Rocks and Tectonic Structure of Slovenia

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Abstract

The rocks that can be seen on Slovenia's surface today formed from at least the early Paleozoic to the Quaternary, or the present. The oldest metamorphic rocks probably date even back to the Precambrian. Sedimentary rocks predominate, covering 65.1% of Slovenia's surface. Among these, two carbonate rocks are especially common: limestone and dolomite. Loose sediments fill the tectonic depressions and river valleys, covering 29.2% of Slovenian territory. Metamorphic rocks account for 4.1% and are mostly concentrated in northeast Slovenia. Igneous rocks account for the smallest share, covering only 1.6% of the territory. Intrusive igneous rocks can only be found on the surface along the Periadriatic Seam and in the Pohorje Hills, whereas extrusive igneous rocks (or volcanic rocks) are scattered across smaller areas of the Alpine hills and mountains. Slovenia lies at the intersection of the following geotectonic units: the Dinarides, Southern Alps, Eastern Alps, and Pannonian Basin. All of these units form part of the Adriatic microplate, and their current distribution was achieved only as late as the Neogene—that is, during the past 20 million years.

Keywords

Physical geography · Geology · Stratigraphy · Rocks · Tectonics · Raw material

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2.1 Slovenia's Basic Geological Characteristics

More than nine-tenths of Slovenia's territory is covered by sediments and sedimentary rocks, which accumulated at the bottom of the sea and in lakes or were deposited by rivers and glaciers. The sedimentary rocks of the Mesozoic Slovenian Basin and the Neogene Paratethys stand out in terms of diversity. Igneous and metamorphic rocks are largely present only in northeastern Slovenia, but they are nonetheless very diverse, even though they cover only 5.7% of the entire territory (Natek and Natek 1998; Verbič 1998).

The diverse rock composition is the result of a long geological history and location at the contact of the Dinarides, Southern Alps, Eastern Alps, and Pannonian Basin. Even though today these tectonic units lie close to one another, even overlapping in places, they have a different development. All of them are part of the Adriatic microplate, which broke away from the African Plate in the Mesozoic. While moving toward the north, it collided with the Eurasian Plate during the Neogene, causing Alpine orogeny. The two plates have continued to move toward one another after their collision, which is the main factor influencing the formation of Slovenia's tectonic structure (Novak 2016).

Due to their diversity, rocks play an important role in Slovenia's landscapes. They largely influence the structure of today's terrain, the network of rivers and creeks, soil types, the spread of many plant species, and human activity in the landscape (Natek and Natek 1998).

Individual rock types are fairly unevenly distributed across the country (Fig. 2.1). Alpine mountains are built primarily from limestone and dolomite, whereas large quantities of carbonate gravel, rubble, and till have accumulated in the valleys. Quartz sandstone and conglomerate and dolomite predominate in the Alpine hills of central Slovenia. The Alpine hills in the northeast are an exception in this regard, consisting of metamorphic and igneous rocks. Carbonate gravel, which has already conglomerated in places,

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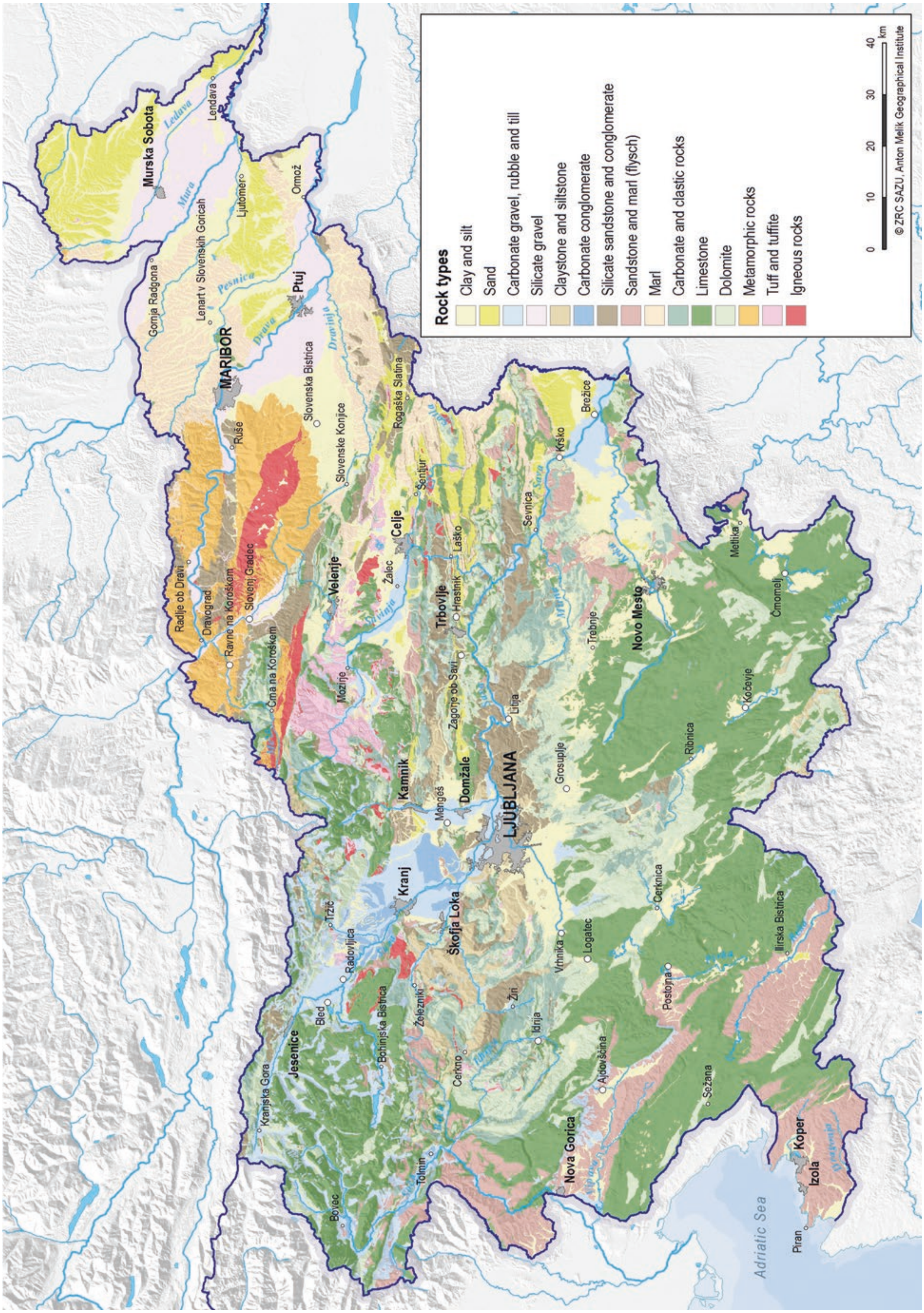

