REGIONE AUTONOMA
FRIULI VENEZIA GIULIA

OBČINA
SEŽANA

KRAS
CARSO
GEOPARK

THE CLASSICAL KARST GEOPARK

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Interreg
ITALIA-SLOVENIJA
UNIONE EUROPEA
EVROPSKA UNIJA
GeoKarst
Progetto standard co-finanziato dal Fondo europeo di sviluppo regionale
Standardni projekt sofinancira Evropski sklad za regionalni razvoj

PUBLISHED BY: Geological Survey - Central Directorate for Environmental Protection, Energy and Sustainable Development of the Autonomous Region of Friuli Venezia Giulia (RAFVG)
in collaboration with the Municipality of Sežana (Slovenia)
For the publisher: Fabrizio Fattor, Director of the Geological Survey RAFVG

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TRANSLATION (in alphabetical order):
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Paul Tout

DESIGN, DIGITAL LAYOUT AND PRINTED BY:
Mosetti Tecniche Grafiche Srl, Trieste, Italia

PRINT RUN:
500 copies

PLACE AND DATE:
Trieste, October 2022
The book is also available in digital format at: **www.karst-geopark.eu**.

The publication of the book was co-financed within the framework of the Slovenia-Italy Cross-border Cooperation Programme 2014-2020 by the European Regional Development Fund and by national funds.
The content of the Italian part was financed with resources from the Geological Service of the Autonomous Region of Friuli Venezia Giulia.

ACKNOWLEDGEMENTS:
The working group that has edited this publication is indebted to many people and in particular to the many researchers who directly and indirectly, with their advice and more generally with their ideas, also sedimented in the numerous scientific researchers over the years, have provided the connection for the concepts set out in this publication. It is impossible to mention the large scientific community and collaborators, whose contributions have made this work possible and to whom we are deeply grateful.

REGIONE AUTONOMA FRIULI VENEZIA GIULIA
Regione Autonoma Friuli Venezia Giulia
www.regione.fvg.it

www.ita-slo.eu/geokarst
Interreg GeoKarst Project Partners:
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Občina Sežana	Javni zavod Park Škocjanske jame	Regione Veneto
www.sezana.si	www.park-skocjanske-jame.si	www.regione.veneto.it

Cover photos: Roberto Valenti *(Forest Service and Forestry Corp RAFVG)*, Mario Saccomano - Shutterstock

Cover design: Fiorella Bieker *(Geological Survey RAFVG)* & Mosetti Tecniche Grafiche Srl

ISBN: 978-88-940394-4-3

To cite, please write:
Bensi S., Novak M., Otoničar B., Calligaris C., Cucchi F., Zini L., Bonini L., Barone V., Škrjanec S., Piano C. Eds (2022): The Classical Karst geopark, Ed. by Geological Survey - Central Directorate for Environmental Protection, Energy and Sustainable Development of the Autonomous Region of Friuli Venezia Giulia, 2022, Trieste

Foreword

This special book, entitled „The Classical Karst geopark“, bears witness to a successful cross-border cooperation that will lead to the creation of a cross-border geopark in the Karst region.

The publication is one of the results of the GeoKarst project, co-funded within the framework of the Interreg V-A Italy-Slovenia Cooperation Programme 2014-2020, while the contents produced by the Italian partners were financed by the Geological Survey of the Central Directorate for Environmental Protection, Energy and Sustainable Development of the Autonomous Region of Friuli Venezia Giulia (RAFVG).

The idea of a cross-border geopark originated during the definition of the proposal of the strategic project KRAS-CARSO (Cross-border Cooperation Programme Slovenia-Italy 2007-2013) and proved to be most appropriate during its implementation. In fact, the feasibility Study on the creation of the geopark showed in technical, economic-managerial and participatory terms that the integration of the Karst area could be achieved through the creation of a cross-border geopark as a development tool for the sustainable use of resources and the well-being of the people living on the Karst Plateau. In 2015 and 2017, the 5 Slovenian and 12 Italian municipalities, which comprise the area concerned, decided to create a cross-border geopark, so that, since 2018, the Geological Survey of RAFVG (coordinator for the Italian part of the geopark) and the Municipality of Sežana (coordinator for the Slovenian part) have been intensively collaborating on the creation and management of the cross-border Karst geopark.

The book describes all the main features of the Karst, which, as the “cradle” of karst studies, is of global significance from a cultural-historical and scientific point of view. In the book you will note the frequent use of bilingual place-names and toponyms, this reflects the rich history of the area, which stands at the intersection of various cultures. Nowadays, the inhabitants of the Karst are mainly Slovenians and Italians. Slovenian language and culture in the Italian part of the Karst is covered by a law protecting the linguistic minority.

Our sincere thanks go to all the contributors who have made this book possible.

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INTRODUCTION

Figure 1.1.1: The Karst in spring time, a view from the inside towards the Adriatic (Photo: Sara Bensi)

1.1 Geoparks and the UNESCO Global Geoparks Network

A geopark is a geographic area with well-defined boundaries and recognized geological importance, in terms of scientific significance, rarity, aesthetic or educational value of the sites of interest contained therein. In a geopark, the primary purposes - that is, the protection and enhancement of geodiversity - are combined with education and sustainable development objectives that particularly involve local communities. A geopark uses its geological heritage, in connection with all other aspects of the area's natural and cultural heritage, to enhance awareness and understanding of the key issues facing society, such as using the Earth's resources sustainably, mitigating the effects of climate change and reducing natural hazard-related risks. By raising awareness of the importance of the area's geological heritage in history and society today, Geoparks give local people a sense of pride in their region and strengthen their identification with the area.

The concept of Geoparks developed around the mid-1990s and is now promoted on an international scale by UNESCO. In the year 2000 the European Geoparks Network (EGN) was formed, which was later (2004) merged into the broader Global Geoparks Network (GGN).

The European Charter of Geoparks, which each EGN member is called on to accept and sign, provides for the development and experimentation of:

- methods of **conservation** of the geological heritage;
- partnerships with local companies to promote and support the creation and **marketing of new products** linked to the area's geological heritage;
- activities to promote **geotourism** and holistic economic development;

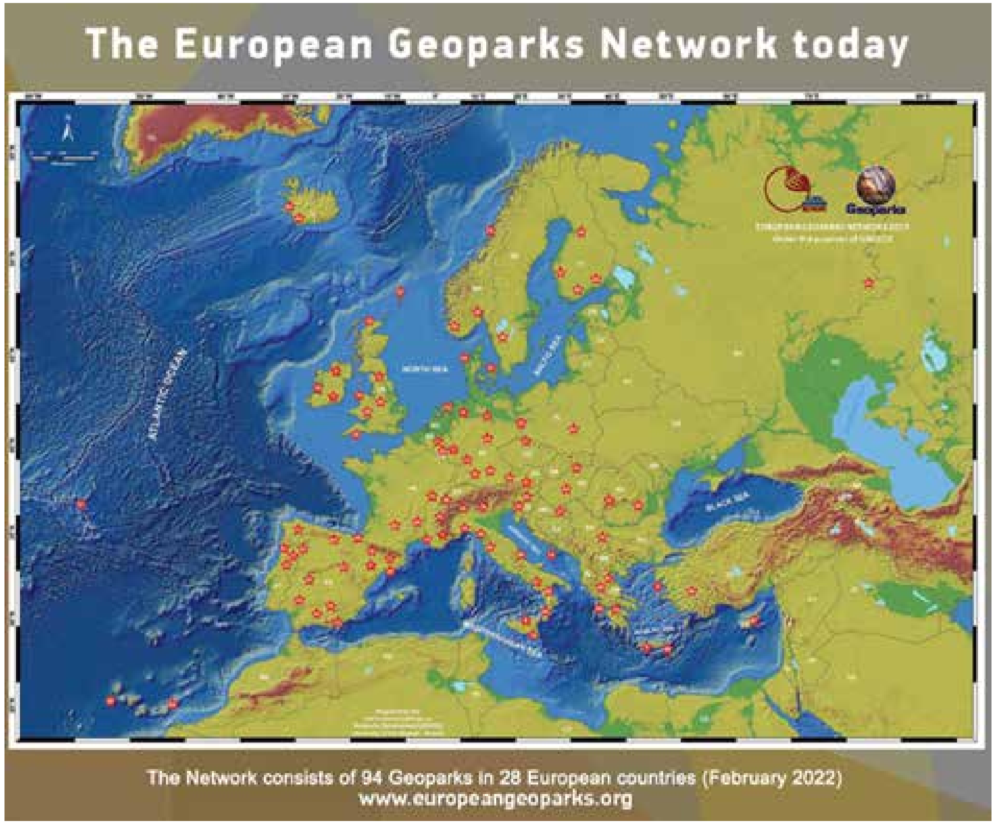


Figure 1.1.2: Map of the European Geoparks Network and, on the right side, the list of Italian and Slovenian Geoparks, including the location of the Classical Karst (from site: www.europeangeoparks.org)

- activities to promote **environmental education and scientific research** in the disciplines of Earth Sciences.

By 2022 there were 177 UNESCO Global Geoparks, distributed in 46 countries over four continents.

Italy and Slovenia are well represented on the international scene with 14 Geoparks recognized in the European Network and in the Global Geoparks Network under the auspices of UNESCO, and in the whole of Europe only 4 of which fall into the category of cross-border geoparks. Kras-Carso-Karst is also a cross-border area of unique geological and geomorphological characteristics of international importance, which has made it a “cradle” of the science of “Karstology” from a cultural-historical and scientific point of view and has been named the “Classical Karst”.

Figure 1.2.1: The underground watercourse of the river Reka/Timavo River at the bottom of Abisso di Trebiciano - Labodnica Cave was reached at 326 metres below the surface in 1841 (Antonio Federico Lindner 1841)

1.2 Why a geopark on the Classical Karst?

Each geopark demonstrates geological heritage of international significance and promotes its significant geological processes, features, periods of time, historical themes linked to geology, or outstanding geological beauty.

The main geological highlights of the Classical Karst geopark are:

- Karst geomorphology, characterized by all kinds of superficial and underground karst phenomena and by a particular hydrogeological network, through which the Classical Karst contributed to the emergence and development of karstology, speleology and speleobiology as scientific disciplines in the 19th century. As a matter of fact, modern speleology (systematic cave exploration and mapping) originated in this area, starting with the search for a water supply for Trieste. In 1841 the underground watercourse of the Reka/Timavo River at the bottom of the Grotta di Trebiciano-Labodnica Cave was reached at 326 metres below the surface (Figure 1.2.1). Due to the distinctive relief forms, local terms for karst phenomena, such as the words “*Kras*”, “*Carso*” and “*Karst*” themselves, while *dolina*, and *polje* have entered the international scientific terminology.

- The geological evolution of the geopark is best reflected in the karst caves formed in the Reka/Timavo hydrogeological system. The Škocjan Caves, an outstanding karst system with one of the largest known underground canyons in the world, formed here. Textbook examples of sinkholes, natural bridges, gorges, potholes, collapse dolines, abysses, an underground canyon, springs, and passages covered with flowstone deposits lend this small area worldwide significance in the study of karst features and processes. Due to their natural and cultural importance, Škocjan Caves have been on the UNESCO World Heritage List since 1986 (Figure 1.2.2). Comparable in their outstanding appearance and size is the Grotta Gigante-Briška jama Cave with the largest hall in a touristic cave in the world.

- The sedimentary succession, covering a timespan of nearly 100 million years from the beginning of the Cretaceous period, about 140 million years ago (mya), to the middle of Eocene period about 45 mya. It records the changing geological environments on a shallow-marine carbonate platform, influenced by the climate changes, eustatic sea-level changes, and global and local tectonic movements.
- One of the most complete and best preserved dinosaurs in the world, found at the Villaggio del Pescatore/Ribiško naselje and other exceptionally well-preserved fossil vertebrates are found in the platy limestones in the areas of Komen and Tomaj, along with very rich and diverse fossil inventory of several faunal and floral elements.
- The Cretaceous-Paleogene (Mesozoic-Cenozoic) mass-extinction event, one of the most devastating mass-extinctions that occurred on the planet, is recorded in different profiles in the area.
- The Karst cultural landscape, strongly characterized by its rocky surface and the use of stone as construction material. The art of dry stone walling, knowledge and techniques was listed by UNESCO in 2018 as intangible Cultural Heritage of Humanity.

The significant presence of geo-related resources of the Classical Karst is complemented by:

- about 80 geosites, many of which are recognized for their international importance and are visited and enjoyed by hundreds of thousands of visitors per year.
- the exceptional biodiversity of plant and animal species and the large number of rare and endemic species, places the Karst among the areas with the highest biodiversity in Europe. It is important for the conservation of habitats of endangered plant and animal species in Europe. The area also has great scientific and research significance for the study of cave flora and fauna.
- a significant natural heritage is also evidenced by 67% of the territory falling within the Natura 2000 network; with two Biosphere Reserves under UNESCO with the intergovernmental programme MaB – Man and Biosphere, namely the Škocjan Caves Park and the Marine Protected Area of Miramare.
- the cultural heritage, characterized by numerous archeological sites in the area; by the fortifications and defence infrastructure of the First World War, which in this area recorded one of the bloodiest pages in history, and by the typical local agri-food resources, from wines to oil, from cheeses to ham, strongly connected with the characteristics of the soil and geology.

Figure 1.2.2: Škocjan Caves, on the UNESCO World Heritage List since 1986 (Photo: Borut Lozej - Photo archives Škocjan Caves Park)

CHARACTERISTICS OF THE KARST

2.1 What is karst?

"Karst phenomena" or more simply "karst" is the morphological expression covering all the processes of rock removal in which the dominant process is the chemical attack on carbonate rocks, with mechanisms which go under the name of karst corrosion or dissolution. Dissolution occurs where water is present in liquid form and therefore in temperate, subtropical and tropical climates. In areas with low rainfall precipitation, or where snow and ice predominate, the karst process is less effective than mechanical processes such as river erosion, glacial abrasion, etc.

In reality, we have to remember that all rocks are soluble in water, but only some lead, in certain morpho-climatic conditions, to the development of the typical karst forms. These rocks are, in order of importance, carbonates, composed of calcite, dolomite, etc., evaporitic rocks, composed of rock salt, gypsum, anhydrite, etc., and the quartzites composed of various forms of quartz.

Limestones and dolomites represent about a quarter of land, are widespread on all continents and are all more or less karstified.

On the surface, karst takes many forms, making it difficult for the average person to recognize. Some, however, are dramatic and scenic. Much of the karst landscape is also hidden below ground in caves. In most karst areas, there is usually no surface water, because most karst waters flow underground. All precipitation quickly infiltrates below the surface through open fissures and crevices. Even relatively large rivers may disappear into ponors in karst landscapes and their waters flow deep underground through known caves as well as through unknown channels and fissures. The karst surface is commonly rocky, without thick soil cover and therefore unsuitable for cultivation. Thus, karst areas have never been densely populated.

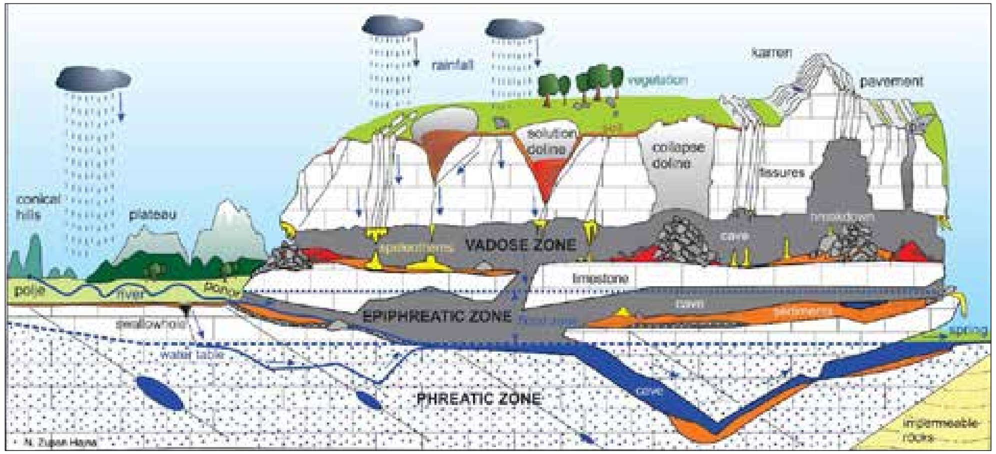


Figure 2.1.2: Conceptual model of the water flow in a karst aquifer with the main surface and underground geomorphological features (from N. Zupan Hajna, 2021)

The toponym "karst" originates from the Paleo-Indo-European word Kar (also Karra) which means rock or stone.

