Mountains of Slovenia

5

Mauro Hrvatin and Matija Zorn

Abstract

Slovenia's mountainous areas comprise Alpine mountains, Alpine hills, and Dinaric plateaus, which together cover over half of the country. Its mountainous landscapes lie at the intersection of the geotectonic units of the Dinarides, Southern Alps, and Eastern Alps. Limestone and dolomite predominate, although there are also extensive areas in the Alpine hills composed of poorly permeable clastic, igneous, and metamorphic rock. In terms of geomorphological development, mountainous areas can be divided into glacial, fluvio-denudational, and karst landscape types. Glacial landscapes are limited to areas that were exposed to glacial erosion and accumulation during the cold Pleistocene periods, and fluvio-denudational landscapes are typical of areas made of poorly permeable rocks and characterized by surface runoff. Karst landscapes developed on carbonate rocks. They are characterized by intense chemical dissolution of the bedrock and subterranean karst hydrology. The high mountains feature a combination of glacial and karst landscapes, or glaciokarst. Due to the Alpine–Dinaric barrier, Slovenia's climate is wetter than average. Over the past decades, the average air temperature has been rising rapidly, which causes frequent droughts in the summer and reduces the duration and depth of snow cover in the winter. Climate change has already resulted in significantly lower discharges of mountain rivers and altered discharge regimes. Water conditions largely depend on the rock composition. Nearly two-thirds of mountainous areas is karst and almost devoid of surface water flows, while elsewhere the river system is highly branched. The predominant soils on carbonate rocks are Rendzina and Chromic Cambisol, whereas Dystric Cambisol predominates on non-carbonate rocks. Forest is the natural vegetation and the predominant land-use type in all mountainous areas. The dominant tree is beech, which creates numerous forest communities. Conifers dominate at higher elevations, especially spruce and larch, which grow up to the tree line between 1,550 and 1,900 m. Late-medieval colonization of higher elevations was a key stage in the permanent colonization of mountainous areas, extending even above 1,000 m. In the Alpine mountains, it was the valleys that were usually settled, and in the Alpine hills people also settled the ridges and slopes. The upper limit of settlement in Slovenia's mountainous areas varies; the highest settlements can be found in the Eastern Karawanks, even at elevations above

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1,300 m. The traditional economic activity is forestry.

Keywords

Rocks · Surface · Climate · Hydrology · Soil · Vegetation · Settlement · Alpine mountains · Alpine hills · Dinaric plateaus · Slovenia

5.1 Introduction

Slovenia's mountainous areas (as defined by Perko in Chap. 3 of this volume; Fig. 5.1) cover 11,531.1 km^2 or 56.9% of the country. They can be divided into:

- Alpine mountains (3,061.8 km^2, 26.5% of mountainous areas, 15.1% of the entire country);
- Alpine hills (4,660.0 km^2, 40.4% of mountainous areas, 23.0% of the entire country); and
- Dinaric plateaus (3,809.3 km^2, 33.0% of mountainous areas, 18.8% of the entire country).

Alpine mountains (for basic morphometric indicators, see Table 4.6 in Chap. 4 of this volume; Fig. 5.1) include the Julian Alps, the Kamnik–Savinja Alps (Fig. 5.2), and the Karawanks. The first two mountain ranges are very imposing, but they are dissected by deep, even glacially transformed valleys that separate individual mountain groups. They are characterized by very steep slopes, which in many places turn into picturesque rockfaces. Prominent karst and wooded plateaus lie on their edges, such as the Pokljuka, Mežakla, and Jelovica plateaus on the edges of the Julian Alps and the Velika Planina, Dleskovec, Golte, Menina, and Dobrovlje plateaus on the edges of the Kamnik–Savinja Alps; rocky karst plateaus (referred to as *podi* in Slovenian) can also be found closer to the center of these mountains, above the tree line. The Karawanks are a distinctly elongated and slightly lower mountain range stretch along the Austrian border. The glacial valley of Belska kočna (Vellacher Kotschna) divides the range into the Western and Eastern Karawanks (Kladnik 1998a).

Because limestone predominates in the rock composition of the Alpine mountains, surface streams are rare and are limited to the deeply cut valleys. The permeable surface gave rise to high-mountain karst, in which karst landforms are closely interwoven with glacial and periglacial ones (Kladnik 1998a).

The extensive **Alpine hills** (for basic morphometric indicators, see Table 4.6 in Chap. 4 of this volume; Fig. 5.1) are composed of several landscapes: the Cerkno (Fig. 5.3), Škofja Loka, Polhov Gradec, and Rovte Hills in western Slovenia, the extensive Sava Hills in central and eastern Slovenia, and the Ložnica and Hudinja Hills and the Velenje and Konjice Hills to the northeast. The Pohorje (Fig. 5.3), Strojna, and the Kozjak Hills extend farthest to the northeast; these are the southern spurs of the Central Alps separated by the deeply cut Drava, Mislinja, and Mežica valleys. The surface is heavily dissected into valleys and ridges with an elevation difference of over 200 m per square kilometer. The slopes are mostly long, steep, and wooded, and in many places they are broken up by shelves and side ridges with sufficient space for isolated farms and small hamlets. The rock composition is very diverse. Carbonate rocks predominates in the western hills, with sandstone and shale exposed only in the lower parts. In the Sava Hills, narrow belts of higher limestone hills and slightly lower shale and sandstone hills follow one another from north to south, whereas hills made of volcaniclastic, igneous, and metamorphic rock dominate the Savinja and Drava basins (Kladnik 1998a).

Dinaric karst **plateaus** (for basic morphometric indicators, see Table 4.6 in Chap. 4 of this volume; Fig. 5.1) extended in what is nearly a contiguous belt from the central Soča Valley in the west to the Kolpa River in southeastern Slovenia. The Kambreško and Banjšice Plateaus lie in the northwesternmost part of the Dinaric region, separated by the deeply cut Soča Valley. The high Dinaric Trnovo Forest (*Trnovski gozd*; Fig. 5.4), Nanos, and Hrušica Plateaus extend to the southeast from there. These transition into the more rugged Idrija Hills in the north and the high

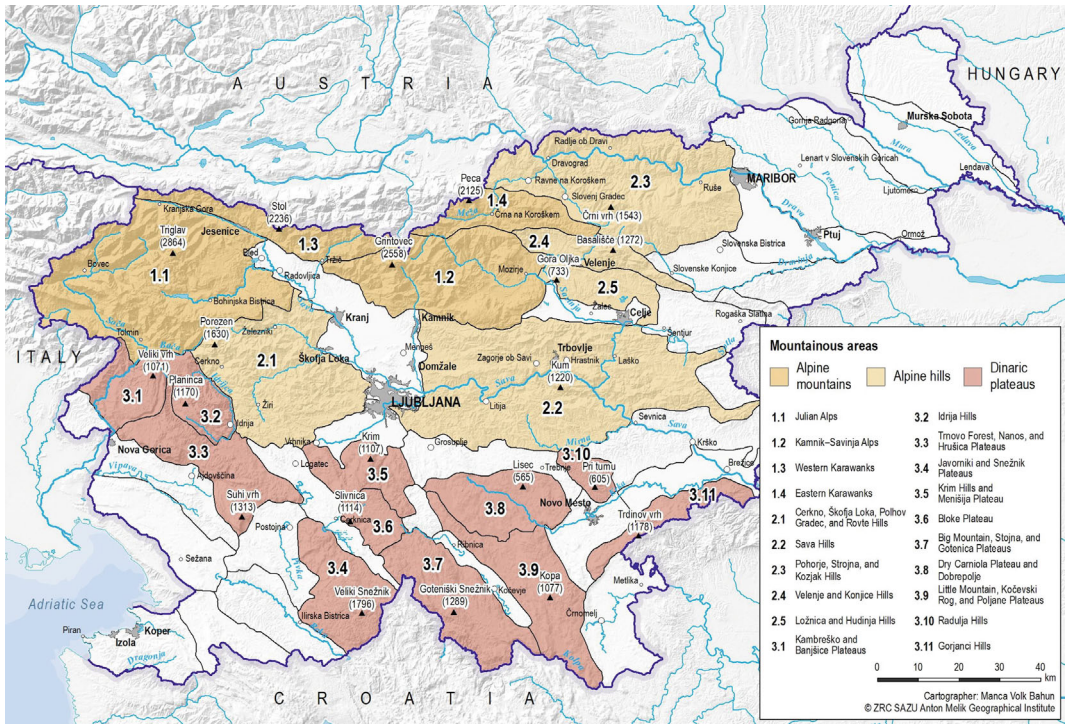

Fig. 5.1 Slovenia's mountainous areas with the Alpine mountains, Alpine hills, and Dinaric plateaus marked separately. (Adapted from Perko and Ciglič 2020a, b)

Dinaric Javorniki (Fig. 5.4) and Snežnik Plateaus to the southeast. East of the Inner Carniola Lowland (*Notranjsko podolje*), a series of slightly lower plateaus extends from the Menišija Plateau and the Krim Hills in the north via the Bloke Plateau to the Big Mountain (*Velika gora*), Stojna, and Gotenica (*Goteniška gora*) Plateaus in the south. The plateau of Dry Carniola (*Suha krajina*) rises above the upper Krka Valley, followed by Little Mountain (*Mala gora*), Kočevski Rog, and Poljane (*Poljanska gora*) Plateaus to the south. The Radulja Hills extend east of the Lower Carniola Lowland (*Dolenjsko podolje*), and the Gorjanci Hills rise above the lower reaches of the Krka River (on its right bank). The Gorjanci Hills extend in a predominantly southwest–northeast direction, which makes them an exception among the Dinaric landscapes. Karst plateaus are heavily broken up by countless karst depressions, conical hills, and rugged rocky terrain. Thick fir–beech and beech forests grow in very unfavorable conditions on these plateaus because there is very little fertile soil on the surface and rainwater drains quickly through the thick limestone layers into the karst underground, only resurfacing in the powerful karst springs below the plateaus (Kladnik 1998b).

5.2 Rocks

Slovenia's mountainous areas lie at the intersection of the Dinarides, Southern Alps, and Eastern Alps. Even though today these geotectonic units are close together and even overlap in places, they have different geological histories. They all belong to the Adriatic microplate, which separated from the African plate during the Mesozoic. While moving north, it collided with the Eurasian plate during the Neogene, causing the Alps to rise. The two plates have continued to approach each other since this collision, which is still the main factor affecting Slovenia's tectonic structure (Novak 2016; Hrvatin et al. 2020; Fig. 5.5).

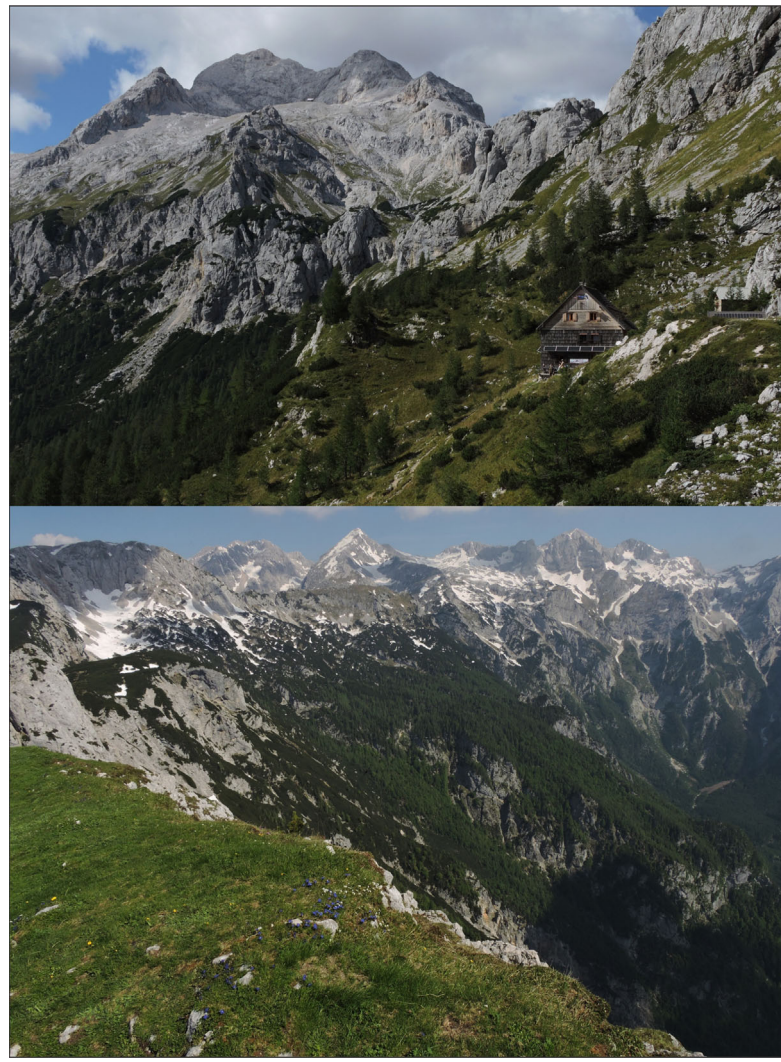

Fig. 5.2 The two highest mountain ranges in Slovenia. Top: Mount Triglav (2,864 m), the highest peak in Slovenia and the Julian Alps, with the Vodnik Lodge (1,817 m) in the foreground. Bottom: the central part of the Kamnik–Savinja Alps with Mount Grintovec (2,558 m) as its highest peak. (Photo by Matija Zorn)

The borders between the geotectonic units run along the Periadriatic (Seam), Labot, Ljutomer, and Sava faults, the thrust front of the Southern Alps, and the external front of the thrust zone of the External Dinarides (Celarc and Placer 2016).

The **Dinarides** are divided into the External and Internal Dinarides, and a transitional zone in between. Slovenia only includes the External Dinarides with the transitional zone. The External Dinarides have a thrust and nappe structure, which formed at the end of the Eocene and the beginning of the Oligocene. It is composed of extensive nappes made of Mesozoic carbonate rocks thrust horizontally on top of one another. The thrusting took place from the northeast toward the southwest, and the nappe units slid across a base made of Paleozoic rocks. In the front part of the mountain range, they are thrust over Eocene flysch layers. Typical examples of thrust tectonics in the External Dinarides include the Trnovo (Fig. 5.4) and Hrušica nappes, and the Snežnik thrust block (Placer 1999, 2008; Celarc and Placer 2016).

In terms of paleogeography, the **Southern Alps** are part of the Dinarides, from which they separated during the Miocene. They are delimited by the Periadriatic (Seam), Labot, and Ljutomer faults to the north, and the Southern Alpine thrust front and the Sava Fault to the south. They are

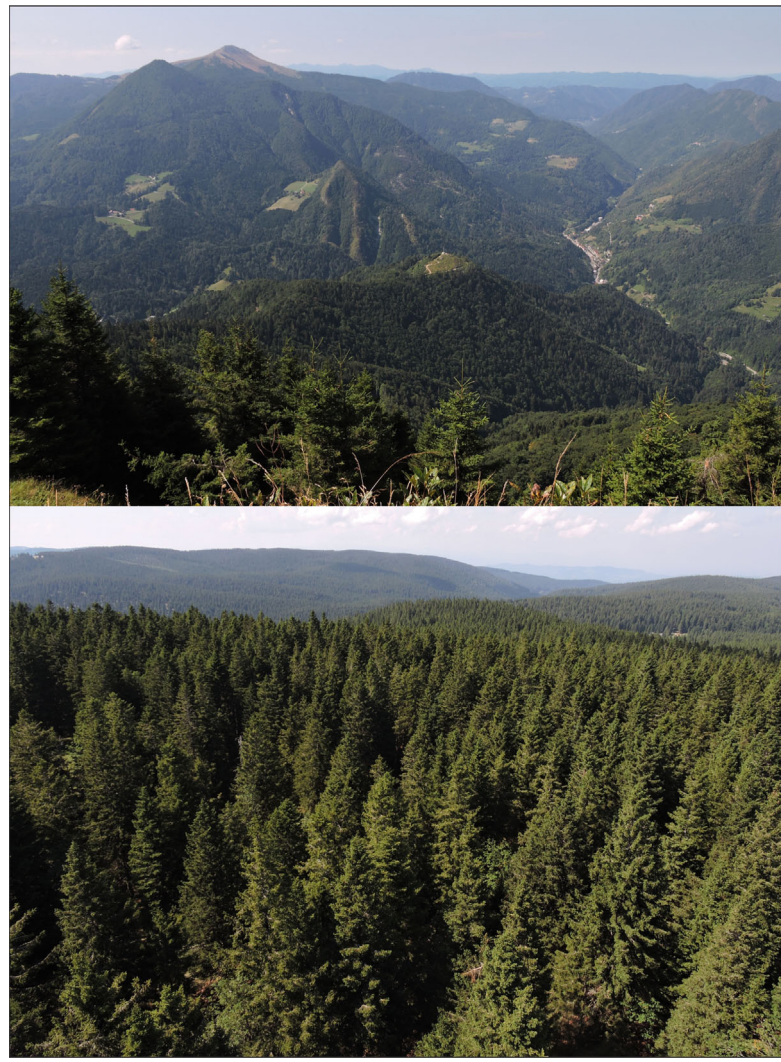

Fig. 5.3 Alpine hills. Top: the Cerkno Hills with Mount Porezen (1,630 m) as their highest peak. Bottom: the wooded Pohorje Hills, whose highest parts rise above 1,500 m. (Photo by Matija Zorn)

made of the Upper Triassic rocks of the Julian Carbonate Platform and the Mesozoic rocks of the Slovenian Basin. The Southern Alps comprise the Julian and Kamnik–Savinja Alps, the Western Karawanks, the Paški Kozjak and Boč hills, the Alpine hills along the Bača and Selška Sora rivers, and part of the Škofja Loka Hills. The thrust sheets of the Southern Alps formed predominantly between the Eocene and Middle Oligocene. Due to the north–south thrust direction, the ridges of the mountains and hills run largely from west to east (Placer 2008).

