Karkonosze Mountains and Jelenia Góra Basin—Unique Variety of Granite Landforms

7

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Abstract

This chapter presents the essential geomorphological characteristics of the Karkonosze Mts. and Jelenia Góra Basin in southwestern Poland. These two adjacent mesoregions were mostly formed on bedrock of one plutonic body. Together, they present a unique example of a granite landscape differentiated by tectonic and denudational factors in Poland. The Karkonosze Mts., which also constitute a border area between Poland and the Czech Republic, are the highest mountain massif within the Sudetes and the entire Variscan belt of Central Europe. They are distinguished from other massifs in the Polish Sudetes by high local elevation, the presence of tree line, clear morphological evidence of Pleistocene mountain glaciation, and periglacial landforms. Harsh environmental conditions of the ridge parts are often compared to the areas of northern Fennoscandia, especially extensive summit planation surfaces, located at an altitude of 1200–1400 m asl and partially occupied by blanket mires. The morphology and origin of the Jelenia Góra Basin are no less intriguing. Its surface resembles an exposed weathering front. Numerous inselbergs rise above the basin floor, reflecting specific fracture patterns in granites and petrographic diversity. The whole area abounds in tors with a rich inventory of microforms due to granite weathering. In the past, the region was subjected to mountain floods at an exceptional scale. They have been well documented, as are mass movements on the mountain slopes, mainly debris flows. The area is also interesting because of the centuries-old human impact on geomorphology.

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Keywords

Granite landforms · Tors · Inselbergs · Planation surfaces · Neotectonics · Glaciations · Periglacial landforms · Debris flows · Floods · Human impact

7.1 Introduction

The Karkonosze Mountains are a massif in the western part of the Sudetes in southwestern Poland. It straddles the border with the Czech Republic, where its name is similar—*Krkonoše*—and comes from words meaning 'dwarf pine' and 'wear'. In German toponymy, the name is different and sounds *Riesengebirge*, which means the *Giant Mountains*. Although the Karkonosze with its highest peak, Śnieżka (1603 m asl), are the most elevated mountain massif among the Variscan ranges of Central Europe, they are classified as medium-elevation mountains (Germ. *Mittelgebirge*). Thus, the name of *Riesengebirge* emphasised a distinctive, steep rise of the Karkonosze above the floor of the adjacent Jelenia Góra Basin, with a total elevation difference of c 1000 m.

The Karkonosze and the Jelenia Góra Basin are linked by a common lithology—granite—and landforms related to its selective weathering—tors (Migoń 1996). The Karkonosze, their foothills, and the Jelenia Góra Basin are often called the Karkonosze region, and this area will be the subject of this chapter. In addition, the Czech part of the Karkonosze will be considered when necessary, although this area was described separately, similar in scope to this one, by Pilous (2016).

The Karkonosze have distinct, altitude- and vegetation-related morphodynamic zones, including those at the footslope, in largely deforested areas, on forested higher slopes, and above the tree line (Treml et al. 2008). The landscape above 1000 m asl hosts numerous landforms related to mountain glaciations (Nývlt et al. 2011; Engel et al. 2014), giving parts of the mountains specific features of an alpine

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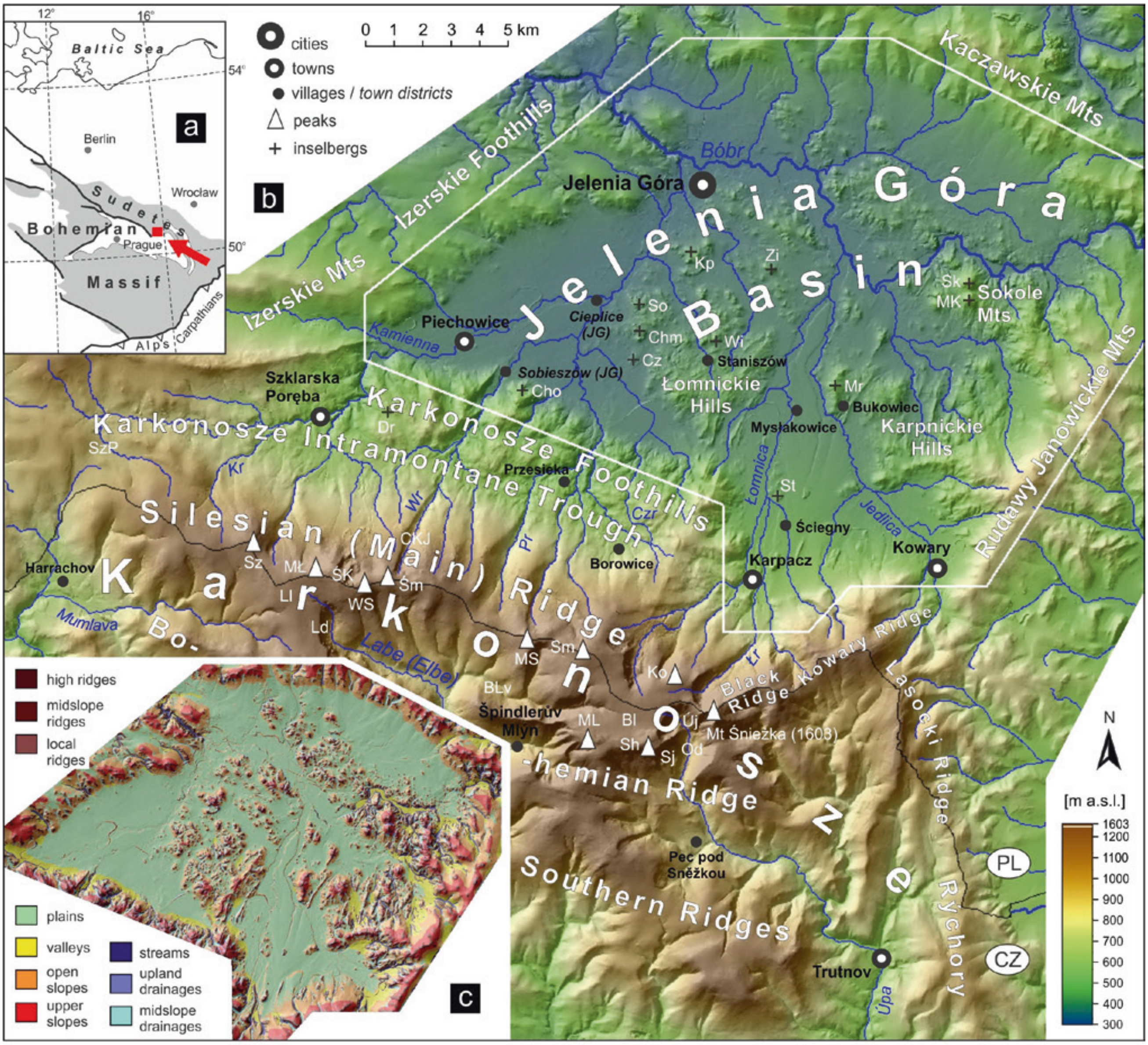
Table 7.1 Climatic conditions of the Karkonosze Mts and Jelenia Góra Basin (after: Sobik et al. 2019, supplemented)

	Jelenia Góra (342 m asl)	Karpacz (650 m asl)	Szklarska Poręba (643 m asl)	Mt Szrenica (1332 m asl)	Mt Śnieżka (1602 m asl)
Average annual temperature [°C]	7.9	6.7	6.5	1.9	0.7
Average January temperature [°C]	−2.4	−2.0	−2.1	−6.8	−7.0
Average July temperature [°C]	17.1	15.4	15.2	10.0	8.5
Average annual precipitation [mm]	699	997	1141	1429	1090.6
Annual average number of days with fog	68	61	34	274	296

environment (Fig. 7.1). In the highest altitude zones, landforms characteristic of the periglacial zone occur, including blockfields, cryoplanation terraces, solifluction lobes, and even relicts of rock glaciers. A distinctive feature of the Main Ridge of Karkonosze is the presence of extensive planation surfaces at the elevation of 1200–1400 m asl, partly occupied by blanket mires (Skrzypek et al. 2009). All this makes the Karkonosze more reminiscent of the *fells* of northern Fennoscandia, such as Pallas-Yllästunturi in Finland, than other European medium-altitude mountain massifs. These similarities also apply to climatic conditions (Table 7.1). The Karkonosze, together with the Izerskie Mts. to the west (Migoń 2016), are the significant orographic barriers in the path of Atlantic air masses traveling to the east. This results in the deformation of the airflow field and, consequently, in the occurrence of strong winds, frequent fog (Błaś et al. 2002), and significant moisture input from the atmosphere, including frost and rime (Migała et al. 2002). Rainfall during summer sometimes exceeds 250 mm/day, which is peculiar to this climatic zone and results in debris flows and dynamic fluvial processes in river valleys. Winter snow conditions are conducive to avalanches. In terms of geomorphology, the Jelenia Góra Basin is no less unique (Fig. 7.2). Its undulating to hilly

Fig. 7.1 View of the ridge part of Karkonosze Mts. In the foreground are the twin glacial cirques of Śnieżne Kotły undercutting the summit planation surface, periglacial granite blockslopes in the foreground and left of the cirques. The highest peak of Mt. Śnieżka in the background, to the left (photograph courtesy of B. Schutty, facebook.com/schuttyphotography)



Bl – Bílá louka
BLv – Bílé Labe valley
Chm – Chmielnik
Cho – Chojnik
CKJ – Czarny Kocioł Jagniątkowski
Cz – Czubek
Czr – Czerwonka river
Dr – Drewniak
Ko – Kopa
Kp – Kopki
Kr – Kamieńczyk river
Ld – Labský důl
Ll – Labska louka
Łr – Łomniczka river
MK – Mt Krzyżna
ML – Mt Luční
MŁ – Mt Łabski
Mr – Mrowiec
MS – Mały Szyszak
Od – Obří důl
Pr – Podgórna river
Sj – Studniční jamy
Sk – Sokolik
Sm – Smogornia
So – Sołtysia
St – Straconka
Sz – Szrenica
Szp – Szklarska pass
ŚK – Śnieżne Kotły
Śm – Śmielec
Új – Úpská jáma
Wi – Witosza
Wr– Wrzosówka river
WS – Wielki Szyszak
Zi – Ziębiniec

Fig. 7.2 Topographic situation of the Karkonosze Mts. and Jelenia Góra Basin. **a** Location within the Bohemian Massif (red rectangle). **b** Hypsometric map with hillshade, names of objects mentioned in the chapter are given, white frame marks the range of the map in figure **c**. **c** Inselbergs inside the Jelenia Góra Basin. Landforms were extracted automatically based on geomorphometric modelling with the use of topographic position index (Wilson and Gallant 2000)

relief, with inselbergs, tors, and boulders, is compared to an exposed weathering front and one of the model types of granite morphology (Migoń 1997), referred to as multiconcave relief. It has no equivalent anywhere else in Poland.

