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# The Mesozoic substratum of the Central Carpathian Paleogene (Podhale-Western Spiš Basin, Polish-Slovak borderland)

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ABSTRACT:

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The Mesozoic outcrops at Haligovske skalý (Hal) and in Bielianske Tatry (TB) seem to show the same lithosomes that continue under the Podhale-Western Spiš Paleogene Basin. Both series contain two characteristic clastic units, a Lower Jurassic one (Gresten facies), and a Lower Cretaceous one, respectively. In the Mesozoic, both sequences (TB and Hal) were parts of the basin fill that once separated the High-Tatric Zone from the Pieniny Klippen Belt realm in the Western Central Carpathians. The TB unit has been thrust over the Krížna Nappe in the eastern part of the Tatra Mountains as the result of retrocharriage most probably in Early Miocene times.

**Key words:** Bielianske Tatry (TB unit); Haligovske skalý (Hal unit); Krížna Nappe; Retrocharriage; Ultranappism.

## INTRODUCTION

This contribution deals with two Mesozoic lithostratigraphic sections located in two extremes (north and south) of the Western Spiš Basin in the Polish-Slovak borderland. These are: the Bielianske Tatry section (TB; Tatry Bielskie in Polish), which constitutes the north-eastern part of the High Tatra Mountains (literally its Sub-Tatric, Mesozoic zone), and the Haligovske skalý section (Hal; Haligowieckie skałki in Polish), which crops out near the Pieniny Klippen Belt (Text-fig. 1). Their distinctness from the Krížna Nappe is the basis for classifying them to a succession other than the Krížna lithostratigraphic succession, namely to the proper Mesozoic substratum of the Podhale-Western Spiš Basin (the Spiš Basin stretches further west towards the Polish Podhale region, thus its expanded name).

The Mesozoic of the Bielianske Tatry is a rather well-known sedimentary succession (Jach *et al.* 2014 and references therein), while less is known about the geology of the Haligovske skalý (Uhlig 1897; Horwitz and Rabowski 1929; Horwitz 1931; Birkenmajer 1959, 1977; Kotański 1963; Köhler and Buček 2000). Both lithostratigraphic basinal sequences show the presence of two clastic lithosomes, namely the Baboš Quarzite Member in the TB unit, and a quarzitic one in the Hal unit, respectively. They are ascribed here to the Gresten facies. Another sequence, consisting of carbonate clastics, is the huge mass of the Lower Cretaceous Muráň Limestone Formation in the TB unit and the so-called Haligovce Limestone Formation of Birkenmajer (1959) in the Hal unit. The western part of the Spiš Basin is infilled with a thick cover of Paleogene flysch deposits, which, however, is not the subject of the present paper. This contribution is a continuation of my previous work (Lefeld 1999), and should be read together with it. The finding of southward-oriented drag folds in the TB unit and its tectonic contact with the Krížna Nappe in the Javorová Valley (Nemčok *et al.* 1994; Lefeld 1999) have allowed the whole tectonic scheme of the eastern Sub-Tatric Zone to be reorganized.

Two small tectonic thrust sheets containing Triassic carbonates and Eocene conglomerates in the Kopy



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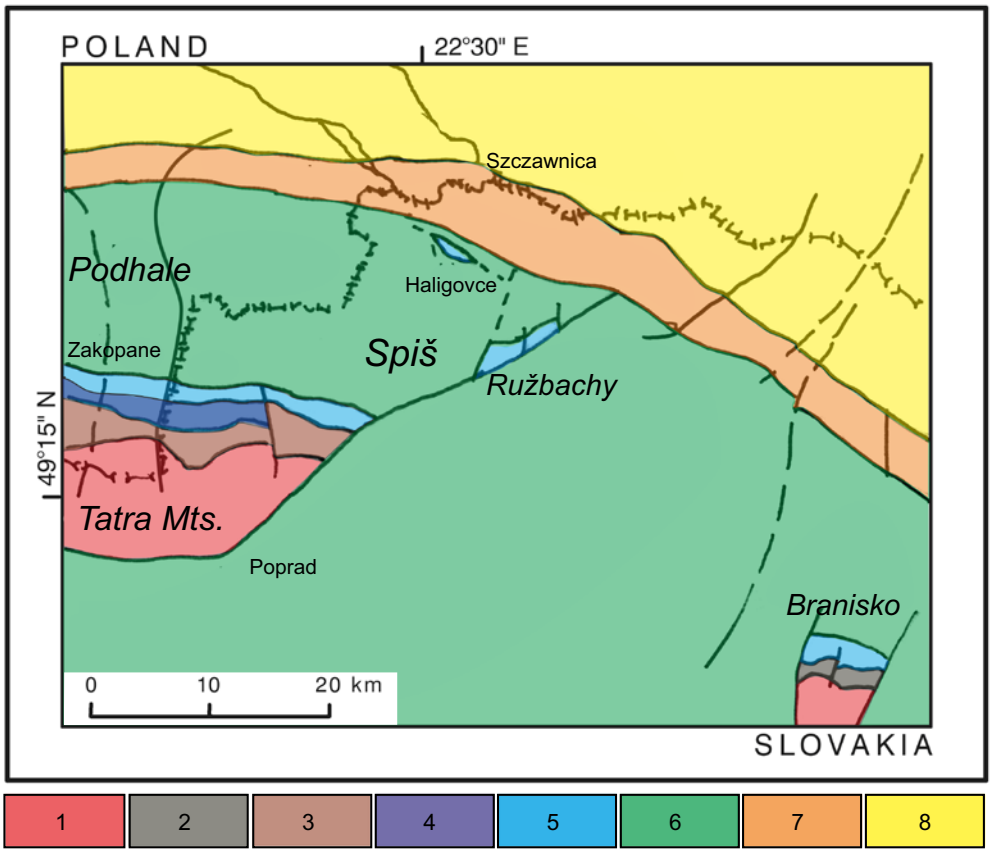
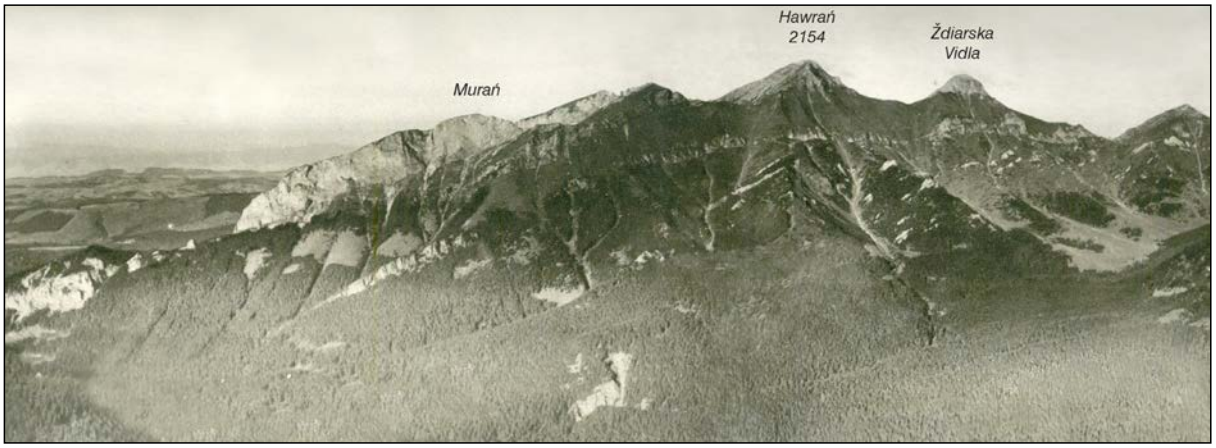



Text-fig. 1. Sketch-map showing the position of the TB and Hal units in the Podhale-Western Spiš Basin. 1 – crystalline basement cores of the Tatra Mountains and Branisko; 2 – Branisko Paleozoic formations; 3 – High-Tatric sedimentary zone; 4 – Krížna Nappe; 5 Podhale-Western Spiš Mesozoic; 6 – Central Carpathian Paleogene; 7 – Pieniny Klippen Belt; 8 – Magura Nappe.