Fig. 2.1 Rock types in Slovenia

predominates on Alpine plains. The Pannonian low hills are made partly of marlstone and partly of loose fine-grained sediments, including clay, silt, and sand. Quartz gravel predominates on the Pannonian plains, and the remaining surface is covered in clay and silt. Dinaric plateaus are made of limestone and dolomite, and Dinaric lowlands exhibit a similar rock composition; the only difference is that in places carbonate rocks are covered by thick clay deposits. The Mediterranean low hills are composed of flysch sandstone and marlstone, and limestone predominates on Mediterranean plateaus (Perko 1998).

2.2 Slovenia's Geological Development

Slovenia's surface structure and landscape features are closely connected with its rock composition and tectonic setting, which developed over several hundred million years (Buser et al. 1989). The rocks making up Slovenia's territory formed over a considerably larger area, but tectonic forces later compressed them onto a smaller area. Many rocks had a unique development, and hence geologists have combined them into several groups and named them after Slovenian places (Buser 1997). For instance, the rocks of the Lower Carboniferous in the wider area of Jezersko along the Slovenian–Austrian border have been named the Jezersko Paleozoic. The Carnian bauxite, sandstone, siltstone, clay stone, tuffite, and breccia in central Slovenia make up the Borovnica Formation. The Eocene marlstone and clay stone with layers of coal between Rogaška Slatina and Velenje can be classified under the Socka beds, and the Bača dolomite is a typical platy rock with chert found in the southern part of the Julian Alps.

2.2.1 The Precambrian and Paleozoic

The oldest rocks in Slovenia are high-grade metamorphic rocks that were formed through a metamorphosis of sedimentary and igneous rocks. They make up the Pohorje Hills, the Kozjak Mountains, and the Mount Strojna and include gneiss, mica schist, amphibolite, and marble. Based on their location and metamorphosis stage, some claim they are of Precambrian and early Paleozoic age (Buser et al. 1989; Fodor et al. 2008), whereas others date them to the period between the Ordovician and Devonian (Hinterlechner-Ravnik and Trajanova 2009; Novak 2016). They were exposed to metamorphosis several times and especially heavily during the Cretaceous. Slates and phyllites are somewhat less metamorphized and younger, and the slates of the Magdalensberg Series along the Austrian border near Dravograd have undergone only partial metamorphosis (Buser 1997).

The oldest sedimentary rocks attested through fossils have been found in the gravel of the Permian conglomerate east of Ljubljana. Based on the fossil remains of cephalopods from the genus *Orthoceras*, it has been established that these are Upper Silurian limestones, which formed approximately 420 million years ago (Vrabec et al. 2009).

Devonian rocks are present in the Karawanks between Jezersko and the Logarska Valley, where they form prominent rocky peaks. They are composed of deep marine platy limestones with conodonts in their lower section, shallow marine massive limestones with corals in the center, and deep marine limestones again in their upper section (Buser 1997).

Due to the collision between Euramerica (or Laurussia) and Gondwana, the Variscan or Hercynian orogeny took place during the Devonian and Carboniferous, causing a sinking of the sedimentation environment at the edge of the continent (Vrabec et al. 2009). Therefore, during the Lower Carboniferous, the area of southern Karawanks was flooded by deep sea, in which flysch shales, sandstones, and limestones were deposited. The tectonic shifts of that time also caused the oldest volcanic activity in Slovenian territory, which is indicated by the porphyritic volcanic breccias and tuffs found around Jezersko (Buser 1997). In the Middle Carboniferous, the Paleo–Karawanks were formed, and after a brief emergence of dry land, quartz sandstones and conglomerates, shales, and limestones with several foraminifers, shells, and corals formed in the shallow sea of the Upper Carboniferous. These rocks contain lead and zinc ore, baryte in the area around Litija, and iron ore in the Karawanks (Buser et al. 1989).