Exploration of the Karkonosze massif started with an intensive search for gold and gemstones between the eleventh and thirteenth centuries and for metal ores (silver, tin, lead, iron, copper, and others), particularly intensive since the twelfth century. Since the Middle Ages, the Karkonosze were deforested for the local glass industry and used for cattle grazing. In the seventeenth century, settlement pressure led to the establishment of numerous villages, even at altitudes of 900 m and above (Szmytkie and Kasprzak 2016). Roads, embankments, and other man-made landforms were created.

At the end of the nineteenth century, the need to protect the natural values of the Silesian part (north side) of the Karkonosze region began to be recognised, primarily because of the impoverishment of the habitats of rare plant and animal species. The first protected areas were designated in 1929, and in 1933, the Karkonosze were declared a plant protection area and the first reserves under state protection were established. It was also the time when impressive granite tors started to be treated as nature monuments. After World War II, the new Polish administration led to the creation of the Karkonosze National Park in 1959 (now with an area of 5951.42 ha and 13,093 ha of buffer zone), which together with the Czech Krkonošský národní park established in 1963, since 1992 forms a UNESCO Biosphere Reserve (MaB) with a total area of over 60 000 ha.

7.2 Geological Setting

The Karkonosze are located in the northeastern part of the Bohemian Massif and were uplifted during the late stages of the Alpine orogenesis. The activity of tectonic processes was most significant from the middle Miocene to the beginning of the Quaternary, i.e. roughly between 16 and 2.6 Ma (Ziegler and Dèzes 2007; Jarosiński et al. 2008, 2009). However, geologically, they are part of an old Variscan orogen, formed in the late Devonian and Carboniferous. They represent its deeper part, exposed due to erosive removal of much of the cover rocks. Its central part is occupied by a granitoid pluton formed in the late Carboniferous, within only a few hundred thousand years, between 313 and 312 Ma (Žák et al. 2013; Kryza et al. 2014; Kusiak et al. 2014), at a depth of 7–10 km. The outcrop of the pluton is elongated in the ENE–ESE direction (Fig. 7.3), which is about 60 km long and 10–25 km wide. The marginal parts of the pluton are covered by a metamorphic complex represented by tectonically deformed rocks.

The plutonic rocks of the Karkonosze are formed by several varieties of granite of different grain sizes and mineral compositions (Borkowska 1966). The most common variety is the porphyritic granite with large feldspar crystals in the medium-grained mineral mass and common biotite schlieren. It occurs mainly in the Jelenia Góra Basin and on the lower slopes of the Karkonosze. The mid-slopes are composed of porphyritic granite or granite with occasional large feldspars; however, this boundary is challenging to capture cartographically (Mierzejewski 2005). The Main Ridge is formed by granites with singular large feldspars and equigranular granites. In the region, there also occurs aplite granite with frequent feldspar–quartz intergrowths. During the solidification of the granitic body, veins of microgranite, quartz, aplite, lamprophyre, and pegmatite were formed from remnant magma. Granitic rocks are characterised by a quasi-regular pattern of fractures resulting from horizontal extension of the rock mass (Aleksandrowski et al. 2019).

Minor intrusions of Cenozoic age occur within granites. Due to their location and size, basaltoids are the best known. The age of this rock was determined to be 26 ± 1.2 Ma (Pécskay et al. 2004), and based on detailed chemical analyses, it is classified as basanite (Kozłowska-Koch 1987). The intrusion, regarded as subvolcanic (Zagożdżon and Zagożdżon 2006), is exposed in the wall of the glacial cirque of the Mały Śnieżny Kocioł, at approx. 1400 m asl.

7.3 Main Landscape Features

7.3.1 Karkonosze Mountains

The length of the Karkonosze range is about 40 km, and its width varies from 8 to 20 km. The area of the mountains is about 650 km^2, of which 185 km^2 (28.5%) belongs to Poland. The Karkonosze consist of the latitudinally running Silesian Ridge, also called the Main Ridge, Black Ridge, and Kowarski Ridge, from which shorter ridges perpendicular to them branch off (Fig. 7.2). On the Czech side, one can distinguish the Bohemian Ridge and the Southern Ridges. In the east, the nearly meridional Lasocki Ridge connects with the Rudawy Janowickie Mts. to the northeast, whereas its extension on the Czech side is known as the Rýchory. The lower parts of the Karkonosze on the northern side of the massif are called the Karkonosze Foothills. They are separated from the Main Ridge by the range-parallel Karkonosze Intramontane Trough.

The Karkonosze form an asymmetric horst, with the steeper slope descending towards the north. This asymmetry results from the nonuniform tectonic uplift of the massif, more substantial in its granite part with lower rock density in relation to the metamorphic complex in the south (Migoń 1991; Pilous and Migoń 2007). The upper part of the Main Ridge is morphologically diversified and contains extensive summit surfaces of low relief. The largest, located at the altitude of 1350–1450 m asl, are the flattenings of Równia pod Śnieżką, Bílá louka, and Labska louka (Fig. 7.4). There are no other such extensive, high-elevation planar surfaces in the whole Sudetes. The slopes of the Karkonosze are generally long and uniformly inclined, rarely incised by river valleys. These valleys are deep, especially on the southern side of the mountains. The valley bottoms of the Labe and Úpa rivers are 500–600 m below the water divides.

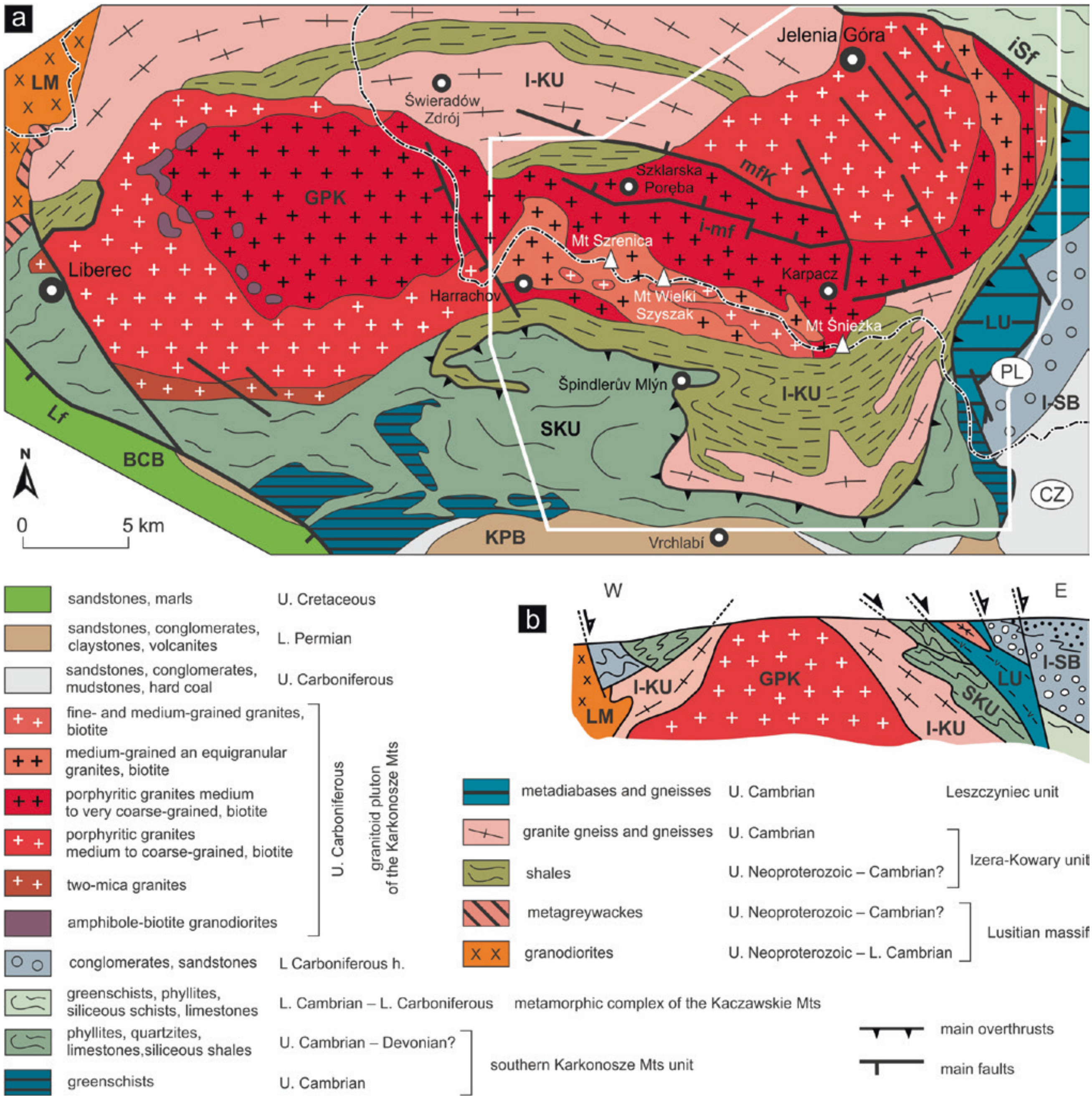


Fig. 7.3 Geology of the Karkonosze Mts. and Jelenia Góra Basin. **a** Simplified geological map. **b** Synthetic cross-section (without scale). Explanations: I-KU—Izera-Kowary unit, LU—Leszczyniec unit, SKU—southern Karkonosze unit, LM—Lusatian massif, I-SB—Intra-Sudetic Basin, KPB—Karkonosze Piedmont Basin, BCB—Bohemian Cretaceous Basin, GPK—granitoid pluton of the Karkonosze; faults: mfK—marginal fault of the Karkonosze, Lf—Lusatian Fault, i-mf—intra-mountain fault, iSf—Intra-Sudetic Fault. The white frame delimits the area shown in Fig. 7.2. Compiled from Žák and Klomínský (2007) and Aleksandrowski et al. (2019), modified by the author

