RELIEF

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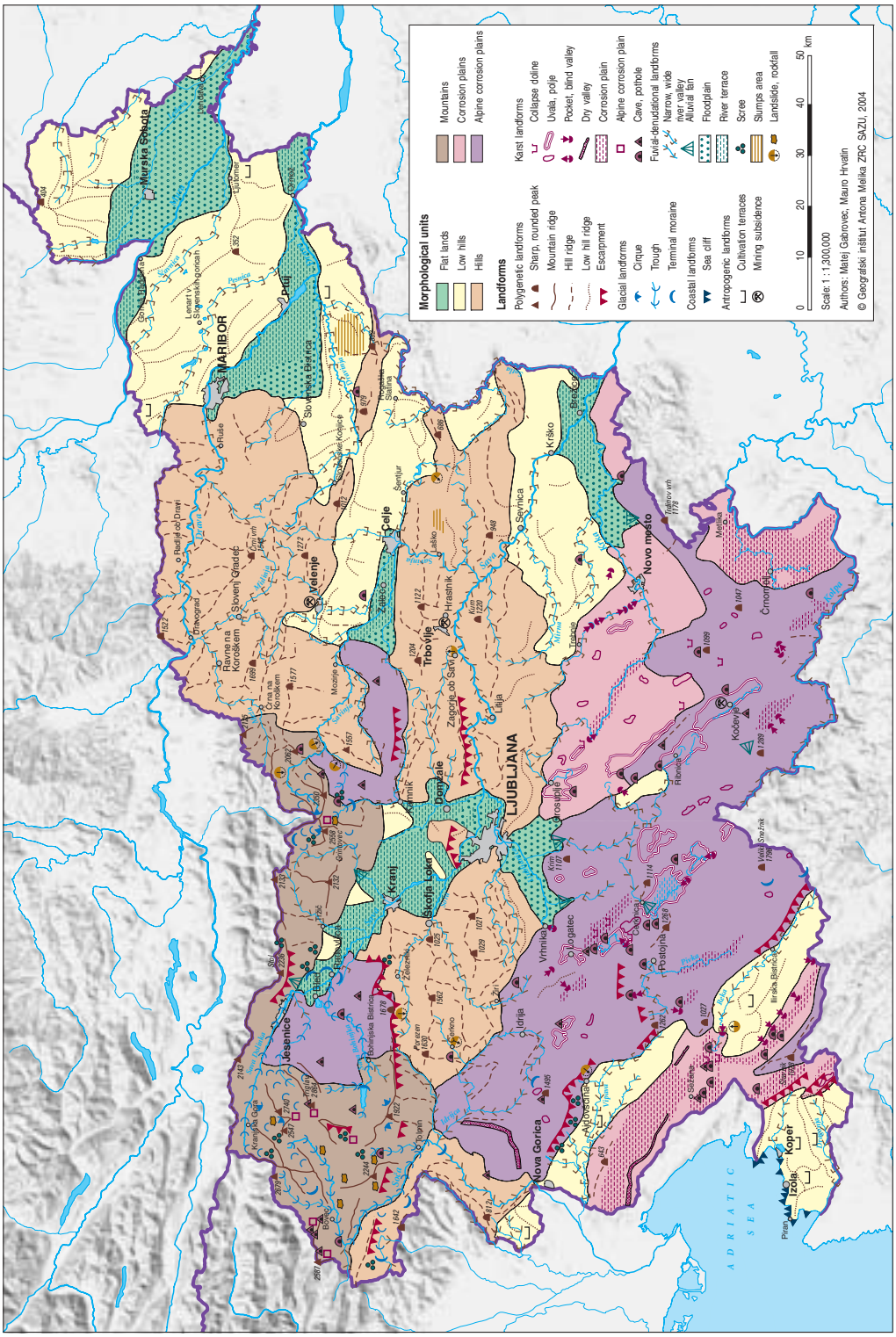
In the middle of the Pliocene, the relief of today's Slovenia was still predominantly level, mainly due to strong chemical weathering and abundant denudation in the moderately humid and warm climate of the time. From this period, numerous flatlands still remain today. The geomorphological processes that leveled the landscape ceased with the tectonic and climate changes in the upper Pliocene and in the Pleistocene. Due to the gradual cooling of the climate, mechanical weathering increased in the upper Pliocene and primarily reduced the surface areas of impermeable rock, which were then much more widespread than they are today. Through vertical and lateral erosion, the rivers carved deep valleys, above which the remains of former terraces have survived. Even greater changes occurred with the frequent climate changes in the Pleistocene. The temperature dropped in the cold periods by more than 10° C, and therefore glaciers formed in the mountain areas. Frequent freezing caused extremely strong mechanical weathering. The rivers deepened their valleys by 100 to 300 meters and at the same time filled young tectonic depressions with huge amounts of gravel. In the Holocene, the initially very rapid river erosion was followed by periodic accumulation of material from the upper parts of the valleys (Šifrer 1994).

