GEOLOGICAL AND GEOMORPHOLOGICAL SETTING

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The Carpathian mountain range forms characteristic arch bordering the Alps to the west and Balkans to the east. Polish segment of the Carpathians represents the part of this range most protruding to the north. In geological terms it is divided (Fig. 1A, B) into the Inner Carpathians composed of the Tatra Mountains and Podhale Basin region, and the Outer, Flysch Carpathians, which are separated by the Pieniny Klippen Belt (Książkiewicz 1972, Birkenmajer 1986, Oszczypko et al. 2006).

The Tatra Mountains are formed of the crystalline core (metamorphic rocks of the Western Tatra and Carboniferous granitoids of the High Tatra) as well as High-Tatric

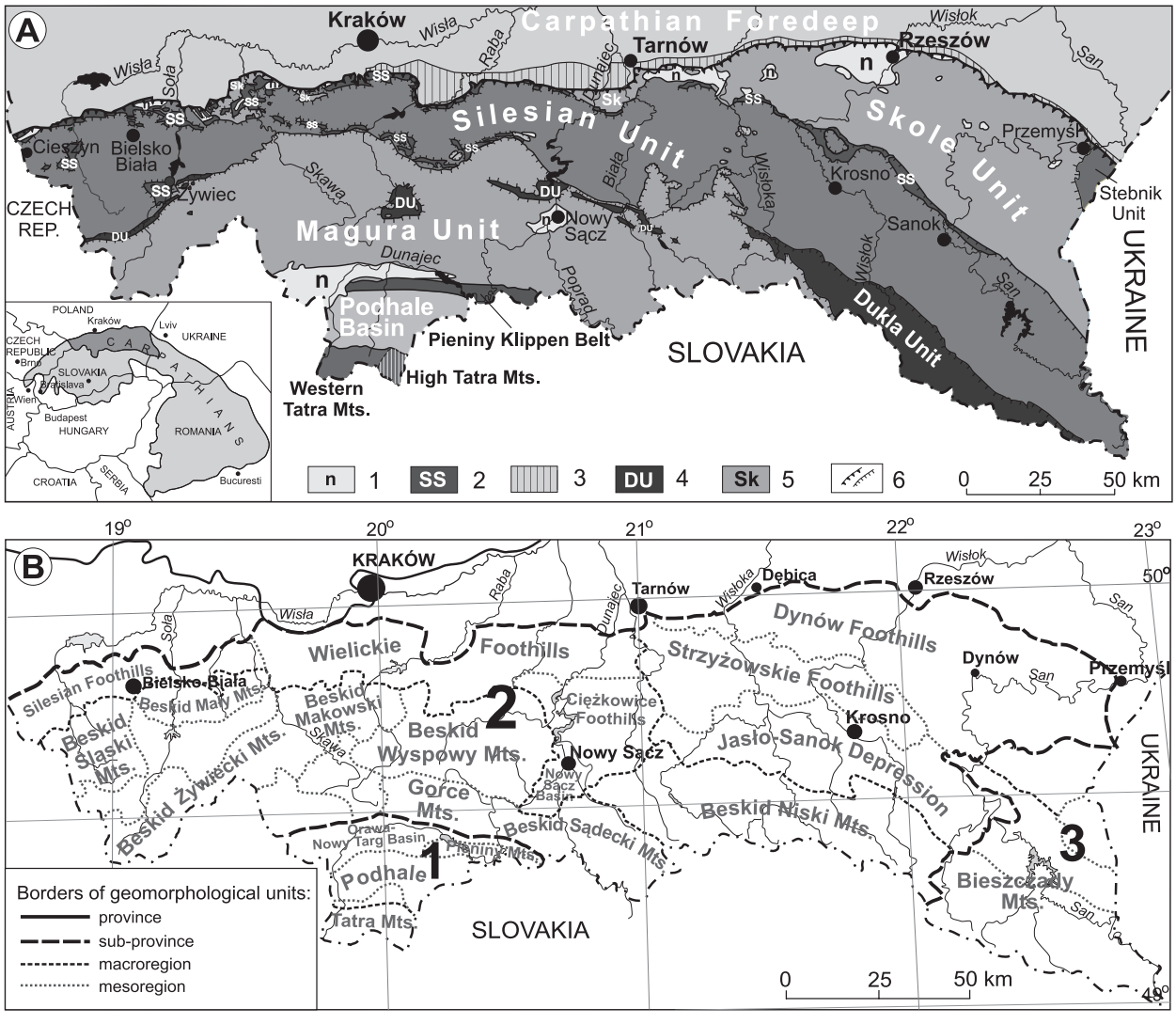

Fig. 1. **A** – Geological map of the Polish Carpathians (after Żytko et al. 1989): 1 – neogene deposits on flysch, 2 – sub-Silesian Unit, 3 – Zgłobice Unit, 4 – Dukla Unit equivalents, 5 – Skole Unit, 6 – overthrusts. **B** – Geomorphological units (after Starkel 1991). Carpathian sub-provinces: 1 – Inner Western Carpathians, 2 – Outer Western Carpathians, 3 – Outer Eastern Carpathhians