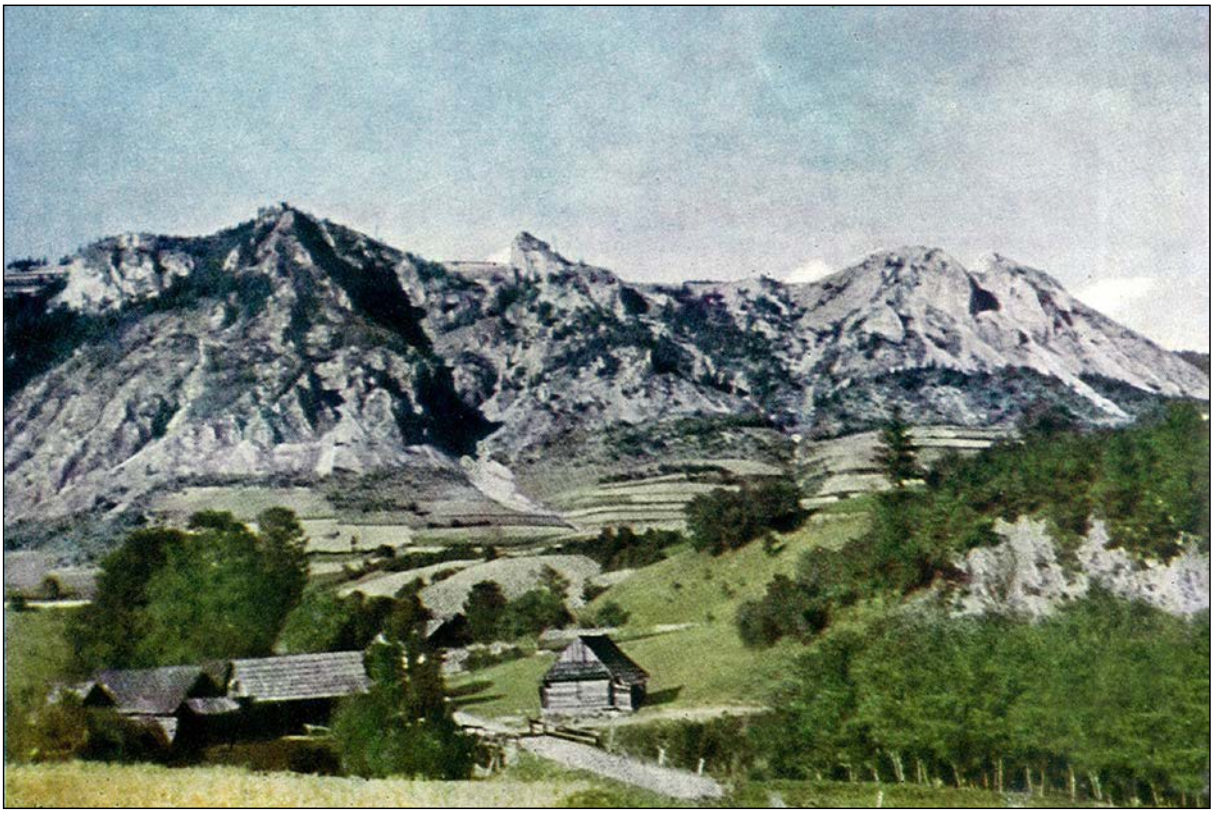
Sołtysie area in the Polish part of the eastern Sub-Tatric Zone (Głazek *et al.* 1998) document Neogene movements that have affected not only the basinal part of the Mesozoic substratum of the Central Carpathian Paleogene (see the results of the Zakopane IG-borehole; Sokołowski 1973), but also the northern, marginal part of the present-day Tatra Mts. The clastic lithosomes, namely the Gresten facies (Baboš Member), and the Muráň Formation, serve here as indicators of adherence to definite tectonic units, respectively. There exists a great difference in topography between these two objects of the present study. The TB unit (Text-fig. 2) exhibits alpine topography with peaks attaining heights over 2000 m (Sokołowski 1950 and references therein), but in the Polish part of the Sub-Tatric Zone (the Kopy Sołtysie area) the same unit shows gentle topography with hills less than 1,500 m high, and it sits in a reversed tectonic position. The Haligovske skalý are but 800 m high (Text-fig. 3), thus resembling other hills of the Magura Spiška region in northeastern Slovakia (Janočko 2000).

## BIELIANSKE TATRY

The Bielianske Tatry Mountains form an outstanding, isolated mountain group in the northeastern part of the Tatra Mts. A monograph was devoted entirely to this mountain group by Sokołowski (1950; Polish version published in 1948). The group is devoid of crystalline basement. Its sedimentary sequence consists of Middle Triassic carbonates (Rychliński and Szulc 2005) and a whole sequence of Jurassic and Lower Cretaceous deposits (Jach *et al.* 2014 and references therein). The unit is tectonically obliterated at its bottom resting on the reduced (at top) Krížna Nappe (Lefeld 1999). There is sedimentary continuity between the Triassic and Lower Jurassic rocks (Gaździcki 1974; Jach *et al.* 2014). The Lower Jurassic is represented mostly by calm, probably slow, basinal deposition of marly-calcareous sediments, commonly known under the name 'Fleckenmergel'. The particular members of that suite have been defined and named by Iwanow (in




Text-fig. 2. Bielianskie Tatry Mts (western part, TB unit) seen from Javorinská Široká. Photograph by K. Guzik (1927).



Text-fig. 3. The Haligovce Klippes (Hal unit), northeastern view. Its southern slopes show Triassic formations (to the left), Lower Jurassic, Middle Jurassic, Upper Jurassic (to the right) and Lower Cretaceous ones (at the summits). Photograph by D. Andrusov (1955).

Lefeld *et al.* 1985). This slow deposition was interrupted by inflow of the quartzitic clastic sediments of the Baboš Quartzite Member (Borza 1958). Sokołowski (1950) was surprised to see such rocks on the southern slopes of the TB unit, as they were not known to him from other parts of the Krížna Nappe elsewhere in the Tatra Mts (at those times the TB unit was classified to that nappe). I also indifferently classified it as a 'nappe' (Lefeld 1999).