According to the geomorphological development in Slovenia, we distinguish fluviodenudational, glacial, karst, and coastal relief.

In some areas, the genetic types of relief intertwine. In the mountains, for example, that were reshaped by glaciers in the Pleistocene, the chemical weathering of carbonate rock dominates today and we speak of glacial-karst relief (Gabrovec and Hrvatin 1998).

Fluviodenudational relief has developed on areas of impermeable rock. Within this type, we further distinguish destruction and accumulation relief. Characteristic of destruction fluviodenudational relief is the interweaving of valleys and intervening ridges. In the mountainous area, rivers in some places carved their riverbeds in the shape of narrow and deep gorges. The small Mlinarica and Mostnica rivers in the Julian Alps, for example, carved gorges several dozen meters deep. Characteristic of mountainous areas are ravines such as Iški vintgar and the valley of the Hudinja River below Vitanje. In hilly areas, the valleys are usually wider and have alluvial bottoms, for example, the valleys of the Pesnica and Ščavnica rivers in Slovenske Gorice. On slopes covered by a thicker layer of weathered debris and soil, slumps are frequent. They are most frequent in Kozjansko and Haloze, where they are triggered mainly by heavy rains. Landslides are more frequent on less resistant sediment in the subalpine hills. Among the largest belong landslides in the upper Savinja Valley, the Posočje region, and below Kladje Pass in the Cerkljansko Hills. Rockfalls and debris flows are periodically triggered from mountain walls and the steep rocky slopes of mountain valleys. The best known in recent years are the rockfalls in Trenta and the debris flow triggered in the Mangart mountain chain that partially destroyed the village of Log pod Mangartom (Zorn and Komac 2002).

Accumulation fluviodenudational relief occurs on plains and basins and on the bottoms of wider valleys and karst poljes. This relief was formed by rivers that deposited several dozen meters of gravel, sand, or clay in tectonic depressions. Rivers that had their watersheds in glaciated areas during the Pleistocene deposited large quantities of material in the cold periods and carved out riverbeds in it during the warmer periods. Numerous fluvioglacial terraces are the result of the many alternations of cold and warm periods and the corresponding depositing and carving by the rivers. The best-preserved terraces are found in Dobrava between Radovljica and Kranj. On older terraces, limestone pebbles


Morphological units
Mountains
Plat lands
Corrosion plains
Low hills
Hills
Alpine corrosion plains
Landforms
Polygenetic landforms
Sharp, rounded peak
Mountain ridge
Hill ridge
Low hill ridge
Escarpment
Karst landforms
Collapse doline
Uvala, polje
Pocket, blind valley
Dry valley
Corrosion plain
Alpine corrosion plain
Glacial landforms
Cirque
Trough
Terminal moraine
Coastal landforms
Sea cliff
Fluvial-denudational landforms
Narrow, wide river valley
Alluvial fan
Floodplain
River terrace
Anthropogenic landforms
Cultivation terraces
Mining subsidence
Scree
Slumps area
Landslide, rockfall
0 10 20 30 40 50 km
Scale: 1 : 1,300,000
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MARIBOR
Murska Sobota
Ptuj
Slovenske Konjice
Celje
Velenje
Slovenj Gradec
Črnomelj
Novo mesto
Trebnje
Sevnica
Krško
Brežice
Trbovlje
Hrastnik
Zagorje ob Savi
Litija
LJUBLJANA
Domžale
Kamnik
Kranj
Škofja Loka
Tržič
Jesenice
Bohinjska Bistrica
Radovljica
Vrhnika
Logatec
Postojna
Idrija
Cerknica
Nova Gorica
Ajdovščina
Vipava
Sežana
Kočevje
Ribnica
Grosuplje
Ilirska Bistrica
Koper
Izola
Piran
ADRIATIC SEA

