Czorsztyn and Niedzica Nappe, especially clearly visible in the diagrams of attitude of strata (Fig. 3a, d, g and k);

— subdivision of the Grajcarek Unit, in respect of a character of small structures, into a part located within the Klippen Belt and along its northern boundary (Fig. 4C, D);

— all the exposures of the Grajcarek Unit within the Pieniny Klippen Belt are located in stream floors below the oldest deposits of the Czorsztyn or Niedzica Nappe (Fig. 6).

Against the retro-arc thrusting hypothesis advanced by K. Birkenmajer (1970, 1979, 1986) are the following facts:

— shortening of the time span, during which the backward thrusting might have been occurred, to only one undocumented nannoplankton zone — Np-6 (K. Birkenmajer *et al.*, 1987*b*);

— not only the youngest Magura Basin deposits were thrusted over the Pieniny Klippen Belt, but also those as old as the Aalenian, inclusive, i.e. the oldest ones known in this area;

— much stronger tectonic deformations in sites of the Grajcarek Unit situated within the klippen units (folded under the klippen units overburden) than in those located north of them (deformed in the forefield of thrusting nappes) and than the deformations of the klippen units (as the youngest and highest unit it would be poorly deformed).

The studies over the Czorsztyn Unit also show the possibility that the klippen units were thrusted over the Magura forefield. K. Birkenmajer (1970, 1971, 1979, 1985) have considered the Czorsztyn Unit at a thrusting stage to be autochthonous, resting in the Jaworki region upon the older crystalline basement which made the unit be rigid and protected from later deformations. This rigidity must have already been marked during the sedimentation. However, the following observations speak against the autochthonous position of the Czorsztyn Unit :

1. Within the Homole Block, considered a relative tectonic monolith, there are serious differences in stratigraphical sections (Fig. 7). So, this area showed a considerable mobility already during the sedimentation. In the vicinity of the Szczobiny quarry (Fig. 7a), a sedimentary contact between white crinoid limestones (Smolegowa Limestone Formation — Bajocian) and green-black shales representing, according

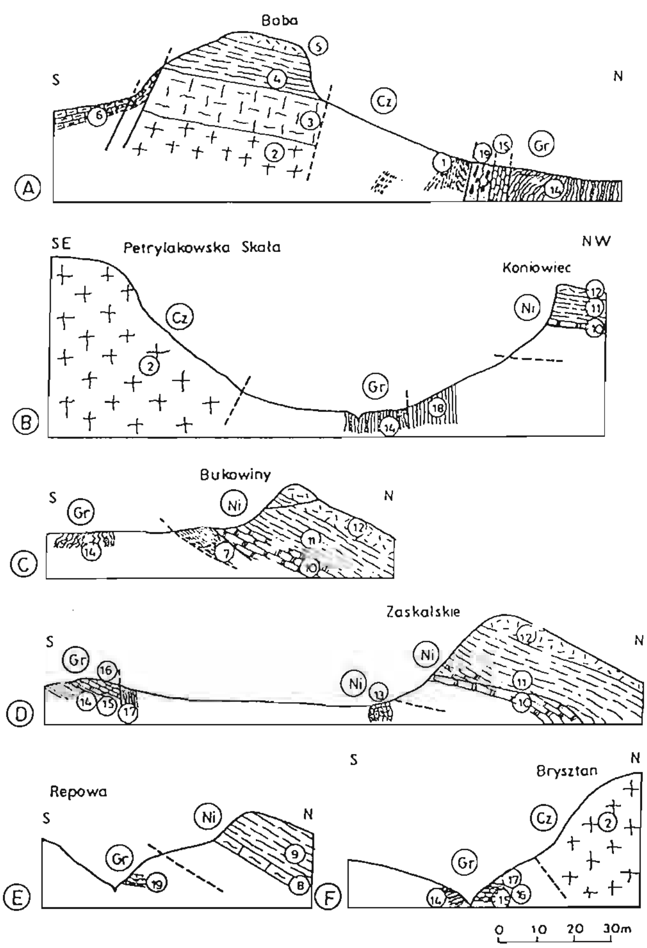


Fig. 6. Types of contacts of the Grajcarek Unit with klippen units (A, B — after K. Birkenmajer, 1963, 1970; location in Fig. 2)