It is a well-known fact that a huge amount of quartzitic clastic material was removed from the High-Tatric overthrust units (such as the Giewont, Czerwone Wierchy and the Horvatský úplaz) during Early Jurassic times (Andrusov 1950; Rabowski 1959;



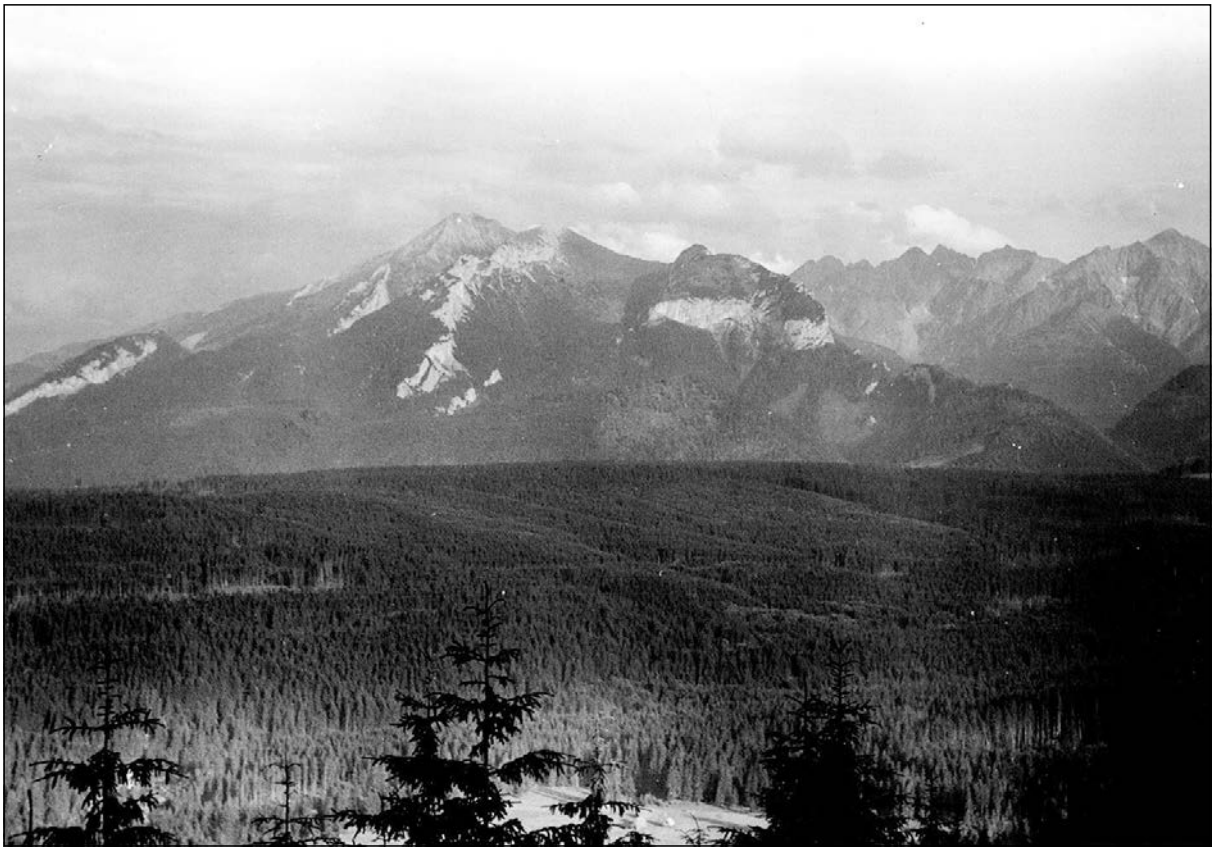
Text-fig. 4. Southern slopes of the Bielianske Tatra Mts as seen from the Široké Sedlo pass. The white outcrops in the central part of the slope are the Baboš quartzite horizon (lowermost Jurassic), Gresten event (1967).

Kotański 1963; Łuczyński 2002). It seems highly probable that those sediments were transported northward to be laid down in the southern margins of the Podhale-Western Spiš Basin as it existed at that time. The outcrops of the Baboš Quartzite Member on the southern slopes of the TB unit exhibit considerable thickness variations (Text-fig. 4). Unfortunately the proximal part of the southern part of the Podhale-Spiš sequence is missing, hence the direct connection with the source areas cannot be restored. The primary position of the source areas was delineated by Kotański (1961), but the denuded area could have been much greater and stretched probably further south beyond the present day Southern Marginal Fault of the Tatra Mts. This inflow of quartzitic clastic material maybe called the 'Gresten event'. The deposits of the Baboš Member show considerable maturity as compared with the ones of the Kominy Dudowe Member (High Tatric Zone; Wójcik in Lefeld *et al.* 1985), which should be regarded as a counterpart of the source area.

The differences in lithology between the Jurassic of the Krížna Nappe and the TB unit have been presented in tables 1 and 2 in Lefeld (1999). Contrary to Sokołowski's (1950) erroneous statements, the TB unit does not contain the Toarcian red Adnet limestone (the Kliny Limestone Member), a lithosome present everywhere in the Krížna Nappe in the Sub-Tatric Zone (Lefeld 1999). Instead there is grey, somewhat siliceous limestone, pale olive (10Y 6/2) to light olive grey (5Y 6/1 in Muncell's scale – The Rock Color Chart) with darker spots, the so called Podspad and Podskalnia members (Iwanow in Lefeld *et al.* 1985).

The nodular limestone – radiolarite vertical symmetry (Lefeld 1968, 1974) consists there of a thin, lower nodular limestone bed and radiolarite, and a fairly thick upper nodular limestone, the so-called Czorsztyn Limestone Formation of Kimmeridgian–Lower Tithonian age (Mišík 1959; Polak *et al.* 1998; Jach *et al.* 2014; Jach and Rehakova 2019).

The Pieniny Limestone Formation ('Biancone') is rather inconspicuous there. The Kościeliska Marl Formation resembles much of that of the Krížna Nappe. In its lower part (but not the lowest) there is a conglomeratic lithosome (2–3 m thick) containing pebbles of brownish limestone (5YR 5/6 light brown to 10YR 5/4 moderate yellowish brown). These are rather subangular carbonate clasts (up to 30 cm) whose lithology resembles highly that of the



Text-fig. 5. Northern slopes of the Bielianske Tatra Mts (western part). Eastward view. White cliffs represent the Muráň Limestone Formation (type locality). The High Tatra crystalline core is visible in the far distance (1974).

High-Tatric limestone of the upper member of the Raptawicka Limestone Formation. This lithosome is known so far only from the southern slope of Muráň mountain above the Gałajdova alpine meadow. The rock has not been analyzed yet. It is unknown from the Krížna Nappe proper.

The Muráň Limestone Formation crops out all over the northern slopes of the TB unit (Text-fig. 5; Lefeld 1974; Michalík *et al.* 1989; Michalík and Sotak 1990). At its type locality, the formation shows northward direction of material transport (Lefeld 1974, 1999). In the Polish part of the eastern Tatra Mts, the formation crops out in the Kopy Sołtysie group of hills (Grabowska-Hakenberg 1963; Sokołowski 1978; Birkenmajer 2012) in reversed tectonic position. At least the uppermost 50 m thick portion of the Muráň Limestone Formation is a result of destruction of the High-Tatric Urgonian-type limestones (the Wysoka Turnia Formation). According to Michalík and others (1989) the sediments were laid down predominantly in submarine canyons.

The Urgonian reef system in the Carpathians stretches from Manín (Central Slovakia), High Tatra Mts, through Humenné (eastern Slovakia), Marmaroš (transcarpathian Ukraine and northern Romania), to the Hăghimaş Mts. (Romania) (Lefeld 1988). It was a huge Early Cretaceous barrier reef complex of the Carpathians. In each of these localities the system is accompanied by an ample zone of detrital, calcareous material – a result of reef destruction. Near Humenné, there is the so-called Barkokalk (Andrusov 1959). In earlier usage, this formation embraced also rocks of other than Lower Cretaceous, which was very confusing. In my opinion, the Muráň Limestone Formation represents the northern zone of destruction products derived from the High-Tatric Wysoka Turnia Formation. The TB unit as a whole has no counterpart south of the Tatra Mts (Andrusov 1959 and oral information).