7.3.2 Jelenia Góra Basin

The Jelenia Góra Basin has an area of about 270 km^2. Its floor has a rhomboidal shape and is located at 350–400 m asl. Isolated hills or groups of hills rise above the bottom of the basin (Fig. 7.2c). In its central part, they reach a height of 450–500 m asl (Łomnickie Hills), and in the eastern part, they even rise to 550–650 m asl (Sokole Mts.). The highest point of the Jelenia Góra Basin is Mt. Krzyżna (654 m asl), and the lowest one is in the riverbed of the Bóbr River west of the town of Jelenia Góra (324 m asl). The basin is surrounded by mountain ranges rising 250–1000 m above

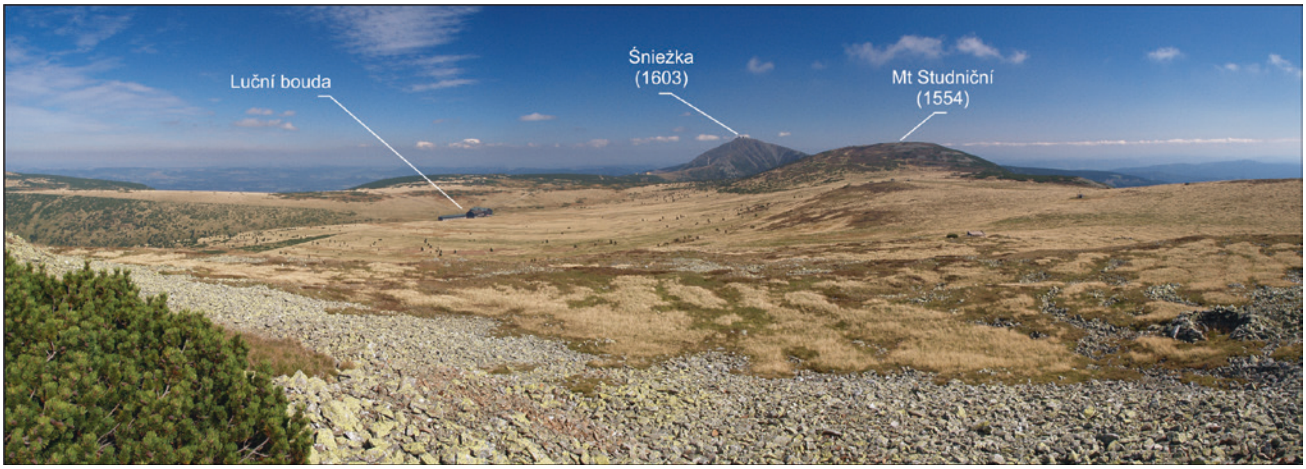


Fig. 7.4 View from the slope of Mt. Luční on the vast summit planation surface at an altitude of c. 1500 m. Its part, on the Polish side of the border, is called Równia pod Śnieżką (photograph by M. Kasprzak)

its floor. Only the north-western border with the Izerskie Foothills is lower and does not exceed 150 m high.

The occurrence of inselbergs determines the extraordinary landscape of the Jelenia Góra Basin (Migoń 1993, 1997). The hills in the vicinity of Cieplice (hills: Sołtysia, Chmielnik, Czubek), in the area of Czarne (Kopki, Ziębiniec), east of the centre of Jelenia Góra (Paulinum, Kamienista), and Witosza hill on the eastern outskirts of the village of Staniszów stand out. However, one of the most characteristic and best-recognised views in the Sudetes is the panorama of the Sokole Mts. against the background of the Karkonosze (Fig. 7.5). The Sokole Mts. are situated in the north-eastern part of Jelenia Góra Basin and consist of six hills. The two highest, Mt. Krzyżna (654 m asl) and Sokolik (623 m asl), rise about 200 m above their surroundings.

7.4 Long-Term Landscape Evolution

The long-term denudation history of the Karkonosze region has been inferred from several complementary sources of information, mainly based on thermochronological data (Danišík et al. 2010; Sobczyk et al. 2015), examination of sedimentary records in the adjacent areas, and landform analysis (Migoń and Danišík 2012). The unroofing of the granite pluton is dated to pre-Middle Triassic times, around 230 Ma (Aleksandrowski et al. 2019), or even earlier, to the Early Permian, around 300–270 Ma (Teisseyre 1957). Three phases of increased denudation were distinguished: the early Permian, the early Triassic, and especially the late Cretaceous. Erosion rates in the latter period may have reached up to 300 m/Ma. Since the turn of the Upper Cretaceous, rocks with a thickness of 3.6 to 6 km have been removed, most of them between 100 and 75 Ma ago. No more than 1.2 km of rock was lost after this period.

The most pronounced fault-generated slopes form the margin of the Karkonosze Foothills on the border with the Jelenia Góra Basin. They stretch from the town of Piechowice in the west to the town of Kowary in the east (Fig. 7.2). The escarpment is most pronounced between Piechowice and the village of Miłków, reaching a relative height of 130–150 m near the village of Podgórzyn and 250 m above Piechowice. The effects of block movements are well visible in the valley morphology (Migoń 1992), also in the area of the Karkonosze Intramontane Trough, which is most probably a graben or half-graben, although its structural preconditioning was indicated before (Cloos 1925; Jahn 1954). In the area of the Karkonosze Foothills, indicators of non-uniform uplift include wind gaps within water-divide ridges and deep, heavily indented gorge sections formed by the largest watercourses.

The Jelenia Góra Basin is polygenetic, and particularly, its boundaries have different genesis (Migoń 1993). The northern and western border with the Kaczawskie Mts. and Izerskie Foothills were formed under protracted etchplanation, lasting through the whole Palaeogene to the Late Miocene. The southern (described above) and eastern borders of the basin are escarpments of tectonic origin, younger than the other borders. During their formation (Pliocene?), the previously formed northern edge of the Basin was additionally uplifted along the Intra-Sudetic Fault (Fig. 7.3). The floor of the Basin represents the effect of selective weathering of granite, most substantial within more densely fractured and plagioclase- and biotite-rich parts of the pluton, and less efficient in the massive dome-shaped compartments, equigranular granites and quartz-rich granites (Migoń 1997; Kajdas et al. 2017). Therefore, the latter are marked by morphological domes and ridges. In places subject to stronger weathering, troughs and secondary basins have developed. This resulted in a hilly relief with rocky hills (inselbergs).

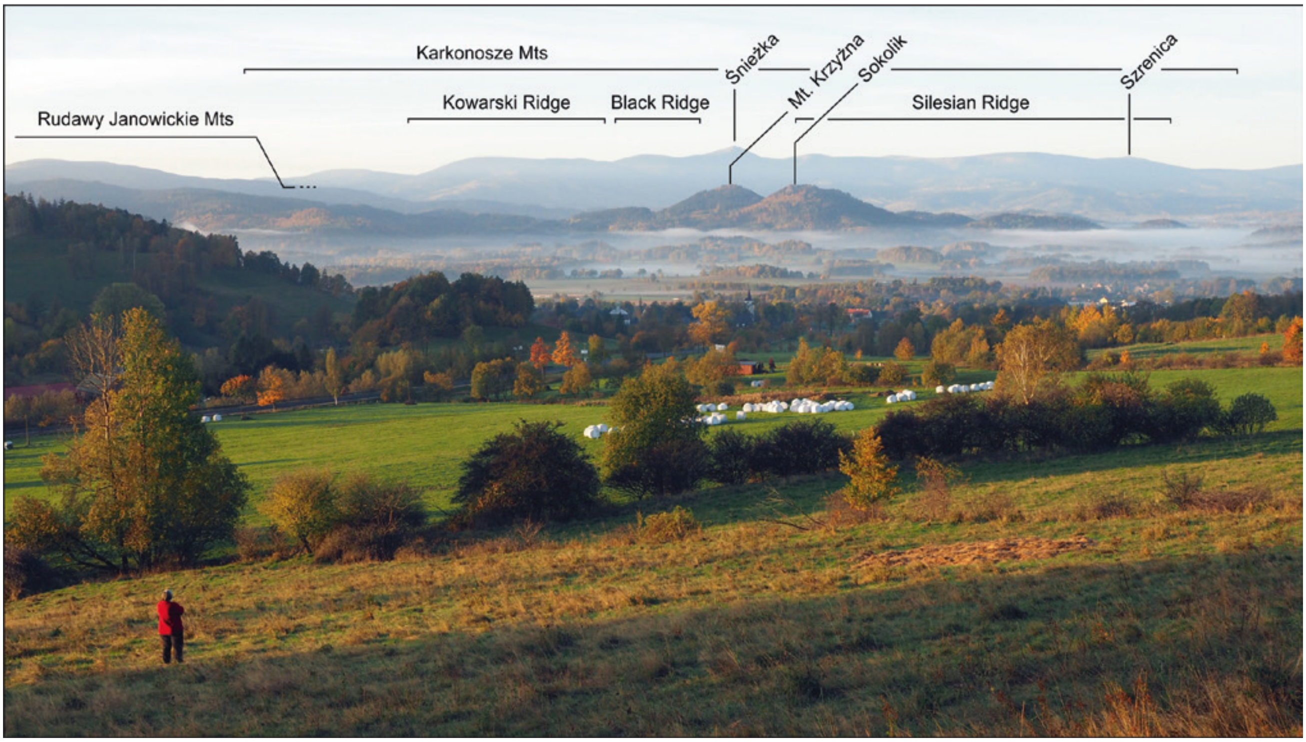


Fig. 7.5 Eastern part of the Jelenia Góra Basin and Karkonosze Mts., a view from the northeast (Radomierska Pass). Note the inselbergs of the Sokole Mts. (Mt. Krzyżna and Sokolik) in the centre of the plan (photograph by M. Kasprzak)

7.5 Specific Landforms

7.5.1 Tors

Tors of various sizes and with numerous peculiar microforms of selective weathering on their surfaces are characteristic denudational landforms of the Karkonosze region (Fig. 7.6). The Karkonosze granite is very heterogeneous and characterised by a great variety of textures. Additionally, it is not uniformly fractured. Local occurrence of particularly fine-grained variants is expressed by the presence of rocky, cone-shaped hills (Mt. Łabski, Mały Szyszak, Szrenica). The tors built of this granite variant are mainly angular in cross-section and consist of regular cuboid blocks forming walls and rock castles. Porphyritic granite, on the other hand, is much more varied, both in terms of its mineralogical composition and orientation of fractures. The weathering is therefore very selective and its efficacy varies from place to place. These tors are usually irregular in shape, formed by chaotically overlapping boulders with varying degree of roundness. Numerous large, loose blocks of granite occur alone or in clusters.

