

## Chapter 2

### High mountains in the Baltic Sea basin

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**Abstract:** The aim of the chapter is focused on high mountain regions in the Baltic Sea basin. High mountain environment has specific features defined by Carl Troll. The presence of timberline (upper tree line) and a glacial origin of landforms are considered as the most important features of high mountains. The Scandinavian Mountains and Tatra Mountains comply with the above definition of the high mountain environment. Both mountain chains were glaciated in Pleistocene: the Fennoscandian Ice Sheet covered the northern part of Europe including the Scandinavian Peninsula while mountain glaciers occurred in the highest part of the Carpathian Mountains.

**Keywords:** U-shaped valleys, glacial cirques, perennial snow patches, altitudinal belts

#### The Baltic Sea and its drainage basin – general characteristic

The Baltic Sea is one of the largest semi-enclosed seas in the world. The sea stretches at the geographic latitude almost 13° from the south to the north, and at the geographic longitude 20° from the west to the east. As a shallow epicontinental sea, it is cut off from the ocean having only a narrow connection with the Atlantic through the Danish belts (Skagerrak, Kattegat). The present connection with the North Sea was established 7000 years ago. The Baltic Sea is connected by artificial waterways to the White Sea *via* the White Sea Canal and to the German Bight of the North Sea *via* the Kiel Canal. The Baltic Sea is divided into the following units: Baltic Sea Proper, Bothnian Bay, Bothnian Sea, Gulf of Finland, Gulf of Riga, and Kattegat (Fig. 2.1). It is about 1300 km long, on average of 193 km wide, and an average of 55 m deep. The maximum depth is 459 m (Landsort Deep). The surface area is ap. 392,979 km<sup>2</sup> (without Kattegat), and the volume ap. 22,000 km<sup>3</sup>. The periphery amounts 8100 km of coastline (Table 2.1, Andersen et al. 2006, Håkanson et al. 2003b).

The Baltic Sea occupies a basin formed by glacial erosion during three large inland ice ages. The latest and most important one lasted from 120,000 until ap. 18,000 years ago. The Baltic Sea underwent a complex development during last several thousand years after the last deglaciation. At present it exhibits a young

**Table 2.1.** Characteristics of the Baltic Sea (Andersen et al. 2006, Håkanson et al. 2003a, [https://en.wikipedia.org/wiki/Baltic\\_Sea](https://en.wikipedia.org/wiki/Baltic_Sea)).

Attribute	Baltic Sea
Geographical latitude [°N]	53–66
Geographical longitude [°E]	10–30
Area (including Kattegat) [km <sup>2</sup> ]	415,266
Max. length [km]	1,601
Max. width [km]	600
Average depth [m]	52.3
Max. depth [m]	459
Water volume [km <sup>3</sup> ]	21,721
Approximate shore length	8,100
Average salinity [‰]	7
Drainage basin [km <sup>2</sup> ]	1,720,270



**Fig. 2.1.** The Baltic Sea basin (red line – the Baltic Sea watershed, background map from <https://topotools.cr.usgs.gov/>).

aquatic ecosystem. The Baltic Sea is a brackish water body of salinity 7–15‰, meaning that it is neither a fresh water, nor a fully marine water (a fully marine environment has salinity 35‰). The present conditions of low salinity prevail approximately in the last 3000 years. Winter ice cover makes the life conditions for fauna and flora difficult. The sea is rich in nutrients and it is polluted. There are following reasons why the Baltic Sea is a unique aquatic ecosystem (Håkanson et al. 2003a):

- it is large,
- very shallow,
- it is a sheltered inland sea with many coastal types,
- it has brackish water,
- it is located mostly in the cold climate,
- it has a heavily industrialized catchment area with a large population and intensive land use,
- it is sensitive to environmental impact,
- its pollution represents threat for people, flora and fauna.