## HALIGOVSKE SKALÝ

The Mesozoic section at Haligovske Skalý (Hal) is located south of the Pieniny Klippen Belt south-



Text-fig. 6. Haligovske skalý as seen from the Polish part of the Pieniny Mts. A deep valley separates the Hal unit (to the right) from the Pieniny Klippen Belt. It marks the boundary between the Inner Central Carpathians (right) and the Pieniny Klippen Belt (left). Photograph by T. Gutry (2005).

ern border fault (northeastern Slovakia, a few kilometers southeast of Szczawnica-Zdrój; Text-fig. 1). This group of hills is separated from the Pieniny Klippen Belt by a deep valley (Text-fig. 6). The Mesozoic sequence there was studied and mapped by Uhlig (1890), then by Horwitz and Rabowski (1929), Horwitz (1931), and finally by Birkenmajer (1959, 1977). The last of these authors classified it as a part of the Pieniny Klippen Belt zone. However, contrary to the Klippen Belt successions it does contain a Triassic substratum. In this, the Hal unit differs substantially from any other Klippen succession. Previously this was a criterion to classify the Hal unit to the High-Tatric group (e.g., the Manín Unit; Andrusov 1936; Birkenmajer 1959). This is no longer the case. Kotański (1963) was the first to classify properly the Triassic carbonates of the Hal unit. He also found there a major unconformity between the Campilian (now part of the Olenekian) and Anisian rocks, and the overlapping Lower Jurassic ones.

On Uhlig's map (1890), the Lower Jurassic arenaceous member of the Hal unit has been unified with the surrounding Central Carpathian Paleogene clastic formations, an interpretation that appeared to be erroneous as the result of further studies (Horwitz 1931; Birkenmajer 1959). Horwitz (1931) found some bivalves, e.g., *Gryphaea obliqua* Goldfuss, 1835 and *G. cymbium* Lamarck, 1819 in this Lower Jurassic sandstone member there and ascribed it on this basis to the Pliensbachian. The molluscs in general, and some bivalves in particular (oysters, for example) are, in some cases, subject to iterative evolution, i.e., similar or even the same morphologic forms of different ages are sometimes classified to the same genus or species. This is highly misleading. Because of that, the fossils classified by Horwitz (1931) as Pliensbachian in age presumably might have been older. Besides that, the deposits of Pliensbachian age in the nearby Pieniny Klippen Belt invariably show carbonate facies (Myczyński 1973). Quartz clastic

Pliensbachian rocks similar to that of the Hal member are not to be found in the vicinity.

In the times of Ludwik Horwitz, sedimentology did not exist as a science (at least in Eastern Europe), so he did not bother about the origin of this lithosome. In the light of the above, the Pliensbachian age of this quartzitic member is highly doubtful. Tentatively, the member maybe regarded as the distal part of the Sub-Tatric Baboš quartzite of the TB unit. Ultimately, this may be a result of secondary redeposition.

The nodular limestone-radiolaritic complex (Callovian–Oxfordian) at Hal consists of a very thin lower nodular horizon and also a not very thick Oxfordian radiolarite package (Birkenmajer 1959, 1977). The Czorsztyn Limestone Member (Kimmeridgian to Lower Tithonian) is thicker. In the opinion of Milan Mišík (oral information), the whole complex does not resemble anything of the Pieniny Succession of the Pieniny Klippen Belt, as postulated earlier by Birkemajer (1977 and other works). In his opinion, the Hal unit does not belong to the Pieniny Klippen Belt, which is in agreement with the opinion of other Slovak geologists. The Upper Jurassic vertical nodular limestone-radiolarite symmetry (Birkenmajer and Gąsiorowski 1961; Lefeld 1974) is very diagnostic in any basinal sequence. In my opinion, it strongly resembles the radiolaritic complex of the TB unit (Jach *et al.* 2019). On the contrary, it is completely unlike the Pieniny Klippen Belt successions. The same can be said about its relations to the Križna Nappe.

A rather thick complex of calcarenite-calcirudite, of probable Hauterivian (in part) – Barremian–Aptian age, has been named by Birkenmajer (1959) the Haligovce Limestone Formation. He stated that it has no counterpart in the Pieniny Klippen Belt, but did not trace it to any place of its probable source area. Search for larger Urgonian-type fossils was unsuccessful (Birkenmajer 1959). The rock is bituminous, similarly to the Muráň Limestone Formation of the Tatra Mts. This unit can be compared to the Muráň Limestone Formation of the TB unit. Its thickness is definitely smaller than that of the latter formation in the type locality (Text-fig. 4). Hence, in the palinspastic reconstruction of the Podhale-Western Spiš basin it may be regarded as a distal part of the Muráň Limestone Formation. Above this limestone member, M. Mišík (oral information) has found typical High-Tatric Albian marls with phosphoric mineralization, etc., comparable to the Zabijak Formation (Krajewski in Lefeld *et al.* 1985) of the High-Tatric zone of the Tatra Mts. The member was not known so far from the Hal unit.

Nevertheless, the Hal unit and the Pieniny Klippen Belt share some younger Cretaceous formations, such as the Jaworki Formation, the Sromowce Formation, and the Jarmuta Formation (see Birkenmajer 1977; Köhler and Buček 2000).

In the light of the above new data and considerations, the Hal unit should be regarded as a distal, northern part of the Western Spiš Basin Mesozoic sedimentary succession, and not as the southernmost Pieniny Klippen Belt succession, as previously postulated by Horwitz and Rabowski (1929), and by Birkenmajer (1959, 1977 and other works).

The overthrust of the Krížna Nappe in the Tatra Mts sedimentary zone has been well known for many years (see Lefeld 1999). The nappe coverage had taken place in pre-Conacian[1] times. All over the northern part of the Tatra Mts, the Krížna Nappe shows typical hilly morphology, known under the local name 'regle'. The same can be said about its presence in the eastern part of the massif, where the Sub-Tatric hills of Czerwona Skałka, Holica and Zadnia Kopa, located south and southwest of the Bielianske Tatry, show typical 'Sub-Tatric' topography. The northward extent of the Krížna Nappe is, in fact, unknown. It may be supposed that its front under the Central Paleogene flysch is highly irregular. In the eastern part of the Tatra Mts, it emerges from under the TB unit in the lower part of the Jaworová valley in a highly tectonically destroyed form (see Lefeld 1999).

Aside of the many northward pointing drag folds found in the rocks of the TB unit, there are some that point unquestionably to southward movement. This means that the area has undergone a small scale retrocharriage during post-Cretaceous times. The exact timing of these movements is impossible to determine. There are no ways of defining the age of formation of these drag folds. In this situation we must turn to look to neighboring regions, such as the High Tatra Mts and the Pieniny Klippen Belt. In the Tatra Mts, there are no indications of such movements, nor are there preserved any younger deposits, which could document the age of the drag folds. In the Pieniny Klippen Belt, movements younger than the Cretaceous have been observed west of the Tatra Mts (Scheibner 1963) and also in the central part of the belt (Birkenmajer 1985). Thus it is highly probable that such movements had taken place also in the Podhale-Western Spiš Basin. These movements were assigned to have taken place in the Early Miocene.

Every newcomer to the Tatras coming from the north is fascinated with the gorgeous view of the

[1] The author, following the Swiss geological school, rejects (*in principio)* the use of Stille's (1924) names of orogenic phases.

Bielianske Tatry highest peaks. In fact, their prominent, isolated position causes surprise and raises questions about their origin. This problem has been the subject of considerations by many since the middle of the 19th century (see Sokołowski 1950 for references). Aside of such arguments as the lack of glacial morphology on their northern slopes, and gentle position of Mesozoic rock sequences, one of the main problems was the origin of the glacially shaped deep and broad valley of Zadné Koperšady. It seems, however, that the main cause of the prominent height of the Bielianske Tatry is the general uplift of the whole eastern part of the High Tatra Mts, the part of which is the TB unit.