The tors are found in all altitude zones, including the main ridge of the Karkonosze. Their highest location is at 1491 m asl (Kasprzak and Traczyk 2019). They are most numerous at altitudes of 500–700 m asl, on the peaks of the Karkonosze Foothills, and in the 1000–1100 m asl belt, on the second-order ridges branching from the Main Ridge. They occur as singular forms or large clusters.

In the Jelenia Góra Basin, tors accompany inselbergs. One specific locality is Mt. Witosza (484 m asl) near the village of Staniszów. Its attractiveness is mainly due to magnificent rock walls up to 20 m high, widespread talus of massive blocks and boulders, narrow clefts, weathering pits of various sizes, rock shelters, and non-karstic caves (Migoń 1997). These rock formations were created where the regular, rectangular joint patterns in the granite bedrock play a subordinate role in respect to the concentric (dome-like) fracture system. The latter consists of curved joint surfaces, convex upwards, of probable stress-release origin (Migoń 1993). Similar dome forms occur in the Karkonosze Foothills, an example being Mt. Chojnik (627 m asl).

The Sokole Mts. have the highest density of exceptionally large, tower-like tors. The tallest ones can be found at the highest elevations. The reason for the evolution of these forms invariably lies in the properties of granite. Mt. Krzyżna and Mt. Sokolik are built of aplitic granite (aplogranite), a variety of granite with reduced content of sodium-calcium feldspar (plagioclase) and biotite. The predominance of potassium feldspars and quartz makes the rock more resistant to weathering.

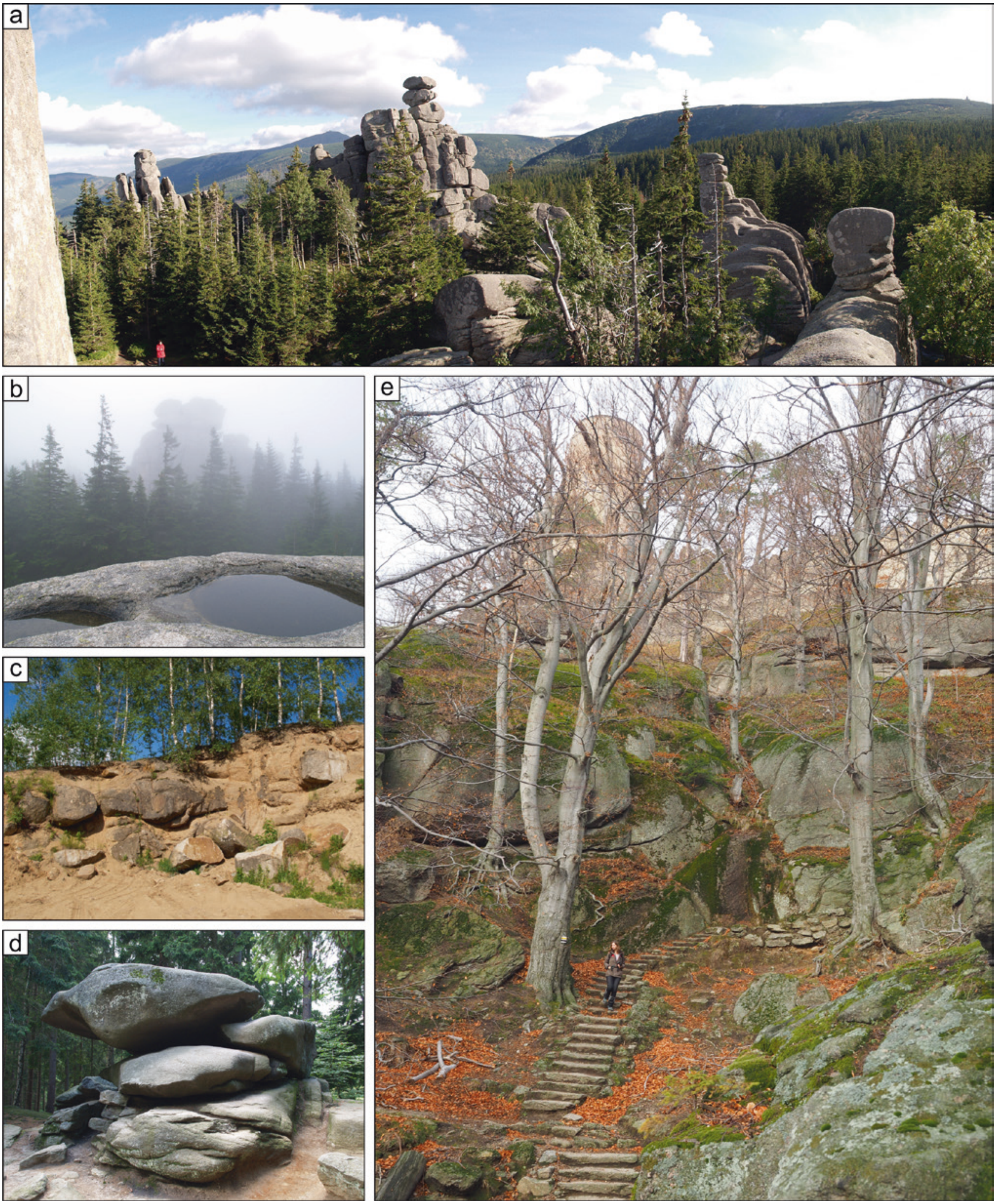


Fig. 7.6 Tors of the Karkonosze Mts. and Jelenia Góra Basin. **a** Pielgrzymy tor group. **b** Weathering pits as a characteristic example of microforms due to surface weathering (Pielgrzymy tor). **c** Selective weathering of granite, with core stones embedded in sandy-gravelly mass, exposed in the former quarry on the Straconka hill, Jelenia Góra Basin. **d** Balancing rock with a movable upper boulder. **e** Medieval Chojnik castle integrated with granite outcrops in the surroundings (photographs by M. Kasprzak)

Among peculiarities of the tors in the Karkonosze region are balancing rocks—loose, locally fairly large boulders of granite resting on the base with a minimal surface of contact (Fig. 7.6d). As a result, it is possible to change their position even by pushing them by hand or loading their edges. The best-known balancing rock occurs in the town of Szklarska Poręba. Others can be found in the Karkonosze Foothills and include the Waloński Kamień tor in the village of Przesieka and two balancing rocks on Drewniak hill above Piechowice.

7.5.2 Glacial Landforms—Evidence of Pleistocene Glaciations

The Karkonosze are characterised by the best-developed Pleistocene glacial landforms in the Bohemian Massif, which were the focus of pioneering research conducted at the turn of the twentieth century (Partsch 1882, 1894; Berg 1915; Fig. 7.7). At least 12 snow accumulation zones and glaciers up to 5 km long functioned here simultaneously, and the existence of further ones remains a matter of speculation (Fig. 7.8). Ice tongues were supplied by well-developed cirques, including six on the Polish side of the mountains (twin cirques of Śnieżne Kotły, Czarny Kocioł Jagniątkowski, twin cirques of Mały and Wielki Staw, Łomniczka cirque). Glaciers flowed mainly towards the northern and eastern side of the massif, leaving the most spectacular glacial cirques inset into the edges of summit planation surfaces. Only the double cirque of Kotelní jamy on the Czech side faces south. There are no distinct landforms of this type exposed to the west. This asymmetry was explained by Jeník (1961), who drew attention to the existence of a particular anemo-orographic system. The deep valleys of the Mumlava and the Bílé Labe (Elbe), with their latitudinal course, channelise a local, western circulation of air masses, thanks to which the snow accumulated on the summit flats is then blown to the east, to the lee-side.

A typical example of glacial erosion is presented by the Śnieżne Kotły cirques (Fig. 7.1). They are twin glacial cirques with headwalls about 100 m high and slopes of 65–70°. The most distant terminal moraines are 20–30 m high, while at the mouth of the cirques, there are larger forms with a height of 40–60 m, perhaps hiding, however, the protuberances of the granite bed (Jahn 1960; Traczyk 2009). The height of the intermediate terminal and lateral moraines is, on average, 10–15 m. The glacier tongue reached a maximum distance of 2.4 km from the back wall of the cirque and descended to an altitude of 920–950 m. The glacial landscape is different in the headwater parts of the Łomnica Valley, where two lakes were created: Mały Staw (Small Lake) and Wielki Staw (Big Lake). The latter is the largest (8.32 ha) natural reservoir in the Sudetes (Kasprzak 2021).