From a scientific point of view, karst is defined as a landscape with characteristic reliefs, caves and groundwater drainage, formed by dissolution processes (Figure: 2.1.2). The term originally referred to the limestone area northeast of the Gulf of Trieste in Slovenia and Italy, named *Carusadus* or *Carsus* in Latin and modified in various languages into *Karst* (German), *Carso* (Italian), and *Kras* (Slovenian). This term was later applied to all areas with similar characteristics. In Slovenian, *kras* means a rocky, bare and dry landscape. The name is often used as a toponym for this type of landscape in the northwestern Dinaric karst of Slovenia and Croatia.

Figure 2.1.1: The Orleška Draga Doline and Mt. Nanos in the background (Photo: Roberto Valenti)

2.1.1 Karst rocks

Dissolution of soluble rock is the most important karst process. Thus, the development of karst landforms is mainly limited to areas where carbonates (e.g., limestone (Figure 2.1.3A), dolomite, chalk, clastic carbonate rocks (conglomerate, breccia), marble, and carbonatite) or evaporites (e.g., gypsum, anhydrite, and salt (Figure 2.1.3C) occur. Of these, limestones and dolomites are the most common. The majority of carbonate as well as evaporite deposits are derived from tropical and subtropical areas where they were deposited on shallow marine carbonate platforms and coral reefs, similar to those found nowadays in the Bahamas (Figure 2.1.4), the coasts of Persian Gulf and Great Barrier Reef of Australia. Later these areas with carbonate platforms were transported from their original position to recent one by plate tectonic processes.

Important properties of carbonate rocks for the formation of karst include porosity, their mineralogical composition, structural and textural characteristics, the degree of impurities and the thickness of the bed in which they occur. Furthermore, the geotectonic regime of certain karstic regions and the geological structures - such as bedding plane partings, fissures, and faults - also play an important role in the formation of karst features and landscapes. Water percolates through open spaces (fissures, fractures, faults, bedding planes,...) in carbonate rocks and simultaneously enlarges them through corrosion processes. The purer the carbonate rock, the less insoluble residues it contains. Dolomite dissolves more slowly than limestone and is more prone to mechanical disintegration.

Figure 2.1.4: Underwater carbonate sand dunes, locally exposed on the land surface (W of Eleuthera Island, Great Bahama Bank, Bahamas (Photo: Bojan Otoničar)

Figure 2.1.3: Karst rocks; A) Upper Triassic bedded limestone of Dachstein Formation (Kanin Plateau, Julian Alps, Slovenia) (Photo: Bojan Otoničar), B) Cretaceous limestone breccia/ conglomerate (Učja Valley, W Slovenia) (Photo: Bojan Otoničar), C) Paleozoic salt (Queshm Island, Iran) (Photo: Bojan Otoničar)

2.1.2 *Dissolution of carbonate rocks*

The intensity of limestone dissolution is influenced above all by the quantity of precipitation and the partial pressure of the available CO_2, both dependent on climate, and the properties of the rock. In general, the more water and CO_2 to form carbonic acid that are available, the faster the rock dissolves. Water causes dissolution according to its chemical composition and mechanical properties, i.e., the quantity and nature of water flow and the characteristics of its contact with the rock. Karstification of carbonate sediments/rocks begins as soon they are exposed to freshwater or a mixture of fresh and salt water. In principle, limestone and dolomite karstification involve the dissolution of the minerals calcite and dolomite, while impurities remain as an insoluble residue. Rainwater enriched with CO_2 from the atmosphere and soil forms a weak carbonic acid. When percolating through carbonate rocks, this weak carbonic acid dissolves them, forming calcium and hydrogen carbonate ions. When the water enriched with the dissolved ions reaches an open cave environment, the difference in CO_2 partial pressure in the cave results in the degassing (bubbling) of the solution, which causes the precipitation of calcite in various forms of calcite deposit, i.e., different forms of flowstone.

Denudation (the uniform lowering of the land surface) of a karst surface indicates the removal of carbonate material from the surface in ionic form. Values are based above all on climate (quantity of precipitation, temperature), evapotranspiration, CO_2 partial pressure and the composition of the rock (minerals, texture, structure, impurities, etc.). According to field data in a temperate climate, the denudation rate of the karst surface is about 20 - 60 metres per million years.

2.2 Surficial and underground karst forms with karst terminology

Surface karst phenomena are formed by dissolution with rainwater (e.g., karren, dolines), by karst groundwaters (e.g., bottoms of poljes, levelled surfaces) and by transferring karst underground features on the surface (e.g., collapse dolines, unroofed caves). Natural cave entrances are part of the karst surface which lead to the underground. These include shafts, ponors, swallowholes, springs and openings in the floors of collapse dolines, as well as openings formed by the erosional intersection of caves and the karst surface. Caves exhibit different patterns depending on the local geology (rock composition and structures such as fissures, faults, bedding planes), location (latitude, elevation), groundwater characteristics (allogenic vs. autogenic…), the dominant mechanism of dissolution (prevailing acid, mixing corrosion, cooling of ascending water etc.), landscape evolution (different geotectonic realms), and climate (temperate, tropical…).

2.2.1 *Karst surface relief features*

The formation of karst features depends on the quantity of precipitation, the type of the host rock, the presence of soil and vegetation and the slope or inclination. Suitable conditions result in the formation of both small-scale dissolution features (e.g., flutes, meanders, solution pans, grikes in limestone pavements, etc.) and medium- and large-scale karst features (e.g., dolines, conical peaks, poljes, etc.).

2.2.1.1 Small-scale dissolution features

Small-scale karst features form on the surface of the rocks due to corrosion by water (precipitation) at the contact point with the rock surface (Figure 2.2.1). Their formation depends on the quantity of precipitation, the nature of the flow and the contact between the water and the surface of the rock.

Figure 2.2.1: Small-scale surface dissolution rock features (Photo: archive of IZRK ZRC SAZU): A) rain (solution) flutes (Classical Karst), B) solution grooves (Kanin, W Slovenia), C) solution pans (kamenitzas) (Classical Karst), D) corrosion grikes (Classical Karst)

Small corrosion features of various sizes form on the surface of the limestone, which makes the surface of the rocks uneven and rough (Figure 2.2.1A, B). Solution pans (kamenitzas) (Figure 2.2.1C) are formed on the flat surface of the bare rock, while grooves and larger gutters (Figure 2.2.1A, B) develop along the dip of the slope. If the grooves were formed under the soil that was subsequently removed - and in some places also moss - they are more or less rounded. When joints or other areas of lower resistance are enlarged by corrosion, grikes form (Figure 2.2.1D), which separate the rock into blocks of a range of sizes. Blocks are larger if the rock is thick-bedded or massive. Areas of chaotically dissected smaller stones or screes are also common especially on thin-bedded limestone (griže).

These small scale features are linked either to the active dissolution of the water flowing on slopes of variable steepness (dynamic solubility) or to the static dissolution by standing water in the depressions (static solubility). The former can be further divided into those set along lines of maximum slope and into those set along the discontinuity planes of the rock mass.

We can thus recognize:

- Solution flutes (Figure 2.2.1A)
  Minute forms represented by short straight furrows (about 1 cm deep, 1-4 cm wide, 5-50 cm long) with a rounded section. They are often grouped in complexes (comb, feather, bundle, island) and are separated by sharp ridges that act as a watershed. Their genesis can be traced back to rainwater corrosion due to dynamic solubility along lines of maximum slope.
- Solution grooves (Figure 2.2.1B)
  These are furrows (more than 5 cm wide, more than 3 cm deep, at least 100 cm long) that follow the maximum slope of the limestone surface. They have a varied morphology: the section is always in the form of a U and the development is usually straight but also tortuous or meandering, the latter more frequent on slightly inclined surfaces. The bottom is smooth, often hollowed out by a secondary groove (minimum percolation flow). These are “gutters”, the genesis of which is linked to the concentrated linear flow of runoff waters, so the morphology depends on the inclination of the flow surface, the presence of plant organisms, the type of climate. They are the classic effect of what is called accelerated corrosion.
- Solution pans or kamenitzas (Figure 2.2.1C)
  Small closed basins (depth from 2 to 50 cm, width from 5 to 200 cm), rounded, of variable diameter, shallow compared to the area covered. The floor is usually almost horizontal, the section is flat or bowl-like, widened towards the bottom. Often, they have an outlet. Their genesis is linked to the standing of water in a micro-depression, sometimes originating or favoured by phytokarst, that is to say the erosion of karst rocks by filamentous algae that burrow into them. They widen faster than they deepen as corrosion is more

active at the edges than at the bottom. At the base of the walls, protruding niches are often created, almost “corrosion grooves”, during the phases of progressive emptying of the solution pan due to the progressive deepening of the discharge groove.

- Grikes (Figure 2.2.1D)
  Deep openings, rarely linked to the anastomoses between holes, more often than the true preferential water outflows driven by fracturing. The sides are always very steep, the bottom is flat or V shaped and poorly opened. From the perspective of their genesis, they are similar to karst furrows, although, while in the furrows it is the maximum slope that guides the water flow, in grikes it is the discontinuities (normally those of fractures) which condition the direction of movement.
- Griže (‘*grih-zhe*’)
  Stony ground created by little rocky blocks isolated by karst along the discontinuity surfaces (stratification and fracturing) from the rocky substrate and developing in place, without transport.
- Limestone pavements
  Rocky outcrops in which there are several dissolutive morphotypes in association such as solution flutes, solution grooves, grikes, solution pans, solution runnels, etc.
- Limestone towers
  Isolated residual blocks (5-10 m in height), bearing witness to the ancient surfaces.

2.2.1.2 Medium-scale karst features

The doline is the most characteristic karst landform of middle latitudes (Figure 2.2.2). Those up to ten metres deep and as much as 50 metres wide prevail. These are closed funnel -or bowl-shaped depressions in karst landscape, the width of which is usually greater than its depth. Usually, their slopes are of a similar rockiness as the surrounding karst landscape with sediment or soil cover up to a few metres thick at the bottom. This same landform can be the outcome of a range of processes, such as dissolution, collapse, the washout of fine-grained sediments and the subsidence of strata above more soluble rocks. This said, many dolines are inherited forms of primary caves and shafts. The most common are solution dolines in which the water in them dissolves the rock from the surface and carries it underground in solution. These form at places where water percolates vertically into the depths and effectively dissolves the rock, mainly as a result of the presence of soil and biological activity. The density of dolines on the karst surface depends on the rock type (they are less frequent on dolomites and very numerous on pure bedded limestones), the inclination of slopes (dolines are not found on steep slopes) and the frequency of fractures. Dolines on limestones are rockier than those on dolomites and have less soil on their flanks. Soil typically accumulates at the bottom of dolines, where fields and vegetable gardens are often located.

Figure 2.2.2: Artificially transformed (levelled) doline for agricultural purposes (Bela Krajina, S Slovenia) (Photo: Bojan Otoničar)

Much bigger than regular dolines are collapse dolines (Figure 2.2.3). These are large karst depressions with steep or even vertical slopes, formed by the collapse of the ceiling of major caves. The presence of these morphotypes is mainly linked to the presence of groundwater flows which, as a result of erosion and dissolution, have removed the collapsed material. Collapse dolines do not usually form suddenly, but rather slowly, by the long-term falling of rock from the cave ceiling until a hole opens at the surface. The bottoms of collapse dolines are usually covered with the fallen rocks, which can block the cave entrances. However, through some collapse dolines underlying caves can be reached. During wet periods, when the underground water level is high, lower parts of collapse dolines can be flooded. Larger collapse dolines are between 50 and 200 metres deep and up to a few hundred metres wide. Their volume can reach millions of cubic metres.

Another typical karst relief form is the uvala, i.e., a larger elongated shallow depression with a U-shaped bottom and a higher perimeter. Uvalas are also common with dolomite as the host rock. They may form by the coalescing of several dolines which have enlarged towards one other. They may also have dolines on their floors, as well as a somewhat larger amount of sediment and thicker soil cover.

As was shown above, the surface of limestone karst is commonly rocky and rugged and therefore relatively impassable, the soil cover is thin or accumulates at the bottom of depressions. The surface of dolomite karst is formed through the reciprocal action of denudation processes and fluvio-erosional geomorphic processes. Thus, the surface of dolomite karst is usually smoother and less rocky (Figure 2.2.4), and traces of surface water flow may be visible. There, dells (*dolci*), typical inclined, elongated karst depressions, rather similar to dolines, are commonly found. On dolomite karst, there is more soil than in limestone karst areas and the landscape is therefore more suitable for settlements and cultivation.

Figure 2.2.3: Osp, collapse doline at the Karst edge (SW Slovenia). At high water the stream springs from a cave under the cliff (Photo: Matej Blatnik)

Figure 2.2.4: Slightly undulating surface on dolostone between Gorenje and Bukovje near Postojna (SW Slovenia) (Photo: Bojan Otoničar)

2.2.1.3 Large-scale karst features

A *polje* (Figure 2.2.5) is the largest type of karst depression with a levelled rocky floor, overlain with a thin cover of sediment and a typical karst drainage system. These can be several dozen kilometres long and wide. Usually it has an elongate perimeter and a sinking stream with springs on one side of the polje and ponors on the other. Most poljes are formed along regional tectonic structures and are widened by lateral dissolution of the base of the surrounding slopes. A fluctuating water level flattens the polje's floor by corro-

Figure 2.2.5: Cerknica karst polje, an intermittent lake, with Javorniki and Snežnik Mts. in the background (SW Slovenia. (Photo: Bojan Otoničar)

sion. Oscillation of the water table causes hydrological phenomena such as springs, ponors, estavelles and floods. When the ponors are no longer able to drain away the additional water carried by the sinking stream, intermittent karst lakes occur. In dry periods poljes are dry and the water level is below the surface.

Figure 2.2.6: -Doberdò-Doberdob Lake during low flow (Photo: Philippe Turpaud)

2.2.1.4 Morphological forms of contact karst

The area, where surface water flows from the river relief to the karst, is called a contact karst. Due to the large amount of water that flows into the typical karst marginal depressions, sinkholes, ponors, floodplains and sinks are formed at the contact with the surface river network developed between impermeable rocks and karst. However, typical relief forms of such contact karst are blind valleys. Due to large amounts of water, the dissolution of limestone in such places is faster than in those karst areas where only rainwater dissolves carbonate rocks.Their bottoms are leveled by the oscillation of groundwater and are usually covered by allogenic sediments brought by sinking rivers. As the conduits of the sinking rivers are formed by

average water flows, these cannot drain the increased inflow during heavy rains, and so floods are frequent here.

As a “non-karstic” element in the karst, dry valleys (Figure 2.2.7) can be considered to a certain extent. These are former river valleys that in the past crossed a given karst area. Old riverbeds, for at least part of the year, have no active watercourse for all or part of their length because the water is lost in the karst or is at a much lower level. The bottoms of the dry valleys are usually more or less karstified, so that dolines and other surface karst phenomena occur there.