Czorsztyn Unit (Cz), formations: 1 — Skrzypne Shale, 2 — Smolegowa Limestone, 3 — Krupianka Limestone, 4 — Czorsztyn Limestone, 5 — Dursztyn Limestone, 6 — Pomiedznik; **Niedzica Nappe (Ni)**, formations: 7 — Skrzypne Shale, 8 — Krupianka Limestone, 9 — Niedzica Limestone, 10 — Czajakowa Radiolarite, 11 — Czorsztyn Limestone, 12 — Dursztyn Limestone, 13 — Kapuśnica; **Grajcarek Unit (Gr)**, formations: 14 — Szlachtowa, 15 — Czajakowa Radiolarite, 16 — Pieniny Limestone, 17 — Kapuśnica, 18 — Malinowa Shale, 19 — Jarmuta

Szkice kontaktów tektonicznych jednostek skałkowych z jednostką Grajcarka (A, B — według K. Birkenmajera, 1963, 1970; lokalizacja na fig. 2)

Jednostka czorsztyńska (Cz), formacje: 1 — łupków ze Skrzypnego, 2 — wapienia ze Smolegowej, 3 — wapienia z Krupianki, 4 — wapienia czorsztyńskiego, 5 — wapieni dursztyńskich, 6 — z Pomiedznika; **płaszczowina niedzicka (Ni)**, formacje: 7 — łupków ze Skrzypnego, 8 — wapienia z Krupianki, 9 — wapienia niedzickiego, 10 — radiolarytów z Czajakowej, 11 — wapienia czorsztyńskiego, 12 — wapieni dursztyńskich, 13 — z Kapuśnicy; **jednostka Grajcarka (Gr)**, formacje: 14 — szlachtowska, 15 — radiolarytów z Czajakowej, 16 — wapienia pienińskiego, 17 — z Kapuśnicy, 18 — łupków z Malinowej, 19 — jarmucka

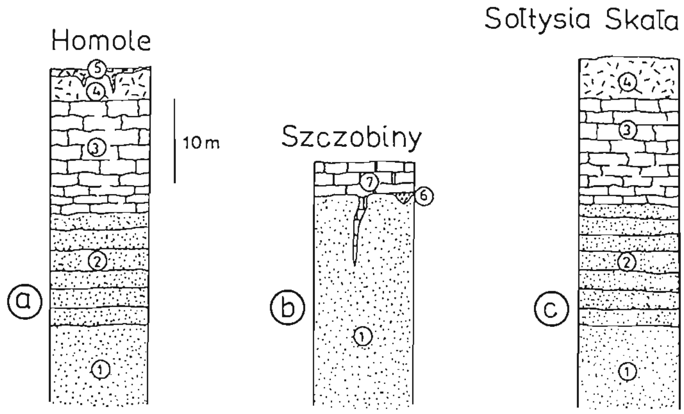


Fig. 7. Litostratigraphical columns of Czorsztyn Unit in the Homole Block (location in Fig. 2)

Formations: 1 — Smolegowa Limestone, 2 — Krupianka Limestone, 3 — Czorsztyn Limestone, 4 — Dursztyn Limestone, 5 — Spisz Limestone, 6 — Chmielowa, 7 — Pomiedznik

Profile stratygraficzne jednostki czorsztyńskiej z bloku Homoli (lokalizacja na fig. 2)

Formacje: 1 — wapienia ze Smolegowej, 2 — wapienia z Krupianki, 3 — wapienia czorsztyńskiego, 4 — wapieni dursztyńskich, 5 — wapienia spiskiego, 6 — z Chmielowej, 7 — z Pomiedznika