and Sub-Tatric nappes (Książkiewicz 1972, Oszczypko 1995). The crystalline core is overlain by shallow-marine sediments of the autochthonous High-Tatric series: sandstones, dolomites, limestones, shales and conglomerates deposited from the Triassic till the Middle Cretaceous. The High-Tatric nappe, built of analogous rocks, thrust over the autochthonous series from the south. In turn, the High-Tatric nappe is overlain by Sub-Tatric nappes: lower, called Križna nappe, middle – Choč nappe and upper – Stražov nappe, which are composed of sedimentary sequence of the Triassic-Lower Cretaceous age (Książkiewicz 1972, Oszczypko 1995, Jurewicz 2012).

The second element of the Inner Carpathians – Podhale Basin, is filled with sediments of the thickness ranging 2.5 km, representing Middle Eocene-Oligocene: conglomerates, nummulitic limestones and thick shale-sandstone series, called Podhale flysch. These rocks underwent slight tectonic deformations (Książkiewicz 1972, Oszczypko 1995).

The Pieniny Klippen Belt is a narrow geological structure of the tectonic suture zone character (Birkenmajer 1986, Oszczypko et al. 2006). The rocks constituting this structure form steep scales and folds, squeezed into the series of the Podhale flysch (to the south) or Magura Unit (to the north). The andesite intrusions took place along the northern margin of the Pieniny Klippen Belt in the Miocene.

The Outer, Flysch Carpathian range, called Beskidy Mountains represents the external zone of the fold-thrust orogenic unit of the Carpathians. Within the Polish territory this range is principally formed of siliciclastic-clayey flysch sediments (turbidites) of the Upper Jurassic-Early Miocene age, occasionally with marl and limestone inserts as well as radiolarites and hornstones (Książkiewicz 1972, Oszczypko 1995). Folded flysch rocks constitute several tectonic units (nappes): Magura Unit, Dukla Unit (and its equivalents), Silesian Unit, Sub-Silesian Unit and Skole Unit (Fig. 1A), overthrust each other and their foreland toward the north (Książkiewicz 1972, Żytko et al. 1989, Oszczypko 1995). In the north-eastern part of the mountain range the Stebnik (Sambir) Unit, composed of folded Miocene rocks occurs (Fig. 1A) (Oszczypko 1995, 2006). Folded flysch sediments are densely jointed and dissected with numerous faults. Several tectonic basins filled with Neogene sediments are situated within the Carpathian range; the largest in the Polish part are: Orawa-Nowy Targ Basin and Nowy Sącz Basin (Fig. 1B).

The northern foreland of the Carpathians, called Carpathian Foredeep, is a basin filled with Miocene sediments. The folded part of these sediments (allochthonous Miocene), called Zgłobice unit, forms narrow and discontinuous structure along the Carpathian margin (Fig. 1A).

The relief of the Carpathians strictly reflects the tectonics and lithology of rock massifs (Starkel 1969). Differentiated hardness of bedrock, tectonic framework as well as neotectonic activity of the Carpathians significantly influenced their morphology, characterized by the levelled relief (Zuchiewicz 2010). The Carpathian region is the area of mountainous and sub-mountainous morphology, which levelled relief (high belt of the Beskidy Mountains and low belt of their foothills) is connected with structural position of particular segments of the orogene during the thrusting stage of the Carpathians' evolution (Jankowski & Margielewski 2012, Jankowski et al. 2012). The highest structural and morphological position is occupied by tectonic elements formed in the earliest thrusting stage. They constitute the most elevated massifs of the Beskidy Mountains. The segments included in the late stage of the thrusting comprise the lower belt of the foothills (Jankowski & Margielewski 2012).

Within the Carpathians four general types of relief predominate: high-mountainous, intermediate- and low-mountainous, foothills and valley-bottoms (Starkel 1972). High mountains (1500–2000 m a.s.l.), characterized by glacial features and rocky slopes, are represented in Polish Carpathians by the Tatra Mountains (with the highest summit in the Polish territory – Rysy Mt., 2499 m a.s.l.), and in the Flysch Carpathians – by the massif of Babia Góra Mt. (1725 m a.s.l). Intermediate mountains (800–1300 m a.s.l.) of steep slopes are represented in the Carpathians by large mountain groups, as the Beskid Śląski, Beskid Żywiecki, Beskid Sądecki, and Gorce, as well as isolated massifs and ridges of the Beskid Wyspowy, Beskid Niski and Bieszczady standing 400–800 m above valleys. Low mountains are often isolated monadnocks with steep slopes standing 200–400 m above surrounding areas carved usually in the less resistant rocks (Starkel 1972).