## THE SEQUENCE OF TECTONIC EVENTS

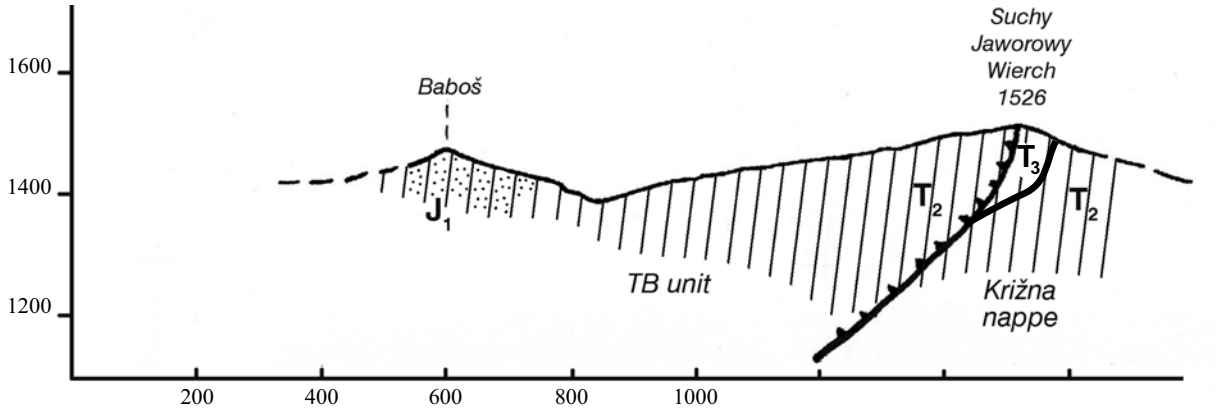
The monotonous Mesozoic plate of the TB unit falls steeply northeastward under the Central Carpathian Paleogene cover. Its present-day tectonic position is the result of the squeeze up of Mesozoic masses at the Western Spiš Basin – horst contact (the High Tatra crystalline massif in this case) most probably due to a kind of retrocharriage. The absolute height of the TB unit in the Bielianske Tatry is due to the slow but steady uplift of the whole High Tatra Mts (Bac-Moszaszwili 1997).

The Hal unit, in turn, is the northernmost, distal part of the Spiš Basin Mesozoic fill. Its geometry is difficult to evaluate. It is not out of question that it is a small horst at the Western Spiš Basin-Pieniny Klippen Belt boundary, located close to the southern border fault of the latter zone, and almost at the turn of the whole Pieniny Klippen Belt structure from its SW-NE to NW-SE course. It is surrounded on all its sides by the Central Carpathian Paleogene. The morphologic diversity of the Haligovske Skalý from the Pieniny Klippen Belt is clearly observable (Text-fig. 6). However, Horwitz (1931) and later also Birkenmajer (1959) regarded the Hal unit as part of the Pieniny Klippen Belt. This is not true, because the unit possesses its own Triassic substratum, which is not the case with the Pieniny Klippen Belt successions. The Triassic and lowermost Jurassic substratum of the Klippen Belt may be looked for, perhaps, in the deeper parts of the Central Carpathians. Hypothetically, it is not out of question that it may be incorporated within the zone of low electric resistivity under the Tatra Massif. Pattern of induction vector azimuths clearly show affinity of the Hal unit to the Inner Carpathian realm (Lefeld and Jankowski 1985). Due to the clockwise rotation of the whole Inner Carpathian realm *versus* the Klippen Belt (Birkenmajer 1985) the paleogeographic and paleotectonic relations of the Hal unit toward the Klippen Belt successions cannot be ascertained.

The overthrust of the Krížna Nappe (and other nappes) in the Tatra Mts is a long known fact (Lugeon 1903; Andrusov 1959). Fixing the date of the retrocharriage, as illustrated in Text-fig. 7, is a difficult task. What is known is that it had definitely taken place after the Mesozoic. It is hardly probable that some movements might have produced retropression onto the Krížna Nappe during the deposition of the Central Carpathian Paleogene. The south directed drag folds (Ramberg 1963; Tollmann 1973) at Havran Mt. (Lefeld 1999) and Skalné vrata (Skalne Wrota in Polish); occurring further to the east and thus beyond the scope of this paper) do not show any hint about their age. They are more numerous in the TB unit, but tracing them in the difficult, highland terrain is not easy. At Havran Mt., the drag folds occur in homogeneous calcareous material of Late Jurassic age. The same can be said about the much more numerous north-oriented drag folds there (see Lefeld 1999, his fig. 2). Those are much older, most probably associated with post-Turonian foldings. The tectonic contact of the Krížna Nappe and the TB unit can be observed at Suchý vrch (Suchy Jaworowy Wierch in Polish) in the Javorová valley (Text-fig. 7). It passes the Široká valley to the west, but tracing it there is almost impossible, because it runs within Middle Triassic carbonates of the same lithology in both tectonic units. In the Široká valley, three ample springs occur (Wywiery in Polish, Pramene in Slovak), which actually supply water to Tatranská Javorina village in Slovakia. The springs occur almost exactly within the said dislocation.

In the Polish part of the Sub-Tatric Zone, some minor retro-arc overthrusts in the Mesozoic/Eocene sequence have been noted by Birkenmajer (2012). There are also two tectonic thrust sheets composed of Middle Triassic carbonates and overlying Eocene conglomerates that are thrust one over another (see Głazek and Sochaczewski 1997, their fig. 4). This means that the movements were definitely post-Eocene or even post-Oligocene in age. Because of that time classification of these tectonic scales to the Krížna Nappe, Głazek and Sochaczewski (1997) were not precise about the timing of the tectonic movements that produced the situation shown in their fig. 4.

It is puzzling why the Mesozoic sequence in the Kopy Sołtysie area (Polish Sub-Tatric Zone), definitely belonging to the TB unit, shows reversed tectonic position (Halicki 1955; Grabowska-Hakenberg




Text-fig. 7. Morpho-tectonic sketch profile of the divide between the Javorová and Široka valleys (northeastern Tatra Mts) showing the tectonic contact of the TB unit (left) and the Krížna Nappe (right). See also Lefeld (1999, fig. 21).

1963; Sokołowski 1978; Głazek and Sochaczewski 1997; Lefeld 1999; Birkenmajer 2012). In the opinion of Halicki (1955), the major Koszysta elevation of the Tatra crystalline core continues further north under the Central Carpathian Paleogene flysch in the Podhale region. Hence this may be the cause (in part) of the reversed position of the TB unit there.

In the core of the Zakopane IG-1 borehole, a reversed rock sequence (possibly two) has been found (Sokołowski 1973; subsurface data of the Podhale depression are given in Wieczorek and Barbacki 1997). This means that tectonically reversed parts of the Mesozoic substratum of the Central Carpathian Paleogene exist in many places, as is the case in the nearby Polish part of the Tatra Sub-Tatric zone (Kopy Sołtysie area). Such tectonic disturbances clearly show that the Mesozoic of the Podhale-Western Spiš Basin was subject to shortening most probably during the Neogene. Nevertheless, the exact dating of those movements is impossible. It is obvious that they preceded the Miocene uplift of the Tatra Massif (Text-fig. 8). Thus, the movements that have disturbed the Mesozoic strata as observed in the Zakopane IG-1 borehole must have taken place during Early Miocene times. Definite southerly vergencies were noted by Scheibner (1963) in the Pieniny Klippen Belt in Western Slovakia. In his opinion, the origin of the southern border fault of the Klippen Belt there is of Early Miocene age. According to Birkenmajer (1985) major folding movements had taken place in the Klippen Belt during Early Miocene times. The same age is ascribed to a part of the Central Carpathian Paleogene tectonics in the eastern part of the Podhale Basin (Mastella 1975). In the opinion of Oszczypko (1997), the origin of the Carpathian peripheral foreland basin is also of Early–Middle Miocene age. No major tectonic movements are known from the Central and Eastern Alps during the Paleogene (Tollmann 1974; Trümpy 1985).