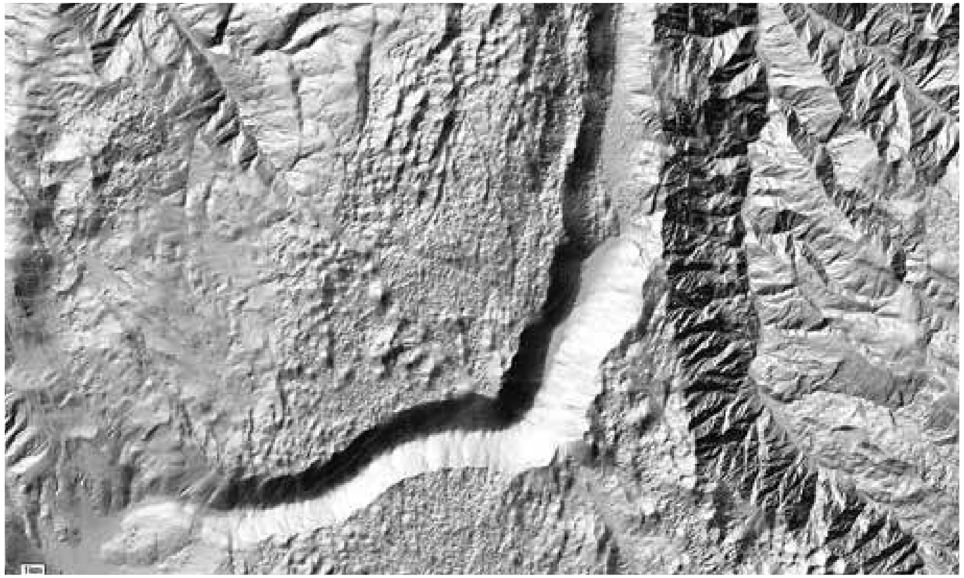


Figure 2.2.7: Lidar DMR (Slovenian Environment Agency) of an almost 500 m deep incised dry valley, the Čepovanski Dol which crosses the high karst plateau of Banjščice (W Slovenia)

2.2.1.5 Karst plain

Karst plains (Figure 2.2.8) represent levelled surfaces, formed by erosion and corrosion. The complex processes that produce corrosion plains in karst have been termed "lateral solution planation" or "corrosion levelling" and involve a combination of vertical dissolution, lateral undercutting of slopes, and springhead sapping. Larger karst planes may cut and level different geological structures.

2.2.1.6 Coastal karst

Coastal karst develops where rocks that are above sea level are in contact with rocks that are generally below sea level. In these environmental conditions, all the karst features are enhanced by marine aerosols, microbial effects and wave motion, which accelerate all karst dissolution and erosion processes. The mixture of sea water and fresh groundwater also promotes the genesis and development of caves and springs.

Figure 2.2.8: View from Trstelj Mt. on slightly dipped, levelled Classical Karst Plateau surrounded by hilly areas (Photo: Bojan Otoničar)

2.2.1.7 Fluviokarst

A karst landscape where the dominant landforms are valleys cut by surface rivers. Erosion prevails over the dissolution processes.

2.2.2 Caves

The most characteristic karst phenomena, without which there is no "real" karst, are karst caves. By anthropogenic definition, caves are underground cavities large enough for humans to enter. They can be vertical or horizontal and filled with water. Caves consist of a series of interconnected passages (galleries, channels...) of various types, such as tubes, canyons, keyholes, fissures, and meanders. Caves can also widen into large cavities and chambers.

Karst caves are formed as a result of the dissolution of rocks along the route of subsurface water flow in various environments. The geological structures and lithological composition of carbonate rocks have a decisive influence on the formation and development of caves. The water in the rock mass follows the geological discontinuities (bedding plane partings, fractures, faults...) and the most soluble porous layers and, in the case of a karst aquifer, chemically and mechanically erodes carbonate rock on its way, forming channels, i.e., karst caves.

The characteristics of cave conduits, from which we can infer their origin, are mainly due to the hydraulic conditions in which they were formed. In the hydrological sense, caves are conduits in a karst massif in which a turbulent water flow is established as a result of dissolution. The water, pushed initially through hairline fractures by constant pressure, dissolves their walls. The flow thus increases and the fracture widens further, since the chemically aggressive water penetrates ever deeper. The continuation of this process leads, via the accelerated growth of the fracture, to a breakthrough point in which the rate of flow increases by several orders of magnitude in a very brief period. Cave channels can be formed in a constantly flooded (i.e., phreatic) zone, where they are created with a slow pressure flow below the karst water level. This is where most cave channels primarily form, while subsequently growing and transforming under a range of conditions, in occasionally flooded (i.e., epiphreatic)

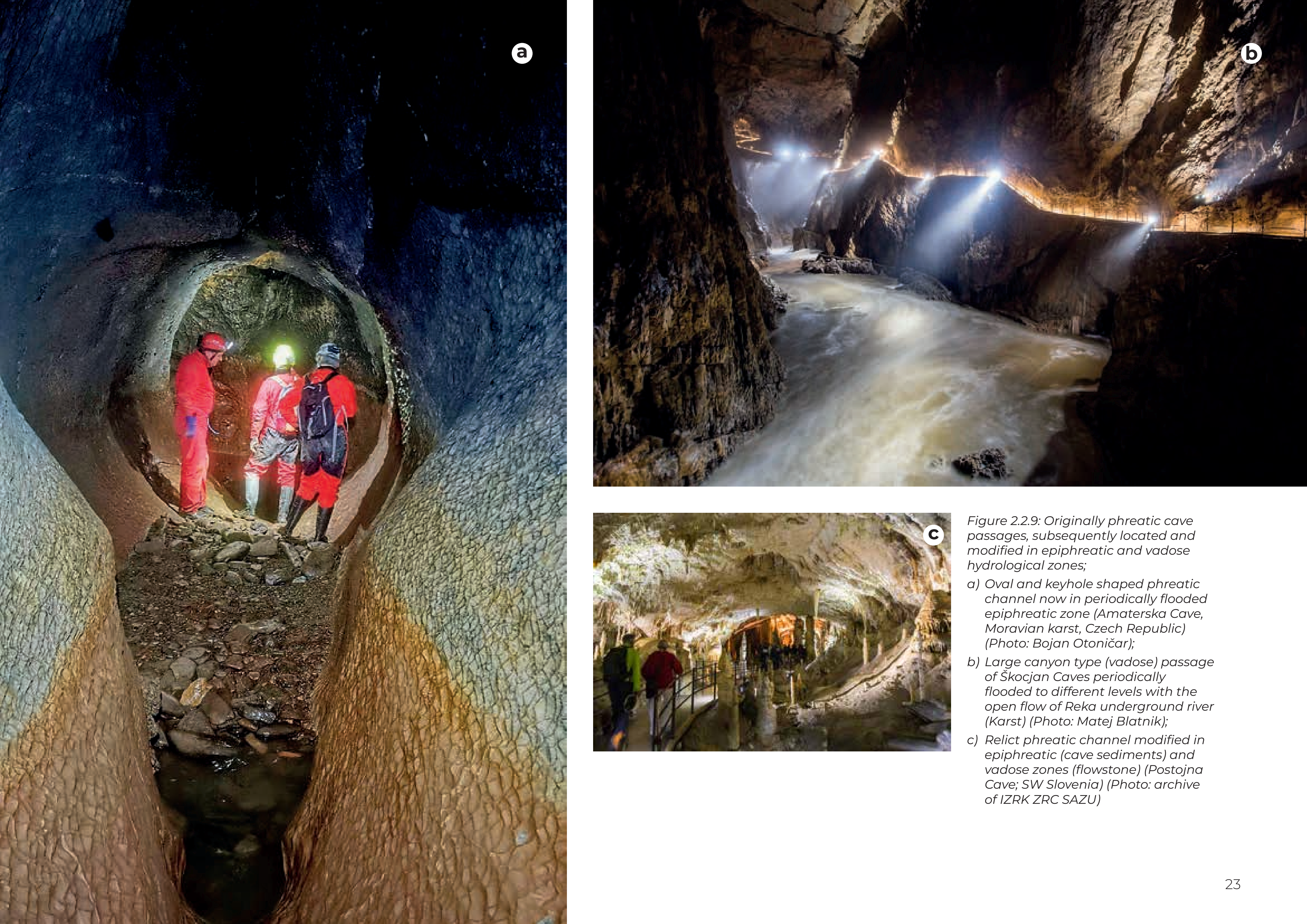


Figure 2.2.9: Originally phreatic cave passages, subsequently located and modified in epiphreatic and vadose hydrological zones;

a) Oval and keyhole shaped phreatic channel now in periodically flooded epiphreatic zone (Amaterska Cave, Moravian karst, Czech Republic) (Photo: Bojan Otoničar);

b) Large canyon type (vadose) passage of Škocjan Caves periodically flooded to different levels with the open flow of Reka underground river (Karst) (Photo: Matej Blatnik);

c) Relict phreatic channel modified in epiphreatic (cave sediments) and vadose zones (flowstone) (Postojna Cave; SW Slovenia) (Photo: archive of IZRK ZRC SAZU) and non-flooded (i.e., vadose) hydrological zones. Although the phreatic zone is dominated by more or less horizontally orientated channels, vertical channels can also form under special conditions, resembling shafts in a plan view.

Conduits develop around their entire circumference, so typical phreatic passages are round or oval in shape (Figure 2.2.9a). In the epiphreatic zone, water usually flows faster through the channels. In the dry season, the water covers only the bottom of the channel or riverbed while during the rainy season the channels are flooded. The largest cave channels are formed in the groundwater fluctuation zones. These passages develop partly in phreatic conditions, i.e. symmetrically under pressure, and partly in vadose conditions, i.e. in a flow with an open surface. The typical shape of passages is usually a combination of the oval (phreatic) shape and the canyon type (vadose) passage (Figure 2.2.9a, b).

When the groundwater level drops for various reasons, the channels pass into the vadose zone, where the water flows according to the principle of free fall, except for perched phreatic horizons. The basic type of a passage in the vadose zone is a chimney and a slightly modified version of a shaft, but meanders are also formed, corroded and mechanically eroded by the perched water flows. In the vadose zone, mechanical erosion gains importance, and the walls of the caves are also strongly modified by collapsing processes. Sand and gravel in karst rivers can mechanically grind and significantly transform cave conduits. In the epiphreatic and vadose zones, cave channels may be filled with cave sediments and flowstones to varying degrees (Figure 2.2.9c). Sediments deposited around the circumference of the passage protect the walls against corrosion. If sediments are deposited on the floor, the passage generally extends in an upwards direction, where the walls continue to be exposed to corrosion. This type of passage development is technically known as "paragenesis".

Vadose caves also form between the karst surface and the karst water table. The water in this zone flows gravitationally and only washes a limited part of the cave ceiling. As a result, most of the caves in the vadose zone are shafts and meanders.

Since in karst areas the water table (and also the surface) commonly lowers over time, phreatic caves travel upwards through the hydrological profile, first into the zone of water table fluctuation (the epiphreatic zone) and then higher into the unsaturated or vadose zone (Figure 2.2.9c). Here they intersect with vadose shafts created by water percolating from the surface. Gradual lowering of the karst surface (denudation) and the water table exposes some karst channels, originally of phreatic origin, at the karst surface, where they form part of the surface karst relief (Figure 2.2.10). These so-called denuded or roofless caves can tell us much about the geological, geomorphological, hydrogeological, and climatic history of a given area, especially when filled with cave sediments. Mechanical sediments and flowstone in fossil cave channels of once phreatic and epiphreatic caves are similarly important. Thus, the term speleogenesis is used to describe the entire life cycle of caves, from their formation to their cessation.

Figure 2.2.10: Old denuded phreatic caves indicating long-lasting geotectonic, hydrogeological and climatic evolution of a given region:

A) completely denuded part of old phreatic cave filled with cave sediments (Kozina, SW Slovenia) (Photo: archive of IZRK ZRC SAZU),

B) partly denuded fossil phreatic cave filled with cave sediments (Kozina, SW Slovenia) (Photo: archive of IZRK ZRC SAZU)

2.3 Hydrogeological characteristics of karst

Karst areas occupy about 15% of ice-free land area. Karst aquifers supply water to about 20% of the world's population, 30% of Europeans, and over 50% of Slovenians. What makes these aquifers so prolific but yet so vulnerable?

Carbonate rocks are exposed to dissolution in groundwater and surface water throughout their life cycle, beginning in the saltwater-freshwater mixing zone of the marine environment. Karst massifs are part of the hydrological cycle. Water flowing through initially porous-fissured carbonates dissolves the rock along the pores or fracture walls, forming networks of dissolution channels (caves). Their development continuously adapts to the geological and hydrological conditions of the area. It can be said that the networks of conduits evolve to provide the optimum discharge from the recharge to the springs.

In a mature karst massif, the distribution of conduits is the result of the long-term geological evolution of the area, which includes uplift, faulting and fracturing, downcutting of the erosional base, changes in hydrological conditions, etc. The existing distribution of conduits in a mature karst aquifer, which largely determines the flow within, is extremely complex and unpredictable.

The recharge of karst aquifers can come from a range of sources. Some recharge always enters karst aquifers as distributed infiltration of precipitation. Many karst areas are also in contact with non-karstic fluvial regions at some point. Surface water in these regions is organised in a fluvial network. When in contact with karst, the evolution of the fluvial network and the evolution of the subsurface karst network may coevolve, one dictating the other and vice versa. The end result may be a river that sinks underground at the contact between soluble and insoluble rocks. In some situations, a surface flow may form within a karst basin and then sink underground as a concentrated flow. Karst springs are unique hydrological features. Karst aquifers are hierarchical, so that water from a large recharge area emerges in a very limited region or even at a single spring and only in karst landscapes can an entire river emerge from the spring with an average discharge of tens of cubic metres per second.

Roughly speaking, all aquifers are divided into a phreatic and a vadose zone. The phreatic zone is permanently filled with groundwater, while the vadose zone is air-filled and water flow is directed to the groundwater surface by gravity. Large fluctuations in recharge, especially in karst systems with allogenic recharge, can result in very large fluctuations in groundwater levels, which in extreme cases can rise as much as 200 m in less than a day.

Due to the large underground water conduits, there are often no surface waters in karst areas. The unsaturated zone in karst aquifers can be more than two kilometres thick. Drilling a few hundred metres from the surface to the water table is the rule rather than the exception.

Water flowing through the karst aquifer may follow a system of large conduit and channels from the inflow to the spring. It may also flow very slowly along systems of tiny fractures and enter hierarchically larger structures and conduits. In fact, most of the water in any aquifer is stored in fracture systems, while most of the water flows through the conduits. The time it takes for a unit of water to travel from the point of entry to the spring in the same aquifer can range from hours to millennia. As a result, karst aquifers are difficult to protect. A contaminant can pass through the aquifer in a matter of hours, but it can also remain in it for decades.

2.4 Types of karst

Different types of karst and caves develop under different geological, climatological and hydrological conditions. Three basic conditions must be met for karst formation: soluble rock, water, and the development of underground drainage. The availability of water is the most important climatic factor for the development of karst. Karst landscapes occupy about 20% of the surface of the continents where soluble rocks such as carbonates (e.g., limestone, dolomite) and evaporites (gypsum, salt) are available. Caves and solution features can also form in other rocks such as quartz sandstones or granites, but they are not formed by the same processes as karstic features of "common" as well as Classical Karst. Caves also form in glaciers and in lava, but with different processes from those that form the above mentioned features and landscapes.

Carbonate rocks cover 15% of the Earth's surface, but the global dissolution rates of limestone are determined by the amount of water and CO_2 in a given setting. Thus, global dissolution rates of limestone are determined by the amounts of water and CO_2 from vegetation available in the environment. Therefore, there are numerous variations of karst landscapes around the world. Their formation depends on geology and climate (precipitation, temperature, type of vegetation, and the amount of biogenic CO_2 in the soil), and this is usually related to their geographical position including their latitude, longitude and altitude. Karst occurs in areas where water is abundant; but aridity and extreme cold hinder its development. These two climatic conditions result in a lack of water in a liquid state, which limits dissolution, and therefore other geomorphological processes may dominate the area's morphological development. In contrast, in permanently or seasonally wet tropical climates, dissolution processes are much more rapid and exaggerated.