The common features of the foothills' morphology are: wide ranges of various dip (10–40%) of slopes, usually concave-convex slopes and flat valley bottoms. In the Carpathians three types of foothills are distinguished: high foothills with ridges standing 200–300 m above valley bottoms, intermediate foothills standing 120–200 m and low foothills, 40–100 m high, carved in the least resistant rocks, occurring in the marginal zone of the Carpathians.

The hillslopes of the Carpathians are covered with blankets formed in the Quaternary period. They are built of silt-debris clays and sandy clayey silts, originated due to weathering of the bedrock in the periglacial environment and their gravitational displacement as well as accumulation, especially within the foothill belt (Stupnicka 1960, Cegła 1963, Starkel 1984). In the intermediate mountains the thickness of weathering blankets formed over sandstones is relatively small, ranging 70–80 cm (Kacprzak 2002–2003). In the foothills the thickness of such covers formed over the shale flysch series is higher, from several meters to more than 20 m, especially in the lower sections of slopes (Starkel 1969). Occasionally in

the foothill zone thick (from several to more than 10 m) blankets of loess (eolian) sediments were deposited in the Weichselian (Cegła 1963, Starkel 1984).

On the slope covers formed upon flysch formations, mainly acid loamy brown soils developed. The main soil types are cambisols, lithosols and regosols (Warszyńska 1995). Large river valley bottoms are covered with fluvisols.

In geographic terms Polish Carpathians are divided into three large morphostructural units of sub-province range (Fig. 1B), differing in the geological structure and morphology: Central Western Carpathians (Tatra Mountains and Podhale Basin), Outer Eastern Carpathians and Outer Western Carpathians (Starkel 1991). Within the Polish segment of the Carpathians, the Outer Eastern Carpathians are represented by the Bieszczady Mountains formed of rocks of the Silesian Unit (in southern marginal zone – also Dukla unit).

Toward the west, the Bieszczady Mountains pass into the Beskid Niski Mountains, belonging to the Western Outer Carpathians. This mountain range is lowered in relation to the neighbouring massifs (Bieszczady and Beskid Sądecki Mts.). The Beskid Niski Mountains are built of rocks of the Dukla Unit (the eastern segment of the range with Cergowa Mt.) as well as the Silesian and Magura Units (the central and western segment of the range). Within the zone of the Dukla Unit occurrence, the ridges are formed of thick-bedded Cergowa sandstones (Oligocene), whereas in the zone of the Silesian Unit occurrence they are formed of Ciężkowice sandstones and Krosno beds, and in the zone of the Magura Unit – of Magura sandstones. Differentiated thickness of rock series generated apparent variability of the relief. This is why the narrow, parallel ridges, homoclinal ridges as well as monadnock-type hills of the inversion relief and vast, flattened plateaus can be distinguished here (Starkel 1972, Baumgart-Kotarba 1974).

The Beskid Sądecki and the Gorce Mountains form wide and high, west-east elongated massif with culminations ranging 1100–1300 m a.s.l. The mountain groups of Jaworzyna Krynicka Mt., Radziejowa Mt., Lubań Mt., and the Turbacz–Gorce Ridge, separated by deep Poprad and Dunajec river valleys often of the gap character, are built of rocks representing the Magura Unit. The high ridges, built of thick-bedded Magura sandstones underlain by less resistant hieroglyphic beds are characterized by inversion relief (Baumgart-Kotarba 1974). Distinct slope breaks formed along the joint surfaces. The Beskid Sądecki and Gorce Mountains are characterized by relatively juvenile relief with narrow ridges, steep slopes and narrow stream valleys of varying gradient (Starkel 1972).

The Beskid Wyspowy Mountains situated north of the Gorce Mountains, are characterized by apparent differentiation of morphology, height ranging 900–1200 m a.s.l. and relative altitudes valuing 400–600 m (Starkel 1972). The western part of this range comprises "island-like" hills, which top parts are built of Magura sandstones underlain by less resistant hieroglyphic beds and variegated shales. Only occasionally single hills (Ciecień Mt.) are built of rocks belonging to the Silesian Unit (Burtan 1974). In the eastern and southern part of the Beskid Wyspowy Mountains compact mountain ranges, stretched west-east occur (e.g. Pasmo Łososińskie range).