The **Eastern Alps** encompass the Precambrian and Early Paleozoic metamorphosed rocks and the Permian and Mesozoic sedimentary rocks north of the Periadriatic (Seam) Fault. In Slovenia, the Eastern Alps include the Pohorje, Strojna, and Kozjak Hills and the Eastern Karawanks with Mounts Peca and Uršlja gora (Placer 2009). The Eastern Alps are made of extensive nappes that formed in the Alpine orogeny between the Cretaceous and the Neogene. In addition to its nappe structure another important feature is plutonism, which is divided into Periadriatic tonalite intrusions of Oligocene age and Pohorje granodiorite pluton with dacitic sills and dikes of Miocene age (Fodor et al. 2008; Placer 2008).

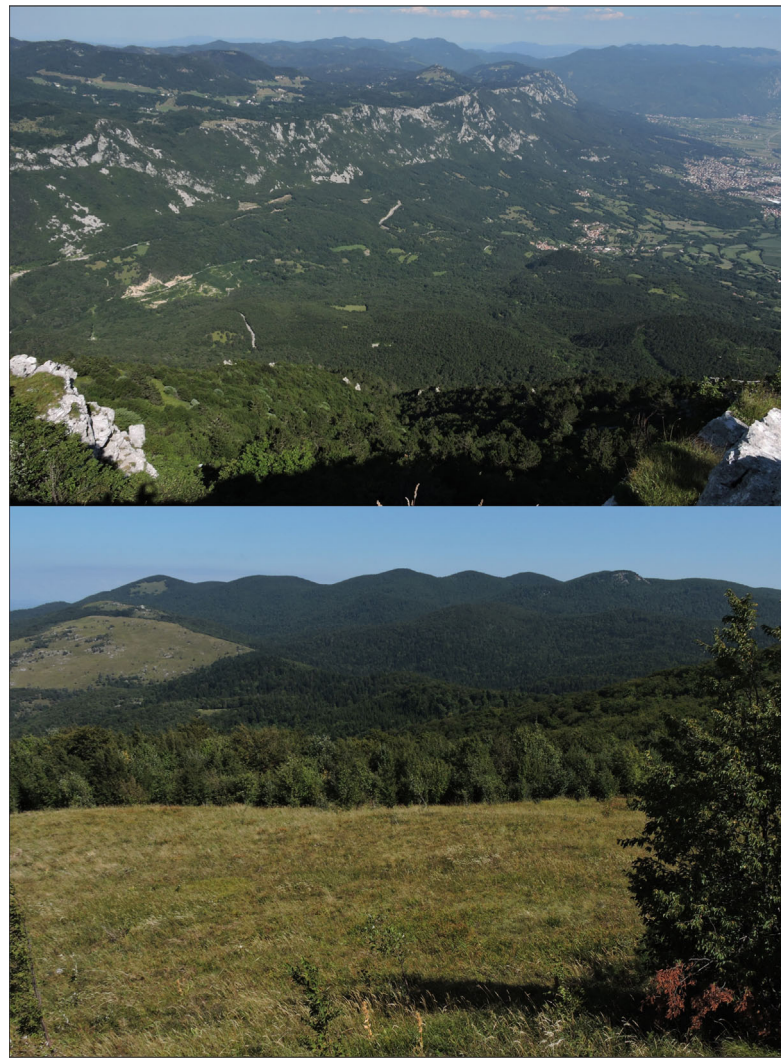

Fig. 5.4 Dinaric plateaus. Top: the thrust structure of the Trnovo Forest Plateau rises to 1,000 m above the Vipava Valley (at approximately 100 m). Bottom: the rounded tops of the Javorniki Plateau, rising above 1,200 m. (Photo by Matija Zorn)

In many places, the geological structure is clearly reflected in the landforms. This especially applies to large geological structures, such as thrusts, folds, and faults. In some places, the thrust fronts take the form of sudden transitions in terrain. The steep limestone slopes of the Trnovo Forest Plateau above the flysch Vipava Valley form the front of the Trnovo thrust (Fig. 5.4). Folded terrain most often takes the form of parallel elongated sequences of ridges and valleys, such as in the Sava Hills. In many places, river valleys are cut into the tectonically damaged rocks along the faults. The Soča and Idrijca rivers cut part of their valleys along the Idrija fault.

The rocks (Figs. 5.6 and 5.7, Table 5.1) shaping the surface of Slovenia's mountainous areas formed from at least the Early Paleozoic to the Quaternary. The oldest metamorphic rocks are probably even of Precambrian age (Novak 2016). Sedimentary rocks predominate, covering 78.1% of the surface. Especially common among these are limestone and dolomite (50.3%) as carbonate rocks, whereas quartz sandstone and conglomerate, shale, and flysch and volcanoclastic rocks predominate among the non-carbonate rocks (27.8%). Loose sediments cover the river valleys and certain slopes, covering 12.0% of the territory. Metamorphic rocks account

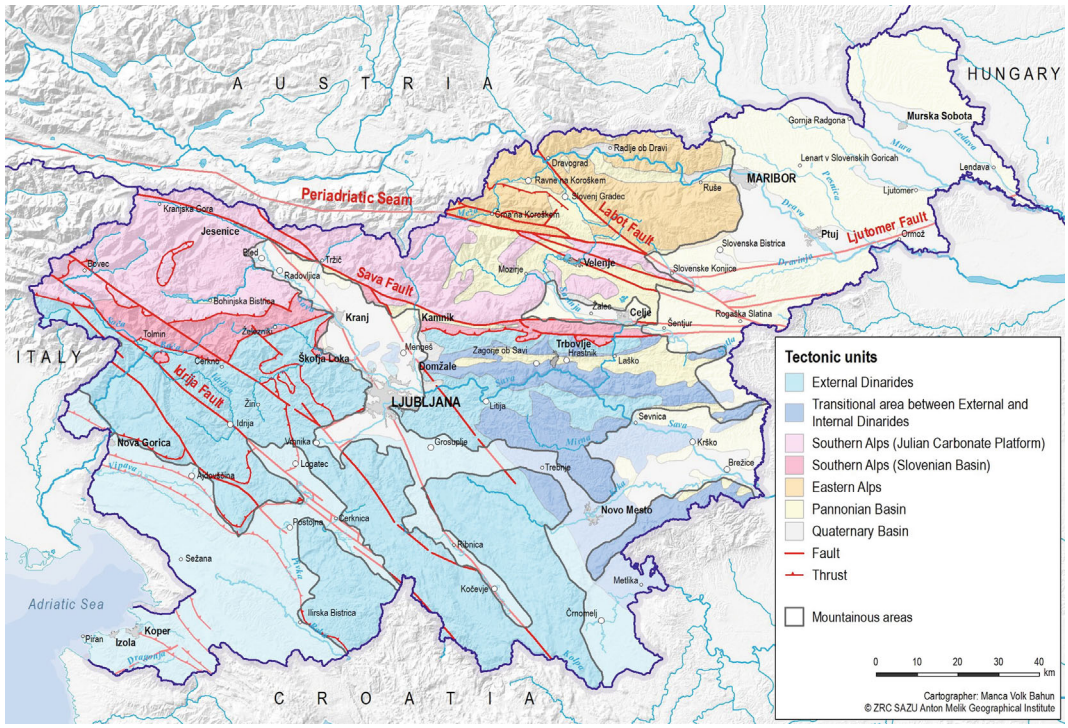

Fig. 5.5 Tectonic structure of Slovenia's mountainous areas. (Adapted from Poljak 2007; Celarc and Placer 2016)

for 7.1% of the territory, and they are predominantly clustered in the northeast of mountainous areas. Igneous rocks account for the smallest share, covering only 2.8% of the territory. Intrusive igneous rocks can only be found on the surface along the Periadriatic Seam and in the Pohorje Hills, and volcanic rocks are dispersed across small patches in the Alpine hills and mountains.

The distribution of individual rock types is fairly uneven. Alpine mountains are predominantly made of limestone and dolomite, whereas carbonate gravel, rubble, and till have accumulated in large quantities in the valleys. Shale, quartz sandstone, quartz conglomerate, and dolomite dominate the Alpine hills of Central Slovenia. Standing out in this respect are the Alpine hills in northeastern Slovenia, which are made of metamorphic and igneous rocks. Nearly all Dinaric plateaus are made of limestone and dolomite. Due to their diversity, rocks play an important role in Slovenian landscapes. They are what largely determines today's landforms, network of rivers and creeks, soil types, distribution of plant species, and human activities in the landscape (Natek and Natek 1998).

5.3 Landscape Types

In terms of their geomorphological development (genesis), one can distinguish between glacial, fluvio-denudational, and karst landscapes in Slovenia's mountainous areas (Figs. 5.8, 5.9 and Table 5.2). Glacial landscapes are limited to areas that were exposed to glacial erosion and accumulation during the cold Pleistocene periods, and fluvio-denudational landscapes are typical of areas made of poorly permeable rocks and characterized by surface runoff. Karst landscapes developed on carbonate rocks. They are characterized by intense chemical dissolution of the bedrock and subterranean karst hydrology (Hrvatin 2004).

Some areas feature a combination of genetic landscape types. For example, glaciokarst is typi-

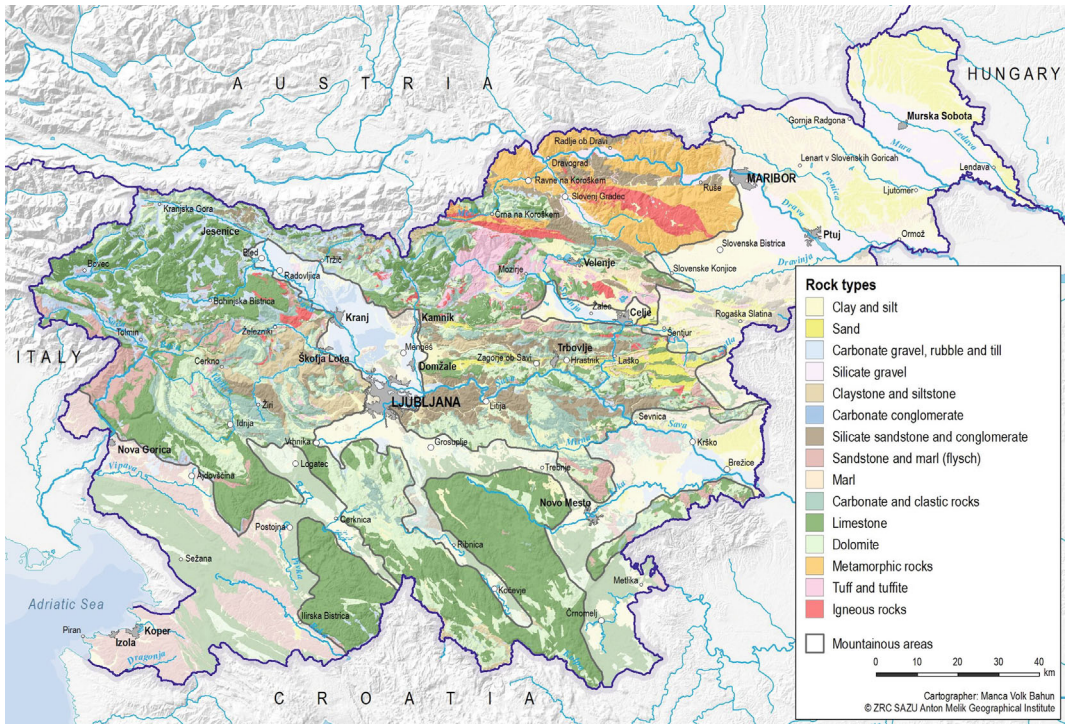

Fig. 5.6 Rock types in Slovenia's mountainous areas. (Adapted from Litostratigrafska ... 2011; Perko et al. 2015)

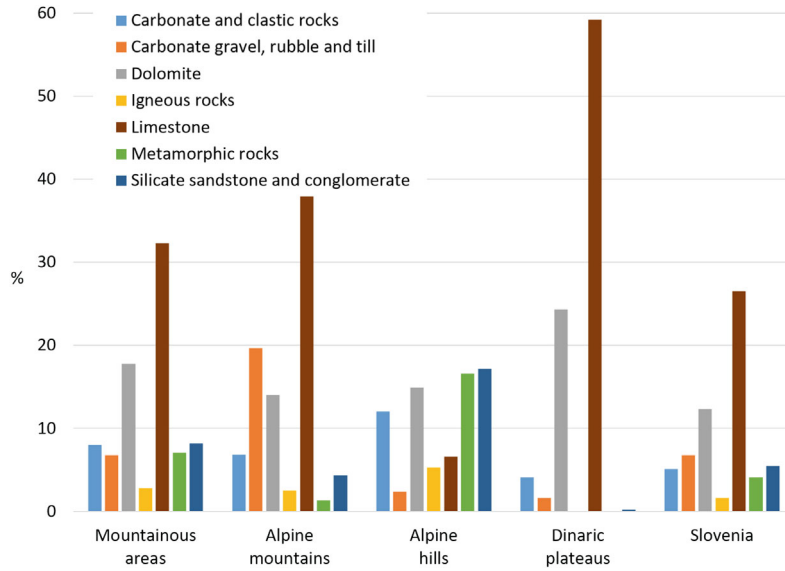

Fig. 5.7 Predominant rock types in Slovenia's mountainous areas. (Based on Table 5.1)

cally found in mountains that were reshaped by glaciers during the Pleistocene and where the chemical dissolution of carbonate rocks now predominates. In addition to landforms that more or less clearly belong to a specific genetic landscape type, there is a variety of those that developed through the interaction of various geomorphological processes and are therefore referred to as polygenetic. The most typical among these are peaks, ridges, and slopes of various

Table 5.1 Rock types in Slovenia's mountainous areas. (Based on Fig. 5.6)

Rock type	Mountainous area			*Alpine mountains*				*Alpine hills*				*Dinaric plateaus*				Slovenia	
	Area (km^2)	% of mountainous areas	% of Slovenia	Area (km^2)	% of Alpine mountains	% of mountainous areas	% of Slovenia	Area (km^2)	% of Alpine hills	% of mountainous areas	% of Slovenia	Area (km^2)	% of Dinaric plateaus	% of mountainous areas	% of Slovenia	Area (km^2)	%
Carbonate and clastic rocks	926.07	8.03	4.57	209.71	6.85	1.82	1.03	559.66	**12.01**	4.85	2.76	156.69	4.11	1.36	0.77	1,040.52	5.13
Carbonate conglomerate	24.83	0.22	0.12	19.98	0.65	0.17	0.10	4.38	0.09	0.04	0.02	0.47	0.01	0.00	0.00	152.49	0.75
Carbonate gravel, rubble and till	777.93	6.75	3.84	602.47	**19.68**	5.23	2.97	112.80	2.42	0.98	0.56	62.66	1.65	0.54	0.31	1,368.59	6.75
Clay and silt	473.83	4.11	2.34	20.47	0.67	0.18	0.10	353.92	7.60	3.07	1.75	99.44	2.61	0.86	0.49	2,628.61	**12.97**
Shale, claystone and siltstone	337.32	2.93	1.66	44.90	1.47	0.39	0.22	252.15	5.41	2.19	1.24	40.27	1.06	0.35	0.20	348.77	1.72
Dolomite	2,051.72	**17.80**	**10.12**	430.80	**14.07**	3.74	2.13	695.11	**14.92**	6.03	3.43	925.81	**24.31**	8.03	4.57	2,504.06	**12.36**
Igneous rocks	326.10	2.83	1.61	77.15	2.52	0.67	0.38	247.64	5.31	2.15	1.22	1.31	0.03	0.01	0.01	332.24	1.64
Limestone	3,723.66	**32.30**	**18.37**	1,160.50	**37.91**	**10.07**	5.73	307.96	6.61	2.67	1.52	2,255.20	**59.22**	**19.56**	**11.13**	5,378.79	**26.54**
Marl	113.31	0.98	0.56	10.28	0.34	0.09	0.05	101.55	2.18	0.88	0.50	1.48	0.04	0.01	0.01	980.92	4.84
Metamorphic rocks	812.30	7.05	4.01	40.29	1.32	0.35	0.20	772.00	**16.57**	6.70	3.81	0.00	0.00	0.00	0.00	831.16	4.10
Sand	143.75	1.25	0.71	0.90	0.03	0.01	0.00	142.63	3.06	1.24	0.70	0.22	0.01	0.00	0.00	913.81	4.51
Sandstone and marl (flysch)	472.76	4.10	2.33	118.69	3.88	1.03	0.59	103.73	2.23	0.90	0.51	250.34	6.57	2.17	1.24	1,443.65	7.12
Silicate gravel	130.08	1.13	0.64	8.10	0.26	0.07	0.04	121.97	2.62	1.06	0.60	0.00	0.00	0.00	0.00	930.93	4.59
Quartz sandstone and conglomerate	941.95	8.17	4.65	133.70	4.37	1.16	0.66	800.07	**17.17**	6.94	3.95	8.19	0.21	0.07	0.04	1,106.23	5.46
Tuff and tuffite	273.59	2.37	1.35	183.26	5.99	1.59	0.90	84.22	1.81	0.73	0.42	6.11	0.16	0.05	0.03	304.81	1.50
Total	11,529.19	100.00	56.89	3,061.20	100.00	26.55	15.11	4,659.80	100.00	40.42	22.99	3,808.20	100.00	33.03	18.79	20,265.58*	100.00