These specific features of the Baltic Sea are influenced by the drainage area which spreads ap. 2500 km from the south (Carpathian Mountains) far to the north (Scandinavian Mountains). This long north-south extension causes differences in climatic conditions and a few climatic patterns occur there: transitional temperate warm, transitional temperate cool, continental, cool. The growing season in the far north is short (a polar day). The drainage area of the entire basin comprises 1,720,270 km<sup>2</sup>, which is more than four times larger than the entire water area of 415,266 km<sup>2</sup> (Table 2.1). The area of 14 countries which are located in the Baltic Sea basin represents about 15% of the area of Europe (Sweden, Finland, Russian Federation, Estonia, Latvia, Lithuania, Belarus, Poland, Germany, Denmark and small parts of Ukraine, Norway, and Slovak and Czech republics). The Baltic Sea basin is densely populated (85 million) and heavily industrialized. The main environmental challenges are eutrophication, heavy metals, dioxin, DDT, PCB, PAH and organic tin compounds, alien invasive species, deliberate illegal discharges from ships, growing risk of oil accidents from oil field exploitation and rapidly growing oil transport, as well as nuclear safety (Sundström, Andersson 2003).

The Baltic Sea basin is composed of a complex of geographical landforms with a high diversity over the area. The lowland (0–200 m a.s.l.) dominates and occupies 72.1% of the whole basin. Lowland spreads around the Baltic Sea forming a broad area of the forested lakelands. After the ice sheet melted away the land had been shaped to form a large number of lakes (lakes account for 6.1% of the whole Baltic Sea basin). The contribution of mountainous area elevated over 600 m a.s.l. accounts 4.3% and areas over 1000 m a.s.l. represent merely 0.6% (Table 2.2). There are following mountains in the Baltic Sea drainage basin: Scandinavian, Sudeten, Beskid, Pieniny, and Tatra. Despite their small share in the Baltic Sea basin, the mountains play a key role in the environment and human life (Rydén 2019). Noteworthy are the high mountains – areas of distinct environments with spectacular and specific features.

### High mountains – what does it mean?

The geographical term “high mountains” has been strictly defined since the Carl Troll (1899–1975), a German geographer and botanist, was engaged in ecology and geography research of mountainous lands. He gave the main concepts and terminology of

**Table 2.2.** Altitudinal belts in the Baltic Sea basin (calculated on the base of <https://topotools.cr.usgs.gov/>).

Altitude	Area	
	[km <sup>2</sup> ]	[%]
0–200	1,239,652.00	72.062
200–600	406,164.30	23.610
600–1000	63,666.15	3.701
1000–1500	10,098.03	0.587
1500–2000	646.51	0.038
2000–2600	42.56	0.002
Total	1,720,269.55	100.000

high mountains, therefore he may be called a pioneer in modern high-mountain geography. Troll developed some ideas of Alexander von Humboldt, especially on the three-dimensional character of climate (i.e. the change of climate by latitude, longitude and elevation) and its influence on the distribution pattern of altitudinal belts, vegetation belts, lifeforms and also on certain landforms (Holtmeier 2015). Timberline (tree line) position in a high-mountain landscape is the most conspicuous and ecologically very important vegetation boundary in most high-mountain landscapes. Troll expressed his scientific opinion in the paper entitled “High mountain belts between the polar caps and the equator: their definition and lower limit” published in *Arctic and Alpine Research* in 1973. High mountain landscape has the following features that distinguish it from other landscape types (Balon 2000, 2002; Kotarba, Migoń 2010; Kozłowska, Rączkowska 2009; Troll 1973):

- it rises above the upper forest limit and above Pleistocene snow line<sup>1</sup>,
- it has a glacial origin, and hence also features, which do not exist in other mountains (e.g. glacial cirques, steep rocky crests, cirque lakes, glaciated rocky knobs, striated rock walls),
- its evolution is affected by the geomorphological processes that are specific only for high mountains, e.g. the periglacial ones,
- is characterized by a definite physiognomy: a mosaic-stripe structure, with highly differentiated units,
- it is a very dynamic system of landscape processes, mainly the geomorphologic ones,
- human impact is more limited there than in other areas.