During the Lower Permian, the shallow marine sedimentation of siliciclastites and carbonates continued in the coastal area of the continental shelf, and bryozoans, crinoids, and algae built reef mounds toward the open sea, providing a habitat for brachiopods. Many of these fossils have been found in the Dovžan Gorge near Tržič (Fig. 2.2). The sedimentation at the end of the Lower Permian was interrupted by an orogenetic phase that caused the sea to recede (Vrabec et al. 2009). During the Middle Permian, the mainland was exposed to a desert climate, and rivers only occasionally deposited violet–red and green quartz clastic rocks; these contain uranium ore in the vicinity of Žiri. During the Late Permian, the sea again gradually covered the saline tidal flats. An extensive shallow continental shelf called the Slovenian Carbonate Platform took shape, with dolomites predominantly being formed on it (Novak 2016).

2.2.2 The Mesozoic

On the Slovene Carbonate Platform, the Late Permian shallow marine sedimentation continued into the Early Triassic.

Fig. 2.2 The Dovžan Gorge near Tržič is distinguished by a great diversity of Paleozoic rocks and fossils. (Photo by Xseon, Shutterstock.com)

Mixed clastic-carbonate sedimentary rocks formed due to the inflow of debris from the nearby mainland (Novak 2016). During the Anisian, the inflow of debris stopped and shallow marine sedimentation of limestone prevailed. This limestone later largely transformed into dolomite (Vrabec et al. 2009).

The Middle Triassic Ladinian stage was the most turbulent stage in Slovenia's geological history. Long and deep faults cut the Earth's crust into large tectonic blocks, and the rifting of the Meliata Ocean began along Pangaea's eastern edge. The central part of what had been a single continental shelf until then sank several hundred meters below sea level. The deepest sea formed in the belt running from the Gorjanci Hills across the Krško Hills, the Bohor Mountains, Mount Boč, and the Tuhinj Valley, Selška Sora River, and Bača River valleys toward Tolmin and Kobarid. A long narrow channel called the Slovenian Basin was covered by the sea for nearly 150 million years until the Late Cretaceous. At first, dark shales alternating with sandstones and tuffs formed in it, and two carbonate continental shelves remained on both edges of the deep basin. On the northern side, the carbonate rocks that make up the Julian Alps, the Kamnik–Savinja Alps, and the Karawanks were deposited on the Julian Carbonate Platform, and on the southern side, the carbonate rocks that make up the Dinaric karst plateaus were deposited on the Dinaric Carbonate Platform (Buser et al. 1989; Novak 2016).

Volcanos along deep faults spewed lava and ash, leaving behind volcanic rocks and tuffs, which appear between layers of other rocks. This suggests that the largely submarine volcanic eruptions repeated several times. The Ladinian tectonic and volcanic activity is also connected with the formation of the Idrija mercury deposits and the Mežica lead and zinc deposits (Pleničar 2004; Novak 2016).

Toward the end of the Ladinian, some blocks rose from the sea as dry land in the area of the Karawanks and Idrija. Erosion there removed part of the older rocks, which were resedimented into colorful conglomerates (Buser et al. 1989).

During the Carnian, massive limestone deposits with frequent fossil remains of calcite algae initially formed on both carbonate platforms. A large portion of this limestone later turned into dolomite. When the inner part of the Dinaric Carbonate Platform turned into dry land for a short while, reddish sandstones, clay stones, and breccias formed alongside bauxite. During the Norian and Rhaetian, reef limestone formed on Mount Begunjščica (2060 m) and in the Bohinj Valley, whereas thick-bedded Dachstein limestone deposits with stromatolites and large megalontidae formed elsewhere on the Julian Carbonate Platform (Fig. 2.3). At the same time, shallow marine limestone deposits formed on the Dinaric Carbonate Platform, which later turned into Main Dolomite (Vrabec et al. 2009).

Approximately 1200 m of Dachstein limestone and Main Dolomite were deposited on the Julian and Dinaric Carbonate Platforms, whereas only 350 m of platy limestone and dolomite with nodules or lenses of chert formed in the Slovenian Basin (Novak 2016).

At the end of the Triassic, Pangaea broke up into Laurasia and Gondwana. During the Atlantic rifting, a narrow oceanic trough initially developed from transform basins. Its expan-

Fig. 2.3 View of thick layers of Late Triassic Dachstein limestone along the ridge of Mount Velika Mojstrovka in the Julian Alps. (Photo by Ales Krivec, Shutterstock.com)

sion during the Jurassic caused the formation of deep marine basins and submarine plateaus, which existed up until the end of the Cretaceous (Vrabec et al. 2009).