* The data in the data layer used do not entirely correspond to Slovenia's actual size: 20,273 km^2

Those covering more than 10% are in bold

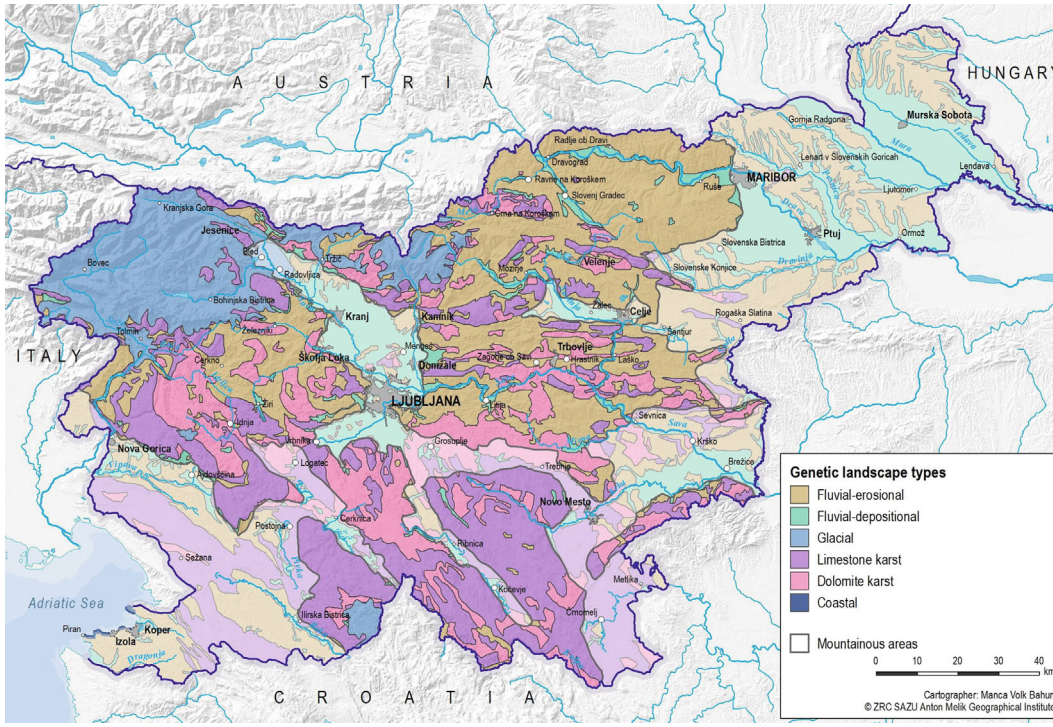

Fig. 5.8 Genetic landscape types in Slovenia's mountainous areas. (Adapted from Gabrovec and Hrvatin 2018)

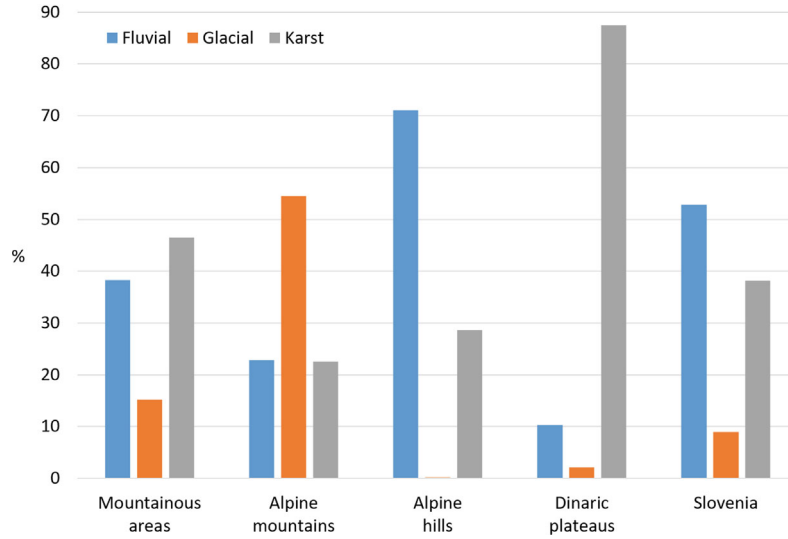

Fig. 5.9 Predominant genetic landscape types in Slovenia's mountainous areas. (Based on Table 5.2)

Table 5.2 Genetic landscape types in Slovenia's mountainous areas. (Based on Fig. 5.8)

Type, *subdivision*	**Description**	**Mountainous areas**			***Alpine mountains***				***Alpine hills***				***Dinaric plateaus***				**Slovenia**	
		Area (km^2)	% of mountainous areas	% of Slovenia	Area (km^2)	% of Alpine mountains	% of mountainous areas	% of Slovenia	Area (km^2)	% of Alpine hills	% of mountainous areas	% of Slovenia	Area (km^2)	% of Dinaric plateaus	% of mountainous areas	% of Slovenia	Area (km^2)	%
Fluvial	Dominates on poorly permeable rocks with surface drainage	4,409.40	**38.24**	**21.75**	701.21	**22.90**	6.08	3.46	3,313.16	**71.10**	**28.73**	**16.34**	395.03	**10.37**	3.43	1.95	10,712.21	**52.85**
Erosion	Characteristic of mountainous and hilly landscapes with valleys and ridges	3,947.31	**34.23**	**19.47**	617.58	**20.17**	5.36	3.05	3,015.70	**64.72**	**26.15**	**14.88**	314.03	8.24	2.72	1.55	7,110.76	**35.08**
Deposition	Characteristic of flat landscapes and plains	462.09	4.01	2.28	83.63	2.73	0.73	0.41	297.46	6.38	2.58	1.47	81.00	2.13	0.70	0.40	3,601.45	**17.77**
Glacial		1,761.04	**15.27**	8.69	1,668.61	**54.50**	**14.47**	8.23	9.94	0.21	0.09	0.05	82.49	2.16	0.72	0.41	1,825.10	9.00
Karst	Characterized by chemical weathering of carbonate rocks (limestone and dolomite), circular surface depressions, and subsurface drainage	5,361.25	**46.49**	**26.45**	691.89	**22.60**	6.00	3.41	1,336.82	**28.69**	**11.59**	6.59	3,332.54	**87.47**	**28.90**	**16.44**	7,731.44	**38.14**
Limestone		3,102.09	**26.90**	**15.30**	477.41	**15.59**	4.14	2.36	429.26	9.21	3.72	2.12	2,195.42	**57.62**	**19.04**	**10.83**	4,874.24	**24.05**
Dolomite		2,259.16	**19.59**	**11.15**	214.48	7.01	1.86	1.06	907.56	**19.48**	7.87	4.48	1,137.12	**29.85**	9.86	5.61	2,857.20	**14.10**
Coastal	Limited to a narrow Adriatic coastal belt																1.75	0.01
Total		11,531.69	100.00	56.89	3,061.70	100.00	26.55	15.10	4,659.93	100.00	40.41	22.99	3,810.06	100.00	33.04	18.80	20,270.50*	100.00

* The data in the data layer used do not entirely correspond to Slovenia's actual size: 20,273 km^2

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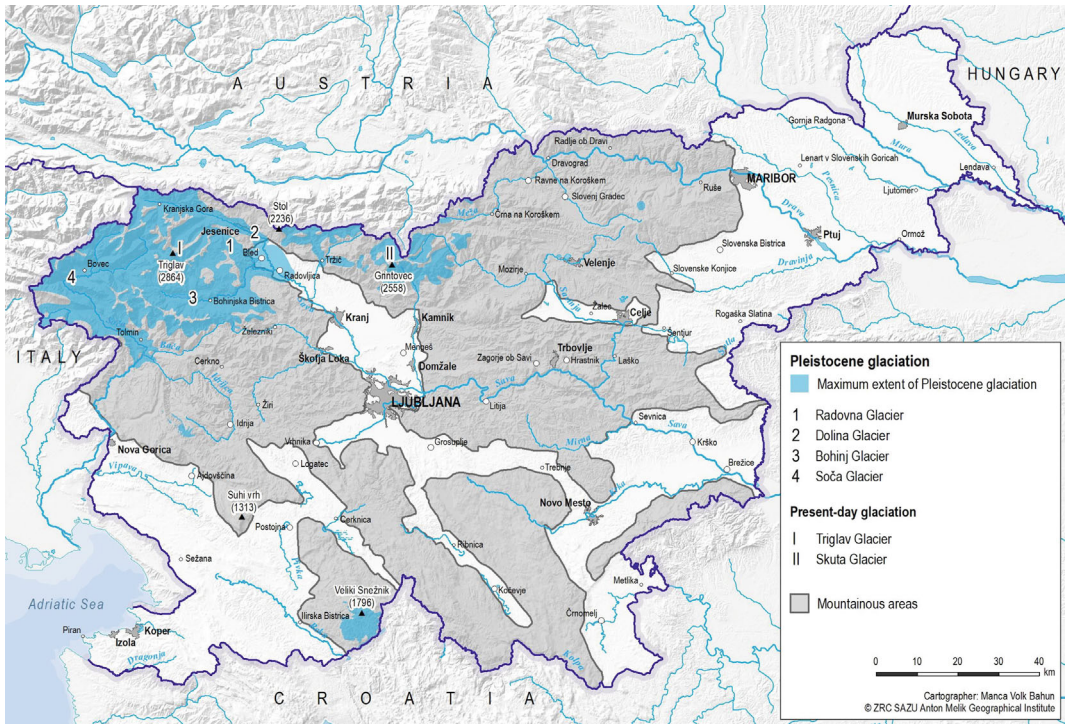

Fig. 5.10 Pleistocene glaciation of Slovenia's mountainous areas. (Adapted from Šifrer 1998; Ferk et al. 2017)

shapes (Gabrovec and Hrvatin 1998; Zorn et al. 2020a, b).

5.3.1 Glacial Landscapes

Glacial landscapes cover over 15.3% of Slovenia's mountainous areas (Fig. 5.10). They formed through glacial erosion and accumulation during the cold periods of the Pleistocene. They are typical of the Alpine mountains, such as the Julian Alps and the Kamnik–Savinja Alps, and partly also the Karawanks, the Pohorje Hills among the Alpine hills, and certain high Dinaric plateaus, such as the Snežnik and the Trnovo Forest plateaus (Ferk et al. 2017). They make up over half of the Alpine mountains, only 0.2% of the Alpine hills, and just over 2% of the Dinaric plateaus.

During the Last Glacial Maximum, the Julian Alps were covered by an ice cap above an approximate elevation of 1,300 m, from which glaciers crept down through the valleys, extending far below the snow line. The greatest volume of ice masses accumulated in the Bohinj Valley, into which ice flowed down from the ridges and high-mountain plateaus on its north, west, and south sides. At Bohinjska Bistrica, the ice masses were as thick as 800 m. From the Bohinj Valley, the glacier descended through the valley of what is now the Sava Bohinjka River all the way down to the Bled–Radovljica Basin (Melik 1930; Šifrer 1969).

Two other glaciers descended toward that same basin. The first crept down the Radovna Valley and the other down the Sava Dolinka (Dolina) Valley. The Radovna Glacier was fed by ice masses coming down from the Krma and Kot high-mountain valleys, as well as from the northern part of the Pokljuka Plateau. The Dolina Glacier accumulated ice masses from the Planica, Pišnica, and Vrata high-mountain valleys, and to a smaller degree also from the Western Karawanks (Gams 1992; Ferk et al. 2017).

Great volumes of ice moved along the Soča Valley. According to an older interpretation, the Soča Glacier reached down to Tolmin or even

Most na Soči (being almost 70 km long) during its maximum extent (Šifrer and Kunaver 1978). However, the glacier's characteristics and the model of its possible dimensions show that the size is most likely exaggerated (being maybe half the size), at least when referring to the periods of most recent major Alpine glaciations, and that during that time the main ice flow in the valley must not have extended farther than the Bovec Basin (Bavec et al. 2004).

Only minor glaciers developed in the Kamnik–Savinja Alps. Ice masses descended from beneath the central peaks and ridges down into the deeply cut valleys, extending further down along them, but these glaciers were not long. They only filled the upper parts of the Kokra (Meze 1974), Kamniška Bistrica (Šifrer 1961), and Savinja valleys (Meze 1966), which still have a high-mountain character, and so they did not extend beyond the mountain range.

As a slightly lower and narrow mountain range, the Karawanks were covered by less ice. In their eastern part, small glaciers developed on Mounts Peca and Olševa (Gams 1970), and in the central part there were several glaciers on the slopes of Mount Košuta to the south and in the area of the Zelenica between Mounts Begunjščica, Vrtača, and Stol, from where ice masses descended down the Završnica Valley (Melik 1932; Šifrer 1969).

During the ice ages, the Pohorje Hills were too low to develop an ice cap, but nonetheless several small cirque glaciers developed in the shady depressions on the northern slopes of the main ridge (Natek 2007; Obu 2011).

In the Dinaric Alps, ice mainly accumulated on the extensive plateaus south of Mount Snežnik. These extended over 1,400 m and thus above the permanent snow line. From them, the ice flowed toward Padežnica hollow and from there down the valley onto Gomance piedmont polje, with the ice-covered area extending contiguously all the way to Mount Risnjak in Croatia. Moraine embankments of various ages suggest the area was exposed to multiple glaciations (Šifrer 1959).

The Pleistocene glaciation of the Trnovo Forest Plateau affected at least 8 km^2. The ice cap was approximately 4,8 km^2 in size, and its maximum thickness was approximately 180 m in the karst depression known as *Smrekova draga*. Outlet glaciers fell across a steep transition in the terrain in the form of seracs. After nearly 4 km, the glacier descending down the plateau into the Trebuša Valley stopped at an elevation of around 350 m (Kodelja et al. 2013; Žebre et al. 2013).

The glaciers heavily reshaped the surface. The debris they carried with them eroded many slopes and widened the highest karst plains. Cirques formed under the rocky ridges high up in the mountains. Large cirques include the *Za Akom* and *Pod srcem* cirques above Gozd-Martuljek in the Julian Alps, and the Okrešelj Cirque above the headwall of the Logar Valley in the Kamnik–Savinja Alps. Glaciers filled the former river valleys, transforming them into glacial troughs with a wide, flat bottom and steep slopes. The most typical glaciated valleys include the Trenta, Lepena, Vrsnik, Možnica, Bavšica, Zadnjica, Lower and Upper Bohinj, Voje, Tamar, Vrata, Kot, Krma, Radovna, and Triglav Lakes valleys in the Julian Alps, the Makek (*Makekova kočna*), Ravne (*Ravenska kočna*), Logar (*Logarska dolina*), Matk (*Matkov kot*), Roban (*Robanov kot*), and Kamniška Bistrica valleys in the Kamnik–Savinja Alps, and the Završnica, Draga, and Podljubelj valleys in the Karawanks (Gabrovec and Hrvatin 1998; Kladnik 1998a).

The interglacial, warmer periods of the Quaternary were characterized by significant deepening of the valleys, which began when the glaciers started to recede. The downcutting of rivers was so pronounced that any new deposition during each of the following ice ages no longer reached the height of the previous one. Thus, six main Quaternary terraces formed down the valleys, with each lower one younger than the previous one and hence less weathered and karstified on the surface. Each consecutive terrace is covered by a thinner layer of weathered material, the gravel in it is increasingly less consolidated and, in the youngest terrace from the most recent ice age, it is even completely fresh (Šifrer 1998).

During the ice ages, the nearby non-glaciated periglacial areas were also exposed to profound surface transformation. Due to extremely low temperatures, forest almost completely disappeared. This was followed by strong mechanical

weathering of rocks and solifluction (i.e., slow downslope movement of water-saturated debris). Significant amounts of periglacial debris can be found in the Lower Soča Valley and below the karst plateaus, from the Banjšice and Trnovo Forest plateaus past the Nanos, Hrušica, Javorniki, and Snežnik plateaus, and onward toward the southeast (Šifrer 1998).