These prerequisites for high mountain environment are fulfilled in the Baltic Sea drainage basin in the Scandinavian Mountains and Tatra Mountains.

<sup>1</sup> Refers to the altitude where the accumulation of snowfall equals ablation (called also equilibrium line).



## Scandinavian Mountains

The Scandinavian Mountains run through the Scandinavian Peninsula and form the second longest mountain range in Europe (after the Ural Mountains). They occupy the western and northern part of the Fennoscandia Peninsula, stretch by a strip up to 200 km wide and 1700 km long, in the territory of Norway, Sweden and partly in Finland. Along its central part, mountain height is strongly variable with peaks higher than 2100 m a.s.l. only in south central Norway and in northern Sweden. Mountain height is particularly low in the southernmost and northernmost parts, but also relatively low in the central parts. The southern part of the Scandinavian Mountains is broader and consists of a series of plateaux and gently undulating surfaces that hosts scattered *inselbergs* (Rudberg 1969). It contains Galdhøpiggen (2469 m a.s.l.) in Norway – the highest peak in the Scandinavian Mountains (Jotunheimen range), whereas Kebnekaise located in Swedish Lapland about 150 km north of the Arctic Circle is the highest peak of the Scandinavian Mountains within the Baltic Sea basin. Areas elevated over 1500 m a.s.l. represent 0.3‰ (ap. 540 km<sup>2</sup>) of the Scandinavian Mountains in the Baltic Sea basin (Fig. 2.2, Table 2.3, Photo. 2.1).

The Kebnekaise massif has two main peaks, of which the southern, glaciated one had the altitude of 2097.5 m a.s.l. in August 2014. There are Kebnepakte, Isfalls, and Stor glaciers flowing towards the Tarfala valley (to the east), Björklings glacier flowing to the southeast, and Rabots glacier flowing to the west, plus several smaller glaciers throughout the area (Fig. 2.3; Photos. 2.1, 2.2). The northern peak is 2096.8 m a.s.l. high and it is free of ice. By August 2018, due to record heat, glacier on the southern peak had melted so that the northern peak is now the highest (Anderson 2018).

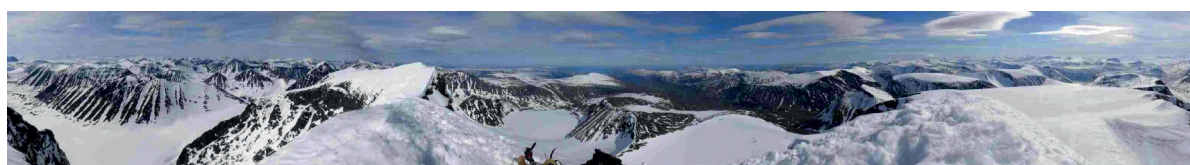
The Scandinavian Mountains were formed in the Caledonian orogenesis as a result of the closure of the Paleozoic Iapetus. They were several times unevenly raised, and eventually uplifted at the turn of the Silurian and Devonian periods. The Scandinavian Mountains are mostly built of crystalline and metamorphic pre-Cambrian rocks, and Ediacaran (Vendian), Cambrian, Ordovician and Silurian-aged sedimentary rocks. Natural resources include iron



**Fig. 2.2.** The highest parts of the Scandinavian Mountains within the Baltic Sea drainage basin (1 – Kebnekaise, 2 – Sarek; details in Figure 2.3; based on Mapa... 1970).

**Table 2.3.** Characteristics of the Scandinavian Mountains within the Baltic Sea drainage basin (Nesje et al. 2008, <https://topotools.cr.usgs.gov/>).