The timing of glaciations in the Karkonosze was long debated. The distinctiveness of local moraines allows us to conclude that there were at least three main, separate phases of glacier development (Traczyk 2009). Initially, based on the now contested TL dating, Chmal and Traczyk (1999) indicated that moraines in front of the Śnieżne Kotły cirques were formed in the interval from about 95 to 10 ka BP. More recent studies based on ^{10}Be exposure ages of morainic blocks at the outlet of Śnieżne Kotły area and in the middle part of the Úpa Valley (Obří důl) suggest that the oldest preserved moraines represent early phases of the Last Glacial Maximum (LGM), 24–21 ka (Engel

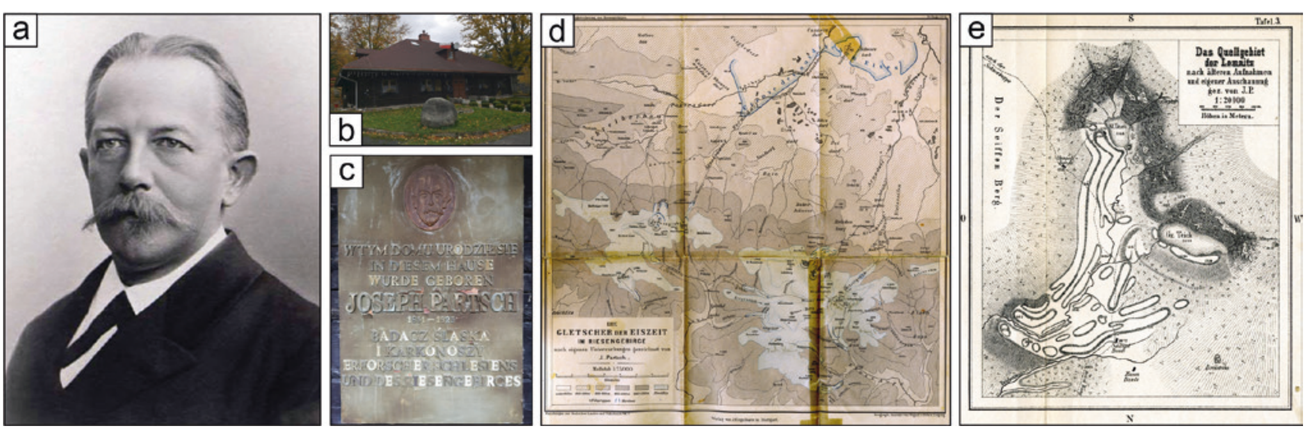


Fig. 7.7 Legacy of Joseph Partsch (1851–1925), pioneer of glacial research in the Karkonosze Mts. **a** Partsch, born in Szklarska Poręba, later rector of the University in Breslau (today University of Wrocław), is considered one of the most prominent geographers of the late nineteenth and early twentieth centuries. **b, c** Plaque commemorating Partsch can be found on the building of the former Josephine glassworks in Szklarska Poręba. **d** Map with the extent of the Scandinavian ice sheet in the Jelenia Góra Basin and the ice cap over the Karkonosze (Partsch 1882), according to contemporary knowledge mountain glaciers occupied only some valleys of this massif. **e** Map of glacial landforms in the Łomniczka Valley (Partsch 1882). Photographs: collection of the University of Wrocław, public domain (**a**), M. Kasprzak (**b**, **c**)

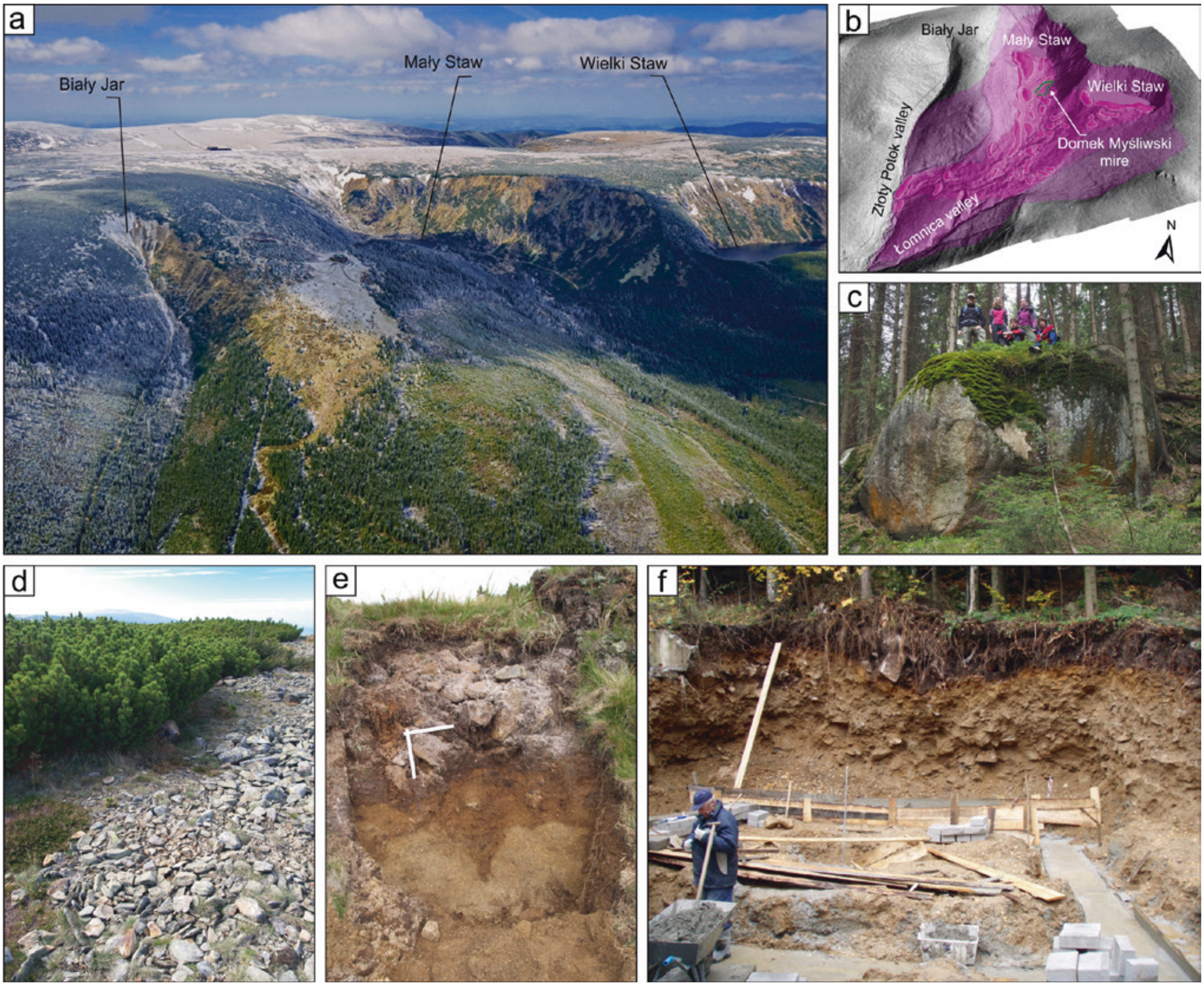


Fig. 7.8 Examples of landforms and sediments formed in glacial and periglacial conditions. **a** Nivation hollow of Biały Jar and glacial cirques filled with lakes, Mały Staw (volume 86.9 m^3, 4.6 m depth) and Wielki Staw (741.5 m^3, 23.5 m). **b** Moraines from at least three glaciations in the Łomnica Valley, the glacier crossed the watershed and occupied a part of the Złoty Potok Valley (cf. Fig. 7.4e, DTM source: CODGiK, geoportal.gov.pl, PD), there was a third lake in the Łomnica Valley, today filled by mineral and organic sediments (peat bog near Domek Myśliwski hut). **c** One of giant moraine boulders in the Złoty Potok Valley. **d** Patterned ground on the Black Ridge. **e** Pseudomorphosis of an ice wedge on the main ridge. **f** Coarse-grained slope cover transformed by solifluction in Karpacz Wilcza Poręba. Photographs courtesy of B. Schutty, facebook.com/schuttyphotography (**a**) and by M. Kasprzak (**c**–**f**)

et al. 2014). ^{10}Be dating of stable morainic boulders and rock samples from cirque headwalls in the Łomnica and Łomniczka Valleys indicated an even younger age (Engel et al. 2011). These results show that the lowest moraine ridges in the Łomnica Valley were formed around 17–16 ka BP. Moraines deposited in cirques were formed at 14–12 ka BP, and remnants of cirque glaciers existed as late as 9–8 ka BP. However, exposure ages from the lowermost zone refer to the termination of the post-depositional moraine surface transformation rather than the deposition period. Particularly interesting information was obtained from the lake sediments in the Labsky důl Valley on the Czech side of the massif (Engel et al. 2010). The retrieved core documents changes in the environment of the Karkonosze over the last 30 ka. The sedimentary record suggests that the bottom of the cirque was ice-free at the end of MIS 3 and that the glaciation re-developed during MIS 2. In conclusion, the local glaciation in the Karkonosze was possibly more extensive during the LGM than in earlier phases of the Weichselian glacial (Engel et al. 2014), contrary to the views presented before (Traczyk 1989). The preserved landforms and settlements do not allow unambiguous interpretations of the landscape evolution during the earlier glaciations.

A separate and unfinished scientific discussion concerns the maximum extent of the Scandinavian ice sheet and its presence in the Jelenia Góra Basin (Hall and Migoń 2010). Currently, contrary to earlier, long-standing opinions, it is claimed that the ice sheet intruded into the intramontane basins of the Sudetes only during the Elsterian glaciation (Badura and Przybylski 1998; Michniewicz 1998). It probably did not reach much beyond the Bóbr river valley in the northern part of the Basin, as Berg (1927, 1940a, b) implied.

7.5.3 Periglacial Conditions and Frost-Induced Landforms

The high-elevation parts of the Karkonosze are the arena of frost processes (Büdel 1937; Traczyk and Migoń 2000; Křížek 2007; Kasprzak et al. 2021). Well visible legacy of the Pleistocene periglacial environment includes frost cliffs and cryoplanation terraces. Well-developed complexes of such forms are found on the Black Ridge, Mt. Smogornia, and Mt. Wielki Szyszak. On the Czech side of the border, such forms are best developed on the northern slopes of Mt. Luční hora.

Coarse-grained slope covers are common. On granite bedrock they may contain large boulders, as it is the case on the slopes of Mt. Łabski, Wielki Szyszak and Mały Szyszak, Śmielec, Szrenica, and Smogornia peaks. On the outcrops of metamorphic rocks (schists and gneisses), they consist of somewhat smaller fractions (e.g., the slopes of Mt. Śnieżka and the Black Ridge). Blockfields occupy the upper parts of the Main Ridge above 1200–1250 m asl, forming extensive surfaces lacking vegetation cover. Smaller, non-forested blockfields are also found in the central parts of the slopes (e.g., in the Łomniczka Valley, on the northern slopes of Mt. Kopa). They have areas ranging from 0.004 to 77 ha (Kasprzak and Traczyk 2019). They also occur at lower altitudes, but are covered by forest (e.g., lower sections of the slopes of Mt. Szrenica or Mt. Łabski). Surface morphology of blockfields located above the upper forest boundary shows the presence of lobes, boulder steps, and closed depressions. During the cold periods of the Pleistocene, in places cemented by ground ice, boulders moved independently from the rest of the blockfields in a manner similar to rock glaciers (Chmal and Traczyk 1993; Żurawek 1999).