Recent geomorphological research has provided new insights into periglacial landforms. In the Pohorje Hills, research has revealed numerous cryoplanation terraces and nivation hollows, as well as the presence of ploughing rocks, blockstreams, and blockfields (Natek 2007; Obu 2011). In the Alpine mountains, detailed laser scanning of the surface has revealed many relict rock glaciers (Fig. 5.11) and nival moraines (Colucci et al. 2016; Triglav Čekada et al. 2016).

Currently, there are only two glaciers left in Slovenia: the Triglav Glacier (Fig. 5.12) in the Julian Alps and the Skuta Glacier in the Kamnik–Savinja Alps. Both are subject to long-term monitoring and hence important for studying past and present environmental changes. The Triglav Glacier lies on the relatively sunny northeastern side of Mount Triglav, at an elevation between 2,400 and 2,500 m. In the second half of the nineteenth century, it still covered nearly forty-six hectares. By 1946, when regular monitoring started, it shrank to fourteen hectares, and it now covers less than half a hectare (Gabrovec et al. 2013, 2014; Triglav Čekada and Zorn 2020). The Skuta Glacier is a cirque glacier, less than a hectare in size, which lies in a year-round shady area at an elevation between 2,000 and 2,100 m (Pavšek 2007; Triglav Čekada et al. 2020). For a long time, the view predominated that both glaciers formed during the Little Ice Age and hence cannot be considered remnants of the Pleistocene glaciation (Ferk et al. 2017). However, the latest uranium–thorium dating of subglacial carbonate deposits in the Triglav Glacier area (Lipar et al. 2021) has surprisingly shown that the sediments were deposited during the Last Glacial Maximum and the Younger Dryas. Exposed subglacial carbonate deposits tend to weather quickly and they erode completely within a few decades (Lipar et al. 2025). Their presence, therefore, indicates that the Triglav Glacier has most likely remained continuously present throughout the Holocene.

Fig. 5.11 Relict rock glaciers can be found in the Alpine mountains, such as the one in the *Beli potok* basin in the Julian Alps with a mean elevation of 1,040 m. Top: lidar image. (*Source* Surveying and Mapping Authority of the Republic of Slovenia) Bottom: steplike surface between two "arches" of the rock glacier. (Photo by Matija Zorn)

5.3.2 Fluvio-Denudational Landscapes

The fluvio-denudational landscape type constitutes nearly four-tenths of Slovenia's mountainous areas. It is the most common in the Alpine hills, covering nearly two-thirds of the total area. In addition, it constitutes just under a fourth of the Alpine mountains and only one-tenth of the Dinaric plateaus. These areas are largely made of poorly permeable rocks, and they are primarily characterized by various slope processes (Komac and Zorn 2007), from slow creeping and leaching

Fig. 5.12 The Triglav Glacier at the end of the nineteenth century (top) and in 2012 (bottom). (GIAM ZRC SAZU archive)

of weathered material to large landslides and rockfalls, and water erosion.

Due to exogenic processes the yearly sediment productions in the Alpine mountains is 1,100 to 1,300 m^3/km^2, and in the Alpine hills 400 to 700 m^3/km^2 (Natek and Natek 1998). Especially in the Alpine hills slumps and landslides are frequent on slopes covered by a thick layer of weathered material and soil; these are triggered in great numbers (up to several dozen per km^2) during heavy rain (Gabrovec 1990). Extensive landslides are common in the Škofja Loka, Idrija, Cerkno, and Sava hills (Komac and Zorn 2007). Rockfalls occasionally develop on the mountain cliffs and steep rocky slopes of mountain valleys (Zorn 2002). In recent decades, they have been especially common in the mountains above the Soča Valley. A significant number of rockfalls developed during the 1976, 1998, and 2004 earthquakes. During the earthquake on April 12, 1998, which had a magnitude of 5.8 on the Richter scale, over a hundred rockfalls of various sizes were triggered, and several million cubic meters of material were moved. During the earthquake on July 12, 2004, which had a magnitude of 4.9 on the Richter scale, thirty-eight rockfalls were recorded in roughly the same area but, because of the smaller earthquake magnitude, they were smaller and primarily only superficial (Vidrih et al. 2001; Komac and Zorn 2007).

An important factor in the transformation of mountainous surfaces is various watercourses. The most important feature of mountain rivers and creeks is their distinctly torrential character, which

shows most clearly in the over tenfold difference between their maximum and average discharges. Between 1991 and 2020, the maximum discharge on the Paka River measured at Šoštanj (137 m^3/s) was 59.9 times higher than average (2,29 m^3/s), the maximum discharge on the Kokra River measured at Kokra was 43.9 times higher than average, and on the Koritnica River at Kal–Koritnica it was 43.3 times higher. A difference of at least 30 times was also recorded on the Kamniška Bistrica River at Kamnik, on the Savinja River at Laško, on the Sora River at Suha, and on the Meža River at Otiški Vrh.

Flash floods are of short duration, but they are extremely violent. They are caused by relatively short but intense rainfall during summer thunderstorms or heavy rain in the fall. They occur along hundreds of small torrents in the mountains and hills, and along certain large rivers, such as the Meža, Mislinja, Savinja, Tržiška Bistrica, Kamniška Bistrica, and Sora. The water rises very fast, transports large amounts of gravel, which it deposits on the fans or floodplains, and then recedes within a few hours (Brilly et al. 1999). The increasing damage from floods in recent years has primarily been the result of ill-considered spatial planning in flood-prone areas (Natek and Natek 1998; Komac et al. 2008).

Alpine mountains and hills are very sensitive to erosion, and so forest is of exceptional importance in these areas. It retains and absorbs water and hinders its runoff but, first and foremost, it prevents the formation of large volumes of unconsolidated erosion debris that surface runoff could transport into the torrents (Horvat 2002).

5.3.3 Karst Landscapes

Karst landscapes are the predominant landform in Slovenia's mountainous areas, covering nearly half of their total area. Taking into account that most previously glaciated areas are also karstified, mountain karst constitutes over 60% of Slovenia's mountainous areas. Most karst landscapes can be found on Dinaric plateaus, where they cover nearly nine-tenths of the total area. Nearly a quarter of the Alpine mountain terrain has a karst character but, if glaciokarst is also taken into account (Fig. 5.13), karst landscapes make up over three-quarters of the Alpine mountains. They also constitute nearly three-tenths of the Alpine hills.

The main characteristics of karst landscapes include intense chemical dissolution of carbonate rocks and underground karst hydrology. Based on the hardness or mineralization of karst waters, it was established that the karst surface in Slovenia lowers by 2 to 10 mm every century; however, on the Trnovo Forest Plateau and Snežnik Plateau and the edges of the Julian Alps, where annual precipitation is up to 3,000 mm, it most likely lowers by more than 10 mm per century locally (Gams 2004). The discovery of unroofed caves has confirmed intense lowering of the surface due to corrosion (Mihevc 2001).

Based on the type of carbonate rock exposed to karstification, one can distinguish between limestone and dolomite karst. **Limestone karst landscapes** typically consist of karst depressions and conical hills (Figs. 5.4 and 5.14). Dolines are the most common karst depressions; in flat areas their density can be exceptional, even over 500 per km^2. There are no dolines at the bottoms of karst poljes and steep slopes; they are also less common in slightly inclined areas (Mihevc and Mihevc 2021). Large karst depressions include uvalas and karst poljes. The best-known ones are located in the lowlands outside the mountainous areas; however, some can also be found in mountainous areas, such as the Dobrepolje–Struge, Bloke and Globodol karst poljes (on Dinaric plateaus), as well as Velo and Malo polje (in Alpine mountains) below Mount Triglav (Fig. 5.13).

Karst hydrology resulted in the formation of many caves and shafts. As of July 2022, the register of the Slovenian Speleological Association included 14,695 karst cavities, 9,956 of which are located in mountainous areas (Kataster ... 2022). With a total length of 43 km, the Migovec Cave System is the longest cave in Slovenia, and the Rombon Cave System is already over 20 km long (both in the Julian Alps). The deepest shafts (i.e., deeper than 1,000 m) to date have been explored on Mounts Rombon and Kanin (the Julian Alps), and on the Dleskovec Plateau (the

Fig. 5.13 Because of the predominantly carbonate bedrock, most Alpine mountains are karstified, and they were also reshaped by glaciers. Top: glaciokarst in the Triglav Lakes Valley in the Julian Alps. (Photo by Bojan Erhartič, GIAM ZRC SAZU archive) Bottom: the Velo polje (right) and Malo polje (left) in the Julian Alps are high-mountain karst poljes. (Photo by Matija Zorn)

Kamnik–Savinja Alps). The Čehi 2 Shaft (1,505 m deep) on the Rombon Plateau is currently the fourteenth-deepest shaft in the world. Collapse dolines formed in places as a result of collapsed cave roofs; they are especially common in the catchment areas of the karst sources of the Ljubljanica and Krka rivers. The Pekel collapse doline between the Little Mountain (*Mala gora*) and the Kočevski Rog Plateau is over 100 m deep, and the Dol collapse doline near Mala Ilova Gora has a volume of 12.7 million m^3, which ranks it among the largest in Slovenia (Stepišnik 2010).

In karst studies, conical karst hills (Fig. 5.4) are mostly typical of tropical areas, and less attention is devoted to those in temperate climate zones. These are landforms that rise, either in isolation or from a common base, several tens of meters high. The hills predominantly have a round base, and they vary in height and slope inclination. It was initially believed that the conical hills typical of Dinaric karst landscapes were a relic of the tropical climate during the Pliocene (Habič 1968, 1980), but more recent research has shown that there are two types of isolated conical hills, reflecting two different formation

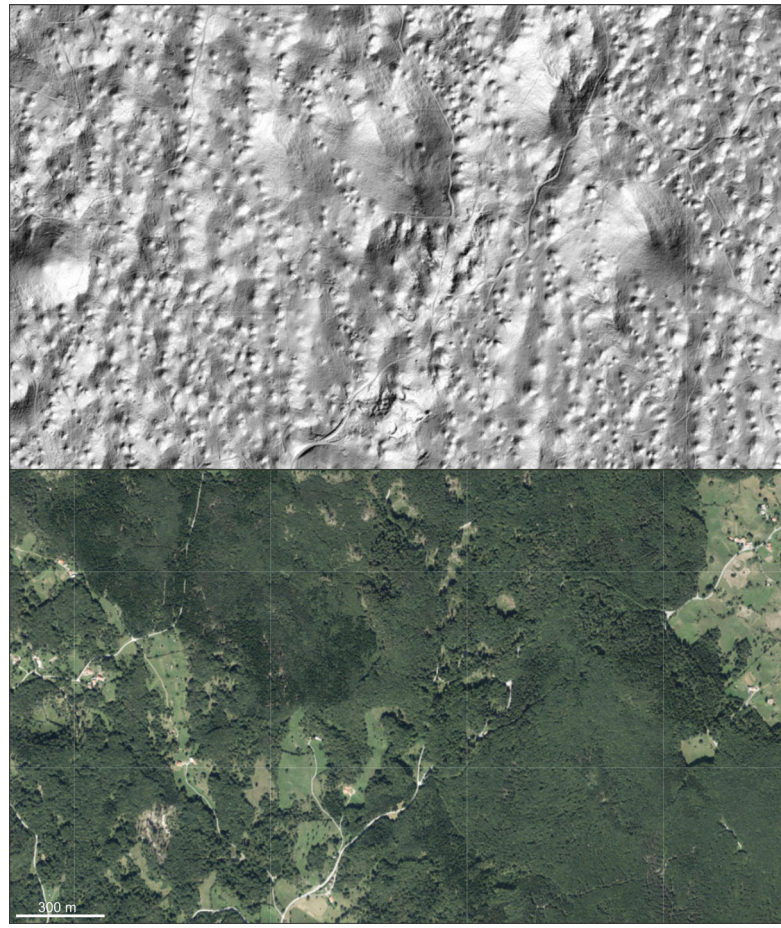

Fig. 5.14 Dinaric plateaus (Dinaric karst landscapes) are characterized by dolines and conical hills (top), which are mostly covered in forest (bottom); the area of the Trnovo cadastral municipality on the Trnovo Forest Plateau at an elevation between 800 and 900 m. (*Source* Surveying and Mapping Authority of the Republic of Slovenia)

mechanisms. The first type is corrosion hills, which, due to their varied rock permeability, lower more slowly than their surroundings. The second type is isolated hills, which can be tectonically defined as vertical uplifts. The types have different morphometric characteristics, with corrosion hills being lower, gentler, and covering smaller areas than the tectonic hills (Stefanovski and Repe 2019).

In **dolomite karst landscapes**, surface karst features are less common, and so their karst character is less pronounced than in the limestone type. Large karst caves are also relatively rare there. Shallow dry valleys, or dells, are typical (Komac 2006). In addition to the chemical dissolution of rock, erosion and denudation are also common on dolomite, which is why in many places dolomite karst landscapes resemble fluvio-denudational landscapes. This landscape type is often referred to as fluviokarst (Komac 2004). Because of the poor mechanical resistance or brittleness of the dolomite, badlands are common in this landscapes.

From a regional perspective, Slovenia's mountain karst landscapes are divided into three main units, which are spatially well separated, but they also differ in a number of natural geographical and other characteristics. Alpine karst landscapes are typical of the Alpine mountains, several small isolated karst areas can be found in the Alpine hills, and Dinaric karst landscapes are common on high Dinaric plateaus. This typology was applied in the outline of Slovenia's speleological characteristics (Gams 1965) and in discussing the hydrographic characteristics of Slovenian karst areas (Habič 1969).

Alpine karst landscapes primarily developed on the Triassic limestone and dolomite of the Julian Alps, Kamnik–Savinja Alps, and Karawanks. They typically have a deep vadose zone perforated with shafts, some of which over 1,000 m deep (Mihevc et al. 2016). Some shafts are connected with subhorizontal passages, forming long cave systems. At the foot of the mountains that rise up to 2,864 m (e.g., Mount Triglav), there are many karst springs. Because the mountains were covered in ice several times during the Pleistocene, the configuration of the terrain is the result of the interaction between glacial and karst processes. High-mountain plateaus and exposed rock areas above the tree line are characterized by limestone pavements—that is, glacially smoothed and heavily karstified rock blocks on top of thick layers of limestone (Kunaver 1983). Another common feature is snow kettles: round rock hollows with vertical walls, in which snow lingers most of the year. In the past, their formation was associated with the corrosive effects of snow melt, but now the predominant belief is that snow kettles are the remnants of former subglacial swallow holes (Stepišnik 2020).

Isolated karst landscapes formed on limestone and dolomite patches surrounded by poorly permeable non-carbonate rock. These patches are small, only a few tens of square kilometers in size, and dispersed across the Alpine hills (Habe 1972). Karst features tend to be less pronounced in these areas, and they are often described as fluviokarst due to the combined interaction of fluvial and karst processes there (Mihevc et al. 2016). Thicker soils that formed through the weathering of allogenic alluvial sediments are common on the surface and in the dolines. Therefore, small suffosion dolines are frequent in this karst landscape type (Mihevc and Mihevc 2021).

Dinaric karst landscapes cover a contiguous karst area in western and southern Slovenia. They are mostly made of Jurassic and Cretaceous limestone and dolomite (Habič 1975). Diverse surface karst features, such as minor karst landforms, various depressions, and conical hills (Figs. 5.4 and 5.14), appear across the entire area. Dolines are the predominant feature (Fig. 5.14). In the past, many dolines were adapted for agricultural use and are thus referred to as "cultivated dolines." High Dinaric karst landscapes consist of plateaus at elevations between 900 and 1,400 m, with individual peaks rising even significantly higher than that. The highest peak, Mount Snežnik, rises to 1,796 m. The high plateaus receive from 1,500 to 3,000 mm of precipitation a year. Because their surface is heavily karstified, water immediately sinks underground, and so there is no surface runoff. The vadose zone is several hundred meters deep and crisscrossed by many shafts (Mihevc et al. 2016). The percolating water resurfaces in the powerful karst springs below the plateaus. The most prominent among them are the Vipava, Ljubljanica, and Krka springs.

5.4 Climate

The climate in Slovenia's mountainous areas (Figs. 5.15 and 5.16, Table 5.3) is the result of various climate factors. Slovenia's position in the middle latitudes relatively close to the Atlantic and the influence of western air circulation are two important factors. Its position on the edge of the Adriatic or in a transitional zone between the Mediterranean Basin and the Eurasian continent also plays a great role. Due to its highly dynamic terrain, elevation is also very important (Ogrin 1996; Ogrin et al. 2023).

Because of its location in the middle latitudes, Slovenia has a temperate and humid climate. Great weather variability is typical, resulting from frequent changes in air masses of various characteristics. The weather is the most stable during the expansion of the Azores or Siberian High. The Azores High causes hot and muggy weather in summer and the Siberian High causes dry and cold weather in winter, with atmospheric inversion and fog in the basins and valleys. When the cold fronts pass through, they bring showers and storms, making the weather deteriorate briefly. Long deteriorations occur with the passing of the Mediterranean cyclones, which bring heavy precipitation and primarily snow in the mountains (Ogrin 2004).