It seems that the primary Podhale-Western Spiš Basin (depression) must had been broader than it is now. The tectonic movements mentioned above might have taken place presumably during late Alpine disturbances, as can be correlated with the young

| Stage | Age | Effects |
|---|---|---|
| recent<br>Pleistocene | 2 | ↑ uplift |
| Pliocene | 7 | ↓ |
| Miocene | 25 | retrocharriage over lower units |
| Oligocene | | |
| Eocene | | |
| Paleocene | | |
| Maastrichtian | | |
| Campanian | | |
| Santonian | | |
| Coniacian | | overthrusts of Sub-Tatric nappes |
| Turonian | 88 | |

Text-fig. 8. Presumable timing of the tectonic phases in the Sub-Tatric sedimentary cover of the eastern part of the Tatra Mts, partly after Bac-Moszaszwili (1997).

Alpine events observed in the Alps (Trümpy 1985). Presumable timing of the tectonic phases in the Sub-Tatric sedimentary cover of the eastern part of the Tatra Mts is presented in Text-fig. 8. There is a slight supposition in Sokołowski's work (1950, p. 42 in the French edition and p. 31 in the Polish edition), about a possibility of tectonic disturbances of Eocene (?) age that affected the Tatra granitic crystalline core. However, he did not continue work on this subject. The Mesozoic carbonate sequence of the Bujači Unit of Andrusov (1936, 1950) in the Bielianske Tatra Mts, as well as in the Polish part of the eastern Sub-Tatric zone, came to their place of repose most probably in result of piggyback transport. Tectonics of the Bujači Unit is not the subject of the present paper.

The problem of uplift of the whole Tatra Massif has been comprehensively treated by Bac-Moszaszwili (1997 and references therein). According to those data, the uplift started about the Badenian–Karpatian boundary, i.e., at 16–18 Ma. Recent studies on apatite samples show an age of 14–19 Ma for this event (Śmigielski *et al.* 2011). It seems to coincide with the Styrian orogenic phase (according to Stille's scheme). These problems are, however, not the subject of this contribution.

## TOPOGRAPHY

The isolated and high position of the Bielianske Tatry mountain range has been widely considered in Sokołowski's monograph (1950 and references therein), although some of his statements are no longer valid in the light of the newly discovered facts (Lefeld 1999). The topography of the range seems to be inert these days. The same can be said, in particular, about its northern slopes with their small, steep, V-shaped valleys. This is most probably a Miocene–Pliocene topography that had been little changed by glacial excavation during the Pleistocene. Only the southern slopes of the range were modelled during the Pleistocene glacial times. The subsequent glaciers had carved the major Zadné Koperšady (Meďodoly) valley (Sokołowski 1950). The tectonic contact of the TB unit with the underlying Krížna Nappe at the base of these slopes is completely hidden under glacial deposits.

The unusually high orographic position of the range is due to the somewhat intricate interaction of two tectonic integrants, namely the general, still active uplift of the eastern part of the High Tatra Mountains (Bac-Moszaszwili 1997 and references therein) and the upheaval of the Bielianske Tatry mountains resulting from retropression of the southwestern part of the Podhale-Western Spiš Basin (possibly also a result of epeirogenic movements in the region). Almost all outlets of the Bielianske Tatry northern streams terminate with distinct steps or small waterfalls, suggesting recent upheavals. In Sokołowski's opinion (1950), the location of the Bielianske Tatry exactly over the Jahňaci-Havran tectonic elevation was of importance in this respect.

In the Polish part of the Sub-Tatric Zone, the TB unit shows a rather 'low', gentle topography, typical all over this zone further west. Its reverse tectonic position there is due most probably to the existence of the Koszysta major elevation (Halicki 1955) and Neogene orogenic movements. In the Slovak part of the eastern Sub-Tatric Zone, the Krížna Nappe at Holica-Zadná Kopa group shows normal tectonic position and a typical, Sub-Tatric low topography.

## DISCUSSION

It was a common practice to include almost every basinal Mesozoic sequence in the Tatra Mountains and their vicinity to the Lower Sub-Tatric Zone, i.e., to the Krížna Nappe. In the west of the Tatra Mts, this was somewhat justified, but in the east there are two different Mesozoic sequences, which cannot be put all together into the Krížna Nappe. In the light of the present contribution, the more southerly sequence belongs to the Krížna Nappe (Czerwona Skałka, Holica-Zadnia Kopa), while the northern one (TB unit; Lefeld 1999), embracing the Bielianskie Tatry in Slovakia and the Kopy Sołtysie area in Poland (eastern Sub-Tatric Zone), belongs to the Western Spiš Basin. In the latter case, the sources of clastic sediments are easy to restore (see above). The sources of the Krížna Nappe sediments are to be found far south in Slovakia.

In this situation, classifying all the basinal sequences in the Tatra Mts to the Lower Sub-Tatric (Krížna) Nappe is pure ultranappism. Recent examples of ultranappism are the papers by Piotrowska (2009) and Birkenmayer (2012). The latter repeats the erroneous introduction of the term Rusinowa Conglomerate Formation to be of Cretaceous age as a certainty (Birkenmajer 2000). In fact, the introduction of this name is invalid because of the following reasons:

– The conglomeratic lithosome is barren of fossils, i.e., its age is unknown;
– There is no comparison to the Gosau Formation in the Low Tatra Mts (Slovakia). The conglomeratic unit is very unlike the Slovak Gosau Formation;
– The comparison to the Gosau Formation of the North

Calcareous Alps is very distant. The source areas of these formations must have been quite different, hence incomparable. Presumably, the likeness was the author's temporary subjective impression;
– The said Rusinowa Formation differs very little (if at all) from the Eocene conglomerates, so frequent in the vicinity. In the opinion of the late Jerzy Głazek this is simply an Eocene lithosome (oral information).

The two sketch maps in Birkenmajer's paper (2012, figs 11 and 12) contain serious errors both of geologic and topographic nature. The tectonic profile (Birkenmajer 2012, fig. 13) is in fact Andrusov's with minor additions by the author, but Andrusov's name is missing. It only appears elsewhere in the text. The allocation of small Werfenian outcrops in the Waksmundzka Valley to the Lower Sub-Tatric Nappe is dubious. There are no basal lithosomes of the Lower Sub-Tatric Nappe elsewhere in the Tatra Mts. This nappe is of the stretch nappe type, hence its lowest units remained far south in the Carpathian orogen. On the contrary, remains of crystalline rocks as detached tectonic fragments are frequent in the High-Tatric Zone in the Western Tatras. Also in the explanations to the "Tectonic Map of the Tatra Mountains" by Cymerman (2024) there are some overuses of the 'nappe" term.

In the light of the above considerations, the ultra-nappistic approach to the Tatric tectonics seems to be unjustified.