Forms of frost sorting are associated with blockfields on the summit plateau, including fields of patterned ground on the Black Ridge, on the summit plain of Równia pod Śnieżką, slopes of Mt. Luční hora and Wielki Szyszak (Fig. 7.8). Patterned ground is generally in the form of stone circles with a diameter of 1–3 m, where debris surrounds an earthy island (Křížek and Uxa 2013). The debris-loamy slope covers common on the slopes were transformed by solifluction (Büdel 1937).

The periglacial-like conditions persisted in some areas of the mountains despite climate warming in the Holocene. During the Little Ice Age, i.e. as recently as 100 years ago, the average annual temperature of the highest parts of the Karkonosze did not exceed 0 °C (Migała et al. 2016). Although the number of days with negative temperatures is lower than in the High Arctic or the Alps, there are more days with the temperature passing through 0 °C than in the aforementioned areas (Troll 1944). Therefore, under specific terrain conditions, especially on moist, clayey ground, further development of patterned ground still occur (Traczyk 1992; Soukopová et al. 1995).

7.5.4 Fluvial Geomorphology as a Response to Tectonics and Climate Changes

The Labe (Elbe), one of Europe's longest rivers, has its source in the Karkonosze, south of Mt. Łabski, at the altitude of 1387 m. On the northern side of the massif, all streams join in the floor of Jelenia Góra Basin, forming two most significant rivers—Kamienna and Łomnica. They flow into the Bóbr River, one of the main tributaries of the Odra. Many streams in the Karkonosze did not form clear valleys and flow within shallow hillslope hollows and troughs. Larger rivers, however, have greater erosive power and have eroded numerous ravine sections, such as the Kamieńczyk River. The section of its valley below the Kamieńczyk Waterfall has the form of a deep (ca. 25 m) rocky gorge. Bedrock channel reaches are common. During the largest floods, the water flow increases by 100–160 more than an average discharge (Kasprzak 2010) and streams have the capacity to transport the largest bed load elements (Walicka et al. 2019).

Waterfalls are numerous in Karkonosze (Fig. 7.9). They are mainly associated with fault-generated escarpments, as in the case of Kamieńczyk Waterfall, the highest in Polish Sudetes (27 m). Even higher waterfalls descend from the rock walls of glacial cirques on the southern side of the massif, e.g., the Pančavský Waterfall (39 m), as a part of the 162 m high cascade in the Labský důl Valley (Pilous 1989).

The formation of a distinct faulted escarpment in the northern part of the Karkonosze significantly affected the local morphology of the valleys. The largest streams such as Kamienna, Wrzosówka, and Podgórna rivers carried enough water for downcutting to keep pace with the tectonic uplift, which resulted in the creation of notched valleys with steep slopes and bedrock channels. In smaller valleys, the intensity of incision was lower; hence, they took on a bottle shape (like Czerwonka Valley) or their floors are suspended above the footline of the escarpment (Sroka 1991; Migoń 1993; Chmal and Kasprzak 2009). In the case of the Łomniczka Valley, the Pleistocene-age uplift of alluvial sediments is about 15 m. The Pleistocene uplifted terraces with coarse-grained sediments of the Wrzosówka River in Sobieszów and the Jedlica River in Kowary are also truncated by scarps of similar height. Continuous tectonic activity of the Karkonosze area is evidenced by reports of seismic phenomena. Several earthquakes were recorded here in the recent past. One of the strongest tremors took place in Kowary in 1903 (Dyjor and Oberc 1983).

The extension of the terrace system of the Karkonosze rivers are alluvial fans in the Jelenia Góra Basin. The most extensive is the Ściegny fan (Kasprzak 2009), reaching as far as the Bóbr Valley in the north (Fig. 7.9c). Its surface is incised, and younger terraces were inserted into the incisions. The complete terrace system consists of two levels, including the fan surface, regarded as Pleistocene (c. 12–20 m and 3–5 m a.r.l.) and two lower ones from the Holocene (c. 1.5–2.5 m and contemporary). In the mountainous parts, fluvial terraces are preserved only fragmentarily. In addition to the Holocene levels, isolated shelves of higher Pleistocene terraces, characterised by coarse-grained sediments, are common.

7.6 Extreme Events

In Silesia, continuous meteorological measurements have been conducted since 1810, followed by regular hydrological observations since the turn of the twentieth century. Historical literature is also abundant, so the knowledge of local natural extreme events is relatively complete. High-energy mass movements occur in the highest parts of the Karkonosze and include rock falls, snow avalanches, landslides, and debris-mudflows (Fig. 7.10). The latter are characteristic for the Karkonosze and are referred to in older literature as *Muren* (Germ.). They occur mainly in ravines dissecting headwalls of glacial cirques, but also on steep slopes of spring hollows and valleys. The largest cluster of debris-flow landforms is located in the upper part of the Łomniczka Valley, where 27 tracks have been identified. Their formation is favoured by steep slopes and thick layer of fine-grained weathering cover which, saturated with water, can move by gravity, sliding on solid rock beneath. In the whole Karkonosze Mts., traces of more than 250 debris flows of various ages have been recorded so far,

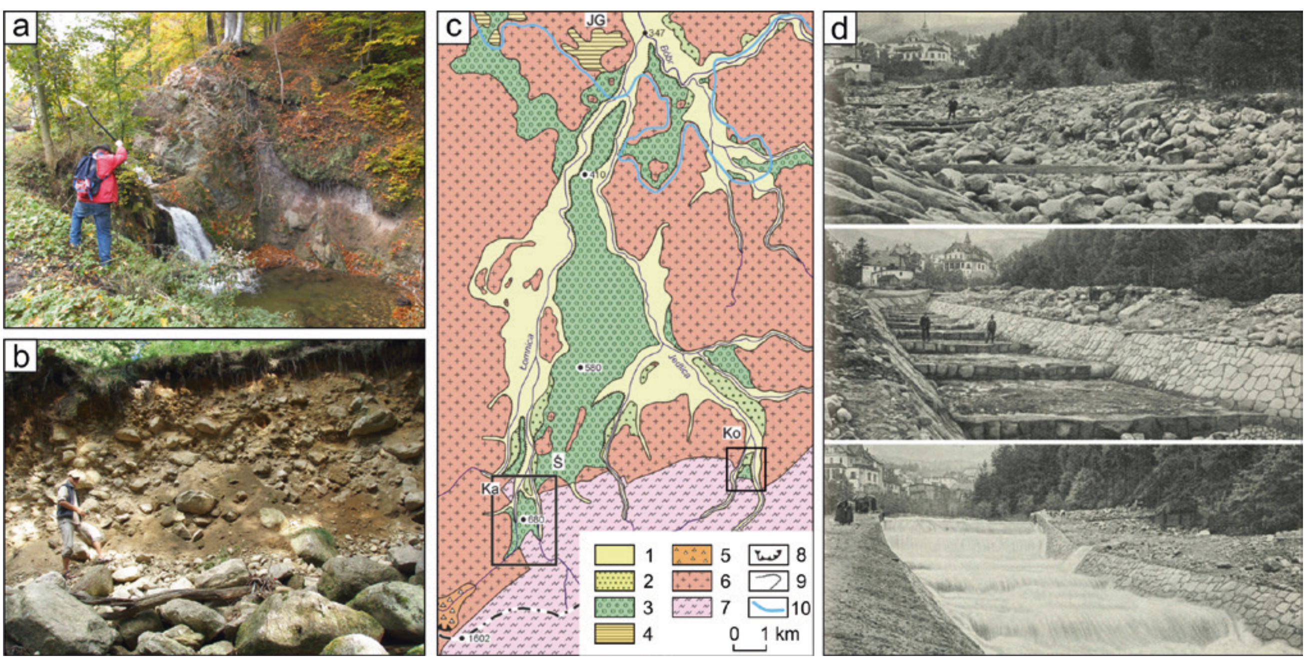


Fig. 7.9 Fluvial landforms in the Karkonosze Mts. and Jelenia Góra Basin. **a** Fault scarps are accompanied by numerous waterfalls and cascades, as in the case of the Piszczak stream, a tributary of the Jedlica River (photograph by M. Kasprzak). **b** Extensive alluvial fans provide evidence of intensive denudation and drainage of the Karkonosze during the cold periods of the Pleistocene, as in the case of the Łomniczka River fan in Karpacz Wilcza Poręba (photograph by M. Kasprzak). **c** Geological-geomorphological sketch of the Ściegny fan stretching from the Karkonosze Foothills to the Bóbr Valley in the southern part of the Jelenia Góra Basin. 1—gravels of river terraces (Holocene), 2—gravels and boulders of river terraces (Late Pleistocene), 3—gravels and boulders of river terraces (alluvial fan, Early/Middle Pleistocene), 4—glacial and glaciolacustrine deposits, 5—boulders of moraines of mountain glaciers, 6—granite bedrock, 7—gneisses and metamorphic schists, 8—glacial cirques, 9—distinct rock bases of river terraces, 10—maximum extent of the Scandinavian ice sheet, JG—Jelenia Góra, Ka—Karpacz, Ś—Ściegny, Ko—Kowary, black frames show tectonically uplifted and incised alluvial fans of the Łomniczka and Jedlica rivers (after Kasprzak 2007). **d** Scheme of river channelisation made in the early twentieth century and common in the region (after Sommer 1913—author of the photograph unknown)

including more than 70 on the Polish side of the mountains (Pilous 1973, 2016; Migoń and Parzóch 2008). The debris-flow furrows visible in the terrain morphology are between 30 and 500 m long and several or so metres wide (Parzóch et al. 2007).

The history of the Karkonosze Mts. and Jelenia Góra Basin contains many accounts of catastrophic floods (Kasprzak and Migoń 2015). The largest were those in 1608, 1736, 1778, 1796, 1813, 1858, 1882, 1897, and 1926. Large floods also occurred in 1958, 1977, and 1997. The flood in 2006 was also peculiar, when intense rainfall from 7 to 8 August was preceded by a four-week long drought. The most severe flood damage in the Karkonosze occurred in the seventeenth and nineteenth centuries. It is worth noting that many valleys experienced catastrophic floods as a result of highly localised storm precipitation at completely different times.