The following three climate types can be distinguished in Slovenia's mountainous areas:

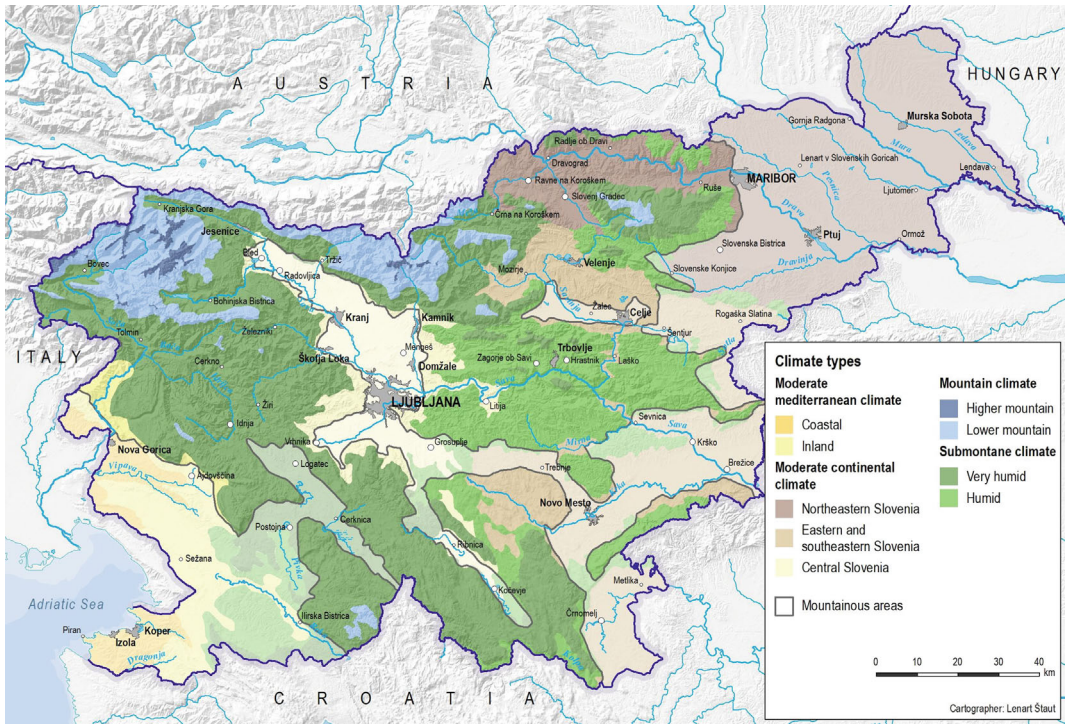

Fig. 5.15 Climate types in Slovenia's mountainous areas. (Adapted from Ogrin et al. 2023)

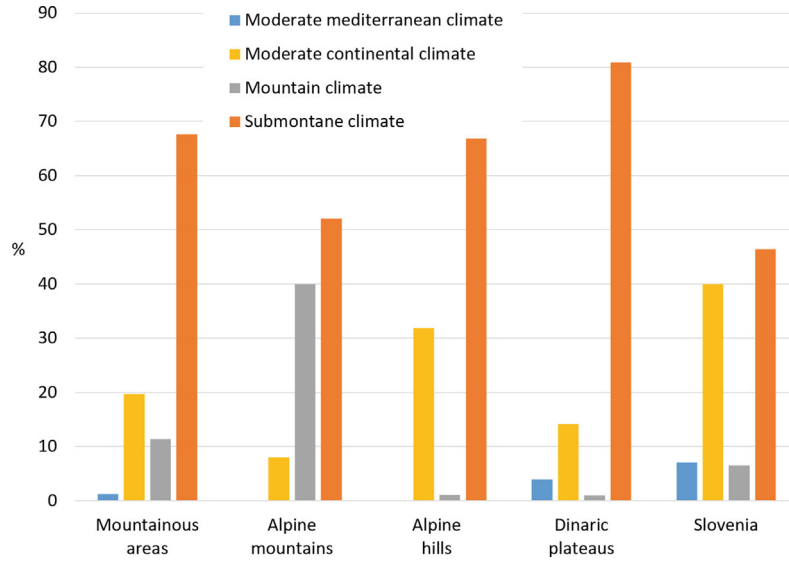

Fig. 5.16 Predominant climate types in Slovenia's mountainous areas. (Based on Table 5.3)

mountain, submontane, and moderate continental climate. Just over a tenth of the area covered by mountainous areas has a mountain climate, two-thirds has a submountain climate, and a fifth has a moderate continental climate.

With elevation, the air temperature usually decreases, precipitation increases, the duration and thickness of snow cover increases, the winds increase, and the vegetation period shortens. Therefore, altitudinal climatic–vegetation zones

Table 5.3 Climate types in Slovenia's mountainous areas. (Based on Fig. 5.15)

Climate types		**Mountainous areas**			***Alpine mountains***				***Alpine hills***				***Dinaric plateaus***				**Slovenia**	
		Area (km^2)	% of mountainous areas	% of Slovenia	Area (km^2)	% of Alpine mountains	% of mountainous areas	% of Slovenia	Area (km^2)	% of Alpine hills	% of mountainous areas	% of Slovenia	Area (km^2)	% of Dinaric plateaus	% of mountainous areas	% of Slovenia	Area (km^2)	%
Moderate mediterranean climate	Coastal	1.09	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.09	0.03	0.01	0.01	487.09	2.40
	Inland	147.91	1.28	0.73	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	147.91	3.88	1.28	0.73	953.01	4.70
Moderate continental climate	Northeastern Slovenia	766.25	6.65	3.78	77.29	2.52	0.67	0.38	688.97	14.79	5.98	3.40	0.00	0.00	0.00	0.00	3,823.89	**18.87**
	Eastern and southeastern Slovenia	995.99	8.64	4.91	120.38	3.93	1.04	0.59	453.25	9.73	3.93	2.24	422.35	**11.09**	3.66	2.08	2,785.88	**13.75**
	Central Slovenia	504.71	4.38	2.49	46.30	1.51	0.40	0.23	341.67	7.33	2.96	1.69	116.73	3.06	1.01	0.58	1,500.67	7.40
Mountain climate	High mountains	101.72	0.88	0.50	101.72	3.32	0.88	0.50	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	101.72	0.50
	Low mountains	1,212.29	**10.51**	5.98	1,122.20	**36.66**	9.73	5.54	50.45	1.08	0.44	0.25	39.63	1.04	0.34	0.20	1,212.29	5.98
Submontane climate	Very humid	5,362.12	**46.50**	**26.46**	1,546.89	**50.53**	**13.42**	7.63	1,244.67	**26.71**	**10.79**	6.14	2,570.56	**67.48**	**22.29**	**12.68**	6,013.98	**29.67**
	Humid	2,438.56	**21.15**	**12.03**	46.58	1.52	0.40	0.23	1,880.80	**40.36**	**16.31**	9.28	511.18	**13.42**	4.43	2.52	3,388.41	**16.72**
Total		11,530.64	100.00	56.89	3,061.36	100.00	26.55	15.11	4,659.81	100.00	40.41	22.99	3,809.47	100.00	33.04	18.80	20,266.95*	100.00

*The data in the data layer used do not entirely correspond to Slovenia's actual size: 20,273 km^2
Those covering more than 10% are in bold

are one of the main characteristics of mountainous areas. The **mountain climate**, typical of the Alps and the highest parts of the Pohorje Hills and the Snežnik Plateau, is the coldest and most humid climate type in Slovenia, with a long-lasting and thick snow cover, which in average winters is deeper than 150 cm. The average temperature of the coldest month is below −3 °C and annual precipitation mostly exceeds 1,600 mm. Areas with a mountain climate in western Slovenia are wetter, with annual precipitation over 2,500 mm and a precipitation maximum in the late fall. Areas in the east receive less precipitation, and summer is the wettest part of the year. Winter has the least precipitation. Due to global warming, the mountain climate zone has been shrinking rapidly over the past decades (Ogrin et al. 2023).

The **submontane climate** is typical of the foothills of the Alps and most of the Alpine hills and Dinaric karst plateaus. It is a transitional climate between the mountain and moderate continental climate on the eastern side of the Alpine–Dinaric barrier and the mountain and moderate Mediterranean climate on the southwestern side of the barrier. The average January temperatures mostly range between 0 and −3 °C, and the average July temperatures are between 16 and 20 °C. Due to the Alpine–Dinaric barrier, the climate is wetter than average, with the least precipitation in winter. Due to lower elevations and higher temperatures, snow cover is less reliable than in mountain climate. Precipitation and temperature conditions form the basis for dividing the submontane climate into very humid, found in the central, highest, coldest, and wettest part of the barrier, and humid, found in the lower and slightly warmer peripheral areas on the continental and coastal sides of the barrier (Ogrin et al. 2023).

The **moderate continental climate** is found in the low-lying areas of the Alpine hills in northeastern Slovenia and in Dry Carniola (*Suha krajina*). The highest average annual temperature amplitude of over 20 °C is typical, along with high maximum summer temperatures. Annual precipitation is below 1,400 mm. Even though the proportion of precipitation is higher in the warm half of the year, summers approach arid conditions due to the high temperatures. Frost is common in winters, along with colder periods when daily temperatures remain below zero. Spring frost is also relatively common, and summer hot spells are often interrupted by storms (including with hail and strong winds), which cause major damage to agriculture (Ogrin et al. 2023).

Over the past decades, the average air temperature in Slovenia has been rising faster than the global and Alpine average. The number of hot days is increasing, droughts are becoming increasingly more frequent, winters are becoming increasingly milder, and extreme weather events, such as heatwaves, are more pronounced and they last longer (Dolinar and Vertačnik 2010). Over the past sixty years, average annual temperatures in Slovenia's mountainous areas have increased by over 2 °C, irrespective of elevation (Table 5.4). In contrast, annual precipitation has been decreasing by as much as several hundred millimeters, or 10% to 20% (Table 5.5). A declining trend has been particularly evident in the number of days with snow cover. In the high mountains, at an elevation of about 2,500 m, the changes have not (yet) been so significant (the station on Mount Kredarica), whereas at elevations close to 1,000 m the number of days with snow cover has already declined considerably, by even more than forty days or approximately 30% a year. At even lower elevations, the decline has been even greater, exceeding fifty days or 50% a year (Table 5.6).

Due to the increasing air temperatures and diminishing snow cover, the discharges of Slovenia's mountain rivers have also decreased significantly (Sect. 5.5), and their discharge regimes have also changed considerably (Kobold and Ulaga 2010; Hrvatin and Zorn 2017, 2020, 2024). Because of the diminished snow cover, water supplies will have decreased by at least a third by the end of the twenty-first century (Dolinar and Vertačnik 2010).

5.5 Hydrology

Water conditions in Slovenia's mountainous areas largely depend on the rock composition of individual landscapes. The river system comprises a multitude of rivers, creeks, and torrents with a total

Table 5.4 Changes in average annual temperature in mountainous areas, 1961–2020 (Hrvatin and Zorn 2017, 2020, 2024; Arhiv ... 2024b)

Region (ID on Fig. 5.1)	Temperature station	Elevation (m)	1961 trend value (°C)	2020 trend value (°C)	1961–2020 trend difference (°C)	1961–2020 trend difference (%)*
Julian Alps (1.1)	**Kredarica**	2,513	−2.26	−0.04	**2.22**	**0.82**
Kamnik–Savinja Alps (1.2)	**Krvavec**	1,742	2.59	4.36	**1.77**	**0.64**
Western Karawanks (1.3)	**Rateče**	864	5.19	7.65	**2.46**	**0.88**
Polhov Gradec Hills (2.1)	**Topol pri Medvodah**	662	7.87	10.48	**2.61**	**0.93**
Sava Hills (2.2)	**Lisca**	947	6.06	8.62	**2.56**	**0.92**
Pohorje Hills (2.3)	**Šmartno pri Slovenj Gradcu**	444	7.06	9.67	**2.61**	**0.93**
Banjšice Plateau (3.1)	**Čepovan**	604	7.88	10.16	**2.28**	**0.81**
Idrija Hills (3.2)	**Vojsko**	1,070	5.19	7.70	**2.51**	**0.90**
Nanos Plateau (3.3)	**Nanos**	896	6.43	9.00	**2.57**	**0.92**
Bloke Plateau (3.6)	**Nova Vas**	720	6.23	8.94	**2.71**	**0.97**

*The trend difference as a percentage is calculated based on the absolute (Kelvin) temperature scale

Table 5.5 Changes in annual precipitation in mountainous areas, 1961–2020 (Hrvatin and Zorn 2020, 2022, 2024; Arhiv ... 2024b)

Region (ID on Fig. 5.1)	Precipitation station	Elevation (m)	1961 trend value (mm)	2020 trend value (mm)	1961–2020 trend difference (mm)	1961–2020 trend difference (%)
Julian Alps (1.1)	**Kredarica**	2,513	1,940.31	2,204.00	**263.69**	**13.59**
Kamnik–Savinja Alps (1.2)	**Solčava**	639	1,627.07	1,506.89	**−120.18**	**−7.39**
Western Karawanks (1.3)	**Javorniški Rovt**	939	1,949.68	1,939.68	**−10.00**	**−0.51**
Eastern Karawanks (1.4)	**Podpeca**	942	1,436.68	1,494.32	**57.64**	**4.01**
Sava Hills (2.2)	**Kal pri Krmelju**	509	1,228.33	1,133.16	**−95.17**	**−7.75**
Pohorje Hills (2.3)	**Mislinja**	622	1,248.93	1,189.11	**−59.82**	**−4.79**
Strojna Hills (2.3)	**Strojna**	940	1,119.74	1,042.30	**−77.44**	**−6.92**
Idrija Hills (3.2)	**Vojsko**	1,070	2,540.49	2,228.16	**−312.33**	**−12.29**
Trnovo Forest Plateau (3.3)	**Lokve**	946	2,546.21	2,275.60	**−270.61**	**−10.63**
Hrušica Plateau (3.3)	**Hrušica**	872	2,222.23	1,776.49	**−445.75**	**−20.06**
Menišija Plateau (3.5)	**Pokojišče**	716	1,656.06	1,387.09	**−268.97**	**−16.24**
Bloke Plateau (3.6)	**Nova Vas**	720	1,482.03	1,535.02	**52.99**	**3.58**
Big Mountain Plateau (3.7)	**Grčarice**	782	1,731.75	1,796.95	**65.20**	**3.76**
Gotenica Plateau (3.7)	**Trava**	520	1,582.08	1,552.43	**−29.65**	**−1.87**
Poljane Plateau (3.9)	**Sinji Vrh**	365	1,361.52	1,407.54	**46.02**	**3.38**

Table 5.6 Changes in the number of days with snow cover in mountainous areas, 1961–2020 (Hrvatin and Zorn 2020, 2022, 2024; Arhiv ... 2024b)

Region (ID on Fig. 5.1)	Precipitation station	Elevation (m)	1961 trend value (days)	2020 trend value (days)	1961–2020 trend difference (days)	1961–2020 trend difference (%)
Julian Alps (1.1)	**Kredarica**	2,513	267.7	259.5	**−8.14**	**−3.04**
Kamnik–Savinja Alps (1.2)	**Solčava**	639	106.2	43.0	**−63.21**	**−59.52**
Western Karawanks (1.3)	**Javorniški Rovt**	939	135.3	83.8	**−51.44**	**−38.02**
Eastern Karawanks (1.4)	**Podpeca**	942	125.0	77.8	**−47.20**	**−37.76**
Sava Hills (2.2)	**Kal pri Krmelju**	509	59.3	31.2	**−28.11**	**−47.40**
Pohorje Hills (2.3)	**Mislinja**	622	111.0	66.3	**−44.70**	**−40.25**
Strojna Hills (2.3)	**Strojna**	940	126.4	59.8	**−66.56**	**−52.67**
Idrija Hills (3.2)	**Vojsko**	1,070	153.0	94.0	**−59.00**	**−38.56**
Trnovo Forest Plateau (3.3)	**Lokve**	946	111.8	48.9	**−62.93**	**−56.29**
Hrušica Plateau (3.3)	**Hrušica**	872	95.6	60.2	**−35.40**	**−37.03**
Menišija Plateau (3.5)	**Pokojišče**	716	71.5	30.2	**−41.30**	**−57.76**
Bloke Plateau (3.6)	**Nova Vas**	720	107.2	62.8	**−44.41**	**−41.41**
Big Mountain Plateau (3.7)	**Grčarice**	782	91.1	52.7	**−38.35**	**−42.12**
Gotenica Plateau (3.7)	**Trava**	520	111.5	72.8	**−38.72**	**−34.72**
Poljane Plateau (3.9)	**Sinji Vrh**	365	76.5	39.0	**−37.55**	**−49.05**

length of nearly 15,300 km. The average density is 1.32 km of watercourses per km^2, which is only slightly lower than the Slovenian average. Surface streams are not evenly distributed, because nearly two-thirds of the mountainous areas are karst landscapes and nearly without surface streams. The density of streams is especially low (i.e., below 0.05 km per km^2) on some karst plateaus, such as the Javorniki (Fig. 5.4), Snežnik, Kočevski Rog, Poljane, and Dry Carniola plateaus. Outside karst landscapes, the river system is highly branched and, in some areas of the Alpine hills (e.g., the Cerkno, Polhov Gradec, Rovte, Pohorje, Strojna, and Kozjak hills), the density of streams exceeds 2.25 km per km^2.