to lithology, the Albian Pomiedznik Formation (K. Birkenmajer, pers. comm.; micropalaeontological analysis in progress) have been discovered. So, there would be a gap comprising Upper Jurassic and Lower Cretaceous times. About 300 m to the west, on the Sołtysia Skała within the Homole Block (Fig. 7c), the following formations occur above the Smolegowa Limestone Formation: the Krupianka Limestone Formation, Czorsztyn Limestone Formation and Dursztyn Limestone Formation (K. Birkenmajer, 1970, 1979). So, there is a sedimentary continuity until the Barremian. About 700 m to the east, in the Homole Gorge (Fig. 7a), there are also the Spisz Limestone overlying the Dursztyn Limestone Formation. Its Hauterivian age has been determined by M. Obermajer on the basis of foraminifers — *Colomisphaera gigantea* (Borza) and *C. heliosphaera* (Vogler) — see K. Borza (1984), K. Obermajer (1986). In this site as well as in the Szczobiny quarry, neptunic veins have been discovered. All these facts indicate that the so-called Homole Block did not act as a block during sedimentation.

2. Limestone series of the Czorsztyn Unit, about 150–300 m thick, giving a plated character to it, were underlain by ductile deposits (Krempachy Marl Formation and Skrzypne Shale Formation, 20–50 m thick), so they might not have been united with the older basement. Therefore, it is most likely that they were detached and pushed northwards by the thrusting nappe units.

3. Numerous intrastratal faults with striae and steps oriented like those in the Niedzica Nappe, are indicative of tectonic transport within the Czorsztyn Unit. Numerous ductile faults, tectonic reductions and drag structures (E. Jurewicz, 1994) typical of gravity sliding tectonics (see A. Price, 1973; J. G. Ramsay, 1981), have also been observed.

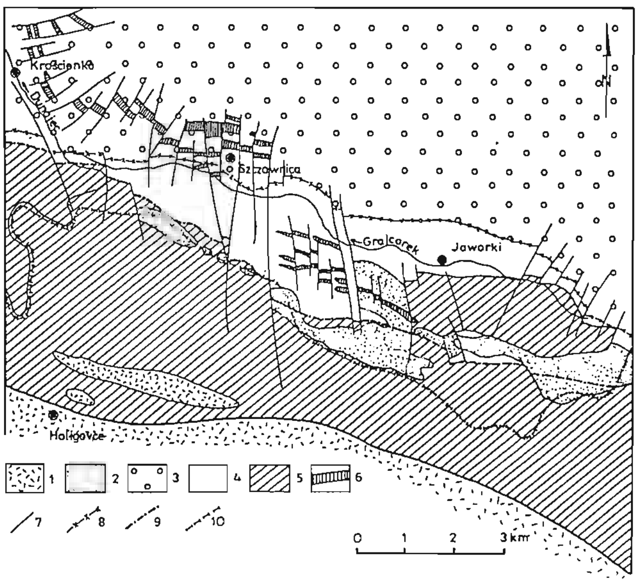


Fig. 8. Position of the Pieniny Klippen Belt (within Grajcarek Unit) between Podhale Trough and Magura Unit near Jaworki, after K. Birkenmajer (1979), and northern boundary of the Pieniny Klippen Belt after the present author

1 — autochthonous Podhale Palaeogene; 2 — autochthonous Magura Palaeogene; 3 — Magura Unit; 4 — Grajcarek Unit; 5 — klippen units; 6 — andesites; 7 — faults; 8 — northern boundary of the Pieniny Klippen Belt after K. Birkenmajer (1979); 9 — northern boundary of the Pieniny Klippen Belt after the present author; 10 — state border

Pozycja pienińskiego pasa skałkowego (z jednostką Grajcarka) między niecką podhalańską i jednostką magurską w rejonie Jaworek według K. Birkenmajera (1979) oraz proponowana przez autorkę północna granica pienińskiego pasa skałkowego

1 — autochtoniczny paleogen podhalański; 2 — autochtoniczny paleogen magurski; 3 — jednostka magurska; 4 — jednostka Grajcarka; 5 — jednostki skałkowe; 6 — andezyty; 7 — uskoki; 8 — północna granica pasa skałkowego według K. Birkenmajera (1979); 9 — północna granica pienińskiego pasa skałkowego według autorki; 10 — granica państwa

4. A gravity sliding character of the thrusts (E. Jurewicz, 1994) might have caused the Czorsztyn Unit to be fractured into blocks which were pushed and dragged by the down-slipping nappes. Therefore, the Czorsztyn Unit need not form a uniform cover under the overlying units, for example within the so-called Skalski Depression, where both in the south in Zaskalskie (Figs. 2, 6D) and in the north, the Grajcarek Unit seems to lie immediately below the Niedzica Nappe.