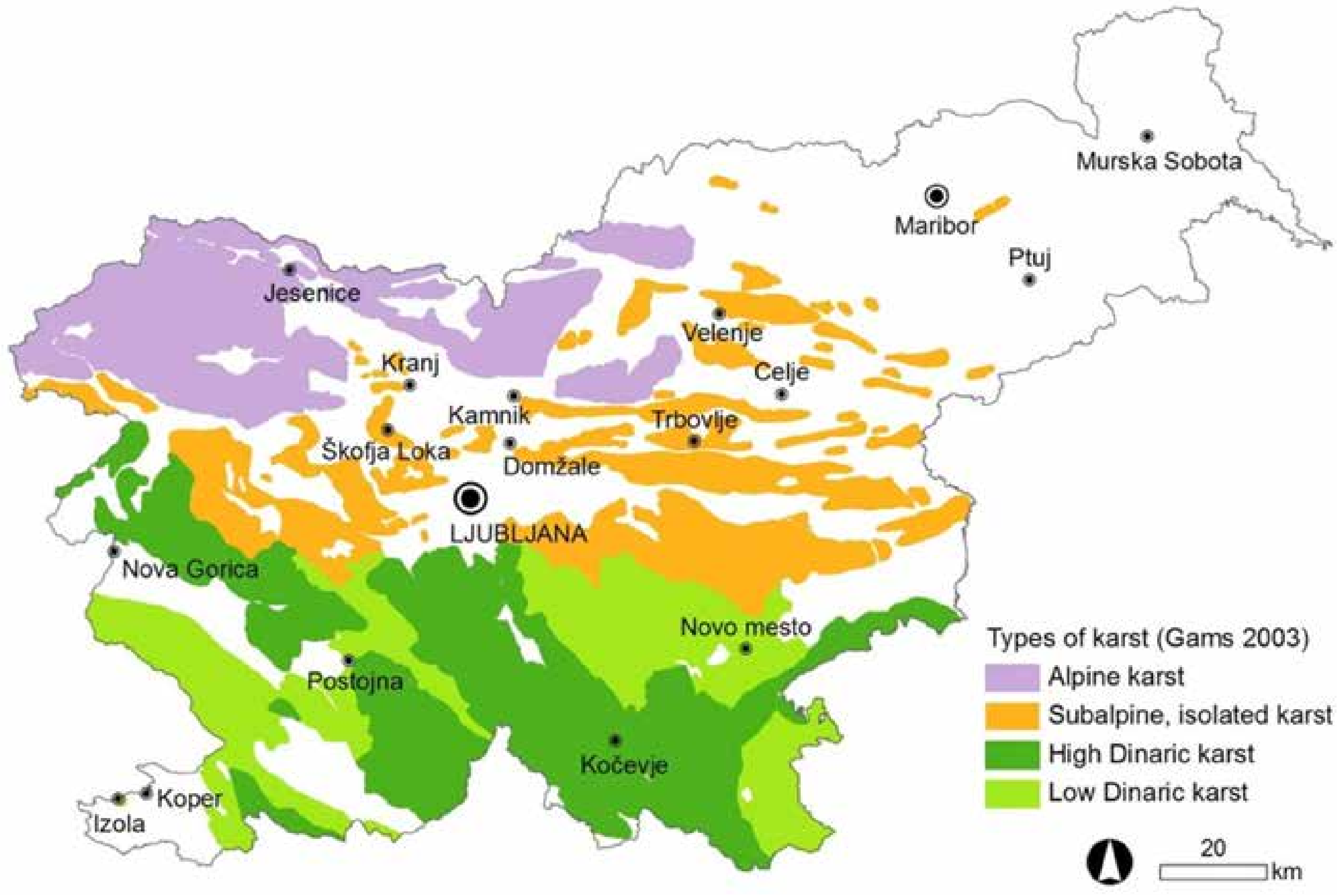


Figure 2.4.1: Map of different karst types of Slovenia (from Gams, 2003)

2.4.1 Main types of karst in Slovenia

Karst represents almost half the land area in Slovenia. According to Habič (1969), karst in Slovenia can be divided into three major units according to geological, hydrological, morphological and landscape settings (Figure 2.4.1): 1) Alpine karst - high mountain and mountain karst of the Julian Alps, Kamnik-Savinja Alps and Mt. Karavanke; 2) Dinaric karst - high and low Primorska, Notranjska and Dolenjska karst; and 3) pre-Alpine, intermediate and pre-Pannonian isolated karst (Idrija, Cerkno and Tolmin areas, Rovte Hills, Polhov Gradec Dolomites, Posavje Folds, Gorjanci and some areas in NE Slovenia), which are further divided into smaller regions according to morphological and hydrological characteristics.

Alpine karst or high mountain karst (Figure 2.4.2) is characterized by pronounced vertical gradients, and a mixture of fluvial, glacial, and karst elements in the landscape, resulting in fluvial valleys deeply incised into mountains and plateaus. It is formed in Devonian to Cretaceous carbonate rocks, while Triassic limestone and dolomite predominate. In the Slovenian alpine karst, characteristic high mountain karst features such as pavements, karrens, small depressions with vertical walls (*kotliči*) and large dolines (*konte*) occur. Underground, deep shafts and vertical cave systems are typical. The deepest caves in Slovenia are located on the Kanin and adjacent plateau (e.g., Čehi 2 is over 1500 m deep).

The Dinaric karst (Figure 2.4.3) is located in the southern part of Slovenia and is divided into Low and High Dinaric Karst (Figure 2.4.4). It is formed in Permian to Paleogene limestones and dolomites, while Cretaceous limestones and dolomites predominate. The main tectonic patterns of the area are represented by the Dinaric (NW-SE) and Cross-Dinaric (NE-SW) fault zones, S-N and NE-SW trending fissures and SW verging overthrust structures. The predominant relief features are extensive levelled surfaces at different altitudes, large closed depressions (e.g., poljes) and cone-shaped hills. Karst rivers occur only on the floors of the poljes. Allogenic rivers that, flowing from non-carbonate regions, either sink at the karst boundary and form blind valleys or cross the karst through deep karst valleys and canyons. There are numerous extensive and complex cave systems formed by sinking rivers and also connected to the surface by numerous vadose shafts. These represent both active and relict drainage pathways. Very well-known are the Škocjan caves, a UNESCO World Heritage Site, and the famous tourist Caves at Postojna, whose formations are associated with relatively large sinking rivers. Various deposits (e.g., allogenic sediments, speleothems) have ac-

Figure 2.4.2: High Alpine karst of the Kanin Plateau (NW Slovenia) (Photo: Bojan Otoničar)

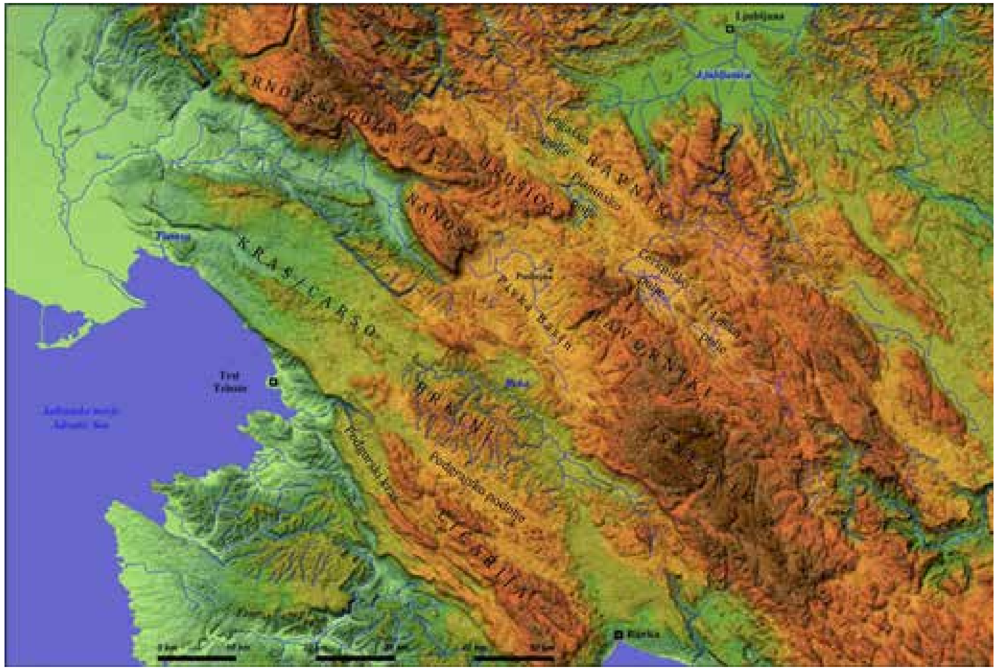


Figure 2.4.3: DEM of SW Slovenia (with parts of Croatia and Italy) showing different karstic regions of Dinaric karst including the Karst Plateau (archive of IZRK ZRC SAZU)

Figure 2.4.4: The Vipava Valley separates the Karst from the Forest of Trnovo and Nanos high Karst Plateaus (upper and right side of the figure) (Photo: Bojan Otoničar)

cumulated in the caves as a result of specific karst development. The morphology of the surface karst is characterized by abundance of karrens, dolines of various sizes, sometimes extensive collapse dolines, cave entrances, unroofed caves and so forth.

In contrast to the large extensively karstified regions of the Alps and Dinarides, intermediate and isolated karst occupy rather small areas. These are surrounded by non-carbonate rocks and developed under the influence of allogenic inflow. Horizontal caves are usually formed by sinking rivers, which generally have a high clastic sediment load. Ponors and springs are common. Karst hydrology and karst features are primarily determined by the location of an individual karst area, while the general evolution of large-scale relief is less important. Intermediate karst areas developed in limestones and dolomites from the Palaeozoic to Neogene age are located in the central part of Slovenia in a west – east oriented belt between the Alps and Dinarides. The main tectonic structures in this part are both Alpine, (E-W), and Dinaric, NW-SE oriented. Isolated karst occurs in smaller patches of carbonate rocks (mainly Miocene in age) in the central and eastern part of Slovenia, i.e., in the area of the Pannonian Basin.

2.4.2 Main types of karst in the Friuli Venezia Giulia Region

In the 7,850 km^2 of the Region there are outcrops of carbonate rocks covering approximately 1,900 km^2, affecting about 5,000 km^2 of mountainous and hilly areas. Almost 7,500 caves have been discovered in this area and inventoried, of which well over 3,000 are in the Italian side of the Classical Karst.

Using geological, morphological and hydrogeological criteria, about sixty karst areas - made up of limestone, dolomitic limestone, limestone dolomite, limestone breccias and conglomerates - have recently been identified and outlined.

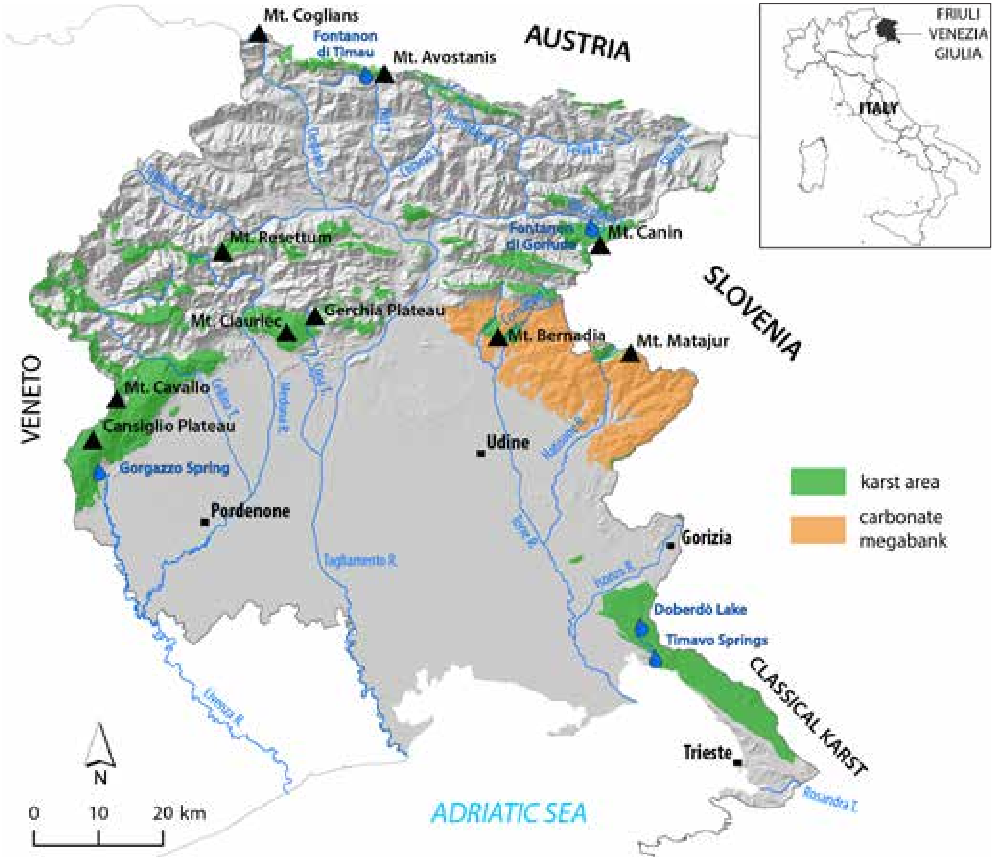


Figure 2.4.5: Karst areas in the Friuli Venezia Giulia Region (Cucchi and Finocchiaro, 2017)

Some 50 of these areas outcrop limestone or dolomite rocks in which karstification is ascertained by the presence of meaningful surface and/or hypogean karst forms (dolines, cave entrances, hypogean karst networks, karst springs, limestone pavements and small corrosion features, poljes, blind valleys, etc.). Of these, about ten are particularly important, with some of them being transboundary and, shared between Italy and Austria or Slovenia.

From a morphological point of view, and thus also from that of karstification, three types of karst areas can be recognised, namely alpine karst, prealpine karst and karst plateau.

Alpine karsts develop in the Carnic Alps in narrow areas aligned along the Austrian border and Julian Alps, shared with Slovenia. These are characterised by a high frequency of caves and intensely karstfied outcrops. They contain isolated but often water-rich aquifers. The regional pride is certainly the karst in the Triassic-Cretaceous succession of Mt. Canin-Kanin. Here, all the epigean karst features of the high mountains can be identified, often exemplary, accompanied by impressive underground systems, such as the Col delle Erbe Complex (over 23 km of development, with dozens of deep shafts reaching -935 m) and the Foran del Mus Complex (over 13 km of development).

In the Pordenone Carnic Pre-Alps and the Julian Pre-Alps there are numerous areas of wooded, pre-Alpine karst, with interesting cavities and widespread and varied surface karst including the areas around Pradis, Mts. Resettum, Ciaurlec, Bernadia and Musi, characterised by a high frequency of caves, dolines, and intensely karstified outcrops as well as rich aquifers. The karst developed in the limestone banks interspersed in the Paleocene and Eocene flysch of eastern Friuli is unusual. It hosts extensive systems of active caves whose springs are revealed by the river network, but for which there few pieces of evidence for karst on the surface.

Figure 2.4.6: The Alpine karst of Mt. Poviz (Photo: Giacomo Casagrande).

Figure 2.4.7: Limestone pavement and grikes on the highlands of Mt. Ciastelat (Pordenone Province) (Photo: Barbara Grillo)

There are two karst plateaus. One is facing the sea, represented by the Classical Karst, the other the vast Cansiglio-Cavallo Plateau, dominating the Friulian plain, whose geological boundaries transcend those of the Region. The polje of Piancavallo and the vast karstified cretaceous limestone outcrops are special. Among the widespread karst features present, the dolines which border the plateau on the eastern slope, symmetrical, dense, deep, with their sides dotted with splendid karrenfelds, and the limestone pavements of the northern sector (Mt. Ciastelat) are the most representative. Of the caves, the main abysses include Bus de la Lum and Bus de la Genziana and the Gorgazzo, Santissima and Molinetto springs, a Spring area of the Livenza River.

Figure 2.4.8: The Gorgazzo Spring at the toe of the Cansiglio-Cavallo karst area (Photo: Franco Cucchi)

GEOLOGY AND GEOMORPHOLOGY OF THE CLASSICAL KARST

3.1 The area covered by the Classical Karst geopark

The Classical Karst (*Kras* (Slovenian), Carso (Italian)) is a limestone plateau that runs north-west – south-east and is bordered by the Isonzo-Soča River (Italy and Slovenia) to the north, the Adriatic Sea to the west, the Brkini hills and the lower course of the Reka River to the south, and the Vipava Valley to the east.