## CONCLUSIONS

The presentation of new facts and the resulting considerations allow several conclusions to be put forth; namely:

- During the Mesozoic, there existed an oceanic basin which separated the High-Tatric Zone from the Pieniny Klippen Belt realm, somewhat comparable to the Myjava one in the west;
- The Bielianske Tatry (TB) and Haligovske skalý (Hal) units represent two extremes of the Mesozoic fill of the Podhale-Western Spiš Basin. The same concerns the Ružbachy Mesozoic sequence and maybe also the Branisko Mesozoic succession;
- The series of the TB unit and the Hal unit belong neither to the Krížna Nappe (the first one) nor to the Pieniny Klippen Belt (the latter one);
- The presence of clastic lithosomes in the TB unit (Baboš Member, Muráň Limestone Formation) exclude their affiliation to the Križna Nappe as it was done before;
- The ascertained retro movement of the TB unit (south oriented drag folds, tectonic contact with the Krížna Nappe in the Javorová valley (Lefeld 1999) prove its independence from any tectonic units overthrusted from the south, first of all the Krížna Nappe,
- The Bielianske Tatra Mts are a morpho-tectonic remnant of the tectonic contact of the High Tatra crystalline massif and the Podhale-Western Spiš Basin;
- The retrocharriage of the TB unit seems to be a derivative of deep seated tectonic tensions between Europe and the Northern Tethys margin;
- The tectonic position and character of the two scales comprising Eocene conglomerates in the Kopy Sołtysie area in the Polish part of the eastern Sub-Tatric Zone (Głazek and Sochaczewski 1997) suggests tectonic movements that had taken place most probably during the Early Miocene;
- The existence of the Podhale-Western Spiš basinal elements within the Sub-Tatric Zone of the Tatra Mts makes the delineation of the Tatra-Podhale tectonic border much more difficult to define than it was done before;
- The substratum of the Podhale-Western Spiš Basin is a depressed, northern part of the Tatra massif;
- There is no depositional transition on the surface from the Podhale-Western Spiš Mesozoic (Hal unit) toward the Pieniny Klippen Belt successions, hence, the contact between these two zones is purely tectonic;
- There is no trace of Laramian tectonic movements in the Tatra Mts (at least in the eastern part of the Sub-Tatric Zone), contrary to Birkenmajer's (2000) faulty statements.

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## REFERENCES


Andrusov, D. 1936. Subdivision des nappes subtatriques sur le versant nord de la Haute Tatra. *Bulletin de l'Association Russe de Recherches Scientifiques*, **4**, 125–134.

Andrusov, D. 1950. Structure tectonique du Massif de la Široka (Hautes Tatras). *Geologicky Sbornik*, **1**, 9–30.

Andrusov, D. 1959. Geologia Československych Karpat, 375 pp. Slovenska Akademia Vied; Bratislava.

Andrusov, D. 1975. Aperçu bref du bâti des Carpathes Occidentales. Proceedings of the 10th Congress of the Carpatho-Balkan Geological Association, 95–108. Geologicky Zbornik; Bratislava.

Bac-Moszaszwili, M. 1997. Wyniesienie Tatr i ruchy neotektoniczne. Przewodnik LXVIII Zjazdu PTG w Zakopanem, 22–25. Wydawnictwa Geologiczne; Warszawa.

Birkenmajer, K. 1959. Significance of the Haligovce Klippe for the geology of the Pieniny Klippen Belt, Carpathians. *Rocznik Polskiego Towarzystwa Geologicznego*, **29**, 73–88.

Birkenmajer, K. 1977. Jurassic and Cretaceous lithostratigraphic units of the Pieniny Klippen Belt, Carpathians, Poland. *Studia Geologica Polonica*, **45**, 1–158.

Birkenmajer, K. 1985. Major strike-slip faults of the Pieniny Klippen Belt and the Tertiary rotation of the Carpathians. *Publications of the Geophysical Institute, Polish Academy of Science*s, **A-16**, 101–115.

Birkenmajer, K. 2000. Gosau-type conglomerate in the Rusinowa Polana area, Polish Tatra Mts. *Bulletin of the Polish Academy of Sciences: Earth Sciences*, **48**, 43–64.

Birkenmajer, K. 2012. Geology of the Lower Subtatric nappe, Kopy Sołtysie area, Eastern Tatra Mts. (Western Carpathians, Poland). *Studia Geologica Polonica*, **135**, 55–116.

Birkenmajer, K. and Gąsiorowski, M. 1961. Sedimentary character of radiolarites in the Pieniny Klippen Belt, Carpathians. *Bulletin de l'Académie Polonaise des Sciences, Série des Sciences Géologiques et Géographiques*, **9**, 175–180.

Borza, K. 1958. Triasove a Liasove kremence Belanskych Tatier. *Geologicky Sbornik Slovenskej Academii Vied*, **9**, 52–65.

Cymerman, Z. 2024. Tectonic Map of the Tatra Mts. 1:50 000. With explanations in Polish and English. Państwowy Instytut Geologiczny P.I.B.; Warszawa.

Gaździcki, A. 1974. Rhaetian microfacies, stratigraphy and facial development in the Tatra Mts. *Acta Geologica Polonica*, **24**, 17–96.

Głazek, J. and Sochaczewski, A. 1997. Trasa A 3. In: Głazek, J., Chowaniec, J., Poprawa, D., Przybycin, A. and Sochaczewski, A. (Eds), Przewodnik LXVIII Zjazdu Polskiego Towarzystwa Geologicznego. Zakopane, 101–113. Wydawnictwa Geologiczne; Warszawa.

Grabowska-Hakenberg, H. 1958. Geology of western part of Kopy Sołtysie. *Geological Quarterly*, **2**, 400–413. [In Polish with English summary]

Halicki, B. 1955. O przebiegu jednostek reglowych w dorzeczu Suchej Wody w Tatrach. *Acta Geologica Polonica*, **5**, 81–97.

Horwitz, L. 1931. Compte-Rendu des recherches geologiques pour la revision des feuilles "Nowy Targ" et "Szczawnica" de l'Atlas geologique de la Galicie. *Sprawozdania Państwowego Instytutu Geologicznego*, **6**, 786–792.

Horwitz, L. and Rabowski, F. 1929. Przewodnik do wycieczki Polskiego Towarzystwa Geologicznego w Pieniny, 1–49. Rocznik Polskiego Towarzystwa Geologicznego; Warszawa.

Jach, R., Rychliński, T. and Uchman. A. 2014. Sedimentary Rocks of the Tatra Mts, 278 pp. Wydawnictwa Tatrzańskiego Parku Narodowego; Zakopane.

Jach. R. and Rehakova, D. 2019. Middle to Late Jurassic carbonate-biosiliceous sedimentation and palaeoenvironment in the Tethyan Fatricum domain, Križna nappe, Tatra Mts, Western Carpathians. *Annales Societatis Geologorum Poloniae*, **89**, 1–46.

Janočko, J. 2000. Vysvetlivky ku geologickej mapie Spišskej Magury, 1:50 000. GUDŠ; Bratislava.

Kotański, Z. 1961. Tektogenese et reconstitution de la paleogeographie de la zone Haut-Tatrique dans les Tatras *Acta Geologica Polonica*, **11**, 187–413. [In Polish with French summary].

Kotański, Z. 1963. On the Triassic of the Haligowce Klippen and the palaeogeographic position of the Haligowce Series. *Acta Geologica Polonica*, **13**, 295–313.

Kotański, Z. 1973. Microfacies characteristic and stratigraphical division of carbonate Triassic rocks from the Zakopane IG 1 borehole. *Bulletin of the Polish Geological Institute*, **265**, 205–228.

Köhler, E. and Buček, S. 2000 Occurrence of the Maastrichtian Jarmuta formation in the Haligovce succession (Pieniny Klippen Belt). *Geologické práce, Zprávy*, **104**, 72–75.