During the early Jurassic, the Slovenian Basin deepened again, with deep marine platy limestones with chert and marl forming inside it. The sea also deepened somewhat on both carbonate platforms and calcite ooids up to 2 mm developed in it, making up thick layers of oolitic limestone. An especially interesting feature found in southern Slovenia is black limestone with white cross sections of lithiotid bivalves (Buser et al. 1989).

During the Lower Jurassic, the Julian Carbonate Platform became mainland for a short while, before sinking again deeper into the sea, where reddish nodular and crinoidal limestones with ammonites formed. In the deep sea of central Slovenia, clay stone, marl, and chert deposits formed. At that time the Slovenian Basin sunk deepest, with radiolarites accumulating from tiny radiolarian skeletons at its bottom (Buser et al. 1989).

During the Upper Jurassic, a large coral reef formed along the northern edge of the Dinaric Carbonate Platform. It ran relatively contiguously from Northern Italy across the Banjšice Plateau, the Trnovo Forest Plateau, and the Hrušica Plateau to Trebnje, Novo Mesto, and White Carniola, and onward toward Croatia. The southern part of this carbonate platform rose above the sea for a short while, with bauxite forming in some places. White platy limestones with chert accumulated in the deep sea of the Slovenian Basin and the Julian Carbonate Platform. At the end of the Jurassic and the beginning of the Cretaceous, extensive beds of green algae thrived in the shallow marine lagoon of southern Slovenia (Buser et al. 1989).

On the Dinaric Carbonate Platform, shallow marine sedimentation with short breaks and deep marine stages continued for most of the Cretaceous. Extensive stretches of limestone with rich deposits of rudists and other fossils formed in what is now the Karst Plateau. In the past, in many places these limestones were quarried as decorative natural stone, but today they continue to be extracted only at the quarry near Lipica (Pleničar 2004; Novak 2016).

During the Cretaceous, Alpine and central Slovenia was covered by deep sea, in which flysch marlstones and sandstones initially formed, and later on also the characteristically red marlstones and marly limestones. Elsewhere in the Alps, these rocks—which have been best preserved near Mount Krn (2245 m)—were largely eroded away. Platy limestones with layers of marlstones and sheets of chert formed in the Slovenian Basin (Buser 1997).

During the rifting of the North Atlantic Ocean in the Cretaceous, the Eurasian Plate broke away from Laurasia. At the end of the Cretaceous, the oceanic part of the Adriatic microplate traveling north collided with the Eurasian Plate, lifting the land and causing the displacement of large quantities of terrestrial and marine sediments and the deposition of various flysch rocks. Flysch initially filled the area of the Slovenian Basin and later on also the territory at the foothills of the rising Alps, reaching and covering the northern edge of the Dinaric Carbonate Platform even before the end of the Cretaceous (Novak 2016).

Fig. 2.4 Most of the Slovenian coast and the cliffs in the Bay of Strunjan are composed of Eocene flysch sandstones and marlstones. (Photo by Dejan K, Shutterstock.com)

2.2.3 The Cenozoic

During the Paleocene and Eocene at the beginning of the Cenozoic, the flysch marlstones and sandstones that make up the Gorica Hills, Vipava Valley, Pivka Lowland, Brkini Hills, and Koper Hills were deposited in the deep sea of southwestern Slovenia (Fig. 2.4). These rocks are also thought to have once covered a large portion of today's Dinaric Karst region, but they have only been preserved in smaller patches in southeastern Slovenia. Shallower sections of the sea were populated by numerous foraminifers, whose tests form the miliolid, nummulitic, and alveolina limestones below Mount Slavnik (1028 m) in southwestern Slovenia (Buser 1997).

The collision between the continental part of the Adriatic microplate and the Eurasian Plate during the Paleogene caused the formation of the Alps, the Dinaric Alps, and the Carpathians, which separated the Paratethys Sea from the Atlantic and Tethys oceans during the Oligocene. The Paratethys covered Slovenian territory up until the Pliocene. Paratethys sediments and sedimentary rocks predominate in eastern Slovenia and in the Ljubljana Basin (Novak 2016).

During the Oligocene, central Slovenia was characterized by large swampy basins, in which layers of marlstones and clastic sediments were deposited. They included thick layers of brown coal, which was mined for decades in Zagorje ob Savi, Trbovlje, Hrastnik, Laško, and Senovo in central Slovenia (Buser et al. 1989).

The lithospheric plate collision along the Periadriatic Seam (Fig. 2.6) caused magma to rise toward the surface. The Mount Smrekovec volcanism became active in the sea, beginning with eruptions of lava flows and continuing with explosive eruptions of volcanic ash. Andesite and its tuff predominate among the rocks of volcanic origin; they can be found among the layers of marine sedimentary rocks in a wide belt along the upper course of the Savinja River and around Radovljica, Celje, and Rogaška Slatina (Novak 2016).

During the Miocene, western and northeastern Slovenia sank quickly, creating the extensive Pannonian Basin, into which rivers deposited large volumes of sediments, which later consolidated into sandstones, conglomerates, and clay stones. In the Pohorje Hills, metamorphic rocks rose to the surface, and a large granodiorite body intruded between them; this process was accompanied by dacitic volcanism (Vrabec et al. 2009).