5. During thrusting of the nappe units, the Czorsztyn Unit was bordered in the north by the deep, flysch Magura Basin, which was being filled up with sediments shed from the eroded cliff composed of the klippen units (K. Birkenmajer, 1970, 1979). Such morphology might have enabled the Czorsztyn Unit to be slipped down to the north.

6. A gravity sliding character of the thrust-nappe folding in the Małe Pieniny Mts. seems to exclude the possibility of backward thrusting without changes in palaeomorphology. Such changes must have been reflected in a sedimentation process, both in the adjoining Magura Basin and in the Pieniny Klippen Belt.

7. The lack of a transition zone between the Czorsztyn and Magura Basins proves a considerable tectonic shortening there.

Basing upon the above-mentioned considerations it is probable that the klippen units which started to be folded during the Upper Cretaceous, in the Palaeocene were thrusted over their forefield, causing it to be partially folded. Isolating the Grajcarek Unit out of the Magura Unit is unjustified because its recently assumed northern boundary is, in fact, a stratigraphic boundary: this is a sedimentary contact between the Jarmuta and Szczawnica Formations, related to a gap between the nannoplankton zones Np-5 and Np-7. This boundary cannot be traced in the field because it is accompanied by neither tectonic deformations nor changes in deposits. It is evidenced only by micropalaeontological studies. The boundary runs somewhere across the southern slopes of the Radziejowa Range and was thought to correspond to the boundary between two geological macroregions. Along this boundary, a clockwise rotation of the Inner Carpathians in relation to the Outer Carpathians, is believed to have been occurred. Acocrding to the present author this boundary should be drawn along the contact between the klippen units and Magura Unit. In the Małe Pieniny Mts., the Homole and Biała Woda Blocks do not structurally belong to the Pieniny Klippen Belt, but is a tectonic cap resting upon the Magura Unit (Fig. 8). This could be an explanation why the early Tertiary tectonic movements were not so strongly pronounced in the Jaworki region (particularly in the Homole Block) as they were in other parts of the Pieniny Klippen Belt, where, owing to compression, reverse overturns took place, e.g. in the Krościenko region west of the Dunajec Fault (K. Birkenmajer, 1979).

THE REPOWA FAULT AND THE TECTONIC POSITION OF THE BRYSZTAN ROCK

The position of the Brysztan rock, belonging to the Czorsztyn Unit and resting upon Eocene deposits (Szczawnica Formation) in the north, and upon older series of the Grajcarek Unit in the south (K. Birkenmajer, 1979), should be explained separately. It seems that in this case, thrusting of the Czorsztyn Unit over the Magura Unit (during the Savian phase) was associated with bending of the Carpathian arc. The Savian phase was of a compressional character and was related to a continent-continent collision, which took place between the North-European Platform and Central-Carpathian–Panonian micro-continent (K. Birkenmajer, 1976, 1986; B. C. Burchfiel, 1980; T. Pescatore, A. Ślączka, 1984; N. Oszczypko, A. Ślączka, 1989). Folding of the Palaeogene cover and formation of a series of parallel longitudinal faults bordering, among others, the Pieniny Klippen Belt, are related to that phase. Along these faults the Carpathian arc was curved and the Central-Carpathian Block was subjected to a clockwise rotation in the late Savian phase (Lower Miocene) (K.