◄ *Figure 1: Morphological units and landforms.*

agglutinated into conglomerate, which in places such as the Udin boršt terrace near Kranj is already well karstified. The thickness of Quaternary alluvium in the areas of accumulation fluviodenudational relief varies substantially, from five to two hundred meters. Where narrow valleys open onto wider valleys or plains, the rivers deposited alluvial fans. Among the larger ones are the Šentjernej fan, which was created by streams coming from the Gorjanci mountain range at the edge of the Krška ravan plain, and the fan of the Iška River at the junction of Iški vintgar and the Ljubljansko Barje moor. Accumulation relief also occurs at the foot of some steep slopes where extensive fossil and recent screes are found.

Glacial relief appears in the mountainous areas, where it originated due to glacial erosion and accumulation in the colder periods of the Pleistocene. Cirques formed high in the mountains below rocky ridges. Larger cirques include Za Akom and Pod srcem in the Julian Alps above Gozd Martuljek and Okrešelj above the Logarska dolina valley in the Kamniške-Savinjske Alps. Glaciers filled former river valleys and reshaped them into U-shaped glacial valleys with broad flat bottoms and steep sides. The effects of glacial erosion are most distinctive in watershed areas of the valleys of the Sava Bohinjka, Soča, Kamniška Bistrica, and Savinja rivers. Smaller glaciers also left traces at places in the Karavanke Mountains and in the Trnovski gozd and Snežnik regions. Terminal moraines mark the outer margins of the former glaciers. On formerly glaciated areas, denudation and karstification dominate today. The glaciers below Mount Triglav and Mount Skuta are not the remains of Pleistocene glaciation since they only formed in the colder period of the Holocene. Because each of them only covers a few hectares, their influence on the formation of the surface is insignificant.

Karst relief is characteristic primarily of the Dinaric and Alpine areas. Common characteristics of karst are the intensive chemical weathering of the rock and the underground karst flow of the waters. On the basis of the hardness or mineralization of karst waters, it was determined that the karst surface in Slovenia lowers by two to ten millimeters per century, less on barren karst and more on karst areas covered by soil (Gams 2003).

We distinguish between limestone karst and dolomite karst relief. The characteristic surface of limestone karst is composed of karst depressions and rounded peaks. The most frequent karst depressions are dolines. In places, their density is extremely high; for example, on the Vrtače and Šahen flats in Ribniško polje and Kočevsko polje, there are more than two hundred dolines per square kilometer. The larger karst depressions include uvalas and karst poljes. In Notranjska, the best known are Cerknica polje and Planinsko polje, and in Dolenjska, Ribniško polje and Kočevsko polje. Slovenia's largest karst corrosion plain is in Bela krajina, a several-kilometer long and wide flat surface that is heavily dotted with dolines. Where waters flow from impermeable rock onto limestone bedrock, blind valleys developed, for example in the limestone Podgrajsko podolje along the streams flowing down from the flysch Brkini ridge. Around the karst springs of the Ljubljanica, Unica, and Krka rivers, pocket valleys were formed that end in steep slopes or even vertical walls. Because of the course taken by the karst waters, numerous caves and shafts were formed in the underground. The largest caves in Slovenia occurred near the sinkholes of major rivers. The Postojna cave system and Planinska cave were formed by the Pivka River, and the Škocjan Caves and Kačna jama Cave by the Reka River. The deepest shafts explored so far, over 1,000 meters deep, are found on Mount Rombon and Mount Kanin and on the Dleskovška plateau. With a depth of 1,533 meters, the Čehi 2 shaft on Rombonski podi is among the ten deepest shafts in the world. Due to the collapse of the ceilings of karst caves, deep depressions were formed on the surface. Among those above the underground streams in the watershed of the karst Ljubljanica River are the 124-meter deep Unška koliševka collapse depression and the Laška kukava collapse depresion. Enclosing a space of 2.75 million m^3, the latter is the largest in Slovenia. Although underground waters dominate in karst regions, some rivers such as the Kolpa and Krka flow on the surface. Among dry valleys, the most distinctive is the Čepovan Valley between the plateaus of Banjšice and Trnovski gozd.