Attribute	Scandinavian Mountains
Water divide	North Sea, Norwegian Sea, Barents Sea, Baltic Sea
Area over 600 m a.s.l. [km <sup>2</sup> ]	ap. 70,000
Length [km]	1700
Width [km]	up to 300
Highest peak [m a.s.l.]	Kebnekaise 2096.8
Timberline [m a.s.l.]	1300 – south, 200 – north
Glaciers	yes
Perennial snow patches	yes
Permafrost	yes



**Photo. 2.1.** Kebnekaise massif in the Scandinavian Mountains (<https://en.wikipedia.org/wiki/Kebnekaise>).



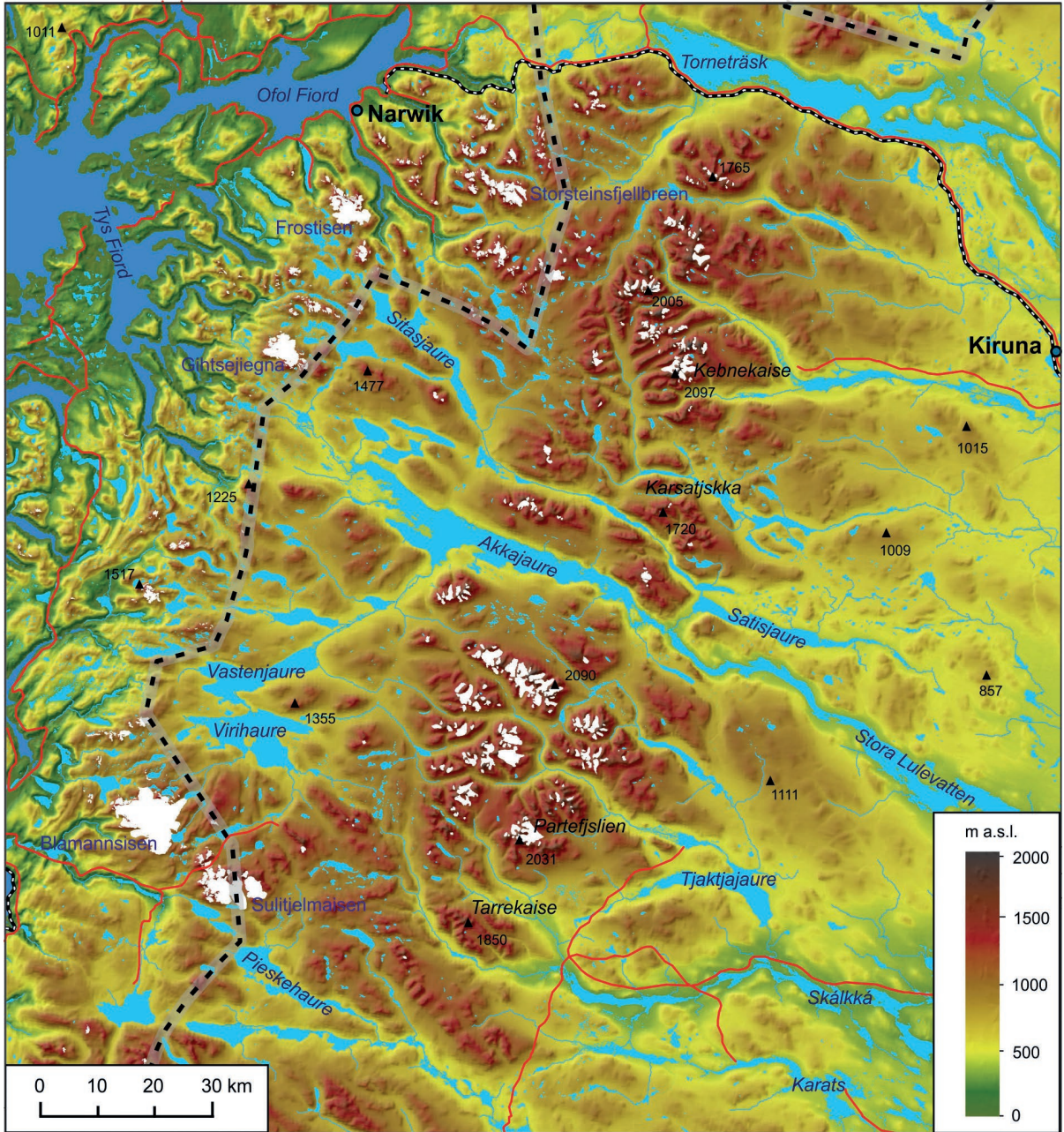


Fig. 2.3. Northern part of the Scandinavian Mountains with Kebnekaise – north of Akkajaure lake (based on <https://topo-tools.cr.usgs.gov/>).