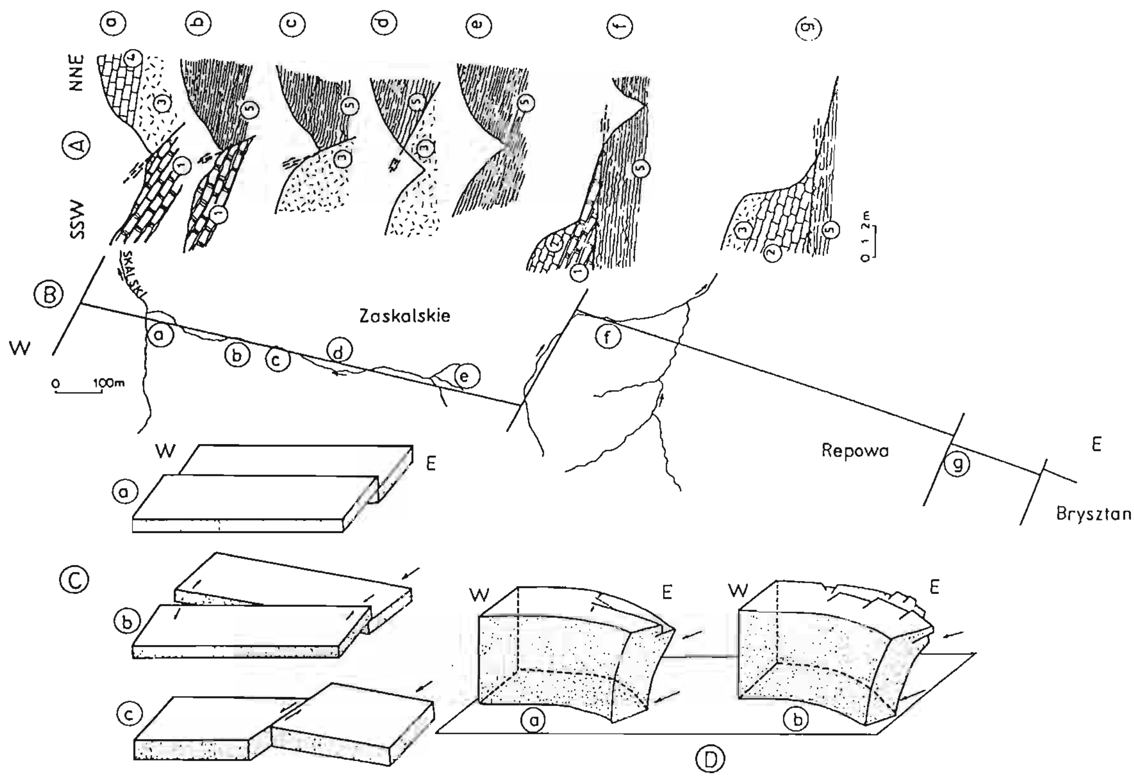


Fig. 9. Transversal geological cross-sections trough the Repowa Fault (A), their location (B) and model of formation of the Repowa Fault and younger transversal faults connected with unductile curving of the Pieniny Klippen Belt (C: a–c; D: a, b)
Niedzica Nappe, formations: 1 — Czajakowa Radiolarite; 2 — Czorsztyn Limestone; 3 — Dursztyn Limestone; 4 — Kapuśnica; 5 — Jaworki Marl

Przekroje poprzeczne przez uskok Repowej (A), ich lokalizacja (B) oraz schemat powstania uskoku Repowej i młodszych od niego uskoków poprzecznych związanych z niepodatnym wyginaniem pienińskiego pasa skałkowego (C: a–c; D: a, b)
Płaszczowina niedzicka, formacje: 1 — radiolarytów z Czajakowej, 2 — wapienia czorsztyńskiego, 3 — wapieni dursztyńskich, 4 — z Kapuśnicy, 5 — margli z Jaworek

Birkenmajer, 1976, 1985, 1986; M. Krs, Z. Roth, 1977; M. L. Baženov *et al.*, 1980; L. H. Royden *et al.*, 1982; N. Oszczypko, A. Tomaś, 1985).