During the Middle Miocene, deposits of lithothamnian limestones, marls, and sands formed in eastern Slovenia, followed by a thick succession of clastic sediments (Buser 1997; Vrabec et al. 2009).

The Neogene shortening of the area south of the Periadriatic Seam caused the folding and thrusting of tectonic blocks in a north–south direction. The thrusting, which began during the Middle Miocene, mostly subsided by the Pliocene, even though it probably still continues in the Julian Alps and its surroundings today (Vrabec et al. 2009).

During the Pliocene, the rivers in eastern Slovenia filled the large depression that remained after the receding sea mostly with quartz gravel. The emerging dry land was broken apart, lifted, and sunken by tectonic forces. During the Middle Pliocene, large tectonic depressions filled by lakes formed in Slovenia's interior. A lignite layer up to 160 m thick formed from the extensive Upper Pliocene forests near Velenje; thinner lignite layers developed at Ilirska Bistrica and near Krmelj (Buser 1997).

The last volcanic eruptions in Slovenia's vicinity took place during the Late Pliocene, with Austrian Styria as the center of volcanic activity. It began with the release of basaltic lava, followed by several explosive eruptions of ash, which formed the basaltic tuff in the Goričko Hills in the northeast of the country (Novak 2016).

Due to large variation in temperature, the Quaternary was characterized by the growth and retreat of glaciers. During the period of the lowest temperatures, glaciers extended from the Alpine high mountains far into the foothills. Their moraine material is still visible in the upper Alpine valleys of both branches of the Sava, Soča, and Savinja rivers, as well as in the Pohorje Hills, and on the Trnovo Forest Plateau and Mount Snežnik. In the Ljubljana, Brežice–Krško, and Celje basins and the Maribor–Ptuj Plain, the rivers deposited enormous quantities of gravel, which has already been cemented into conglomerates in places (Fig. 2.5). In the Ljubljana Marsh, the gravel is also covered by silt and clay (Šifrer 1969; Buser 1997; Novak 2016).

2.3 Tectonic Division

The structure of Slovenian territory is connected with the development of the Tethys Ocean and its shrinking during the Mesozoic and Cenozoic due to the African and Eurasian plates drifting closer to one another. An important role in this was played by the intermediate Adriatic microplate, which, seen from a geotectonic perspective, is the edge of the African Plate (Placer 1999).

Slovenia is located at the intersection of the geotectonic units of the Dinarides, Southern Alps, Eastern Alps, and Pannonian Basin (Fig. 2.6). Their current distribution was largely achieved only as late as the Neogene. All of its structural units are part of the Adriatic Plate, and the boundaries between them run along the Periadriatic, Lavanttal, Ljutomer, and Sava faults as well as the South Alpine thrust front and the external front of the thrust area of the External Dinarides (Poljak 2007; Celarc and Placer 2016).

The Dinarides are divided into the External and Internal Dinarides and a transitional area between the two. Slovenia only includes the External Dinarides and the transitional area, whereas the Internal Dinarides, which are characterized by deep marine sediments and ophiolites, are located in neighboring Croatia. In terms of sedimentation, the External Dinarides cover the majority of the Dinaric area and a smaller part of the Adriatic area of the Adriatic–Dinaric Mesozoic Carbonate Platform.

Fig. 2.5 Peričnik Falls in the Vrata Valley near Mojstrana cascades over a 52-m Pleistocene conglomerate cliff. (Photo by Sasha Taran, Shutterstock.com)