The largest regional flood happened at the end of July 1897 (Fig. 7.11). It was triggered by prolonged rainfall, which on 30 July exceeded the previous records of daily intensity in the Western Sudetes. In the Łomnica drainage basin alone, 20 million m^3 of rain fell daily (average 171 mm, Czerwiński 1991). On the Bóbr River in Jelenia Góra from noon of 29th July to morning of 30th July, 5 m of water was added. The discharge for Pilchowice gauging station to the north of Jelenia Góra was calculated as 1187 $m^3\ s^{-1}$ at mean annual flow (MAF) of 11.6 $m^3\ s^{-1}$. The discharge of the Łomnica River was 400 $m^3\ s^{-1}$ (MAF 2.16 $m^3\ s^{-1}$) and that of the Kamienna River 500 $m^3\ s^{-1}$ (MAF 3.19 $m^3\ s^{-1}$) (Partsch 1911). In Jelenia Góra, the waters inundated a wide floodplain and the water level reached the roofs of the lowest houses. The villages on the Karkonosze Foothills suffered most. The town of Kowary, where the Jedlica river formed a new riverbed, was severely affected (29 houses completely destroyed, 14 partly damaged). Similar destructive processes affected the Łomniczka River. In Karpacz, five houses and a mill were damaged, and in the village of Łomnica, nine houses perished. Losses were also recorded in many other villages. Most mountain roads were destroyed. On the Silesian (northern) side of the Karkonosze the flood claimed four victims, on the Czech side of the mountains, depending on the source, from 120 to 135 victims.

Snow avalanches may also have serious consequences in the Karkonosze. On 20 March 1968 the most tragic snow avalanche in Poland took place here, killing 19 people (Mazurski 1969). It happened in the Biały Jar Valley. The amphitheatrical valley head promotes snow deposition and is the source of frequent avalanches.

7.7 Human Impact

In the Karkonosze Mts., one of the reasons for changes in surface morphology was mining activity. Among other things, cobalt ore, pyrites, and pegmatites were extracted. Numerous heaps and sinkholes marking the location of small shafts and adits, and in some places also, fragments of underground mines, as in the vicinity of Szklarska Poręba, have survived from this period (Borzęcki et al. 2018). There are larger post-mining landforms from iron ore extraction in the Kowary area. Exploitation initiated in the fourteenth century was carried out in small open pits and shallow shafts, and in the sixteenth century reached a depth of 130 m. Mining works connected with uranium ore exploration in the 1950s were even more extensive (Borzęcki and Wójcik 2017). These resulted in a total of 5.5 km of underground mine workings. The remnants of this episode are heaps, on which a bound of 28 thousand m^3 of rock spoil was accumulated.

With intensive deforestation for metallurgy in the Middle Ages, including smelters moving up the valleys to find sources of fuel, e.g. from Piechowice through Szklarska Poręba to Jakuszyce and Orle in the Izerskie Mts., the slopes were adapted for agriculture and pastoralism. Agricultural terraces were formed, and larger stones were removed from the surface and collected along field borders in the form of stone ramparts or stone walls. The remains of such walls can be found in the village of Borowice, as well as in other areas of the Western Sudetes (Duma et al. 2020). In villages, mill canals were created, and the land was planted for weaving and linen-making.

Considerable changes in the landscape were caused by hydro-engineering works (Fig. 7.9d), undertaken after the floods in 1888 and 1897 (Budych and Majewicz 1999). In the first two decades of the twentieth century, a project of regulation of the Odra's mountain tributaries was implemented. It included building of retention reservoirs (Karpacz), dry flood control reservoirs (Mysłakowice, Sobieszów), systems of check dams, and the transformation of riverbeds into artificial cascades. In 2001, a drinking water reservoir next to the village of Sosnówka was put into operation.

In the seventeenth century, the Karkonosze region became a tourist destination, and over time, it developed into one of the most visited tourist regions in Central Europe (Fig. 7.12). Ski and sledge infrastructure was created on the slopes of Karkonosze. Such a complex was created, among others, in Szklarska Poręba, unsuccessfully competing with the Bavarian town of Garmisch-Partenkirchen for the organisation of the Winter Olympic

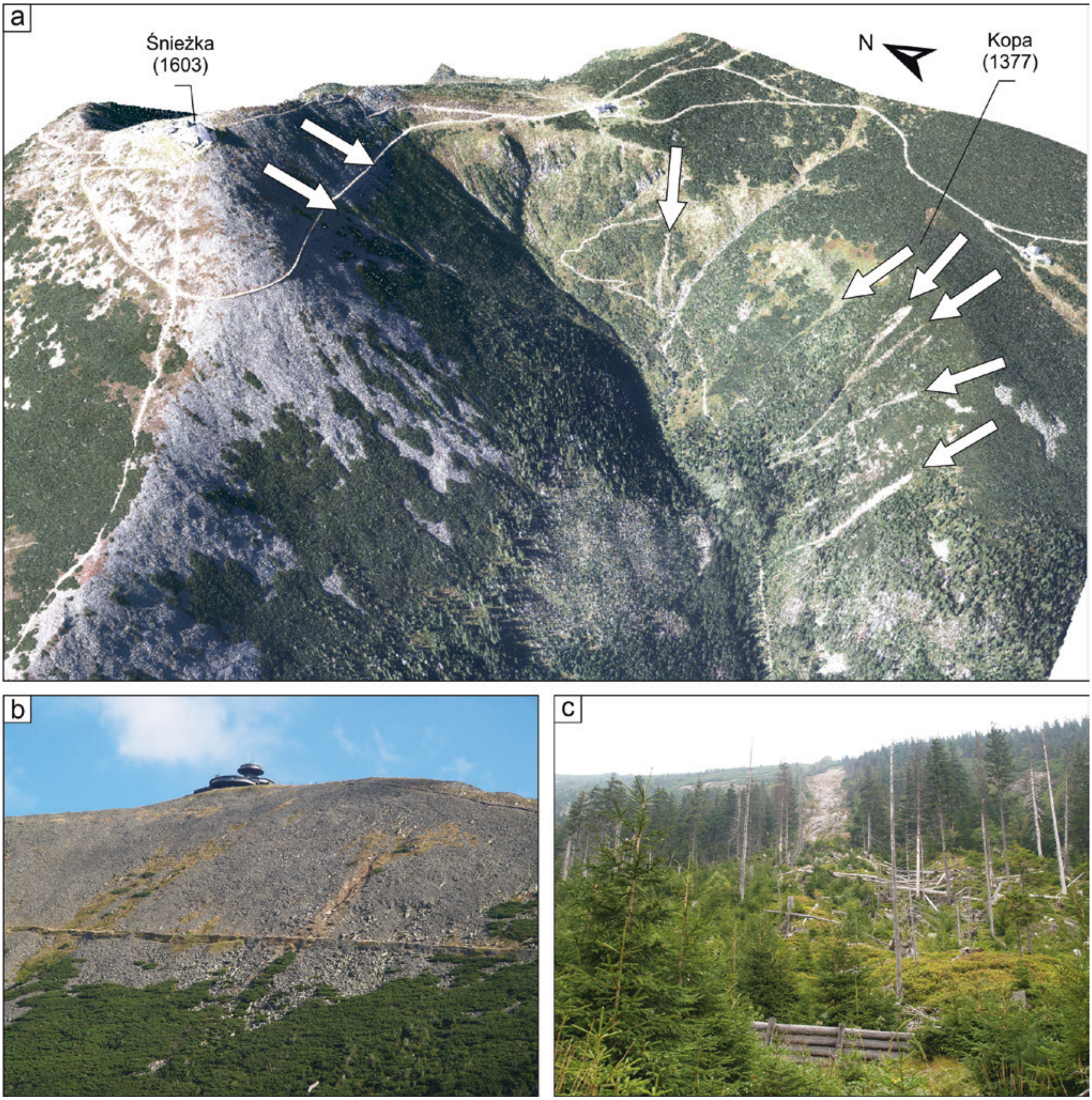


Fig. 7.10 Relief transformation by debris flows in the Karkonosze Mts. **a** Slopes of the Łomniczka glacial valley between Mt. Śnieżka and Mt. Kopa, arrows show fresh debris-flow scars, dated to 1964 and 1994. **b** Debris-flow tracks on the slope of Mt. Śnieżka. **c** Attempt to stop subsequent erosion within a debris-flow channel on the slope of Mt. Kopa (photographs by M. Kasprzak)

Games in 1936. From the end of the nineteenth century, following the trend of that time, natural areas were artificially made more apparently attractive for tourists. For example, water reservoirs were created above waterfalls to temporarily increase the discharge of rivers, and exotic, high-mountain plant species, such as edelweiss, the symbol of mountain hikers, were introduced into the environment.