The plateau is gently dipping toward the north-west from the 674 m summit of Mt. Kokoš-Cocusso down to the sea level at the springs of the River Timavo. It consist largely of limestone and dolomitic rocks, the latter outcropping less frequently, mostly in the hills.

The Classical Karst geopark covers 936 km2, 213 km^2 within Italy and 723 km^2 in Slovenia; it includes 17 municipalities, in some cases in their entirety, others only partially, such as the urban centres of Trieste and Monfalcone. On the Italian side there are 12 municipalities, while there are 5 on the Slovenian side of the border. The Italian municipalities involve both the Gorizian Karst (Savogna d'Isonzo-Sovodnje ob Soči, Sagrado, Fogliano Redipuglia, San Pier d'Isonzo, Ronchi dei Legionari-Ronke, Doberdò del Lago-Doberdob and Monfalcone), and the Karst of Trieste (Duino-Aurisina - Devin-Nabrežina, Sgonico-Zgonik, Monrupino-Repentabor, Trieste and San Dorlingo della Valle-Dolina). The five Slovenian municipalities within the Classical Karst are Sežana, Miren-Kostanjevica, Hrpelje-Kozina, Divača and Komen.

The Geopark is crossed by important infrastructural networks running both east-west and north-south. These are routes of continental importance, which on the one hand facilitate connections with other European regions and, on the other, increase its environmental vulnerability.

The landscape of the Karst is characterized by some peculiar aspects, that exhibit the full typology of karstology, and which can be summarized as follows:

1. **Underground waterways, springs and karstic lakes**, accompanied by a reduced surface area with a hydrographic network and a scarce presence of valley systems shaped by erosion.
2. **Irregular, undulating plateaus**, with rounded, domed reliefs and extensive flat areas, harsh in appearance.
3. **Closed, hollow depressions** (dolines).
4. **Broad rocky outcrops**: *Karrenfeld* modelled by various dissolutive forms, called microforms, to distinguish them from macroforms (dolines, uvalas and poljes).
5. **Cavities, potholes, abysses, caves and caverns**.

Figure 3.1.1: The movement of the morphologies of the Classical Karst (Photo: Roberto Valenti)

The landscape of the Classical Karst is also characterized by its tectonic setting, with a Dinaric structural trend. In Italy this structure has created a wide anticline with an axis running north-west - south-east, but asymmetrical, i.e. with a vertical south-western flank and a north–eastern flank much less inclined. It is precisely here that the Karst Plateau develops.

As a result of its proximity to the Adriatic and to Mediterranean climate, the Karst has been continuously inhabited since the Paleolithic Era. Due to its thin soils, rocky nature and the lasting summer drought, land use has traditionally been directed towards pastoralism and the rearing of livestock. Only on the richest land has agriculture developed, which in recent years has been marked by the excellence of its wines and olive oil. The city of Trieste, close to the area covered by the Classical Karst, is an important attraction for services, tourism and employment of the residents of the geopark. Geotourism has a long tradition in the area, linked in particular - but not only to - the presence of caves, amongst which the Škocjan Caves and the Grotta Gigante-Briška jama Cave stand out as attractions.

Figure 3.1.2: The area of the Classical Karst geopark with municipalities boundaries (by ZaVita d.o.o.)

Figure 3.1.3: The map of the infrastructures and the watercourses of the area of the geopark (by ZaVita d.o.o.)

3.2 A history of exploration and research on the Classical Karst

3.2.1 Geological investigations

Although pioneering, the first geological studies on the territory of the Classical Karst date back to the late 1700s and are well established by the early 1800s. Their value, however, is to be considered historical. More detailed and modern studies and investigations started in the second half of the 19th century when Austrian geologists and paleontologists laid the foundations for a geological cartography of use in the knowledge of the geological evolution of the area and its surroundings.

The first geological maps drawn up by Adolphe Morlot date from 1848 while those elaborated by Torquato Taramelli are from 1874, but the most significant advances in the geology of the Classical Karst and neighbouring areas are from 1859 to 1920 (Figure 3.2.1), and to Guido Stache, a talented geologist and paleontologist, who for a long-time was director of the *Geologische Staatsanstalt* (the Austrian Geological Survey). His volume *Die Liburnische Stufe und deren Grenz-Horizonte* (The Liburnian and its borders) printed in 1889 is a fundamental work, just as important as his other writings, and is an essential work for later geologists.

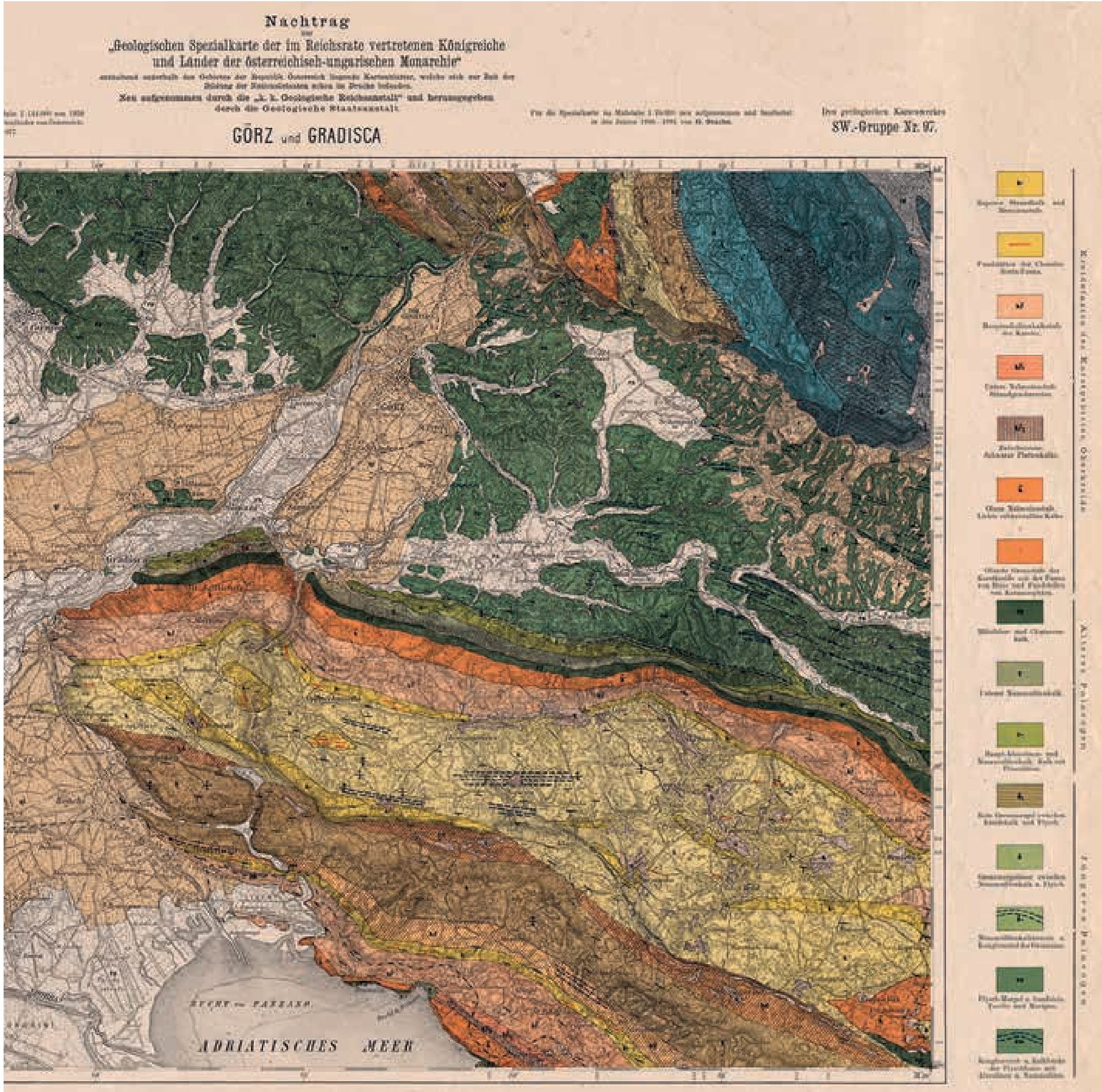


Figure 3.2.1: Extract of the map Gorz und Gradisca, *edited in 1920 by Guido Stache on behalf of the Austrian Geologischen Staatsanstalt.*

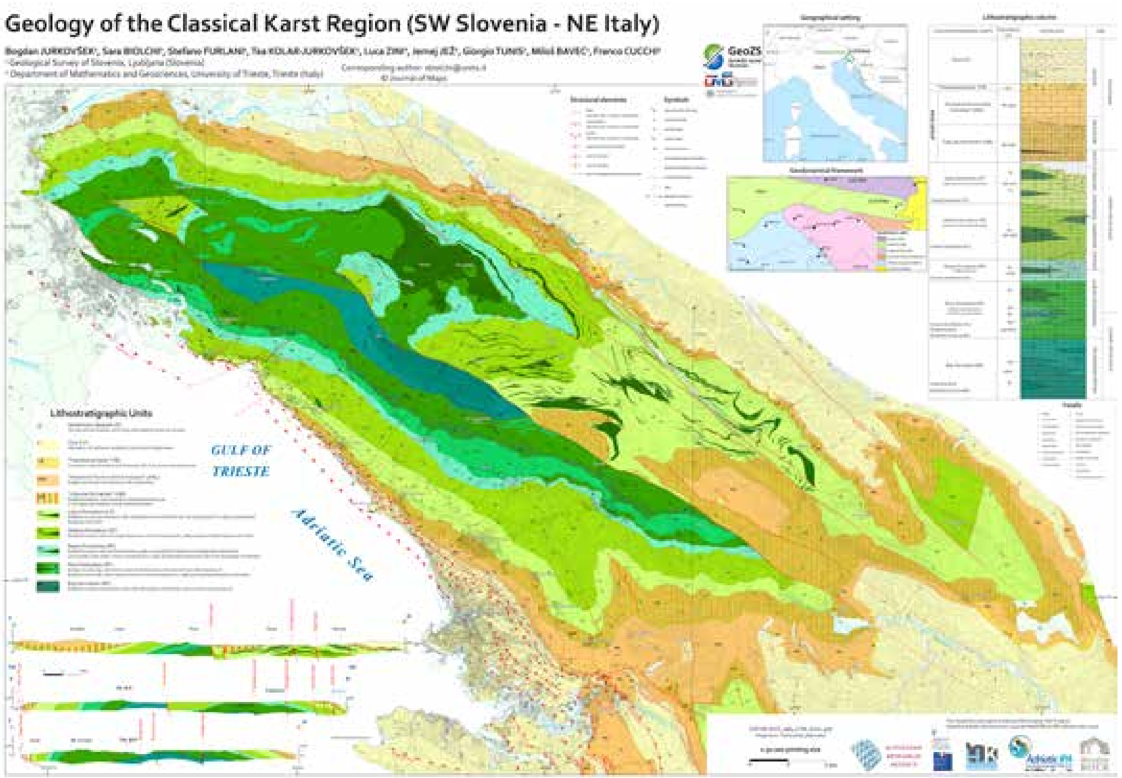


Figure 3.2.2: Classical Karst geological map realised in the aim of the INTERREG Italia-Slovenia Projects as HydroKarst and RoofOfRock (Jurkovšek et al., 2016)

In the second half of the 19th century, the special attention of paleontologists was attracted by finds of the fossil fish and reptiles in the laminated and platy limestones that occur within the various Cretaceous formations in Classical Karst. The first study was published in 1850 by J. J. Heckel, and the most comprehensive one in 1895 by C. Gorjanović-Kramberger, describing as many as 27 fish species from those layers.

After the World War I the Karst was studied in detail mostly by Italian geologists, such as Carlo D'Ambrosi from 1925 to 1955, Alvise Comel from 1927 to 1940 and the German-Austrian Franz Kossmat from 1935 to 1938. They wrote numerous sheets and related explanatory notes for the "*Carta geologica delle Tre Venezie*" at the scale of 1:100,000.

After the World War II, research by numerous Italian and Slovenian geologists continued, but separately, with the development of a new traditional local geological maps at the scale of 1:25,000 and 1:100,000. For Italy, research was led by Bruno Martinis from 1949 to 1975. In Slovenia, elaboration of geological maps were conducted within the scope of Basic Geological Maps project of the former SFR Yugoslavia (scale 1:100,000), led by Stanko Buser from 1967 to 1973 and by Mario Pleničar from 1969 to 1973. The last period of detailed geological research in Slovenia, beginning in the 1990s under Bogdan Jurkovšek, resulted in the production of geological maps of the southern and northern parts of the Trieste-Komen Plateau (Jurkovšek et al., 1996; Jurkovšek, 2008, 2010). Also the correct approach to problems related to the complex geological structure began in this period, especially by Ladislav Placer who, from 1969 to date, has produced numerous works on post-Cretaceous Alpine-Dinaric geodynamics.

Starting from 1999, the Geological Survey of the Autonomous Region of Friuli Venezia Giulia in collaboration with the University of Trieste, through the Technical Geological Map (*Carta Geologico Tecnica* - CGT) and GEO-CGT projects created new digitized geological maps at scales of 1:5,000 and 1:10,000 of some areas of the Region, including the topographic sheets "Trieste", "Caresana", "Gorizia" and "Grado", which comprise the Classical Karst. As a result of the collective work, the geological map of the italian part of the Classical Karst in scale 1:50,000 has been published in 2013 (Cucchi & Piano, 2013).

In the early 21th century, through a series of INTERREG Projects, collaborations between Italian and Slovenian geologists have became more intensive. As a result of the aforementioned modern national maps and the cross-border collaboration, in 2016 a geological map, at a scale of 1:50,000 of the entire area of the Classical Karst was published (Figure 3.2.2).

3.2.2 Speleological and hydrogeological research

As far as geomorphology and speleology are concerned, Posidonius of Apameia (135-50 B.C.E) may be considered the first investigator of the Karst, but, regretfully, we know only that he mentions the Reka sink running to the Timavo. Only a millennium later, did Ferrante Imperato start to work at the Timavo springs to discover whether the Reka that sinks in the Škocjan Caves is the same that reappears at the Timavo Springs. He tried to prove it using floats and he published his observations in 1599. Athanasius Kircher illustrated his explanation of "hydrophylacia" as a theory of underground reservoirs connected with the sea by an example from the Rhaetian Alps. The picture includes the actual area of Slovenia, and the Timavo Springs rising beneath "*Timavus Mons*" are also drawn in. In the volume *Mundus Subterraneus* Kirchner (1964) mapped the mouths already declaimed by Virgil from which the Timavo flowed, recalling that it had long been assumed that the waters came from Škocjan.

The birth of scientific speleology in the Classical Karst area is down to the Slovenian Johann Weikhard von Valvasor, who in 1687 described the hydrogeology of Cerknica Lake and the surrounding territories and his most famous work *The Glory of the Duchy of Carniola* contains descriptions of the most famous caves of the Karst, such as that of Postojna and Škocjan. Although Valvasor (1689) did not take such a profound interest in the Karst as he did in in the karst phenomena of Notranjska and Dolenjska, his publications aroused a great interest in karst phenomena.

In 1748 the court's mathematician Josef Anton Nagel, commissioned by Emperor Francis I, arrived in Carniola to see and to report on what was true in the news of "unusual and miraculous phenomena". In his report from the Karst he described the Vilenica Cave which at that time had been a "show cave" for a good 100 years already. His description is accompanied by several fine illustrations. It should be remembered that this area is not only the cradle of scientific speleology, but also of speleological tourism. The first book of the signatures of visitors to the caves of Skocjan dates back to 1819, but there is a document from 1633 which indicates that Count Petazzi, then the owner of the land in which the Vilenica Cave near Lokev opens, ceded part of the proceeds from visits to the cave itself to the local community, which therefore can boast of being the first tourist cave in the world.