The divide between the Black Sea and the Adriatic runs across Slovenia. Rivers drain to the Black Sea several hundred kilometers from four-fifths of Slovenia's mountainous areas, and to the nearby Adriatic from only one-fifth of this areas. The Black Sea watershed comprises the Drava, Sava, and Kolpa basins, and the Adriatic watershed includes the Soča and Reka basins.

The mountainous **river system** is characterized by short watercourses, with only seventeen rivers longer than 20 km. The Soča River is the longest, measuring 91 km in the mountainous part of Slovenia, followed by the Savinja (70 km) and Drava (67 km); the only two other rivers longer than 50 km in this part of Slovenia are the Sava (61 km) and Idrijca (58 km). In terms of water volume, the Drava is in first place, with an average annual discharge of 262 m^3/s at Dravograd, where it enters Slovenia from Austria. Lagging only slightly behind is the Sava at Radeče (230 m^3/s), and the discharge of the Soča at Solkan (94 m^3/s) is already less than half that. An average annual discharge of over 50 m^3/s is also typical of the Kolpa River, the Savinja River has a discharge of over 40 m^3/s, and the Ljubljanica and Idrijca over 20 m^3/s.

The runoff coefficients, which show the percentage of water flowing into rivers, vary considerably across the mountainous areas. The differences are primarily due to precipitation volume and regime, and rock and topographic characteristics. The highest values (i.e., over 70%) can be observed in the Upper Soča and Bohinj valleys (the Julian Alps). Runoff coefficients between 60 and 70% are typical of the rest of the Alpine mountains and the western parts of the Alpine hills and Dinaric plateaus. Values between 45 and 60% predominate in the eastern areas of the Alpine hills and Dinaric plateaus (Frantar 2008).

Even a few decades ago, most mountain rivers still had a very pronounced snow–rain discharge regime. Due to snow retention, the minimum discharges were in winter, and the primary discharge maximum was in spring when the snow melted. A secondary discharge minimum was in summer, due to stronger evapotranspiration, followed by a secondary discharge maximum in the fall resulting from heavy rain (Hrvatin 1998). The past decades have seen notable decreases in the discharge and gradual changes in the discharge regimes of all mountain rivers. The reasons for this include higher average temperatures, which accelerate evaporation, a smaller volume of annual precipitation, a shorter duration and smaller amount of snow cover, and an increase in the share of wooded areas. In nearly all rivers, the fall discharge maximum has already exceeded the spring maximum, and the summer discharge minimum is already very close to the winter minimum. Because of the shorter duration and smaller amount of snow cover, and stronger evapotranspiration, there has been a decrease in the late spring and early summer discharges, along with an increase in discharges between October and December, which indicates that winter is "running late" (Hrvatin and Zorn 2017, 2020, 2024).

For example, changes in the discharge regimes from 1961 to 1990 and from 1991 to 2020 (Arhiv ... 2024a) can be clearly seen on the Meža River (Fig. 5.17). Its November rain maximum has already significantly exceeded its spring high-flow conditions, which are primarily the result of snow melting in the mountains and hills. At the same time, due to summer droughts, its August minimum has already exceeded its winter minimum, which is the result of snow retention.

Natural **lakes** are rare and small in Slovenia's mountainous areas. In terms of origin, they can be divided into glacial and karst lakes. The largest and best-known glacial lakes are Lake Bohinj and Lake Bled (Fig. 5.18). Lake Bohinj covers an area

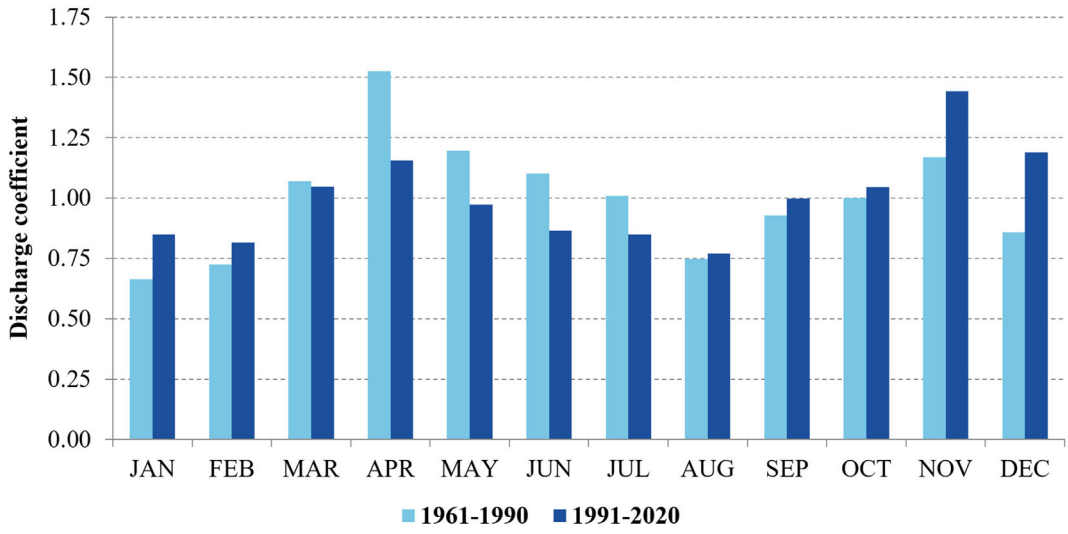

Fig. 5.17 Changes in the discharge regime of the Meža River at the Otiški Vrh gauging station, 1961–1990 and 1991–2020

of 3.18 km^2 and has a maximum depth of 44.5 m. It is a drainage lake with a karst catchment area. Its main tributary is the Savica River, which collects karst groundwater from the Triglav Lakes Valley area (the Julian Alps). The lake's watershed is part of Triglav National Park and almost completely unpopulated, and so the lake is in very good ecological condition (Remec-Rekar and Bat 2004; Remec-Rekar 2016).

Lake Bled is smaller (area: 1.40 km^2, maximum depth: 30.6 m). It is without a major freshwater inflow, and its catchment is considerably urbanized, burdened by traffic, and exploited for agriculture, fishing, and tourism. Eutrophication advanced heavily in the second half of the twentieth century, but the lake's ecological condition was significantly improved though various measures (Remec-Rekar and Bat 2004; Remec-Rekar 2016).

Both lakes are popular tourist destinations. The mean monthly temperature of Lake Bled in summer exceeds 22 °C, and the temperature of Lake Bohinj is 2 to 3 °C lower (Bat 1997). There are several other small glacial lakes in the high mountains of the Julian Alps, the best known among them being the Triglav Lakes, Križ Lakes (*Križka jezera*), and Krn Lakes (*Krnska jezera*) (Brancelj 2002).

Marshes are also rare and small, just like lakes, and they are categorized as wetlands with permanent or intermittent water retention. They are overgrown with hygrophilous plants, which, due to the shortage of air, do not decompose into humus, but turn into peat in the process of coalification. In their original form, peat bogs now only remain on the Pokljuka Plateau (the Šijec, Veliko Blejsko barje, and Goreljek bogs) and Jelovica Plateau (the Ledina and Za blatom bogs) in the Julian Alps, and in the Pohorje Hills (the Lovrenc and Ribnica bogs; Bat 1997; Beltram 2004; Vreš et al. 2014).

Snowfields and glaciers are important but very changeable elements of high-mountain landscapes. A comparison between their condition as reported in various historical sources and the current situation shows that the number and size of once frequent and large mountain snowfields are decreasing significantly (Triglav Čekada and Ajdova 2023). The Triglav Glacier (Fig. 5.12) and Skuta Glacier mentioned above have also been shrinking rapidly over the past decades (Gabrovec et al. 2014).

Groundwater, which in Slovenia's mountainous areas primarily includes karst water, is significantly greater in volume than surface water. Karst water feeds the sources of the Soča, Sava, Idrijca, Vipava, Ljubljanica, Krka, and

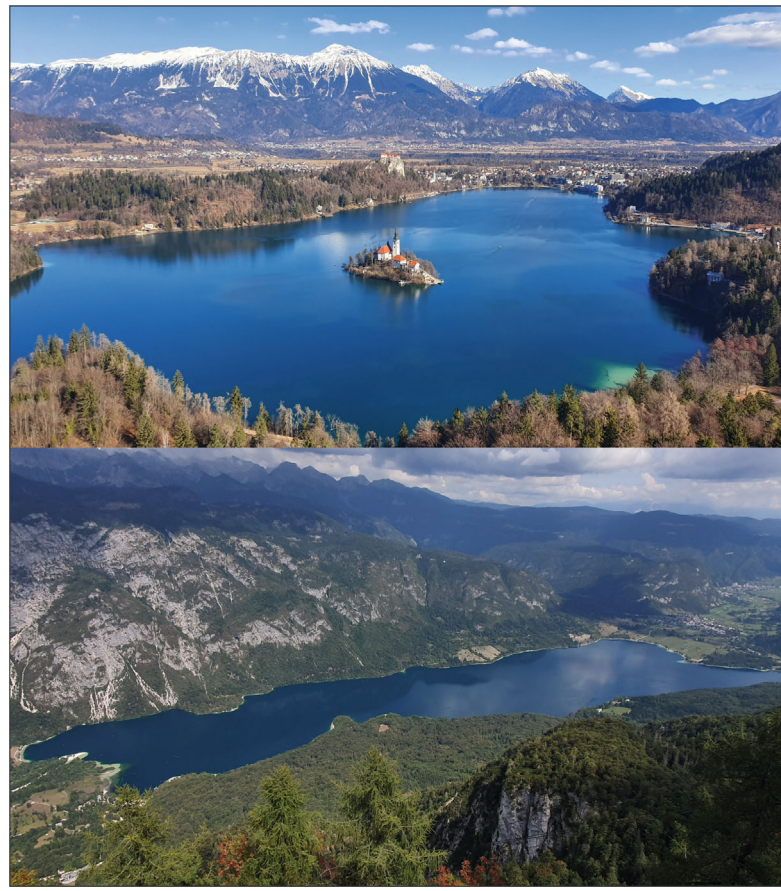

Fig. 5.18 The largest and best-known glacial lakes in Slovenia are Lake Bled (top; Western Karawanks with their highest peak, Mount Stol (2,236 m), background) and Lake Bohinj (bottom). (Photo by Matija Zorn)

Kolpa rivers and many of their tributaries. Some karst springs, such as Malenščica, Podroteja, and Mrzlek springs, are important for the water supply of entire regions, supplying three-quarters of all available water reserves during droughts (Kranjc 1998).

5.6 Soil and Vegetation

In Slovenia's mountainous areas, the impact of pedogenesis factors, including rock composition, climate, topography, water, plant and animal species, and human factors, changes greatly over short distances, which is why the **soil types** are relatively diverse (Figs. 5.19 and 5.20, Tables 5.7 and 5.8). The most common types are Rendzina and Chromic Cambisol, which formed on limestone and dolomite, and together they cover over half of mountainous areas, or even over four-fifths of Dinaric plateaus. On steep slopes, they are mostly overgrown with forest, and on flat, non-rocky surfaces they are covered in meadows. Because the soil is shallow, fields are rare (Vidic et al. 2015; Vrščaj 2017). Dystric Cambisol predominates on non-carbonate rocks; it covers just under a third of mountainous areas, but over half of Alpine hills.

Forests are the **natural vegetation** in all of Slovenia's mountainous areas except in the high mountains above the alpine forest line and in very wet habitats. Over the centuries, people burned and cut down forests to obtain space for pastures and fields, and by using forest resources they also radically changed the forest composition. Only a few fully natural forests remain today, such as the highly protected forest reserves in the Kočevje region and remote mountains, but most

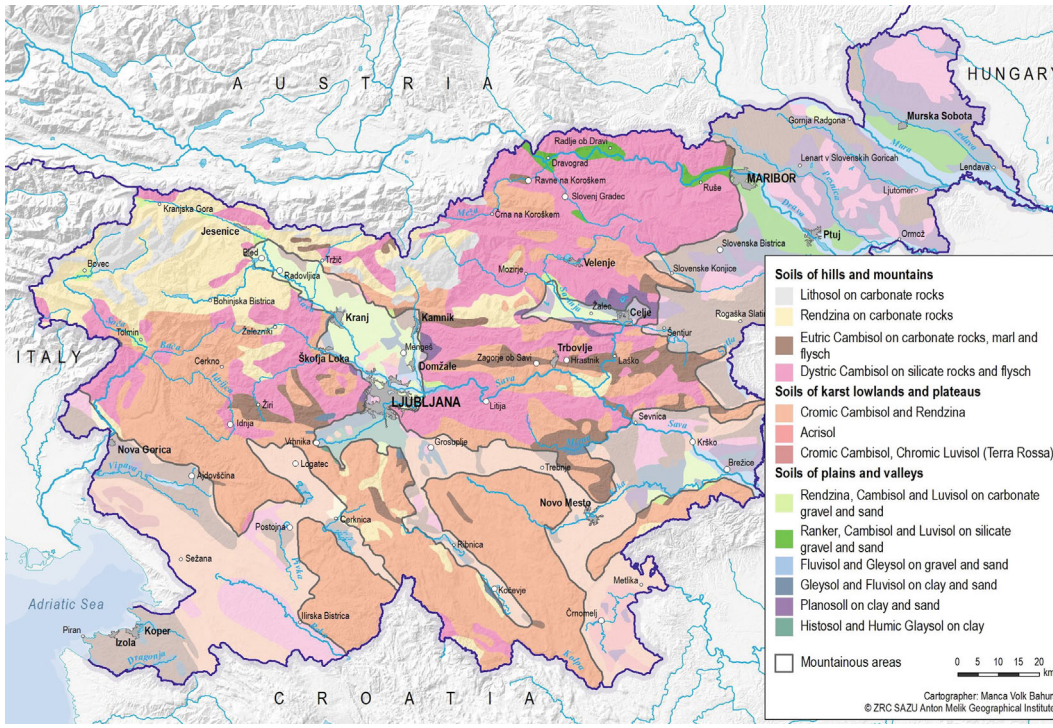

Fig. 5.19 Pedogeographical soil types in Slovenia's mountainous areas. (Adapted from Lovrenčak 1998)

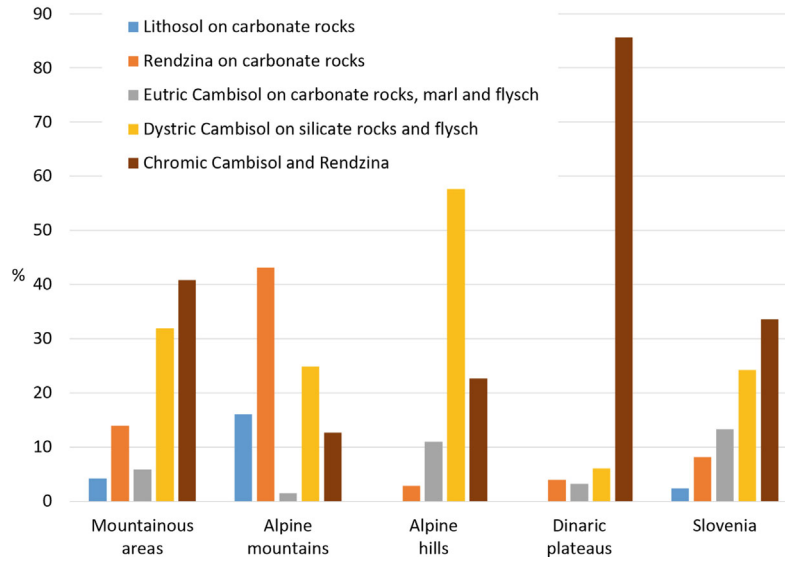

Fig. 5.20 Predominant pedogeographical soil types in Slovenia's mountainous areas. (Based on Table 5.7)

Table 5.7 Pedogeographical soil types in Slovenia's mountainous areas. (Based on Fig. 5.19)

Soil type		Mountainous areas			*Alpine mountains*				*Alpine hills*				*Dinaric plateaus*				Slovenia	
		Area (km^2)	% of mountainous areas	% of Slovenia	Area (km^2)	% of Alpine mountains	% of mountainous areas	% of Slovenia	Area (km^2)	% of Alpine hills	% of mountainous areas	% of Slovenia	Area (km^2)	% of Dinaric plateaus	% of mountainous areas	% of Slovenia	Area (km^2)	%
Soils of plains and valleys	Rendzina, Cambisol, and Luvisol on carbonate gravel and sand	89.26	0.77	0.44	51.08	1.67	0.44	0.25	26.35	0.57	0.23	0.13	11.83	0.31	0.10	0.06	640.57	3.16
	Ranker, Cambisol, and Luvisol on silicate gravel and sand	107.28	0.93	0.53	0.01	0.00	0.00	0.00	107.26	2.30	0.93	0.53	0.00	0.00	0.00	0.00	443.39	2.19
	Fluvisol and Gleysol on gravel and sand	12.13	0.11	0.06	0.00	0.00	0.00	0.00	11.25	0.24	0.10	0.06	0.89	0.02	0.01	0.00	437.54	2.16
	Gleysol and Fluvisol on clay and sand	49.44	0.43	0.24	0.01	0.00	0.00	0.00	27.41	0.59	0.24	0.14	22.02	0.58	0.19	0.11	805.50	3.97
	Planosol on clay and sand	102.17	0.89	0.50	4.06	0.13	0.04	0.02	98.12	2.11	0.85	0.48	0.00	0.00	0.00	0.00	1,030.26	5.08
	Histosol and Humic Gleysol on clay	6.00	0.05	0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	6.00	0.16	0.05	0.03	105.09	0.52