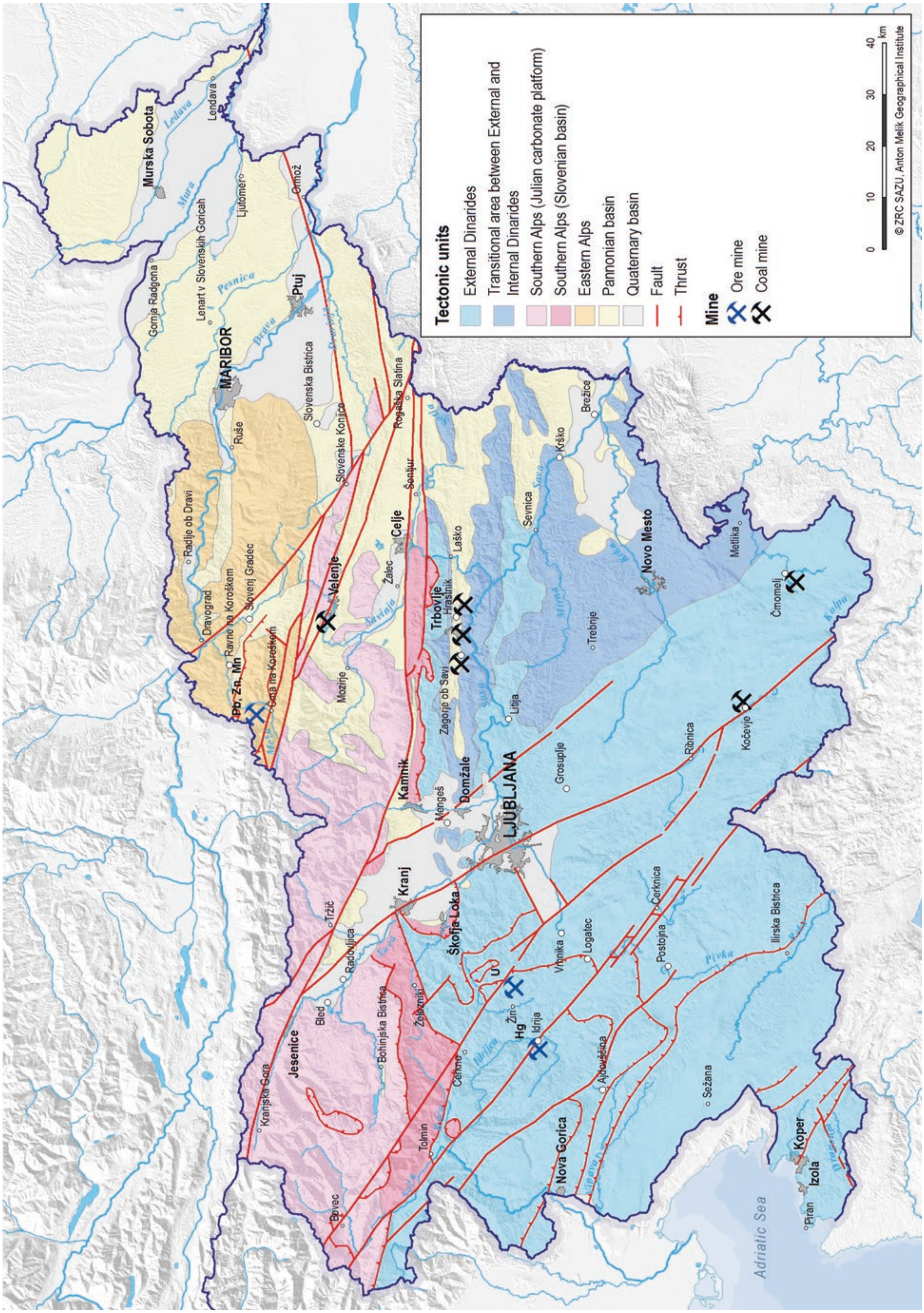

Fig. 2.6 Slovenia's tectonic structure

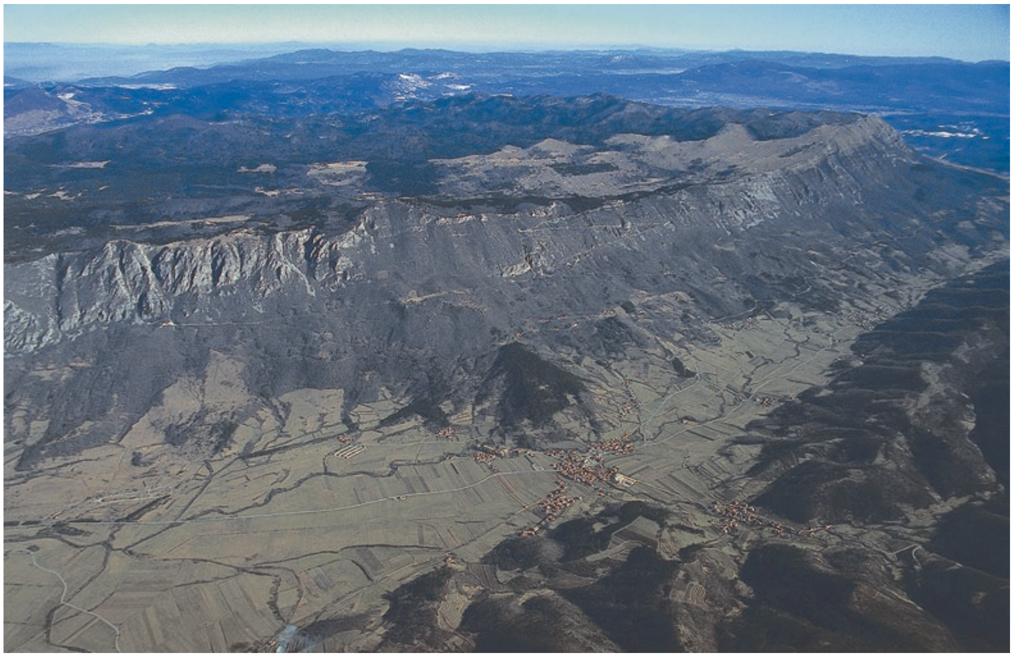

Fig. 2.7 The steep thrust front of Mount Nanos above the flysch Vipava Valley. (Photo by Marjan Garbajs, GIAM ZRC SAZU Archive)

The External Dinarides are characterized by the thrust and nappe structure that formed at the end of the Eocene and the beginning of the Oligocene. It is composed of extensive Mesozoic carbonate rock nappes thrusted one on top of the other. The thrusting proceeded in a northeast–southwest direction, with thrust sheets sliding across the Paleozoic bedrock. They are thrusted onto soft Eocene flysch layers at the front.