The evolution of Speleology in the area of the Classical Karst is linked with the economic life of Trieste. The granting of the status of Free Port by Charles VI in 1719, led to a significant increase in naval traffic and to the importance of the city: it is estimated that in 1780 a quarter of all the trade of the Empire passed through Trieste. Within a century the city underwent major transformations: the port was enlarged and new neighbourhoods were built. Consequently, the water requirements also increased.

The *Teresianischer Aquädukt* (the Maria Teresa aqueduct) had already been built in the mid-1700s, drawing water from the flysch slopes leaning against the Classical Karst and feeding fountains located in the main squares. However, the flow rates were never so high as to definitively solve the problems of water supply in the city and the port. The speleological research of the underground Timavo was linked to these issues.

At the beginning of the 19th century it was the research of individuals, enthusiastic and eager for knowledge that prevailed. A good example is Eggenhöfer who swam the Reka River from its ponor through Mariničeva and Mahorčičeva jama to Mala dolina in 1816. Soon after, collective and organised research started.

The involvement of the Municipality of Triest and the interest of some prominent figures of the city in this topic have been documented since the early 1800s. In 1828 a Commission for water was appointed in charge of evaluating the area's water resources, from Aurisina-Nabrežina to Škocjan. In 1838 A. F. Lindner started a systematic research on the places (blow holes) where, during the floods of the Timavo, the air was expelled by the rising waters in the oscillation zone of the underground aquifer. The goal was to identify an intermediate point along the underground Timavo. This was discovered in the Trebiciano-Lobodnica Cave. The exploration was an exceptional undertaking for those times, lasting 5 months of excavations with the opening of bottlenecks and even the use of mines. On April 5th 1841, Luca Kral of Trebiciano-Trebče and Anton Arich, a miner from Idrija, descended into the great cave of the Abyss, at the bottom of which flowed the Timavo at depth of 326 metres. Thus, the first window on the river's underground course was opened. The news went around Europe, so much so that until the beginning of the 20th century the cave was considered the deepest in the world.

During one of the first descents, specimens of *Pterostichus fasciatopunctatus* were collected, a beetle characteristic of the upper Timavo Valley, scientific proof of the connection between upper and underground Timavo and one of the earliest examples of a biological tracer.

But the discovery did not solve the water problems of the city, the altitude (12 m a.s.l.) was too deep to exploit. The construction of fixed stairs was financed and the characteristics of the water and the level of the river were studied to assess the extent to which the water could rise. In the following years, the construction of the *Südbahn* (Southern Railway) further aggravated the problem of Trieste's water supply, and the project of derivation from the caves of the Classical Karst was abandoned and it was decided to exploit the springs at Aurisina-Nabrežina. It is worth remembering that at the initiative of the Southern Railway constructors Adolf Schmidl started to explore the caves in the Classical Karst in the middle of the 19th century to discover the possibilities for cave tourism.

In the 1880s, numerous speleological groups belonging to the various mountaineering associations of Trieste were founded, which began to operate in the area in search and exploration of caves. In the early 1900s, through a series of experiments with chemical tracers, dyes and the radioactive marking of water, Renato Timeus demonstrated the water connection between the sinkhole of Škocjan, the Abyss of Trebiciano and the Springs of San Giovanni-Štivan. It was the scientific confirmation of the many hypotheses and attempts, often empirical, which, starting with those made by the pharmacist Ferrante Imperato at the end of the 1500s, and that had followed one another for three centuries.

In 1888 Kačna Cave was discovered and in 1889 cavers, guided by Anton Hanke (SK DÖAV) reached its bottom where high waters of the Reka appear.

In 1890 speleo-explorers reached the final siphon of the caves of Škocjan and the cave was almost entirely explored, with exception of the part called *Tiha Jama* which was only discovered in 1904. At the same time as the explorations, the cave was also prepared for tourist-mountaineering visits. In 315 days in the years 1894 to 1895 five local workers succeeded in building the wooden stairs and ladders down the 186 m deep vertical entrance shaft which allowed them to enter the cave without additional equipment. This construction was unique in the world and probably was their greatest technical achievement.

During the First World War the front reached the Karst. The explorations did not cease but were redirected for military purposes. A special group guided by Hermann Bock, a speleologist, prepared the plans for changing the caves into shelters, magazines, hospitals etc. Some projects were also implemented and in some caves there was enough room for 2,000 men!

The end of the World War I represented an epochal change for the city of Trieste and also for Karst research. In the following years the figures of Luigi Vittorio Bertarelli and Eugenio Boegan acquired ever more importance. In 1926 they published the volume *2000 Grotte* (2000 Caves), a synthesis of the speleological knowledge of the time and above all the first attempt to draw up a complete list of the caves of the Classical Karst. In 1929 the foundation of the state institute, the *Istituto Italiano di Speleologia* at Postojna contributed a lot of research. The Institute published the main Italian speleological journal, the *Grotte d'Italia*. In the following years Boegan deepened and synthesized his knowledge on the underground course of the Timavo and in 1938 he published *Il Timavo*, a volume that for decades has remained one of the best examples of "study on subaerial karst hydrography and underground", as the subtitle says.

After The Second World War, both the Slovenian and Italian sides of the Karst increased their research with the aim of spreading speleological knowledge and discovering caves of the underground Reka/Timavo system.

3.3 GEOLOGICAL HISTORY OF THE GEOPARK AREA

Paleogeography

The Classical Karst owes its identity to the mostly white to pale grey rock called limestone that represents its backbone. That limestone was formed in ancient seas over a period of nearly 100 million years. Since calcium carbonate in the form of the minerals calcite and aragonite is soluble in fresh water, when these rocks are exposed above sea level, this water acts as a fine chisel to carve the limestone into characteristic features. The variety and beauty of these features are so remarkably well represented in the Classical Karst area that they are referred to as karstic and the geomorphological phenomenon itself took the name "karst" from this area.

Although limestones across the Karst Plateau may appear almost uniform to the inattentive visitor, an observant eye can notice differences in the thickness of the layers, colour variations and peculiar fossils. But the trained geologist - with the aid of a handlens - is able to read fragments of the long book of geological history in every piece of these rocks. The nature of these layers and the contacts between them, and especially the rock's inner structure and tiny fossils, called microfossils, are the pages and letters of this geological chronicle. They convey fascinating information on the depth, temperature, salinity, and oxygenation of the ancient seas in which these limestones were formed, telling of what life and the environment in the geological past looked like and how it changed over time. We use the prefix "paleo-" to denote prehistoric phenomena, with words such as paleotemperature, paleoenvironment, paleogeography, or paleokarst, and indeed, the episodes of the chronicle of the geopark are set a long time before the history of humankind, in the geological periods of Cretaceous and Paleogene, during the Mesozoic and the Cenozoic eras. They cover a timespan of almost 100 million years from the beginning of the Cretaceous, about 140 million years ago (mya), to the middle of Eocene about 45 mya.

Today we hear a lot of discussion about climate change, the greenhouse effect, sea level rise, CO_2 emissions and the potential effects of these phenomena on humankind, on society and on the Earth's ecosystems. In this perspective, the story told by the rocks of the Classical Karst is particularly interesting. The Early Cretaceous epoch was indeed one of the warmest times in Earth's history. Back then, the mean annual temperature in the northern hemisphere during summer months was about 18.4 °C, more than 4 °C warmer than today. With such high temperatures, no polar ice-caps existed and sea level was much higher than today. By the end of Cretaceous, the temperature had fallen to about 16.2 °C, and to 13.9 °C by the middle Eocene. The temperature variations were paralleled by strong oscillations in sea level that rose by more than 120 m and dropped by more than 40 m with respect to its present-day level. The boundary between the Cretaceous and the Paleogene, which also represents the boundary between the Mesozoic and Cenozoic eras, was marked by a major extinction event, associated with the impact of a large asteroid in the area now occupied by the Yucatan Peninsula in the Gulf of Mexico. This event drastically changed life on Earth, wiping out 73% of living species, including dinosaurs, ammonites, and many other organisms that had thrived on the continents and in the oceans for millions of years.

In the Cretaceous, not only the environment in which the rocks building the Karst Plateau were formed, but the entire world, looked a lot different from that we know today. Only at the beginning of the Late Cretaceous, did the Southern Atlantic Ocean open up between Africa and South America, and India finally separated from

Madagascar and started on its journey that would eventually bring it into collision with Asia. North America was still attached to Europe, and Australia to Antarctica. Towards the end of the Cretaceous, the previously large, dismembered land masses of the old Gondwana supercontinent moved towards Eurasia, causing the formation of a large Alpine-Himalayan mountain belt (Figure 3.3.1).

In the Cretaceous, as a consequence of a warm climate and high sea levels, large portions of the continents that nowadays are emergent land were occupied by vast shallow, epicontinental seas (meaning "on continents"). This gave way to a vigorous burst of marine life, including those life forms that later, in the Cenozoic, would successfully conquer the Earth, such as corals, molluscs,

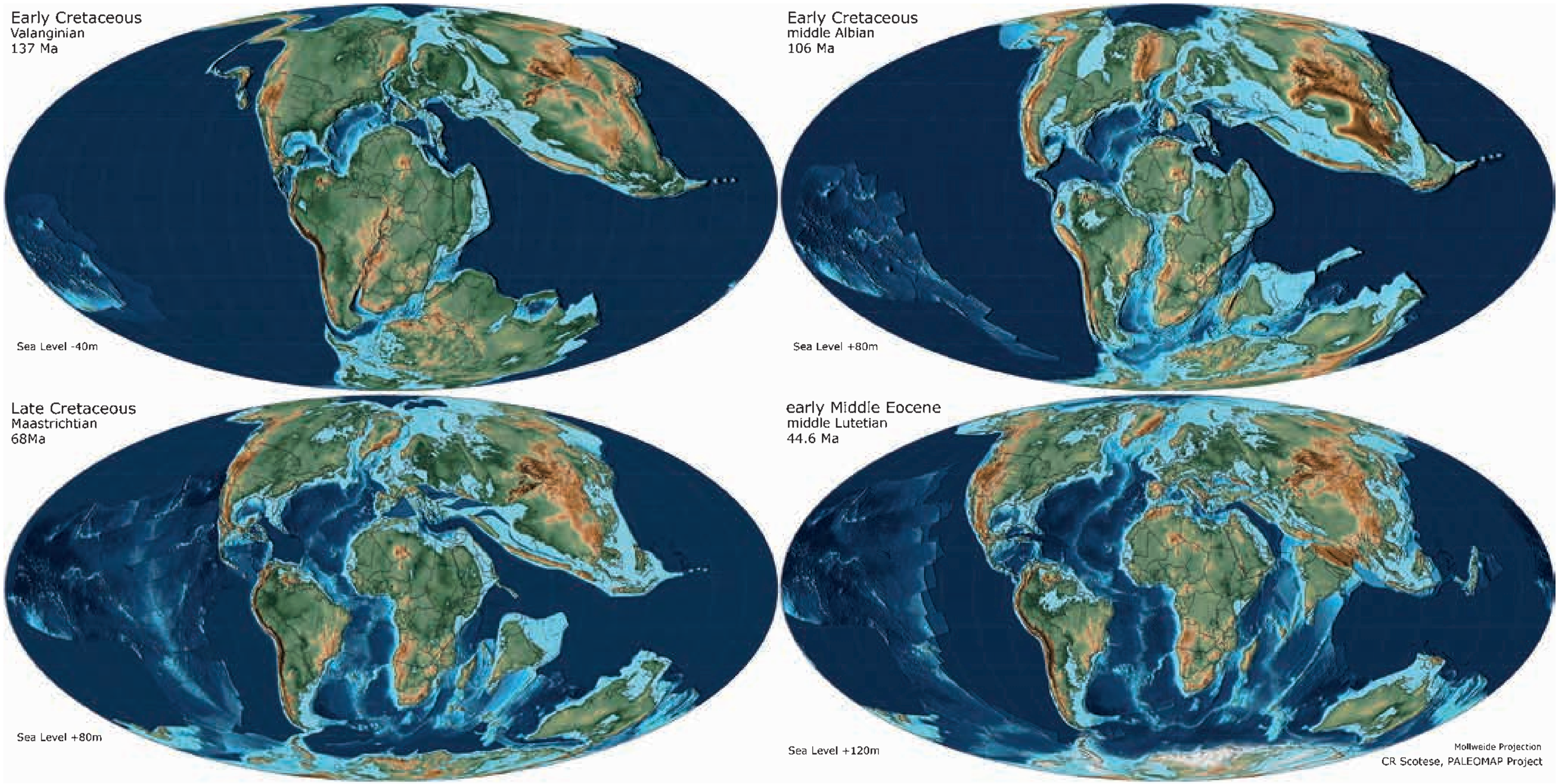


Figure 3.3.1: The changing world from Early Cretaceous to Middle Eocene, in times of formation of rocks that build the geopark (after Scotese, 2014)

echinoderms, crabs and fish. The Earth's poles were free of ice, and seawater had a weaker circulation and was less well-oxygenated. This, at times, led to the accumulation of black, organic-rich sediments on the seafloor.

The Classical Karst area is made up of sedimentary rocks of the former Adriatic-Dinaric Carbonate Platform (Figure 3.3.2). A carbonate platform develops when the accumulation of limestone in the sea is such that a relief is built up on the seafloor. The uppermost portion of this so-called build-up is often close to sea level and flat (and therefore termed a "platform") so that an area with relatively shallow waters exists, similar to a lagoon. At the outer edges of a platform, slopes of variable steepness link its top to the surrounding deeper ocean floor in a manner that resembles the aprons of debris at the base of a mountain. In some cases, these platforms can be very large. Modern examples include, for instance, the Bahamas in the Gulf of Mexico or the Great Barrier Reef in Australia. The Adriatic-Dinaric Carbonate Platform was indeed a large example, as evidenced by its rocks outcropping from northeastern Italy, along the entire length of the Dinarides, as far down as Montenegro. The platform developed when the breakup of the mega-continent called Pangea brought about the formation of two separate continental masses, Laurasia and Gondwana, with the opening of the Tethys Ocean. At first the Tethys was a gulf that later became a broad seaway that stretched approximately east - west at tropical latitudes. One of constituent parts of Gondwana was the African Lithospheric Plate. The Adriatic-Dinaric Carbonate Platform formed on the Adria Microplate, which was initially connected to the African Plate and became an independent plate from the Mesozoic onwards. During the Cretaceous, the Adria Microplate was located approximately 2,000 km to the south, within a (sub)tropical climate belt. At these latitudes, conditions were ideal for the formation of limestone. The platform existed for millions of years, from the Jurassic to the early Eocene until tectonic movements connected to the collision between the lithospheric plates brought about the rise of the Alpine chain and to the platform's foundering in the oceans. This event is testified to by the sandstones of the flysch that derive from

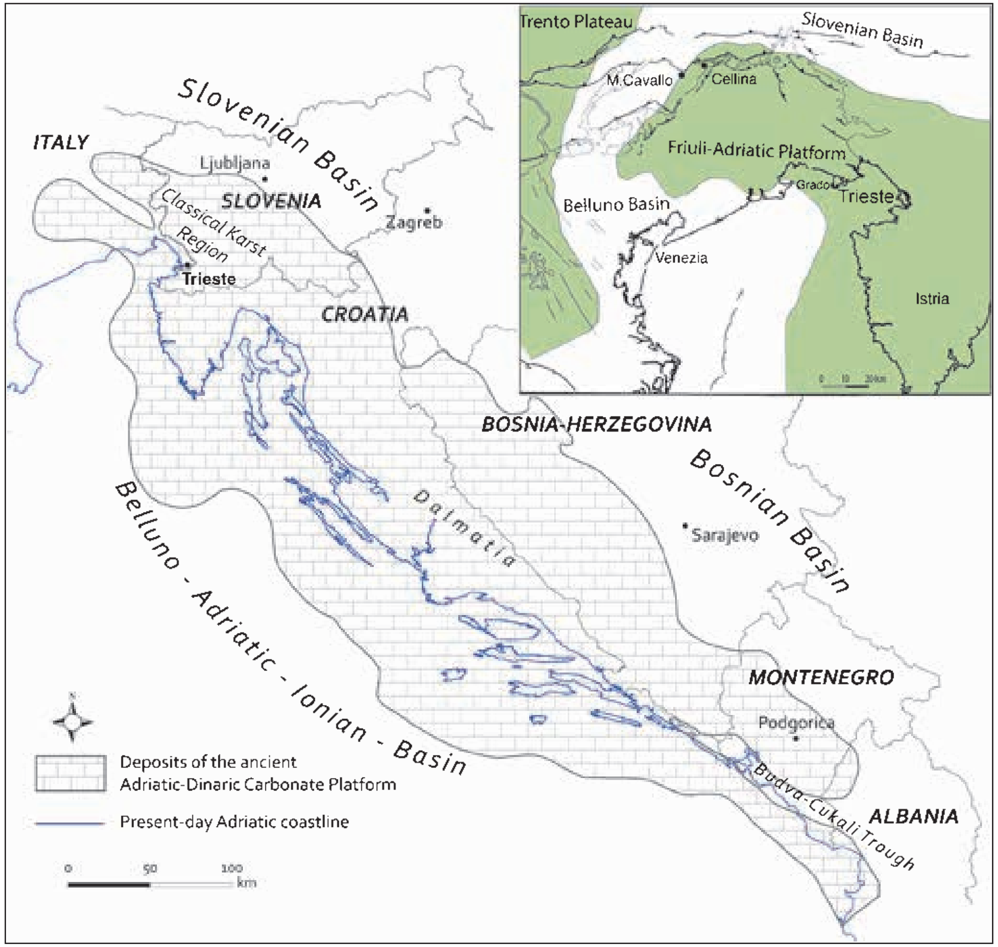


Figure 3.3.2: Present-day geographic map overlain by one showing the extent of the Adriatic-Dinaric Carbonate Platform deposits (modified from Dragičević & Velić, 2002) and a detail of the northern part with the Friuli-Adriatic Platform (modified from Consorti et al., 2021)

the erosion of uplifting mountains, and which were deposited when the area where the platform once stood was occupied by a deep sea at the beginning of the Cenozoic period (66 mya).