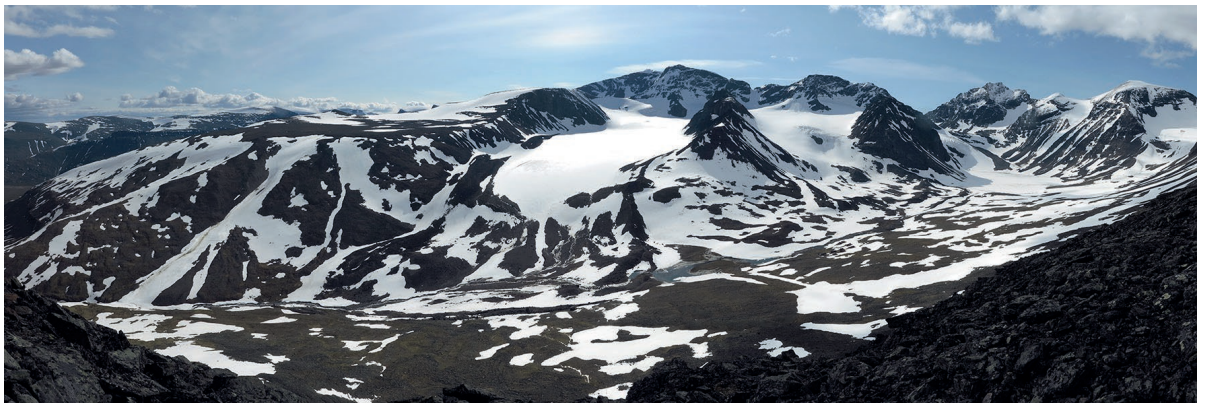


Photo. 2.2. Glaciers over the Tarfala valley in Kebnekaise massif ([https://en.wikipedia.org/wiki/Tarfala\\_Valley](https://en.wikipedia.org/wiki/Tarfala_Valley)).



(Kiruna), as well as copper, zinc and lead, nickel, molybdenum. During half of the last 2.75 million years the Scandinavian Mountains hosted mountain-centered ice caps and ice fields. During the Last Glacial Maximum all the Scandinavian Mountains were covered by the Fennoscandian Ice Sheet (in the same time mountain glaciers were in the Tatra Mountains). Recession of the ice sheet margin led the ice sheet to be concentrated in two parts, one part in southern Norway and another in northern Sweden and Norway. This time the Scandinavian Mountains has been sculpted by glacial erosion. There are U-shaped valleys, glacial cirques – at some locations coalesced cirques form *arêtes* and pyramidal peaks forming an “alpine topography” (Photo. 2.3; Lundqvist et al. 2011, Stupnicka 1978).

Glacial activity is marked strongly in the western part of the mountain chain where drowned glacier-shaped valleys constitute the fjords of Norway. In the eastern part of the mountain chain reshaped by glaciers, numerous mountain summits contain blockfields which escaped glacial erosion either by having been nunataks. Bare rock surfaces are common, mountain slopes are mantled by deposits of glacial origin including till blankets, moraines, drumlins and glaciofluvial material. It is interesting that distribution of “alpine topography” in the Scandinavian Mountains does not relate to altitude: for instance cirques in southern Nor-

way can be found both near sea level and at 2000 m a.s.l. Most cirques are found between 1000 and 1500 m (Hall et al. 2013, O’Dell 1961).