(continued)

Table 5.7 (continued)

Soil type		Mountainous areas			*Alpine mountains*				*Alpine hills*				*Dinaric plateaus*				Slovenia	
		Area (km^2)	% of mountainous areas	% of Slovenia	Area (km^2)	% of Alpine mountains	% of mountainous areas	% of Slovenia	Area (km^2)	% of Alpine hills	% of mountainous areas	% of Slovenia	Area (km^2)	% of Dinaric plateaus	% of mountainous areas	% of Slovenia	Area (km^2)	%
Soils of hills and mountains	Lithosol on carbonate rocks	491.81	4.26	2.43	491.81	**16.06**	4.26	2.43	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	492.05	2.43
	Rendzina on carbonate rocks	1,605.10	**13.92**	7.92	1,321.86	**43.18**	**11.46**	6.52	133.36	2.86	1.16	0.66	149.88	3.93	1.30	0.74	1,656.57	8.17
	Eutric Cambisol on carbonate rocks, marl, and flysch	680.49	5.90	3.36	43.89	1.43	0.38	0.22	512.99	**11.01**	4.45	2.53	123.61	3.24	1.07	0.61	2,705.96	**13.35**
	Dystric Cambisol on silicate rocks and flysch	3,679.88	**31.91**	**18.15**	762.13	**24.89**	6.61	3.76	2,686.00	**57.64**	**23.29**	**13.25**	231.75	6.08	2.01	1.14	4,914.75	**24.25**
Soils of karst plains and plateaus	Chromic Cambisol and Rendzina	4,708.22	**40.83**	**23.23**	386.60	**12.63**	3.35	1.91	1,057.59	**22.69**	9.17	5.22	3,264.04	**85.67**	**28.30**	**16.10**	6,814.36	**33.62**
	Acrisol	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	155.45	0.77
	Chromic Cambisol, Chromic Luvisol (Terra Rossa)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	69.09	0.34
Total		11,531.79	100.00	56.89	3,061.45	100.00	26.55	15.10	4,660.32	100.00	40.41	22.99	3,810.02	100.00	33.04	18.80	20,270.59*	100.00

*The data in the data layer used do not entirely correspond to Slovenia's actual size: 20,273 km^2
Those covering more than 10% are in bold

Table 5.8 Basic characteristics of the main pedogeographical soil types in Slovenia's mountainous areas. (Adapted from Vidic et al. 2015; Zorn et al. 2020a, b)

Groups of pedogeographical soil types	ID on Fig. 5.19	Pedogeographical soil type	Basic characteristics
Soils of hills and mountains	Lithosol on carbonate rock	Lithosol/Lithic Leptosols (Calcaric)	**Horizons**: (A)–R **Texture**: — **pH**: 7–8 **Parent material**: limestone and dolomite **Land use**: not suitable for agriculture and forestry **Comments**: incipient soil development
	Rendzina on carbonate rock	Rendzina/Rendzic Leptosols	**Horizons**: Ah–R **Texture**: silty loam **pH**: 5.5–7.0 **Parent material**: limestone and dolomite **Land use**: forest, alpine pasture **Comments**: grassland above the forest line
	Eutric Cambisol on carbonate rock, marl, and flysch	Eutric Cambisol	**Horizons**: A–Bv–C **Texture**: silty clay, clay **pH**: 5.5–6.5 **Parent material**: marly limestone **Land use**: arable land, orchards, vineyards, meadows, forest **Comments**: limitation in soil workability can be expected due to high clay content **Horizons**: A–Bv–C, A–BCa–C **Texture**: silty clay loam, silty clay **pH**: 5.5–8 **Parent material**: Eocene flysch **Land use**: vineyards, orchards, arable land, meadows, forest **Comments**: land use adapted to Mediterranean and sub-Mediterranean conditions
	Dystric Cambisol on silicate rocks and flysch	Dystric Cambisol	**Horizons**: A–Bv–C **Texture**: sandy loam **pH**: 4–5 **Parent material**: igneous rocks **Land use**: forest, grassland, arable land **Comments**: arable land limited due to slope conditions, liming required **Horizons**: A–Bv–C **Texture**: silty clay loam, silty clay **pH**: 4.5–5.5 **Parent material**: non-calcareous and low calcareous flysch and decalcificated marlstone **Land use**: grassland, arable land, forest **Comments**: limitation in soil workability can be expected due to texture, liming required
Soils of karst plains and plateaus	Chromic Cambisol and Rendzina	Chromic Cambisol and Rendzina/ Chromic Cambisol and Rendzic Leptosols	**Horizons**: Ah–C, A–Brz–C **Texture**: silty loam, silty clay loam, silty clay **pH**: 5.5–7 **Parent material**: limestone and dolomite **Land use**: forest, meadows **Comments**: possible surface rockiness, possible soil water deficiency

(continued)

Table 5.8 (continued)

Groups of pedogeographical soil types	ID on Fig. 5.19	Pedogeographical soil type	Basic characteristics
	Acrisol	Acrisol	**Horizons**: A–E–Bt–C **Texture**: silt, silty clay loam **pH**: 3.5–4.2 **Parent material**: limestone **Land use**: forest, grassland, arable land **Comments**: abundant liming is required as well as selection of acid-tolerant plants
	Chromic Cambisol, Chromic Luvisol (Terra Rossa)	Chromic Cambisol (Terra Rossa)	**Horizons**: A–Brz–C, A–E–Bt–C **Texture**: silty loam, clay loam **pH**: 4.5–6 **Parent material**: limestone **Land use**: vineyards, grassland, forest **Comments**: limitations in vineyard land use due to the variable solum thickness **Horizons**: A–Brz–C **Texture**: clay loam, silty clay loam **pH**: 5–6 **Parent material**: limestone with chert **Land use**: vineyards, grassland, forest **Comments**: limitations in vineyard land use due to the variable solum thickness and the amount of skeleton
		Luvisol	**Horizons**: A–E–Bt–C **Texture**: silty loam, silty clay loam **pH**: 4–5.5 **Parent material**: limestone and dolomite **Land use**: grassland, forest, arable land **Comments**: abundant liming is required, tillage limitations due to variable solum thickness

other forests are also well preserved (Natek and Natek 2008).

In 2020, forests covered three-quarters of Slovenia's mountainous areas (Grafični ... 2020). They account for 83.3% of Dinaric plateaus and 74.5% of Alpine mountains, and the smallest share (68.1%) can be found in the somewhat more populated Alpine hills.

The predominant tree species in Slovenian forests is beech. At elevations between 500 and 600 m, it forms a wide variety of forest communities. Submontane beech forests combined with European hornbeam, sessile oak, and linden predominate on carbonate rocks up to elevations of 700 m and, above them, montane beech forests mixed with sycamore, elm, and maple extend up to elevations of 900 m. Mountain beech forests, which may already include spruce and fir in addition to deciduous trees, extend to 1,400 to 1,500 m in elevation, and the highest elevations above 1,500 m are covered in subalpine beech forests. On non-carbonate rock, thermophilic beech forests mixed with European hop-hornbeam, manna ash, and whitebeam predominate on sunny slopes, whereas elsewhere acidophilic beech forests combined with sessile oak and sweet chestnut and, in shady locations, spruce are the most common (Marinček and Čarni 2002; Figs. 5.21 and 5.22, Table 5.9).

Communities of Dinaric fir and beech forests, which contain large volumes of timber-growing stock and are among Slovenia's most important commercial forests, stand out among the mixed forests (Kordiš 1993).

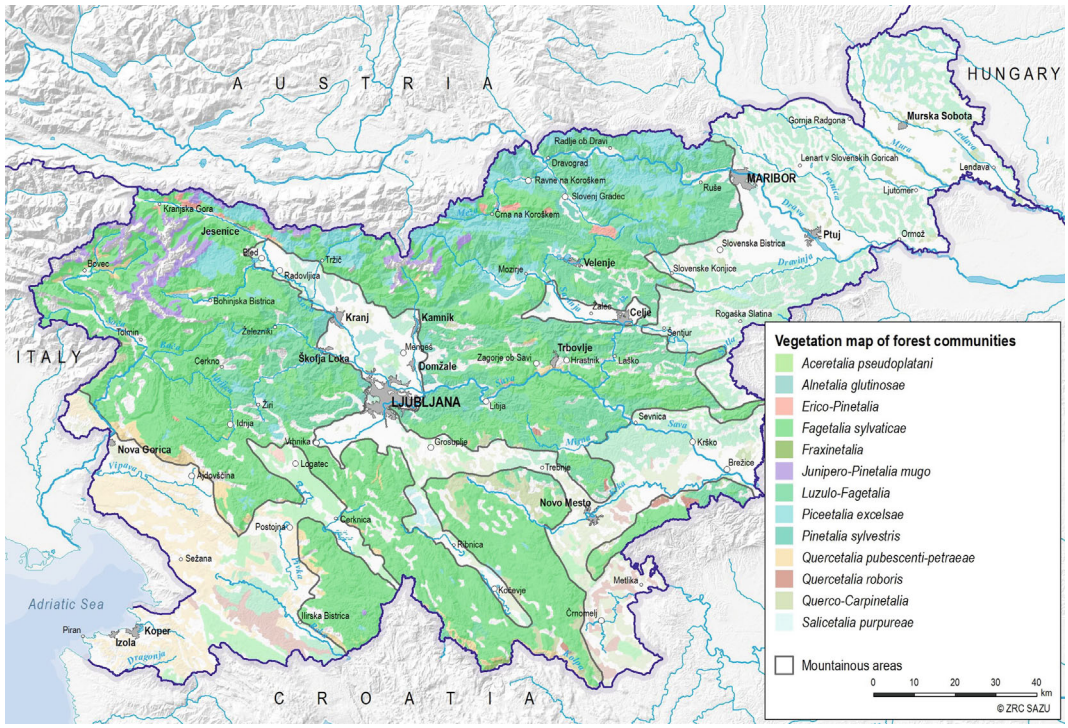

Fig. 5.21 Forest communities in Slovenia's mountainous areas. (Adapted from Čarni et al. 2002; Šilc et al. 2020)

Most Slovenian spruce forests are secondary forests growing at the site of former acidophilic beech forests. After beech forests were cleared, pastures were first arranged at their site in the Alpine hills and at lower elevations in the Alpine mountains. These were later largely reforested with spruce. The only natural spruce forests are the acidophilic spruce forests at higher Alpine elevations (between 1,400 and 1,600 m) and in the cold air pools of high Dinaric plateaus. In Alpine Slovenia, spruce forests extend up to the alpine forest line and, as elevation increases, they also include more larch (Kaligarič 2004).

Low temperatures, short vegetation periods, strong and persistent winds, and long-lasting snow cover prevent tree growth in the highest parts of the Alpine mountains and Dinaric plateaus. Because of these factors and anthropogenic changes, the alpine forest line in Slovenia varies between 1,550 and 1,900 m. A belt of mountain pine grows above this line, followed by highly diverse communities of high-mountain vegetation at even higher elevations, which becomes increasingly sparse and discontinuous with elevation (Lovrenčak 2003).

5.7 Settlement and Land Use

Archeological research shows that humans have been present in the Slovenian mountains for a very long time. Tens of thousands of years ago, during the Paleolithic, hunters and gatherers found shelter in caves in the mountains, such as Potočka zijalka (1,675 m) on Mount Olševa, Medvedova jama (1,525 m) on Mount Mokrica (both in the Kamnik–Savinja Alps), or Divje babe (448 m) in the Idrija Hills. The finds of weapons from the Bronze Age are the first accumulated evidence of people visiting the Slovenian high mountains (Cevc 2006). Moreover, the finds indicate that routes over mountain passes were used since ancient times; for example, the passes in the Karawanks or those in the Julian Alps connecting the Soča and Bohinj

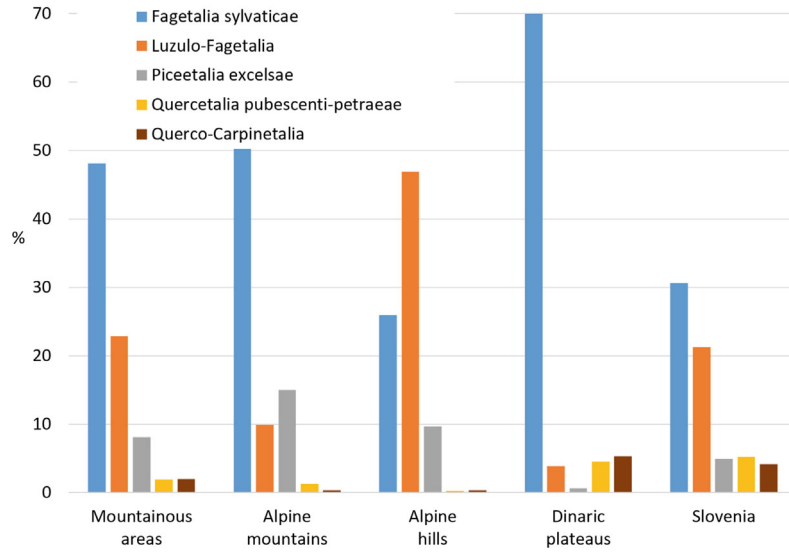

Fig. 5.22 Predominant forest communities in Slovenia's mountainous areas. (Based on Table 5.9)

Table 5.9 Predominant forest communities in Slovenia's mountainous areas (in %). (Based on Fig. 5.21)

Forest community	Mountainous areas	*Alpine mountains*	*Alpine hills*	*Dinaric plateaus*	Slovenia
Fagetalia sylvaticae (beech forests on nutrient-rich soil)	**48.10**	**50.73**	**25.98**	**73.05**	**30.63**
Luzulo-Fagetalia (acidophilic beech forests)	**22.83**	9.89	**46.87**	3.82	**21.29**
Piceetalia excelsae (mountain spruce and fir forests)	8.10	**15.03**	9.70	0.59	4.91
Quercetalia pubescenti-petraeae (thermophilic deciduous forests)	1.92	1.25	0.24	4.51	5.25
Querco–Carpinetalia (oak and hornbeam forests)	1.97	0.33	0.35	5.27	4.15

Those covering more than 10% are in bold

valleys (Horvat 2013). These routes became especially important with the expansion of trade in the Middle Ages; for example, the routes over the Ljubelj (Loibl) Pass (1,370 m), Jezerski Vrh (Seeberg) Saddle (1,218 m), and Koren (Wurzen) Pass (1,073 m) in the Karawanks (today all on the border between Slovenia and Austria), or over the Predel (Predil) Pass (1,156 m) in the Julian Alps (today on the border between Slovenia and Italy; Kosi 1998; Mikša and Zorn 2016). The development of road network also had an important impact on settlement pattern (Senegačnik 2012).

Archeological finds also show that during Roman times the Slovenian high mountains were already used for grazing. The number of herdsmen's huts increased during the decline of the Roman Empire, when people withdrew from the exposed areas in the valleys to the mountains. The presence of Alpine dairy farming proper

was already reported from the High Middle Ages onward (Horvat 2013).

The first-stage colonization of higher elevations between the thirteenth and fifteenth centuries, resulting from the agrarian overpopulation of flatland areas, and the second-stage colonization that took place in the sixteenth century were key to the **settlement** of Slovenia's mountainous areas. The former affected hilly and wooded areas, where the number of settlements was even larger than today in some places, and the latter affected partly the extensive wooded areas and partly the surroundings of old settlements, completing the scale of today's settlement. In the late Middle Ages, colonization was intense up to elevations of 1,000 m and, in the eastern part of the mountainous areas, even up to 1,300 m. In the Alpine mountains, people usually settled the valleys, whereas in the Alpine hills they also settled the ridges and slopes. Forestry and animal husbandry were the main economic activities. Most alpine pastures were also created during that period; there were over six hundred of them, according to various sources (Grafenauer 1991; Kosi 1997; Kladnik 1998a; Senegačnik 2012). The numerous iron ore deposits in the eastern Julian Alps and certain parts of the Karawanks led to the expansion of ironworking as early as the sixteenth century. The industry died away by the end of the nineteenth century. Today, the mountainous areas play an important role in tourism (Fig. 5.23) and recreation. Animal husbandry is still a significant economic activity in these areas, along with forestry-related activities, especially on the Dinaric plateaus (Kladnik 1998b; Senegačnik 2012).