The thick carbonate rock succession of the Classical Karst region was formed in the inner part of the Adriatic-Dinaric Carbonate Platform, an area that resembled the lagoon of the Bahamas today. The Italian portion of the Classical Karst area is also called the Friuli Platform and corresponds to the northwestern limb of the Adriatic-Dinaric Carbonate Platform that, during the Cretaceous, was bordered by two stretches of deep sea: the Slovenian Basin to the northeast and the Belluno Basin to the west (Figure 3.3.2). The environment that characterized the platform did not change much for several millions years during the Cretaceous. A more pronounced differentiation started in the younger part of the Late Cretaceous when the platform started becoming involved in the tectonic movements connected to the Alpine orogenesis.

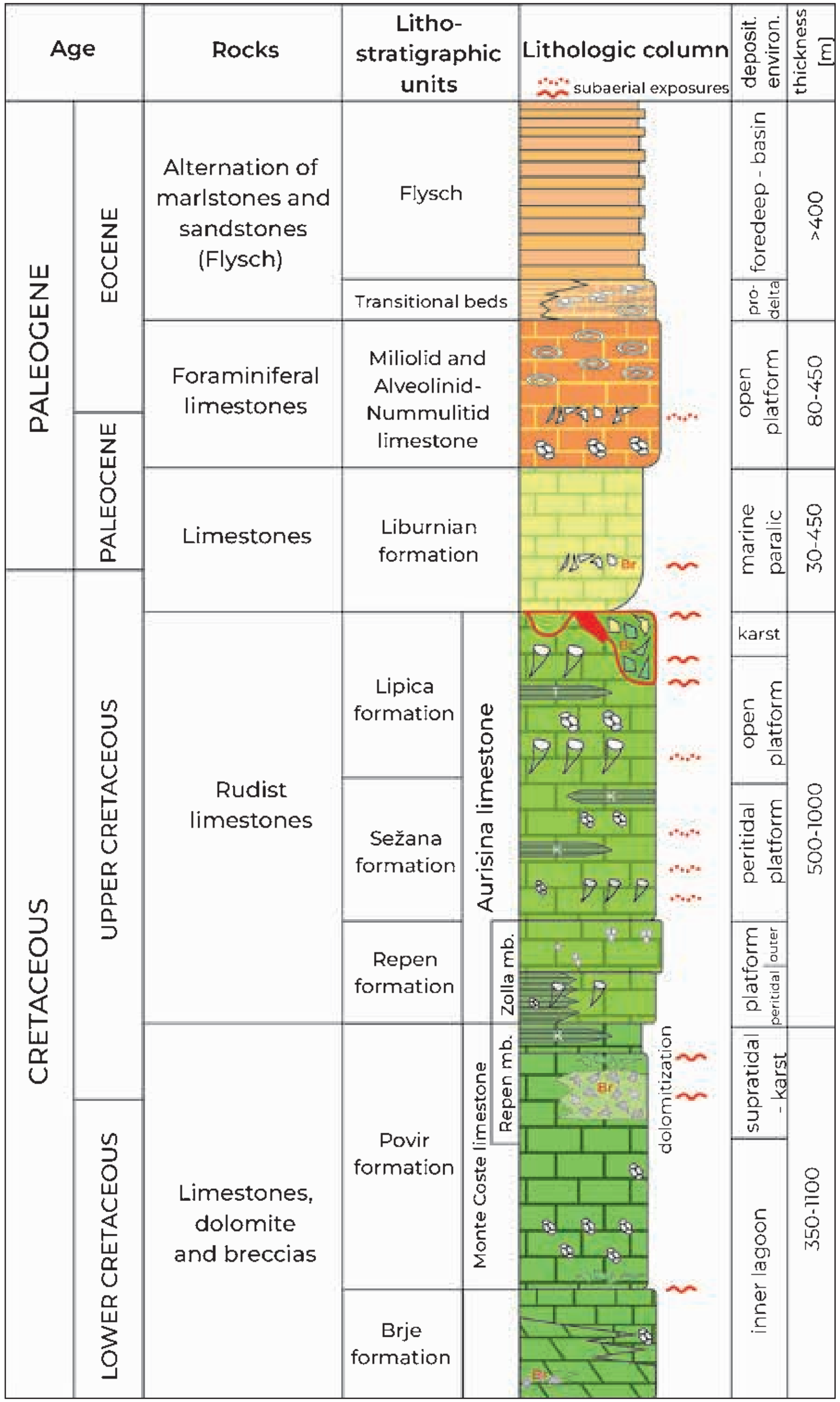


Figure 3.3.3:
Geological column, depicting geological units building the geopark (Br – breccia, K – Komen limestone, T – Tomaj limestone) (after Jurkovšek et al., 2016 and Consorti et al., 2021)

Rocks and fossils of the geopark

As a result of the long-lasting stability of the sedimentary environment, a thick pile of carbonate sediments deposited right across the Adriatic-Dinaric Carbonate Platform. The characteristics of these sediments unequivocally tell geologists that they were deposited in a warm, shallow sea. In these waters microscopic organisms, such as foraminifera, coccolithophorids and diatoms thrived. On the carbonate platform, thousands of forms of corals, echinoderms, brachiopods, crustaceans, and other animal groups were abundant. In addition to them, a peculiar group of clams (technically bivalve molluscs), called rudists developed. These unusually shaped bivalves first appeared at the beginning of the Cretaceous, but flourished in the Late Cretaceous and, together with many other plants and animals, became extinct at the end of the period. The rocks of the Classical Karst also show evidence of multiple short- and long-lasting subaerial exposures, times in which the platform top emerged above sea level.

The succession of rocks of the Classical Karst, nearly 1500 m thick, has been subdivided into several geological units, that group together rocks that are genetically related. One way of representing such units, called *formations* by geologists, -sometimes further subdivided into smaller parts called *members*, or grouped into larger ones called *groups*, is the lithostratigraphic column (Figure 3.3.3). In this type of representation, formations are depicted from the oldest at the bottom to the youngest at the top. The lithostratigraphic column of the Classical Karst highlights the main phases of the evolution of the environment in this area in a period of over nearly 100 million years. The physical distribution of formations is shown in the geological map. For some of these units, Slovenian and Italian geologists use different names and some parts of the succession are also subdivided differently. In this book, a simplified scheme was adopted in which the rocks of the Classical Karst are subdivided into their most distinctive units. The following description presents them in stratigraphic order, that is from the oldest to the youngest.

✦ Lower to Upper Cretaceous limestones, dolomites and breccia

These are the oldest carbonate rocks of the Karst Plateau deposited during the Early Cretaceous, between approximately 140 and 90 mya, mainly in a calm, shallow lagoon environment that resembled that of today's tropical islands. Most of these rocks are limestone, although there is also dolomite. Whereas limestone is mainly composed of the mineral calcite, dolomite is a rock that is made in great part of the mineral dolomite, closely related to calcite (both are *carbonate minerals*), but has a slightly different chemical composition and different structure. It is not uncommon to encounter dark grey dolomite among the oldest rock units of the Classical Karst.

The environment during the Cretaceous did not change dramatically in the area occupied by the Classical Karst, but, being very shallow-water, it was easily exposed when sea level oscillated. It is important here to keep in mind that sea level can change on different time scales and for a range of reasons. We all know about tides, sea level oscillations that occur every day and are caused by the gravitational attraction of the Moon. There are also longer scale phenomena that can cause these variations. For instance, these include the formation or the melting of ice sheets at the poles, or vertical movements, up or down, of the Earth's crust, such as those that cause the growth of a mountain chain. Carbonate platforms are particularly prone to be exposed or flooded because most of their surface sits at depths so shallow that even a modest oscillation of the sea level can cause the emersion or the submersion of vast areas. In times when sea level dropped, large portions of the platform became emergent, exposing the limestone to dissolution with the formation of karst features in all ways similar to those that are formed today. Phenomena indicating ancient karstic weathering, such as karst cavities filled with sediments and flowstones, are called paleokarst and a trained eye can recognize them in the rocks of the Classical Karst. There is actually evidence that this area of carbonate platform emerged multiple times during the Cretaceous, but a particularly prolonged episode occurred about 110 mya and is thought to represent a worldwide lowering of sea level (called "eustatic sea level fall" by geologists). It is testified to by a layer of breccia (a sedimentary

Figure 3.3.4: Breccia testifying to the important emersion episodes that the carbonate platform underwent (west of Povir) (Photo: Bogdan Jurkovšek)

rock composed of angular rock fragments cemented together) that outcrops in a narrow band stretching across the Classical Karst. This breccia probably formed because the rocks of the platform, once exposed, were fragmented and eroded into cavities produced by the ongoing karstic dissolution (Figure 3.3.4).

After this time of emersion, the sea rose again and this brought with it the re-establishment of marine conditions in the area of the Classical Karst. Limestones formed in this period contain numerous fossils such as foraminifera, a type of unicellular organism, and dasycladacean algae. Rudist shells can also be found, sometimes concentrated in levels that deposited during storms, but are not as abundant.

In some places within this carbonate succession brownish stained irregular bodies of calcite mineralisation occur in the otherwise dolomite host rock. It represents calcitized dolomite or so called dedolomite.

✦ Upper Cretaceous rudist limestones with fossiliferous platy limestone layers

Limestone also continued to accumulate in the shallow sea on the Adriatic-Dinaric Carbonate Platform during the Late Cretaceous. The circulation of waters on the shallow lagoon of the ancient Classical Karst was, however, not evenly distributed. There were areas where water circulation was more sluggish and thus oxygen concentrations were lower. Furthermore, although the seafloor topography was rather flat, some parts were characterized by deeper waters. This led to the formation of some of the most interesting and paleontologically important rocks in the geopark, the platy limestones. The dark-grey, thin-bedded, laminated limestones contain thin layers or lenses of chert, a hard, dense flint-like rock composed of microcrystalline quartz, and can smell of bitumen when broken (Figure 3.3.5). This is because they contain high concentration of organic matter, the conservation of which was favoured in the poorly oxygenated waters. This latter feature also allows for quick fossilization and enables excellent preservation of even the finest structures of organisms. Such limestones occur as thicker, individual packages within various thick-bedded shallow-water limestones which belong to the different Upper Cretaceous formations between 95 and 80 million years ago. One of them, named the Komen Limestone after the village of Komen (known also as “Komen shale” - and even “Fish shale” in the older literature by a famous Croatian paleontologist Gorjanović-Kramberger in 1895) contains the remains of fishes, various reptiles, and plants in an exceptional state of preservation (Figure 3.3.6).

Another, slightly younger platy and laminated limestone with thin lenses or layers of chert is the Tomaj Limestone. It frequent-

Figure 3.3.5: Upper Cretaceous platy and laminated Komen Limestone with chert at the village of Skopo (Photo: Stanko Buser)

Figure 3.3.6: Fish fossil from the Komen platy limestone at Komen (Photo: Bogdan Jurkovšek) and the drawing of the holotype (the first described specimen) of a fossil fish Coelodus vetteri *from the monograph on fossil fish by Gorjanović-Kramberger, published in 1895.*

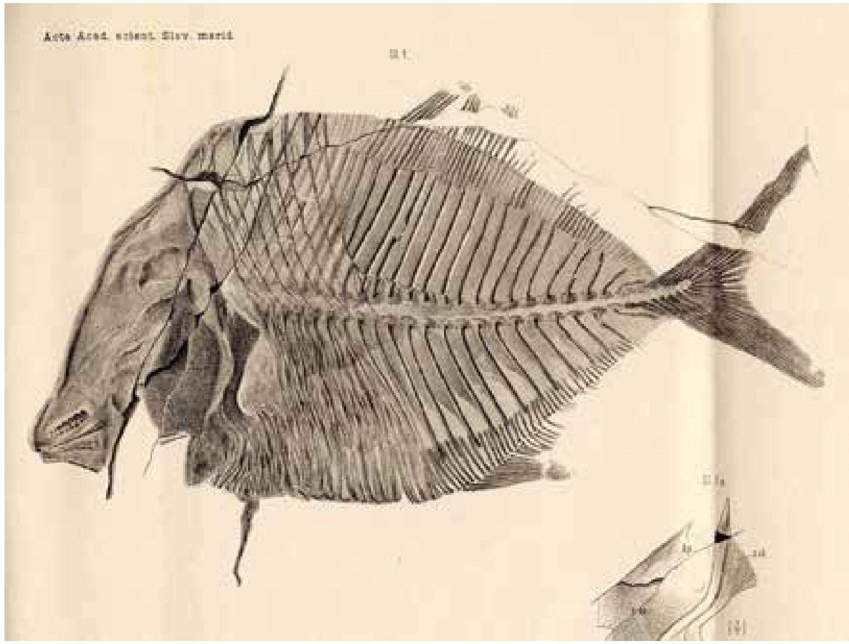
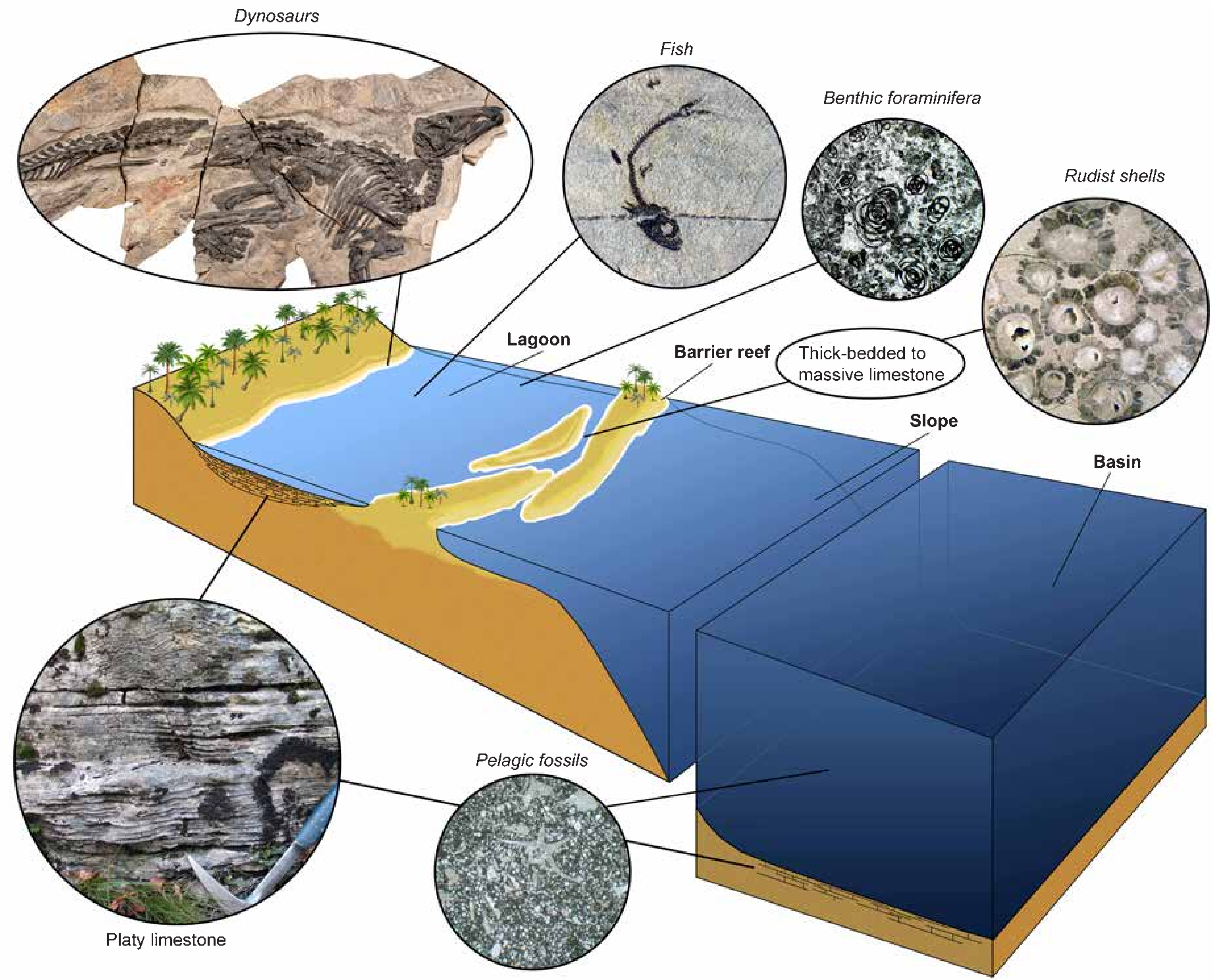