Due to a considerable meridional extent, the Scandinavian Mountains lie in three climatic belts: moderate warm in the south, moderate cold (central areas) and polar (in the north). The mountain range plays a role of a topographic barrier for wet air masses influenced by the Golf Stream: precipitation totals reach 3500 mm per year on the western side of the mountains and 400 mm on the eastern side (precipitation shadow). Due to high precipitation and low snow line position (ap. 700 m a.s.l. in the southern part of the mountains), the Scandinavian Mountains are the most glaciated area in Europe. Field glaciers and outlet glaciers are typical for the Scandinavian Mountains. There are also valley glaciers. The mountains are headwaters of most major Scandinavian rivers as: Torne, Kalix, Lule, Skellefte, Ume, Angerman, Indal, Ljungan, Ljusnan, Dal and Klarälven (Fig. 2.1). Steep river channels and weakly diversified river discharge variability throughout the year favor use of water energy by power plants. There are numerous postglacial lakes with elongated SE-NW oriented shoreline (Photo. 2.4; Nesje et al. 2008; Mydel, Groch 2000, Trepínska 2002).

There are variations in timberline elevation in the Scandinavian Mountains: from a maximum height of 1300 m a.s.l. in the southern part to ap. 200 m a.s.l.



**Photo. 2.3.** The mountain Pierikpakte in the Äpar massif with “alpine topography”, Sarek National Park ([https://en.wikipedia.org/wiki/Sarek\\_National\\_Park](https://en.wikipedia.org/wiki/Sarek_National_Park)).



**Photo. 2.4.** The lake Torneträsk located in the tectonic valley – Torne river outflows from the lake into the Baltic Sea (Photo. J. Siwek).

in the northern part of the mountains. Lower parts of the mountains are covered with mixed forest in the south and coniferous forest in the north. The mountain birchwood (*Betula pubescens*) spreads over forest zone. Above this lies a narrow belt of willow shrub and above a belt consisting of meadow with herbs, grass, and heath. Peat bogs and mires are common in the depressions. The highest parts of the mountains is a glacial zone. Tundra communities (dwarf shrubs, sedges and grasses, mosses, and lichens) are typical for the northern part of the mountains (Odland 2015, Podbielkowski 2002).

There are numerous national parks in the Scandinavian Mountains with typical alpine landforms, i.a. Sarek, Padjelanta, Stora Sjöfallet, Abisko.

### Tatra Mountains

The Tatra Mountains are the highest mountains of the entire Carpathian Mountains (Photo. 2.5). The Carpathian Mountains form the third longest mountain range in Europe (Fig. 2.4). They begin near the Danu-

be river at the border of Austria and Slovakia, stretch to the north-east (Czech Republic, Hungary, Slovakia, Poland – the Western Carpathian Mountains), then turn to the east (Poland, Slovakia, Ukraine – the Eastern Carpathian Mountains) and south (Romania, Serbia – the Southern Carpathian Mountains) to end at the borders of Romania and Serbia. The entire mountain range is over 1500 km long and occupies the area of 209,000 km<sup>2</sup>. Except the Tatra Mountains, another high part of the Carpathian Mountains, with the highest peaks exceeding 2500 m a.s.l., is in Romania (the Fagaras, Parang, Retezat and Bucegi mountains). The Carpathian Mountains are geologically young. They were formed during the Alpine orogeny in upper Mesozoic and Tertiary, together with mountain ranges like the Alps, Caucasus, Pyrenees, Rocky Mountains or Himalayas.

The Tatra Mountains (Fig. 2.5) are divided into the Western Tatra Mountains and Eastern Tatra Mountains (composed of the High Tatra Mountains and Belianske Tatra Mountains). They are located in northern Slovakia (about 78% of the area) and southern Poland



**Photo. 2.5.** The Tatra Mountains from the south: the Western Tatra Mountains on the left and in the center, the High Tatra Mountains on the right. The right edge of the photo shows a pronounced elevation gradient between the mountains and the neighbouring foothills. The dark belt below the snow zone shows forests dominated by Norway spruce (*Picea abies*, Photo. L. Holko).