Typical examples of thrusting in the area of the External Dinarides include the Trnovo and Hrušica nappes and the Snežnik thrust block (Fig. 2.7; Placer 1999, 2008; Celarc and Placer 2016).

Paleogeographically, the Southern Alps are part of the Dinarides, but they separated during the Miocene. They border the Periadriatic, Lavanttal, and Ljutomer faults in the north and the South Alpine thrust front and the Sava fault in the south. They are composed of the Upper Triassic rocks of the Julian Carbonate Platform and the Mesozoic rocks of the Slovenian Basin. They include the Julian Alps, the Kamnik–Savinja Alps, the western Karawanks, the Paški Kozjak Hills and Mount Boč, the Alpine hills along the Bača and Selška Sora Rivers, and part of the Škofja Loka Hills.

The thrust sheets of the Southern Alps largely formed between the Eocene and Middle Oligocene. Because of the north–south direction of thrusting, the ridges of the mountains and hills predominantly run in a west–east direction (Placer 2008).

The Eastern Alps are composed of the Precambrian and Early Paleozoic metamorphized rocks and the Permian and Mesozoic sedimentary rocks north of the Periadriatic Seam. The Kozjak Mountains, Pohorje Hills, Mount Strojna, and eastern Karawanks with Mount Peca and Mount Uršlja gora form part of the Eastern Alps in Slovenia (Placer 2009).

The Eastern Alps are made of extensive nappes called the Austroalpine nappes. These are pressed and stretched remnants of rocks that were deposited on the edges of the intermediate sea between the Adriatic and Eurasian plates. The nappes formed during the Cretaceous and Tertiary orogeny, and because of their close links to the thrusted Adriatic microplate, they are considered part of this plate. In addition to its nappe structure, another important feature of the Eastern Alps is plutonism, which is divided into Periadriatic tonalite intrusions and Pohorje granodiorite pluton with dacitic sills and dykes. The Periadriatic intrusion, which includes the southern belt of the Eisenkappel magmatic zone, dates back to the Oligocene (c. 32 million years ago), and the Pohorje pluton with dacite dates back to the Miocene (18–19 million years ago). Because of the age difference and a different location, the Pohorje granodiorite is not classified under Periadriatic intrusions (Placer 2008; Fodor et al. 2008).

The Pannonian Basin includes a series of Paleogenic and Neogenic depressions filled with Paratethys Sea sediments. The Paratethys Sea was the sea that stretched between the Pannonian Plain and the Black Sea in parallel with the Tethys Ocean during the Neogene (Placer 2009).

The Pannonian Basin began to form more intensely with the post-collision tectonic escape of the Eastern Alps toward the east during the Early Miocene. Due to the interchanging extensional and compressional conditions, this was a polyphase development. The results of these processes are the numerous subbasins in northeastern Slovenia, which developed from the Mura–Zala Basin and the Styrian Basin. The western edges of the Pannonian Basin also feature isolated basins in the Eastern and Southern Alps and the Dinarides, the most prominent among which are the Smrekovec, Celje, Tunjice–Motnik, Laško, Planina, Senovo, Krško, and Bohinj basins (Jelen et al. 2008; Placer 2008).

Another geotectonic unit in Slovenia's immediate vicinity is the Adriatic–Apulian foreland, which represents the solid core of the Adriatic microplate. It covers the major portion of Istria and is composed of the rocks of the Adriatic–Dinaric Mesozoic Carbonate Platform and the flysch rocks that formed during its degradation. The foreland extends to the border with the External Dinarides, which runs across the northern part of Croatian Istria (Placer 2008).

Slovenian territory is intersected by numerous faults and fault zones, which developed after the collision of the Adriatic and Eurasian plates. The most prominent is the Periadriatic tectonic zone, which runs from west to east and is bordered by the Periadriatic Seam in the north and the Sava Fault in the south. The Šoštanj and Donat faults are the most important faults in the Periadriatic tectonic zone, which is diagonally intersected by the Lavanttal Fault. The Periadriatic Seam east of Zreče runs along the Ljutomer Fault (Placer 1999).

The Mid-Hungarian or Zagreb tectonic zone runs in a wide belt between Krško and Zagreb in a southwest–northeast direction or toward central Hungary. The zone has not been thoroughly studied yet, and so there is no agreement on where individual faults run. More important among them are the Orlica Fault in the northwest of the zone and the Zagreb Seam in the southeast (Placer 1999).

The Idrija tectonic zone includes faults in the External Dinarides running from northwest to southeast. The central place belongs to the Idrija Fault, and other important faults also include the Divača, Raša, Sovodnje, Želimlje, and Stična faults (Placer 1999). The Periadriatic, Mid-Hungarian, and Idrija fault zones make up a triangle in which the Sava folds formed (Placer 1998).

During the Late Pliocene and Early Pleistocene, numerous faults cut Slovenian territory into large blocks. High plateaus, such as Pokljuka and Jelovica, formed on raised blocks, with extensive basins, such as the Ljubljana, Brežice–Krško, and Celje basins, lying in between (Buser et al. 1989).