The upper limit of settlement in Slovenia's mountainous areas varies (Fig. 5.24). The elevation of permanently settled areas is the highest in the Alpine mountains, extending above 1,300 m in the Eastern Karawanks between Mounts Raduha, Olševa, and Peca. The highest farm in Slovenia, the Bukovnik (Bukovc) Farm, stands below Mount Raduha (2,062 m), at an elevation of 1,327 m. The Kamnik–Savinja Alps are settled above an elevation of 1,000 m, whereas the Western Karawanks and the eastern Julian Alps are settled up to an elevation of 1,000 m (Fig. 5.25). Settlements above the Selška Sora Valley on the southern edges of the Julian Alps, on the border with the Škofja Loka Hills, can be found above 1,000 m (Fig. 5.25). Zgornje Danje is among the highest settlements in Slovenia (1,120 m). In the Alpine hills, the area of the Pohorje, Strojna, and Kozjak is settled up to a maximum elevation of approximately 1,200 m on Mount Košenjak (1,522 m) in the northwest, and below 900 m in the eastern Pohorje Hills. In the Velenje and Konjice Hills, settlements reach a maximum elevation of approximately 1,000 m, and in the Sava Hills they extend up to approximately 800 m. In the Škofja Loka and Cerkno Hills, farms can be found at elevations between 900 and 1,000 m, or even higher in the Davča area (1,100 m). On the Dinaric plateaus, such as the Banjšice and Trnovo Forest plateaus, the highest settlements are located at 900 m and 1,000 m, and in the Idrija Hills they can even be found above 1,000 m (e.g., Vojsko, which stands at 1,077 m). The highest settlements on the Dinaric plateaus of southern Slovenia are at elevations between 800 and 900 m (Gams 1960).

In terms of population, the Alpine hills stand out among Slovenia's mountainous areas, with a population density of seventy-six people per km^2 (Table 5.10), which is below Slovenia's average (approximately hundred people per km^2), but significantly higher than the population density on the sparsely populated Dinaric plateaus (seventeen people per km^2) and in the Alpine mountains (thirty people per km^2). Dinaric plateaus also lag far behind in terms of settlement size, with settlements having an average of eighty residents, in contrast to settlements in the Alpine hills, which have an average population of over two hundred, and those in the Alpine mountains with an average population of just under three hundred. The higher population density of Alpine hills may relate to their central locations and the consequent development of main roads and industrialization (Senegačnik 2012). Over the past century, there has been a significant decline in population especially on the Dinaric plateaus, whereas in the Alpine hills the population has increased (Table 5.10).

Fig. 5.23 Slovenia's mountainous areas have an important tourism function, but some places are already overburdened by tourism, such as the Rogla ski resort (approximately 1,500 m) in the Pohorje Hills in summer. (Photo by Matija Zorn)

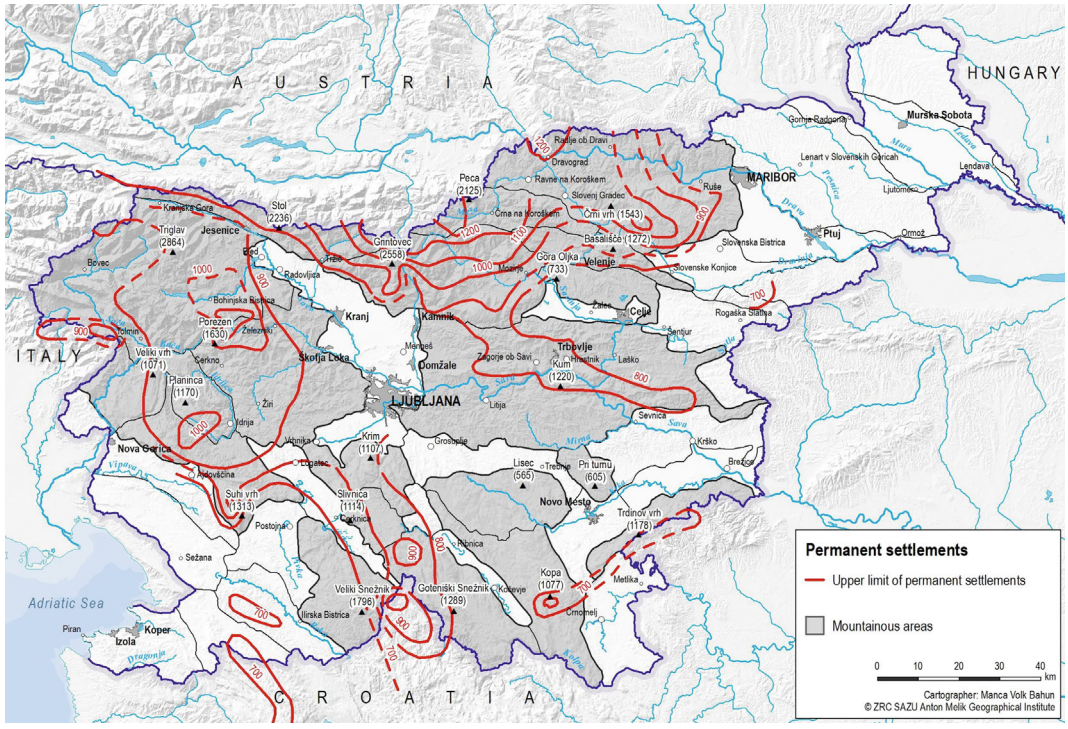

Fig. 5.24 Upper limit of settlement. (Adapted from Gams 1960)

Fig. 5.25 The maximum elevation of Gorjuše (top) on the Pokljuka Plateau in the Julian Alps is 1,080 m, and that of Ravne (bottom) in the Selška Sora Valley on the southern edges of the Juian Alps, on the border with the Škofja Loka Hills, is 1,060 m. (Photo by Matija Zorn)

In terms of **land use**, forests predominate heavily in Slovenia's mountainous areas. They cover over four-fifths of Dinaric plateaus and, on some of them, even over 90% of land. They cover three-quarters of Alpine mountains, and they account for the smallest share in the Alpine hills (they cover just over two-thirds of land), although that is still above Slovenia's average (just over three-fifths of the country). The presence of fields is greatly below Slovenia's average (i.e., just under a tenth of land), accounting for only 0.5% in Alpine mountains, 1.3% on Dinaric plateaus, and 3.1% in Alpine hills. The share of built-up areas in Slovenia's mountainous areas is also significantly below average, especially in Alpine mountains and on Dinaric plateaus. These two regions also have a below-average share of orchards, in contrast to Alpine hills, which have an above-average share. There are almost no vineyards in Slovenia's mountainous areas (Table 5.11 and Fig. 5.26).

Table 5.10 Basic information on the settlement of mountainous areas (Orožen Adamič et al. 1995; Perko and Orožen Adamič 1998; Perko and Ciglič 2020b; Perko et al. 2021; SiStat 2024)

ID on Fig. 5.1	Landscape type/region	Population in 1931	% of population in 1931	Population in 1961	% of population in 1961	Population in 1991	% of population in 1991	Population in 2011	% of population in 2011	Population density in 2011 (people per km^2)	Number of settlements in 2011	Settlement density in 2011 (number per 100 km^2)	Average size of settlement in 2011 (population)	Largest settlement (elevation, m)	Largest settlement in 2023 (population)	Highest peak (elevation, m)
	Alpine mountains	82,379	5.91	89,621	5.63	92,224	4.69	89,581	4.38	29.26	303	9.90	296	Jesenice (584)	13,702	Triglav (2,864)
1.1	Julian Alps	34,480	2.47	30,642	1.93	30,664	1.56	29,020	1.42	18.82	136	8.82	213	Tolmin (200)	3,228	Triglav (2,864)
1.2	Kamnik–Savinja Alps	20,352	1.46	20,098	1.26	20,916	1.06	21,657	1.06	24.37	114	12.83	190	Mozirje (340)	2,328	Grintovec (2,558)
1.3	Western Karawanks	16,994	1.22	26,586	1.67	29,466	1.50	28,447	1.39	85.90	25	7.55	1,138	Jesenice (584)	13,702	Stol (2,236)
1.4	Eastern Karawanks	10,553	0.76	12,295	0.77	11,178	0.57	10,457	0.51	34.90	28	9.35	373	Mežica (495)	3,127	Peca (2,125)
	Alpine hills	260,837	18.66	292,985	18.41	339,024	17.24	354,244	17.29	76.02	1,528	32.79	232	Velenje (390)	25,235	Porezen (1,630)
2.1	Cerkno, Škofja Loka, Polhov Gradec, and Rovte Hills	39,255	2.81	34,954	2.20	39,343	2.00	45,251	2.21	46.25	287	29.33	158	Žiri (492)	3,743	Porezen (1,630)
2.2	Sava Hills	121,713	8.71	132,142	8.30	136,848	6.96	142,184	6.94	74.47	857	44.89	166	Trbovlje (287)	13,678	Kum (1,220)
2.3	Pohorje, Strojna, and Kozjak Hills	66,146	4.73	83,773	5.26	98,652	5.02	99,510	4.85	77.34	218	16.94	456	Ravne na Koroškem (394)	7,160	Črni vrh (1,543)
2.4	Velenje and Konjice Hills	15,992	1.14	23,027	1.45	42,329	2.15	41,522	2.03	172.05	51	21.13	814	Velenje (390)	25,235	Basališče (1,272)
2.5	Ložnica and Hudinja Hills	17,731	1.27	19,089	1.20	21,852	1.11	25,777	1.26	105.49	115	47.06	224	Vojnik (270)	2,460	Gora Oljka (733)
	Dinaric plateaus	102,613	7.34	77,143	4.84	63,992	3.24	65,565	3.21	17.21	809	21.24	81	Idrija (325)	5,848	Veliki Snežnik (1,796)
3.1	Kambreško and Banjšice Plateaus	15,271	1.09	11,644	0.73	9,328	0.47	8,108	0.40	29.84	50	18.40	162	Kanal (103)	1,070	Veliki vrh (1,071)

(continued)

Table 5.10 (continued)

ID on Fig. 5.1	Landscape type/region	Population in 1931	% of population in 1931	Population in 1961	% of population in 1961	Population in 1991	% of population in 1991	Population in 2011	% of population in 2011	Population density in 2011 (people per km^2)	Number of settlements in 2011	Settlement density in 2011 (number per 100 km^2)	Average size of settlement in 2011 (population)	Largest settlement (elevation, m)	Largest settlement in 2023 (population)	Highest peak (elevation, m)
3.2	Idrija Hills	14,715	1.05	12,712	0.80	11,628	0.59	10,881	0.53	45.54	31	12.97	351	Idrija (325)	5,848	Planinca (1,170)
3.3	Trnovo Forest, Nanos, and Hrušica Plateaus	7,940	0.57	5,919	0.37	4,534	0.23	4,662	0.23	9.17	30	5.90	155	Črni Vrh (683)	699	Suhi vrh (1,313)
3.4	Javorniki and Snežnik Plateaus	0	0	0	0	0	0	21	0	0.05	1	0.22	21	Snežnik (1,000)	17	Veliki Snežnik (1,796)
3.5	Krim Hills and Menišija Plateau	6,185	0.44	4,745	0.30	4,691	0.24	7,042	0.34	23.46	82	27.31	86	Kamnik pod Krimom (351)	1,001	Krim (1,107)
3.6	Bloke Plateau	4,533	0.32	3,293	0.21	2,424	0.12	2,380	0.12	16.53	80	55.57	30	Nova vas (720)	273	Slivnica (1,114)
3.7	Big Mountain, Stojna, and Gotenica Plateaus	12,266	0.88	7,884	0.50	5,564	0.28	5,413	0.26	9.79	133	24.04	41	Sodražica (550)	871	Goteniški Snežnik (1,289)
3.8	Dry Carniola Plateau and Dobrepolje	18,466	1.32	15,336	0.96	13,362	0.68	14,349	0.70	33.87	166	39.18	86	Žužemberk (220)	1,056	Lisec (565)
3.9	Little Mountain, Kočevski Rog, and Poljane Plateaus	8,501	0.61	3,054	0.19	1,730	0.09	1,571	0.08	2.69	75	12.84	21	Velike Poljane (637)	151	Kopa (1,077)
3.10	Radulja Hills	6,796	0.49	5,637	0.35	4,979	0.25	5,485	0.27	47.36	74	63.89	74	Mokronog (250)	737	Pri turnu (605)
3.11	Gorjanci Hills	7,940	0.57	6,919	0.43	5,752	0.29	5,653	0.28	26.69	87	41.08	65	Orehovec (219)	229	Trdinov vrh (1,178)
	Slovenia	1,397,650	100	1,591,523	100	1,965,986	100	2,050,189	100	101.13	6,030	29.74	340	Ljubljana (298)	287,076	Triglav (2,864)

Table 5.11 Land use in mountainous areas (%) (Perko and Ciglič 2020b)

ID on Fig. 5.1	Landscape type/ region	Fields	Vineyards	Orchards	Meadows and pastures	Forests	Built-up areas
	Alpine mountains	0.53	0.00	0.49	**12.68**	**74.38**	1.64
1.1	Julian Alps	0.29	0.00	0.30	**11.38**	**70.49**	1.46
1.2	Kamnik–Savinja Alps	0.84	0.00	0.77	**14.83**	**76.58**	1.65
1.3	Western Karawanks	0.18	0.00	0.21	**11.60**	**80.71**	2.15
1.4	Eastern Karawanks	1.23	0.00	0.95	**14.16**	**80.93**	1.98
	Alpine hills	3.11	0.17	2.18	**21.74**	**68.12**	4.03
2.1	Cerkno, Škofja Loka, Polhov Gradec, and Rovte hills	1.53	0.00	1.13	**21.85**	**72.28**	2.92
2.2	Sava Hills	3.42	0.19	2.33	**23.11**	**66.24**	4.15
2.3	Pohorje, Strojna, and Kozjak Hills	2.96	0.20	2.12	**18.51**	**71.37**	3.93
2.4	Velenje and Konjice Hills	2.80	0.19	2.95	**21.22**	**65.90**	5.69
2.5	Ložnica and Hudinja Hills	8.04	0.48	4.76	**28.16**	**51.28**	6.46
	Dinaric plateaus	1.26	0.24	0.61	**12.87**	**83.21**	1.47
3.1	Kambreško and Banjšice Plateaus	0.80	0.01	1.15	**15.98**	**78.86**	2.38
3.2	Idrija Hills	0.46	0.00	0.76	**15.88**	**80.30**	1.94
3.3	Trnovo Forest, Nanos, and Hrušica Plateaus	0.51	0.02	0.25	**11.30**	**86.25**	1.03
3.4	Javorniki and Snežnik Plateaus	0.12	0.00	0.02	9.08	**90.16**	0.17
3.5	Krim Hills and Menišija Plateau	0.95	0.00	0.60	**12.43**	**83.26**	2.57
3.6	Bloke Plateau	1.37	0.00	0.68	**27.26**	**68.79**	1.73
3.7	Big Mountain, Stojna, and Gotenica Plateaus	0.35	0.00	0.37	9.70	**88.31**	1.01
3.8	Dry Carniola Plateau and Dobrepolje	4.03	0.22	0.88	**20.05**	**72.23**	2.37
3.9	Little Mountain, Kočevski Rog, and Poljane Plateaus	0.29	0.03	0.32	6.50	**92.23**	0.54
3.10	Radulja Hills	7.19	2.27	2.74	**22.72**	**61.03**	3.98
3.11	Gorjanci Hills	3.56	2.56	1.53	**14.45**	**75.32**	2.49
	Slovenia	9.71	0.94	1.76	**18.47**	**61.90**	5.01

Those covering more than 10% are in bold

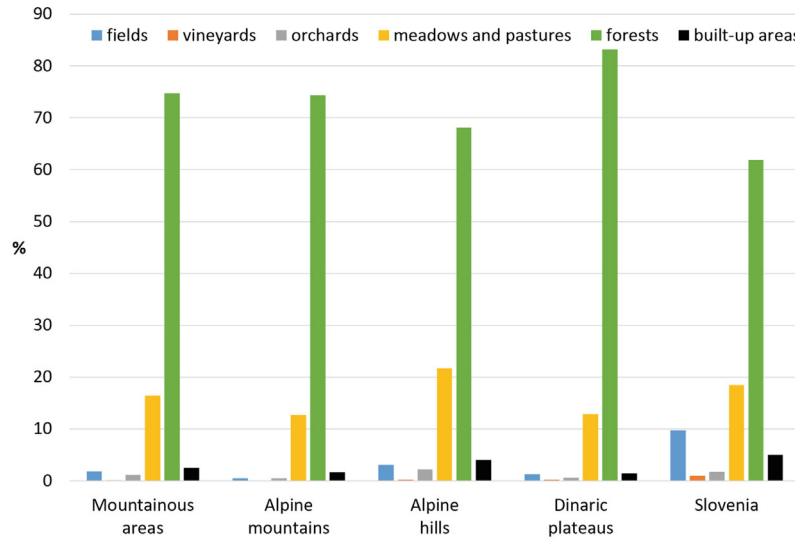

Fig. 5.26 Land use in Slovenia's mountainous areas. (Based on Table 5.11)

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