Lefeld, J. 1968. Stratigraphy and palaeogeography of the High-Tatric Lower Cretaceous in the Tatra Mountains. *Studia Geologica Polonica*, **24**, 1–115. [In Polish with English summary]

Lefeld, J. 1974. Middle–Upper Jurassic and Lower Cretaceous biostratigraphy and sedimentology of the sub-Tatric succession in the Tatra Mts. Western Carpathians. *Acta Geologica Polonica*, **24**, 277–364.

Lefeld, J. 1988. Urgonian formations in the Carpathians. In: Nairn, E.M. (Ed.), Evolution of northern margins of Tethys. The results of IGCP Project 198. *Mémoires de la Société Géologique de France, Paris, Nouvelle Série*, **154**, 141–145.

Lefeld, J. 1999. Tectonics of the Subtatric Units, Eastern Tatra Mts. *Studia Geologica Polonica*, **115**, 139–166.

Lefeld, J. and Jankowski, J. 1985. Model of deep structure of the Polish Inner Carpathians. *Publications of the Geophysical Institute, Polish Academy of Science*s, **A-16**, 71–100.

Lefeld, J., Gaździcki, A., Iwanow, A., Krajewski, K. and Wójcik, K. 1985. Jurassic and Cretaceous litostratigraphic units of the Tatra Mts. *Studia Geologica Polonica*, **84**, 1–93.

Lugeon, M. 1903. Les nappes de recouvrement de la Tatra et l'origine des klippes des Carpathes. *Bulletin de la Société Vaudoise des Sciences Naturelles*, **39**, 17–63.

Łuczyński, P. 2002. Depositional evolution of the Middle Ju-

rassic carbonate sediments in the High-Tatric succession, Tatra Mountains, Western Carpathians, Poland. *Acta Geologica Polonica*, **52**, 365–378.

Mastella, L. 1975. Flysch tectonics in the eastern part of the Podhale Basin. *Annales Societatis Geologorum Poloniae*, **45**, 361–401.

Michalík, J. and Soták, J. 1990. Lower Cretaceous Shallow marine buildups in the Western Carpathians and their relationship to pelagic facies. *Cretaceous Research*, **11**, 211–227.

Michalík, J., Soták, J., Barath, I. and Vašiček, Z. 1989. Poznamky k llitologii,stratygrafii a biofaciam muranskeho suvrstvia a jeho postaveni v spodnokriedovom slede. In: Acta Geologica et Geographica Universitatis Comenianae. Geologica. Conference "50 Years of Teaching of Geology", 31–43. Geologický ústav Dionýza Štúra; Bratislava.

Mišik. M. 1959. Litologicky profil suvrstvim vyššieho liasu ("Fleckenmergel") Belanskych Tatier. *Geologicky Sbornik*, **10**, 183–190.

Myczyński, R. 1973. Middle Jurassic Stratigraphy of the Branisko Succession in the vicinity of Czorsztyn, Pieniny Klippen Belt, Carpathians. *Studia Geologica Polonica*, **42**, 1–122.

Nemčok, J., Bezak, Y., Biely A., Gorek, A., Gross, P., Halouzka, K., Janak, M., Kahan, S., Kotański, Z., Lefeld, J., Mello, J., Reichwalder, P., Rączkowski, W., Roniewicz, P., Ryka, W., Wieczorek, J., Zelman, J., 1994. Geological Map of the Tatra Mts, 1:50 000. Geologický ústav Dionýza Štúra; Bratislava. [In Slovak]

Nowicka, M. 1973. Opracowanie petrograficzne utworów mezozoicznych występujących pod serią reglową i utworów dolnego triasu, kajpru i synemuru serii reglowej z otworu wiertniczego Zakopane IG1. *Biuletyn Instytutu Geologicznego*, **265**, 241–278.

Oszczypko, N. 1997. The Early–Middle Miocene Carpathian peripheral foreland basin (Western Carpathians, Poland). *Przegląd Geologiczny*, **45**, 1054–1063. [In Polish with English abstract]

Piotrowska, K. 2009. Wykaz jednostek strukturalnych Tatr. LXXIX Zjazd Naukowy Polskiego Towarzystwa Geologicznego (Bukowina Tatrzańska, 2009), 27–28. Wydawnictwa Geologiczne; Warszawa.

Polak, M., Ondrejčkova, A. and Wieczorek, J. 1998. Lithostratigraphy of the Ždiar Formation of the Križna nappe (Tatry Mts.). *Slovak Geological Magazine*, **4**, 35–52.

Rabowski, F. 1959. High-Tatric series in Western Tatra. *Prace Instytutu Geologicznego*, **27**: 1–178. [In Polish with English summary]

Ramberg, H. 1963. Evolution of drag folds. *Geological Magazine,* **100**, 97–106.

Rychliński, T. and Szulc, J. 2005. Facies and sedimentary environments of the Upper Scythian–Carnian Succession in the Belianske Tatra Mts., Slovakia. *Annales Societatis Geologorum Poloniae*, **75**, 155–169.

Scheibner, E. 1963. Relationship between material and tectonic style and selective tectonics in the Klippen Belt of Western Carpathians. *Geologické práce, Zprávy*, **28**, 59–68.

Sokołowski, S. 1950. Les Tatry Bielskie. La geologie de leurs versants meridionaux. *Prace Państwowego Instytutu Geologicznego*, **4**, 1–56.

Sokołowski, S. 1973. Geology of Palaeogene and Mesozoic basement of the Podhale Trough southern limb in the column of the deep borehole in Zakopane. *Biuletyn Instytutu Geologicznego*, **265**, 5–103. [In Polish with English summary]

Sokołowski, S. 1978. Geology of the Sub-Tatric zone of the Tatra Mts. between the Sucha Woda Valley and the Białka River. *Prace Muzeum Ziemi*, **28**, 35–61. [In Polish with English summary]

Stille, H. 1924. Grundfragen der vergleichenden Tectonik, 443 pp. Borntraeger; Berlin.

Śmigielski, M., Krzywiec, P., Stuart, F., Persano, K., Sinclair, H. and Pisaniec, K. 2011. Realizacja projektu Thermo Europe w Tatrach. Tatrzańskie Warsztaty Geologiczne, Zakopane, 91.

Tollmann, A. 1973. Grundprincipien der alpinen Deckentektonik, 420 pp. Deuticke; Wien.

Trümpy, R. 1985. Die Plattentektonik und die Entstehung der Alpen. *Naturforschende Gesellschaft in Zürich*, **187**, 5–47.

Uhlig, V. 1890. Geologische Special Karte der Österreichisch-Ungarischen Monarchie, k.k. geol. R.A., Zone 8, Kol. XXIII, Alt Lublau (Stara Lubowla) und Szczawnica. Wien [also in Polish, Atlas geologiczny Galicyi, Komisya Fizyograficzna Akademii Umiejętności w Krakowie, 1914 – arkusz Szczawnica].

Uhlig, V. 1897. Geologie des Tatra Gebirges. Einleitung und Stratigraphisches Theil *Denkschriften der Akademie der Wissenschaften, mathematisch-naturwissenschaftliche Classe*, **64**, 643–684.

Wieczorek, J. and Barbacki, A. 1997. Geological cross-section through the Podhale Basin and its substratum based on seismic and borehole data: implications for geothermics. *Przegląd Geologiczny*, **45**, 84–86. [In Polish].

Wieczorek, J. and Olszewska, B. 1999. Mesozoic basement of the Podhale Basin (Western Carpathians, Poland). *Geologica Carpathica*, **50**, 84–86.

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