The Beskid Makowski (Beskid Średni) Mountains, is composed of parallel ridges of the height 700–900 m a.s.l., built of Magura sandstones dipping toward the south (Starkel 1972). The levelled ridges are separated with narrow valleys of steep slopes, carved in less resistant hieroglyphic beds. The Beskid Makowski massif is dissected by gap valleys of Raba and Skawa rivers about 300 m deep.

The Beskid Mały Mountains form a compacted massif, divided by the Soła river valley gap into two parts, which are built of rocks of the Silesian and Sub-Silesian Units. The Sub-Silesian Unit occurs in its northern marginal zone, while the core part of the massif is formed of the Silesian Unit. The highest part of the ridges is built of Upper Cretaceous, thick-bedded Godula sandstones. The Beskid Mały Mountains are characterized by differentiated relief. The levelled ridges radially branched, are 800–900 m a.s.l. high. The main ridge and tributary ridges are dissected with deep stream valleys of the depth ranging 400–500m (Starkel 1972). Significant altitude differences and steep slopes (dipping up to 30°) as well as uneven valley bottoms indicate the young age of the relief.

The Beskid Śląski Mountains is a massif characterized by levelled ridges and altitude ranging 1000–1200 m a.s.l (Starkel 1972). It is formed of the Silesian unit. The ridges are built of Cretaceous sandstones of Godula beds, Lgota beds and Istebna beds, dipping to the south. The steep slopes, straight and convex, dipping 20–35°, are transformed by mass movements.

The Beskid Żywiecki Mountains, situated south of the Beskid Śląski Mountains, is the highest range of the Western Outer Carpathians, with the culminations of Babia Góra Mt. (1725 m a.s.l.) and Pilsko Mt. (1557 m a.s.l.). It was formed of the Magura Unit rocks: thick-bedded Magura sandstones usually regularly dipping, underlain by hieroglyphic beds (Sikora & Żytko 1960). The common features of the Beskid Żywiecki relief are compact ridges, deep and narrow stream valleys (up to 800 m deep) and convex, straight or concave-convex slopes dipping 20–30° (Starkel 1972). However, each mountain group is characterized by individual morphological features. Wielka Racza Mt. group has fork-like ridge pattern, Pilsko Mt. group is a dome-like massif, whereas Babia Góra Mt. range is composed of the homoclinal and inversion ridges (Starkel 1972).

The peripherial part of the Carpathians is represented by the belt of foothills. The most eastern segment of

Polish part of these foothills, the Pogórze Dynowskie (Dynów) Foothills, represents the Bieszczady Mountains foreland and is relatively wide (up to 30 km). It was shaped in the medium resistant rocks of the Skole Unit: Inoceramian beds and Krosno beds. It is vast but compact upland with wide, levelled ridges of the altitude 350–450 m a.s.l., divided by large river valleys into several plateaus (Starkel 1972). Slopes are usually convex-concave and steep (up to 20°) only in the upper parts of the stream valleys. Next to the west, the Pogórze Strzyżowskie Foothills, formed of rocks representing the Silesian Unit and, in marginal part, Skole Unit, is characterized by much differentiated morphology. Systems of parallel, spindle-shape ramparts (culminated at 480–540 m a.s.l.) and depressions are related to the geological structure. The culminations are built of hard Inoceramian beds or Ciężkowice sandstones. Occasional isolated monadnocks occur here (Starkel 1972). South of the Pogórze Strzyżowskie Foothills (and north of the Beskid Niski Mts.), the Jasło-Sanok Depression is situated. The area being the erosional-tectonic depression (in geological terms called Central Carpathian Depression) is the deep basinal structure of tectonic nature (Jankowski et al. 2012). The area of the Jasło-Sanok Depression comprises a range of flat troughs separated by low hills ranging 300–380 m a.s.l. (Starkel 1972).

The northern peripherial zone of the Beskid Makowski, Beskid Wyspowy and (partly) Beskid Niski Mountains is covered by vast hill range of the Pogórze Wielickie Foothills, formed of various rocks of the Silesian Unit and – in some places – Sub-Silesian and Magura Units. The Pogórze Ciężkowickie (Ciężkowice) Foothill – the southern sub-region of the Pogórze Wielickie Foothills, comprises compacted massif of high and intermediate foothills ranging 450–550 m a.s.l., formed of Silesian Unit and (in the southern part) Magura Unit rocks. Dome-shape hills built of sandstones are separated by narrow and deep stream valleys (Starkel 1972).

Narrow and very narrow (5–15 km) zone of the Pogórze Śląskie Foothills stretched between Skawa and Olza river valleys in the periphery of the Beskid Śląski and Beskid Mały Mountains, is a platform 400–300 m a.s.l. high, inclined to the north. Its surface, built of rocks of the Silesian unit, is composed of low hills separated with shallow (up to 50 m deep) stream valleys.