The Brysztan rock is located on the Repowa Fault (Figs. 2, 8), about 4 km long, which is parallel to the belt. In the eastern part, the southern wall of the fault was thrusted over the northern one, whereas in its western part both its walls were drawn aside (E. Jurewicz, 1994). So, in the western part, this fault is normal with a throw gradually decreasing eastwards, and farther on it grades into a reverse fault with increasing net slip. In the western part of the Repowa Fault, there is a contact between the Niedzica Nappe and Grajcarek Unit, farther east — between two scales of the Niedzica Nappe, farther still — between the Niedzica Nappe and Czorsztyn Unit, and in the eastern extreme — between the Czorsztyn Unit and Grajcarek and Magura Units. This fault dies out westwards in the region of the Homole Block, but there is an andesite dike of the Savian phase age on its prolongation (K. Birkenmajer *et al.*, 1987*a*). The Brysztan rock, situated in a place where this fault reaches its maximum amplitude i.e. on its eastern extreme, was thrusted directly over the Eocene deposits of the Magura Unit. So, the Repowa Fault is trending obliquely to the older structures (although it partly follows them), causing them to be thrusted over the younger ones. Such a complex tectonic structure came into existence probably when the Pieniny Klippen Belt was being bent to form an arc. The bending radius of the deeper parts of the belt was smaller than that of the shallow ones due to increasing flexuring ductility: ductile flexuring took place in higher depths, thrusting occurred closer to the surface and normal faults were formed at their prolongation (Fig. 9D). Later on, during the Styrian phase, the Repowa Fault was cut by a series of transversal faults which were responsible for sigmoidal bending of the strata (Fig. 9C).

CONCLUSIONS

1. The Czorsztyn Unit was not of an autochthonous character during thrust-nappe folding and, together with the upper klippen units, was detached and then thrusted over the Magura forefield.

2. The occurrence of the Magura deposits within the Pieniny Klippen Belt, interpreted so far as tectonic caps of the back-thrusted Grajcarek Unit, are in fact tectonic windows, in which the Magura Unit emerges from below the Pieniny Klippen Belt.

3. The Homole and Biała Woda Blocks are an isolated patch of the Pieniny Klippen Belt units within the Magura Unit (tectonic caps), which are structurally out of the Pieniny Klippen Belt and therefore they avoided being deformed typically of this belt during the younger Tertiary.

4. Boundary between the Pieniny Klippen Belt and Magura Unit, so far accepted, is a sedimentary contact between the Jarmuta and Szczawnica Formations within the Magura Unit.

5. Northern boundary of the Pieniny Klippen Belt should be drawn along the contact between the klippen units and the previously distinguished Grajcarek Unit.

6. The Grajcarek Unit should be included into the Magura Unit, distinguishing within the former a near-contact deformation zone related to thrust-nappe folding of the Pieniny Klippen Belt.

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KONTAKT PIENIŃSKIEGO PASA SKAŁKOWEGO Z JEDNOSTKĄ MAGURSKĄ (MAŁE PIENINY)

Streszczenie

Zaproponowano likwidację wydzielanej przez K. Birkenmajera (1965, 1979) jednostki Grajcarka, zbudowanej z osadów pochodzących z basenu magurskiego i wstecznie nasuniętej w fazie laramijskiej na ukształtowany już w wyniku fałdowań płaszczowinowych pas skałkowy. Rozważane jest nasunięcie postępowe jednostek skałkowych na przedpole magurskie, które było kontynuacją trwających od mastrychtu po paleocen środkowy fałdowań płaszczowinowych. Z przytoczonych argumentów wypływają następujące wnioski: (1) jednostka czorsztyńska na etapie fałdowań płaszczowinowych nie była autochtoniczna; (2) stanowiska osadów magurskich, interpretowanych dotychczas jako czapki tektoniczne wstecznie nasuniętej jednostki Grajcarka, są oknami tektonicznymi jednostki magurskiej; (3) blok Homoli i Białej Wody to czapki tektoniczne jednostek skałkowych na jednostce magurskiej, które w sensie strukturalnym znalazły się poza pasem skałkowym i dlatego uniknęły typowych dla niego deformacji młodotrzeciorzędowych, zachowując relikty struktur powstałych na etapie fałdowań płaszczowinowych; (4) jednostkę Grajcarka należy włączyć do jednostki magurskiej, wydzielając co najwyżej pas deformacji związany z fałdowaniami płaszczowinowymi w pasie skałkowym; (5) dotychczasową granicę pienińskiego pasa skałkowego należy uznać za kontakt sedymentacyjny formacji jarmuckiej i szczawnickiej w obrębie jednostki magurskiej; (6) granicę pasa skałkowego należałoby przesunąć na kontakt jednostek skałkowych z wcześniej wydzielaną jednostką Grajcarka.