Also in the nineteenth century, the Jelenia Góra Basin belonged to the most fashionable holiday and tourist areas. It was visited by Caspar David Friedrich, John Quincy Adams, Frederic Chopin, Izabela Czartoryska, and Johann Wolfgang Goethe. They were attracted by the health resort in Bad Warmbrunn (after 1945 Cieplice Śląskie-Zdrój, from 1976 within Jelenia Góra), castles and palaces, which were the seats of Silesian dukes, the Prussian royal family (e.g., kings of Prussia: Wilhelm III and Wilhelm IV), aristocracy and nobility of Polish, German, Czech, and Austrian families such as Radziwiłł, Czartoryski, Schaffgotsch, or Hohenzollern. In

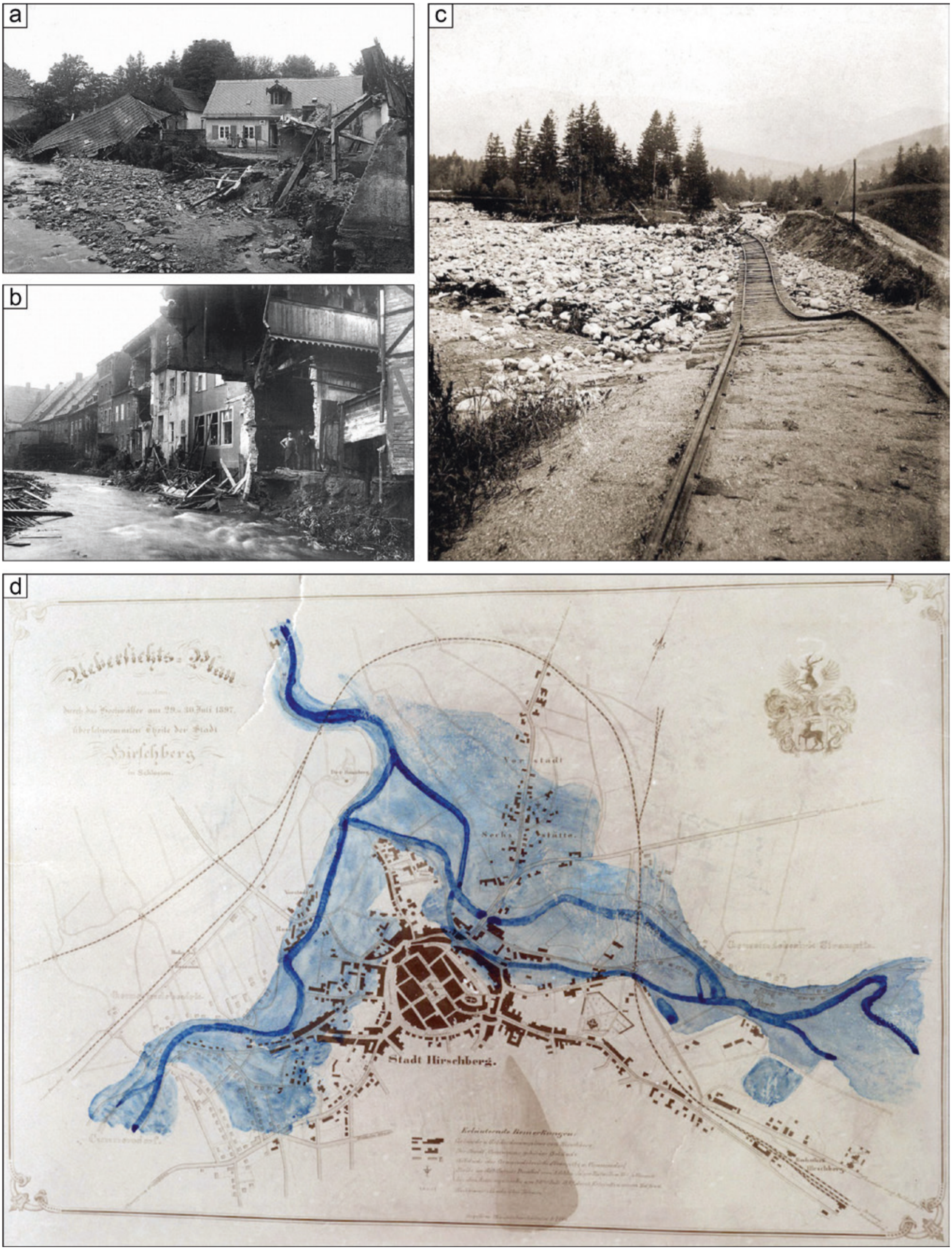


Fig. 7.11 Results of the largest known flood in the Karkonosze region on 29–30 July 1897. **a, b** Destruction of buildings due to lateral erosion in the Jedlica riverbed in Kowary. **c** Damaged railway track over the Łomnica River in Miłków. **d** Extent of flood inundation in Jelenia Góra. Sources: *Die Hochwasser-Katastrophe*… 1897 (**a–c**), State Archive in Wrocław, Jelenia Góra Branch, public domain (**d**)

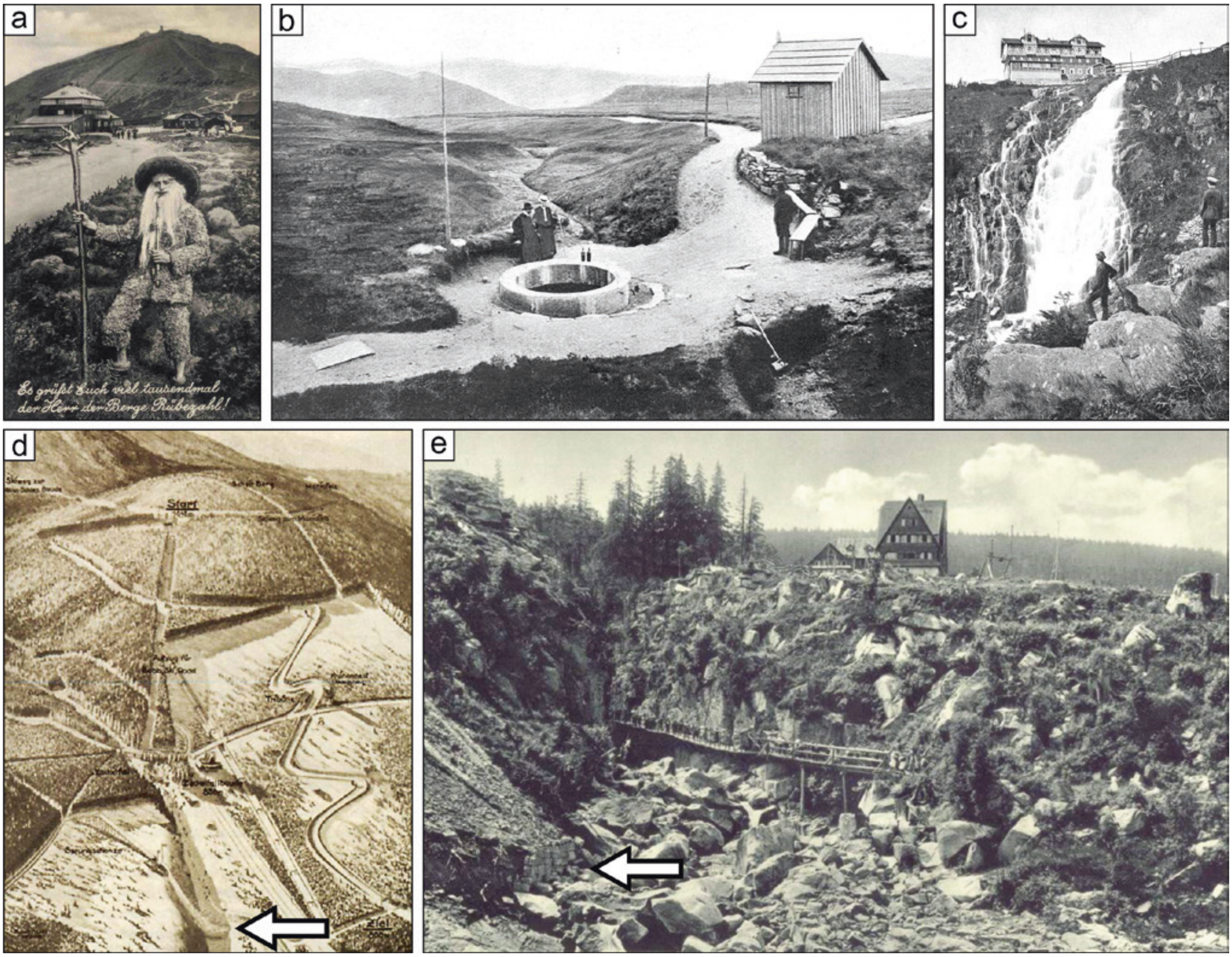


Fig. 7.12 One of the components of centuries-old human impact on the landscape of the Karkonosze Mts. is mass tourism experienced already in the nineteenth century. **a** Man dressed as Rübezahl (mountain ghost) on the pass at Śnieżka. **b** Tourists at the source of Elbe. **c** Elbe waterfall with artificially increased discharge. **d** Project of a sport complex intended for the Winter Olympics in 1936 (now non-existent). **e** Kamieńczyk gorge open to the public, white arrow shows the ski-jump's landing place visible in picture **d**. Source: Old postcards, authors unknown (**a**, **d**, **e**); Seifert (1906) (**b**, **c**)

many cases, palace and palace gardens were uniquely incorporated into agricultural and forest landscapes. The park establishment in the village of Bukowiec is worth mentioning as an excellent example of a romantic landscape park (Migoń and Latocha 2008). It covers an area of over 20 ha of morphologically diversified terrain with a central depression, several breeding ponds, granite hills on its eastern side, and an elongated ridge on a long microgranite vein on its western side. Further to the west rises Mt. Mrowiec (513 m asl), once a developed and highly regarded lookout point. The landscape of granite rocks has been skilfully integrated with older defensive castles: Sokolec on Mt. Krzyżna and Chojnik in the Karkonosze Foothills. Most of these lost their splendour after World War II and have been restored in the last three decades.

Contemporary geomorphological processes, responsible for denudation (Cielińska 1961; Bieroński et al. 1992; Katrycz 1998), were briefly intensified during the so-called 'environmental catastrophe' of the 1980s. At that time, West Sudetic spruce monoculture forests were dying off en masse due to the acidification of the atmosphere by the nearby lignite-fired power plants (Mazurski 1986). Today, erosion processes on the hiking trails in the Karkonosze are intensified by huge tourist traffic, and haphazard urbanisation becomes a threat to the aesthetic values of the geomorphological and cultural landscape of the Jelenia Góra Basin.

7.8 Conclusions

The Karkonosze Mountains and the adjacent Jelenia Góra Basin constitute an exceptional area on the geomorphological map of Poland. They stand out not only against the background of the Sudetes but also the European medium-altitude mountains. They form a unique landscape, strictly dependent on structural features of granite and its internal differentiation. The Karkonosze are distinguished by strong late Cenozoic uplift, numerous tors, clear traces of Pleistocene glaciation, and periglacial cryogenic processes. The Jelenia Góra Basin may be regarded as the only example of exposed granite weathering front in Poland. In spite of exceptionally long tradition of geological and geomorphological studies of this region, not all issues of relief development have been satisfactorily explained. Some of the older views also need revision given the advance in knowledge and the development of research techniques, including absolute dating of sediments and rocks. Observations of contemporary geomorphological processes await their continuation in the face of climate change and increasing human impact.

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