Fig. 2.4. The Carpathian Mountains, the rectangle shows the Tatra Mountains (based on [www.mapy.cz](http://www.mapy.cz)).

(about 22% of the area). The mountain range is about 57 km long and about 18.9 km wide (Kondracki 1998). The Tatra Mountains represent the only part of the Carpathian Mountains that has a larger-scale rocky high alpine landscape. Despite their relatively small area of 785 km<sup>2</sup>, the mountains represent a remarkable landscape.

The highest peaks of the Tatra Mountains are not located on the main ridge, but on the southern branches, i.e. Gerlachovský štít (2655 m a.s.l.) and Lomnický štít (2634 m a.s.l.) in the High Tatra Mountains, and Bystrá (2248 m a.s.l.) and Jakubíná (2194 m a.s.l.) in the Western Tatra Mountains. Gerlachovský štít and Lomnický štít are the highest peaks of the entire Carpathian Mountains, wherein the first one is the highest peak in the Baltic Sea drainage basin (Table 2.4).

The geological structure of the Tatra Mountains is typical of mountains with alpine folding. They started to rise in lower Neogene. They are mainly formed by crystalline rocks (schist, paragneiss, migmatite) and granodiorite. Mesozoic rocks (dominated by limestone and dolomite) occur along the western, northern and eastern boundaries (Passendorfer 1983). Present relief was significantly influenced by the Pleistocene glaciation that left the U-shaped valleys, series of cirque basins and knife-edged *arêtes*,

Table 2.4. Characteristics of the Tatra Mountains within the Baltic Sea drainage basin (Hess 1965, Kondracki 1998, Mapa... 1970).

Attribute	Tatra Mountains
Water divide	Black Sea, Baltic Sea
Area [km <sup>2</sup> ]	785
Length [km]	57
Width [km]	up to 18.5
Highest peak [m a.s.l.]	2655 (Gerlachovský štít, Slovakia)
Timberline [m a.s.l.]	1550
Glaciers	no
Perennial snow patches	yes
Permafrost	no?

and glaciofluvial and fluvio-glacial sediments (Lukniš 1973). During the Last Glacial Maximum the Tatra Mountains were covered by 55 valley and cirque glaciers, which occupied an area of 279.6 km<sup>2</sup>. The average thickness of ice amounted 88 m. There was an asymmetry of glaciation: the southern slopes were occupied by glaciers longer than on the northern slopes. It was caused by the asymmetry of topography: the southern facing valley heads were located at higher elevation compared to the northern facing





**Fig. 2.5.** The Tatra Mountains (based on [www.mapy.cz](http://www.mapy.cz)). The rounded rectangle on the left marks the Jalovecký Creek research catchment (area 22.2 km<sup>2</sup>, mean elevation 1500 m a.s.l.); 1 – gauge on the Belá river (Podbanské) which has the longest record of annual runoff among the small mountain catchments of the Tatra Mountains (since 1895); 2 – the high mountain meteorological station Kasprowy Wierch (Western Tatra Mountains, 1991 m a.s.l., windward position, established in 1937); 3 – the high mountain meteorological station Skalnaté Pleso (High Tatra Mountains, 1778 m a.s.l., leeward position, established in 1939); 4 – meteorological station Štrbské Pleso (High Tatra Mountains, 1354 m a.s.l., leeward position, established in 1902); 5 – meteorological station Zakopane (the foothills, 855 m a.s.l., windward position, regular data since 1911); 6 – meteorological station Liptovský Hrádok (the foothills, 640 m a.s.l., leeward position, established in 1881).

slopes (Photo. 2.6). The higher altitude ice-surfaces favored bigger alimention rate for southern glaciers. There are about 300 postglacial lakes (mostly in the High Tatra Mountains on the southern slope) that cover about 0.41% of the Tatra Mountains (3.23 km<sup>2</sup>). Cirque, bedrock-moraine dammed, inter-sheepback, and moraine lakes prevail (Photo. 2.7). Eight of lakes exceed an area of 0.1 km<sup>2</sup> (Klimaszewski 1988, Kłapyta et al. 2016; Molnár, Pacl 1988).