2.4 Mineral and Energy Raw Materials

Mineral raw materials include minerals and rocks of economic significance. They are divided into metallic and nonmetallic mineral raw materials. Metal raw materials comprise ores, from which metals are extracted, including native elements, sulfides, oxides, hydroxides, carbonates, and silicates. Native elements include mercury and copper, sulfides include cinnabar, galena, sphalerite, and chalcopyrite, and oxides include uraninite, hematite, and magnetite (Drovenik 1993).

In Slovenia, mercury, lead–zinc, uranium, antimony, copper, iron, and manganese ores formed in various geological eras, rocks, and conditions (Drovenik 1993). Here, special mention should be made of the Idrija mercury mine and the Mežica lead and zinc mine.

The Idrija mine is the second-largest mine in the world in terms of the volume of mercury extracted. Ore mining began as early as 1490, and over nearly five centuries, 144,000 tons of mercury were extracted from it; this equaled 13% of the total world production (Cigale 2005). Mineralization was triggered by Middle Triassic magmatic and tectonic activity, which affected Late Paleozoic and Early and Middle Triassic sedimentary rocks. The ore mineral extracted was cinnabar, but native mercury was also mined in the last years of the mine's operation (Fig. 2.8; Drovenik 1993).

The 1.5-km-long and 300- to 600-m-wide ore deposit lies directly below the town of Idrija. The mineralized area is 420 m deep, and the total length of shafts maintained exceeded 150 km. Even though the ore deposit had not been fully exhausted, production was temporarily halted in 1977 and terminated for good in 1986 (Cigale 2005). The abandoned Anthony's Shaft has been converted into a museum.

Lead and zinc deposits in the Upper Mežica Valley between Mount Peca and Mount Uršlja gora were already discovered by the Romans. The first written sources on mining date back to 1665 (Fajmut Štrucl 2005). The Middle Triassic carbonate rocks mineralized with galena and sphalerite contain approximately 5% lead and zinc. The ore minerals formed during sedimentation and later processes taking place within the sediments. Galena has no accessory components, and therefore extremely pure lead was produced by the smelting plant at Žerjav. In contrast, sphalerite contains some cadmium and germanium. In Mežica, a molybdenum concentrate containing up to 23% molybdenum was also extracted from wulfenite (Drovenik 1993).

The processing industry developed in parallel with the Mežica mine. In the second half of the nineteenth century, zinc ore was mined alongside lead ore. Zinc concentrate was extracted from the zinc ore and sold to the Celje zinc plant and abroad. Toward the end of the twentieth century, the use of lead declined, and the mine was closed, also because of environmental problems (Fajmut Štrucl 2005). Part of the mine's shafts are now open to visitors.

In the past, mercury ore was also mined in Podljubelj north of Tržič, lead ore was extracted in Litija and elsewhere in the Sava Hills, antimony ore was mined at Trojane, and copper ore was extracted on Škofje Hill above Cerkno. An iron ore called siderite was extracted in the area between Jesenice and Tržič, and near Vitanje, and crusty limonite ore and iron pisolites were extracted on the surface on the

Fig. 2.8 Reddish cinnabar ore was mined for five centuries in Idrija. (Photo: Rudnik živega srebra Idrija, GIAM ZRC SAZU Archive)

Pokljuka and Jelovica plateaus in the Julian Alps. Of economic relevance was also the manganese ore mined at Mount Begunjščica northwest of Tržič (Drovenik 1993).

Economic exploitation of nonmetallic mineral raw sources is also important in some places. The most important raw materials of this type include quartz sand, chert, calcite, clays for the ceramics and brick industry, cement raw materials, and natural, decorative, and technical stone (Pirc and Herlec 2009).

In Slovenia, extracting energy raw materials, such as coal, hydrocarbons, and nuclear raw materials, is primarily intended for fulfilling domestic needs. Coal has a low calorific value because Slovenia barely has any real hard coal. Brown coal and lignite are more common and important. The brown coal at Trbovlje, Hrastnik, and Zagorje ob Savi formed during the Oligocene, whereas the brown coal in Kočevje and Kanižarica and the lignite in Velenje date back to the Miocene and Pliocene (Pleničar 2004; Bajželj 2005).

Many coal mines were closed after 1970. Slovenia now has only one left (in Velenje), and so it needs to import its coal, which is a vital energy raw material. The country generates approximately one-third of its electricity from the coal-fired power plant in Šoštanj (Bajželj 2005).

Oil and natural gas were discovered in 1943 near Lendava. Immediately after the Second World War, hydrocarbons began to be extracted at the Petišovci oil and gas field and the Dolina gas field. Production is currently very low (Pirc and Herlec 2009).

The Middle Permian Gröden layers at Žirovski Vrh near Žiri contain uranium ore. Both ore minerals (uraninite and coffinite) are dispersed in a cement of gray quartz sandstone, and the ore-bearing zone is up to 200 m thick. Ore began to be extracted in 1982, but the production of uranium oxide was not economical and therefore halted as early as 1990 (Drovenik 1993). Uranium ore deposits around Žirovski Vrh are estimated at 25,000 tons, more than 15,000 of which could be extracted. These ore deposits are sufficient to fuel one nuclear power plant for more than 20 years (Viler 2005).

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