Surface karst forms are more rare on dolomite karst, and therefore this type of karst relief is usually less distinctive than limestone karst relief. Larger karst caves such as Jama near Sveti Trije kralji near Rovte are also relatively rare. Small and shallow dry valleys called dells are characteristic. Along with the chemical dissolving of the rock, erosion and denudation also play an important role on dolomite and therefore dolomite karst relief in many places resembles fluviodenudational relief. This type of relief, characteristic of the watershed of the Temenica River, is often called »fluviokarst«. Due to its lack of resistance to mechanical weathering or brittleness, erosion foci are frequent on dolomite.

The coastal type of relief is limited to a narrow belt along Slovenia's Adriatic coast. The most distinctive relief features are overhanging cliffs up to seventy meters high formed by abrasion erosion and eroded at their feet by the waves. The largest cliffs rise between Izola and Piran. Along the coast below the surface of the sea spreads a several-dozen-meters wide abrasion terrace that ends in a sharp edge at the depth of nine meters (Orožen Adamič and Rejec Brancelj 1998).

In many places the geological structure is clearly visible in the relief. This applies above all to larger geological structures, among which we include faults, folds, and thrusts. In many places, river valleys have been carved in tectonically damaged rock along faults. The Soča and Idrijca rivers carved part of their valleys along the Idrija fault, and on karst, the Notranjska valley system formed with numerous karst poljes. A folded area can be reflected in the form of a parallel oblong series of ridges and valleys, for example in the Posavsko Hills. In some places, the fronts of thrusts are visible as distinctive relief levels. The steep limestone slope of Trnovski gozd above the flysch Vipava Valley is the front of the Trnovo thrust.

Human intervention is increasingly evident in the relief. Among the most important anthropogenic relief features are transportation right of ways, quarries and other excavations, and cultivation terraces. Major changes in relief occur due to the subsidence of the ground above abandoned mine shafts. The worst consequences of subsidence due to coal mining are visible in the vicinity of Velenje and Trbovlje. Lakes developed where groundwater filled the subsidences over mines. Cultivation terraces that made cultivation easier and simultaneously reduced soil erosion on slopes are frequent in the hills above Koper.

Along with the relief features described above, which more or less incontrovertibly fall into individual genetic types of relief, there is a multitude of those that developed due to the interaction of various geomorphological processes and are therefore called polygenetic features. Among the more typical relief features of this kind are variously shaped peaks, ridges, and slopes.

Relative to the dissection of the surface, we distinguish six types of relief: plains, low hills, hills, mountains, and low and high plateaus. Plains developed through accumulation processes. Today, accumulation occurs only on the youngest flood plains of rivers and streams. Older conglomerate terraces are already karstified. In the low hills and hills, denudation and erosion processes dominate. These two relief types are distinguished according to the differences in altitude between the ridges and the valleys: in low hills, they reach 300 meters at most, and in hills, between 300 and 1,000 meters. In the mountains, the peaks and ridges reach above the tree line. In Slovenia, the tree line is at around 1,700 meters. The mountains were glaciated during the Pleistocene, and numerous glacial features have survived. Today, fluviodenudational and karst processes dominate here. The low hills, hills, and mountains are dissected by numerous valleys, but on plateaus valleys are found only exceptionally due to the dominant karst processes. On plateaus, rounded peaks alternate with various karst depressions. Low plateaus reach up to 700 meters above sea level, while on high plateaus the peaks reach over 1,000 meters.

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