The Tatra Mountains are located in a transitional position of the temperate climate influenced by polar oceanic air-masses from the west and polar continental air-masses – in the minority – coming from the east and north-east (Trepínska 2002). Rapid pressure changes and temperature inversions are typical for the Tatra Mountains. The annual air temperature ranges from 6°C in the lowest climatic belt to ap. –4°C in the fell belt. In spite of relatively favorable climatic conditions there are no glaciers due to lack of suitable orographic conditions (too steep mountain slopes, rocky walls). Perennial snow patches and firn-ice patches – an embryonic form of glaciers called *glacieret* – occur in shady places. They accumulate snow avalanches and wind-blown snow (Gašek 2011, Photo. 2.8).

Vegetation belts are well-developed in the Tatra Mountains. The forest belt spread to an elevation



**Photo. 2.6.** The northern facing slopes of the Tatra Mountains at the time of snowmelt season in May 2014 (Photo. J. Pociask-Karteczka).



**Photo. 2.7.** The High Tatra Mountains – the Czarny Staw pod Rysami and Morskie Oko lakes (Photo. A. Śliwiński).

1550 m a.s.l. and is dominated by spruce. The sub-alpine belt between 1500 and 1800 m a.s.l. is covered by continuous or sparse dwarf mountain pine (*Pinus mugo*) which is replaced by mountain alpine meadow at the elevation of 1880 m a.s.l. The uppermost periglacial belt of rock faces, rock debris and locally permanent snow patches lies over the altitude 2300 m a.s.l. (Kotarba 1992).

Most of the area of the Tatra Mountains, both in Slovakia and Poland, is protected in national parks (the Tatrarský národný park since 1949 and the Tatrzanski Park Narodowy since 1954).

### Comparison and conclusions

The Scandinavian Mountains and Tatra Mountains are the only regions representing the high mountain environment in the Baltic Sea drainage basin. There are water divides in both regions: the water divide of the North Sea, Norwegian Sea, Barents Sea and Baltic Sea in the Scandinavian Mountains, and the Main European Water Divide of the Black Sea and Baltic Sea in the Tatra Mountains. Gerlachovský štít – the highest peak of the Tatra Mountains – is located within the Baltic Sea drainage basin while Galdhøpiggen – the highest peak of the Scandinavian Mountains – lies out of the Baltic Sea drainage basin (in the Norwegian Sea drainage basin), and Kebnekaise (2096.8 m a.s.l.) is the highest peak of the Scandinavian Mountains within the Baltic Sea drainage basin.



**Photo. 2.8.** Perennial snow patches in the Tatra Mountains late summer (Photo. J. Pociask-Karteczka).

The snow line in the Tatra Mountains is located much higher than in the Scandinavian Mountains due to the difference in geographic latitude. Presence of glaciers in the Scandinavian Mountains and their absence in the Tatra Mountains represents the essential difference between these two mountain chains. Glaciation consists of ice fields with outlet glaciers, which appear with fjords on the western slope, and deep valleys with long lakes and wetlands on the eastern slope of the Scandinavian Mountains. There are barely perennial snow and firn-ice patches in the Tatra Mountains located in shady, leeward deep sites (also below the snow line). There are numerous landforms and lakes which are evidences of the Pleistocene glaciation in the Tatra Mountains (U-shaped valleys, glacial cirques, *arête*, steep rocky crests, cirque lakes). Permafrost is an exclusive feature of the Scandinavian Mountains (the northern part) while its presence has not been proven in the Tatra Mountains. Altitudinal belts (i.a. vegetation, climate) are typical in both regions. There is a dwarf pine belt over the forest belt in the Tatra Mountains while the montane birch forest and tundra communities are typical for the Scandinavian Mountains.

In spite of dissimilarities in abiotic and biotic components of natural environment of these two mountain ranges, the high mountain landscape – common in both regions – makes them spectacular and exceptional.