Figure 3.3.7: Reconstruction of a Late Cretaceous shallow-sea environment with typical inhabitants found as fossils on Karst Plateau (Drawing: Barbara Jurkovšek)

ly contains numerous and well-preserved fossil fish, ammonites, planktonic crinoids, and other inhabitants of the open sea (Figure 3.3.7). The presence of fossil plants with conifers dominant indicates the close proximity of land to the south of the lagoon (Figure 3.3.8; see also Chapter 4).

These rocks are mostly found in the central and northern areas of the Classical Karst Region (Figure 3.3.9). The Komen and Tomaj

Figure 3.3.8: Depositional environments of platy, thick-bedded and massive (non-bedded) limestones within a shallow-water carbonate platform, platform margin (barrier reef), and adjacent deep marine basin (model after Vlatko Brčić; Photo: Bogdan Jurkovšek and Marino Ierman, Civic Museum of Natural History Trieste)


Dynosaurs
Fish
Benthic foraminifera
Rudist shells
Lagoon
Barrier reef
Thick-bedded to massive limestone
Slope
Basin
Pelagic fossils
Platy limestone

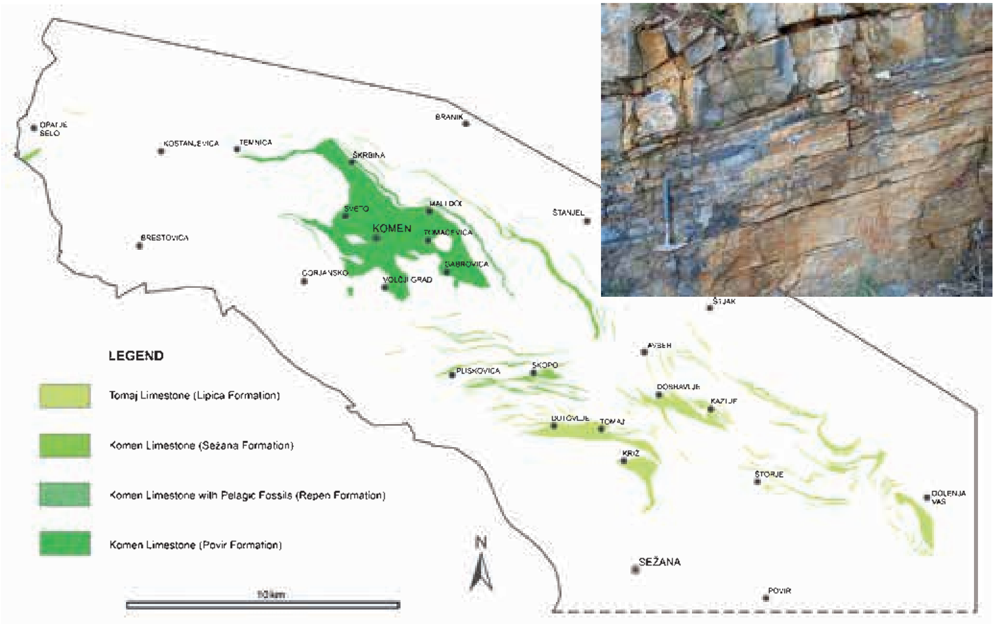


Figure 3.3.9: Upper Cretaceous platy limestones of different age in the Slovenian part of the Karst area (modified from Jurkovšek et al., 2013). Top right: Laminated Komen limestone with chert lenses at Škrbina (Photo: Bogdan Jurkovšek)

Figure 3.3.10: Rudist limestone in the road-cut at Divača (Photo: Bogdan Jurkovšek)

limestones are undoubtedly one of the oldest building materials in Classical Karst region. Even in the late 19th and early 20th centuries, local people collected slabs of these rocks for paving and roofing. A thick layer of reddish-brown soil called *terra r*ossa can form when these rocks are exposed to atmospheric agents. The vines are growing very good on this soil.

Besides these peculiar black, laminated rocks, most of the Upper Cretaceous of the Classical Karst is represented by grey and pale grey limestone. One of the most striking features of this rock is the abundance of rudists. During this period rudist bivalves, perfectly adapted to living attached to a variety of substrates, evolved into an amazing number of species with different shapes, which help geologists to determine the relative age of the rocks in question. Most typical ones resemble a cow horn. The two valves are completely different with the big conical valve usually the one sitting on the seafloor, and the small cap-shaped upper valve serving as the cover. During the Upper Cretaceous rudists thrived in the shallow waters on the carbonate platform and formed extensive colonies. Their shells represent an important constituent part of the Cretaceous carbonate rocks and are one of the geological signatures of the Classical Karst. In some instances, they grew in such high numbers that rocks appear nearly entirely made up of their shells (Figures 3.3.10 and 3.3.11).

Extensive deposits of rudist limestone in in the Classical Karst area are found, for instance, near Lipica, Kazlje, Vrhovlje, Povir, Gorjansko, Aurisina-Nabrežina, Borgo Grotta Gigante-Briščiki Col and Repen and these rocks are still being extracted in many quarries as a valuable architectural stone.

In the limestone, rudist shells can be more or less abundant, fragmented in pieces of various sizes or preserved whole. Depending on this, the colour of the rocks and their appearance when they are cut and polished, makes them more or less suitable to being carved. This has brought about many local names that are used by quarriers

Figure 3.3.11: Polished slab of Lipica Limestone displaying a cross-section of rudist cluster (Photo: Bogdan Jurkovšek)

Figure 3.3.12: Upper Cretaceous limestone with chondrodont shell fossil from north of Sežana (Photo: Bogdan Jurkovšek)

to identify the rocks they are extracting and selling. Some examples include Lipica (Figure 3.3.11), Repen, Kopriva and Granitello (see Chapter 5.1).

Due to its structure and homogeneous texture, the limestone belonging to this unit represents the most commercially valuable rock found in the Classical Karst Region. The Cava Romana Quarry at Aurisina-Nabrežina in Italy dates back to the 1st century B.C.E.. The largest quarry of Lipica/Aurisina Limestone today is Lipica 1 in Slovenia, where large blocks of massive rudist limestone are extracted (see Chapter 4).

Other typical fossils that can be found in the Upper Cretaceous limestone include those of the bivalve *Chondrodonta ioannae*. These fossils appear as leaves with many lobes and can be several centimetres long (Figure 3.3.12). Abundant accumulations of chondrodont shells can be found near Sežana and at the Monrupino-Repentabor sanctuary.

Figure 3.3.13: Paleokarstic surface denoted by small scale depression in a motorway road-cut at Kozina. Note colour contrast between light grey shallow marine limestone and dark grey palustrine (freshwater wetland) limestone (Photo: Bojan Otoničar)

✦ Upper Cretaceous-Paleocene limestone, a witness to major changes at the Cretaceous/Paleogene boundary

Major environmental changes took place at the end of Cretaceous. Some parts of the Adriatic-Dinaric Carbonate Platform surfaced again from the sea and were subjected to intense karstification. Both surface and underground karst phenomena were created (Figure 3.3.13). This happened because the movements of the plates of Earth's crust were causing the African continent to move towards the European one. This would ultimately result in the formation of the Alps and of many other mountain chains such as the Pyrenees, the Carpathians, and the Himalayas. As a consequence of this uplift, the environment on the Adriatic-Dinaric Carbonate Platform became characterized by shallower waters that could now become less saline because of the input of meteoric freshwater. This environmental change was reflected in the paleontological content of these rocks which is very diverse and features animal and plant fossils indicative of environments that could be terrestrial or aquatic with brackish or saline water. Vegetation was so abundant on the emergent parts of the platform that coal deposits can be found in these rocks at Vremski Britof, Rodik, and in the wider Basovizza- Bazovica, Lipica and Štorje areas. These were mined in the 19th and early 20th century.

The existence of many areas above sea level permitted the life of both amphibious and larger terrestrial animals. This is evidenced by the discovery of fossil remains of crocodiles, and the bones and teeth of herbivorous dinosaurs belonging to several families (Hadrosauridae, Iguanodontidae, and Dromeosauridae). The most exquisitely preserved fossils have been found in the dark, finely laminated limestones from this period and exposed near Villaggio del Pescatore-Ribiško naselje in Duino Aurisina-Devin Nabrežina Municipality (Figure 3.3.14). There, two complete skeletons of the hadrosauroid

Figure 3.3.14: Laminated limestones near Villaggio del Pescatore-Ribiško naselje, in which dinosaur fossils were found (Photo: Sara Biolchi)

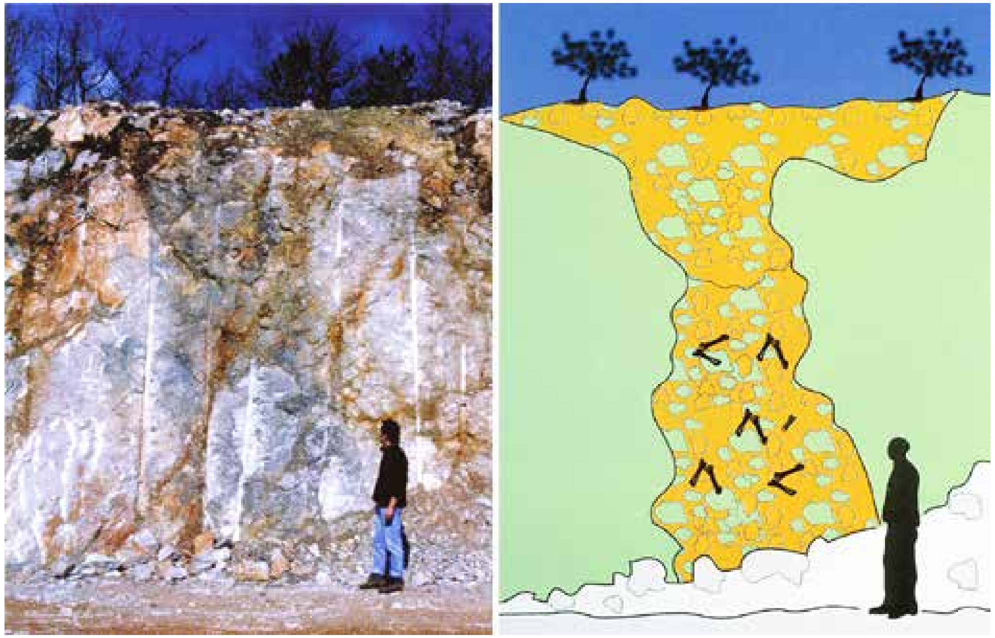


Figure 3.3.15: The locality of dinosaur bones in the breccia with limestone clasts of the Liburnia Formation that fills the paleokarstic cavity in limestones of the Lipica Formation in the road-cut at Kozina (after Košir et al., 1999)

Figure 3.3.16: The bones of dinosaurs, crocodiles and other terrestrial vertebrates in the paleokarstic breccia (left) (Photo: Matevž Novak) and the structure of dinosaur bones through the microscope (right) (after Košir et al., 1999)

Figure 3.3.17: Slivia-Slivno old quarry exposing paleokarstic breccia (from Consorti et al., 2021) (Photo: Maurizio Ponton)

species *Tethyshadros insularis* were found. Besides the hadrosaurs, this limestone also contains the remains of pterosaurs, crocodilians, fish, and other vertebrates (see Chapter 4). Fossil remains of Upper Cretaceous vertebrates, mainly dinosaur teeth and bones, have also been found in limestone breccia in a paleokarstic shaft near Kozina (Figures 3.3.15 and 3.3.16).

The Slivia-Slivno abandoned quarry exposes breccia made up of disorganised limestone blocks (Figure 3.3.17). This collapse breccia also indicates a longer emersion episode accompanied by the development of an extensive palaeokarst system. The Slivia Breccia, also known comercially as “Napoleon Slivia” or “Breccia Carsica Marble”, was widely used as ornamental building stone.

Within the Upper Cretaceous-Paleocene limestone, a very important moment of geological history is recorded: the Cretaceous-Paleogene boundary (K-Pg boundary), marking one of the most devastating mass-extinctions to have ever occurred on the planet and coinciding with the impact of a large asteroid. The changes that occurred at the K-Pg boundary were so severe that geologists have placed the transition between the Mesozoic and the Cenozoic eras at this point in time. Numerous animal and plant species, both on land and in the oceans, went extinct including dinosaurs and ammonoids as well as the rudists that cannot be found in rocks younger than this event. In the Classical Karst the, K-Pg boundary is well exposed at Dolenja vas.

✦ Paleocene and Eocene foraminiferal limestones

At the end of the Paleocene, the sea level slowly began to rise again and marine conditions predominated once more. Another sequence of limestone records this phase of the history of the Classical Karst area. Fossils in the Paleocene and Eocene rocks tell us how life in the seas changed after the end of the Mesozoic era. Many forms of algae and foraminifera are found but are very different from those that can be observed in the Cretaceous rocks. Foraminifera, in particular, saw the appearance of many new species and became progressively larger so that in the youngest parts of these rocks they can be so large as to be seen with the naked eye. As a result of the presence of a range of large benthic (seafloor-dwelling) foraminifera, in some strata these accumulated in large numbers, these limestones are easily identifiable (Figure 3.3.18). Some of the foraminifera resemble ancient coins and therefore were given the name of Nummulitids (from the Latin word *nummus* meaning the coin) (Figure 3.3.19) by paleontologists, while others, called Alveolinids, had a peculiar structure characterized by the presence of numerous cavities that, when observed with a hand-lens, look like small circular holes (Figure 3.3.20). There are actually many different species of these fossils which again helps geologists to assign an age to the rocks in which they occur.

Figure 3.3.18: Foraminiferal limestone with Nummulitids and Alveolinids from west of Kozina (Photo: Matevž Novak)

Figure 3.3.20: Alveolinid foraminifer as seen through the microscope (Photo: Matevž Novak)

✦ Flysch of the middle Eocene deep ocean basin

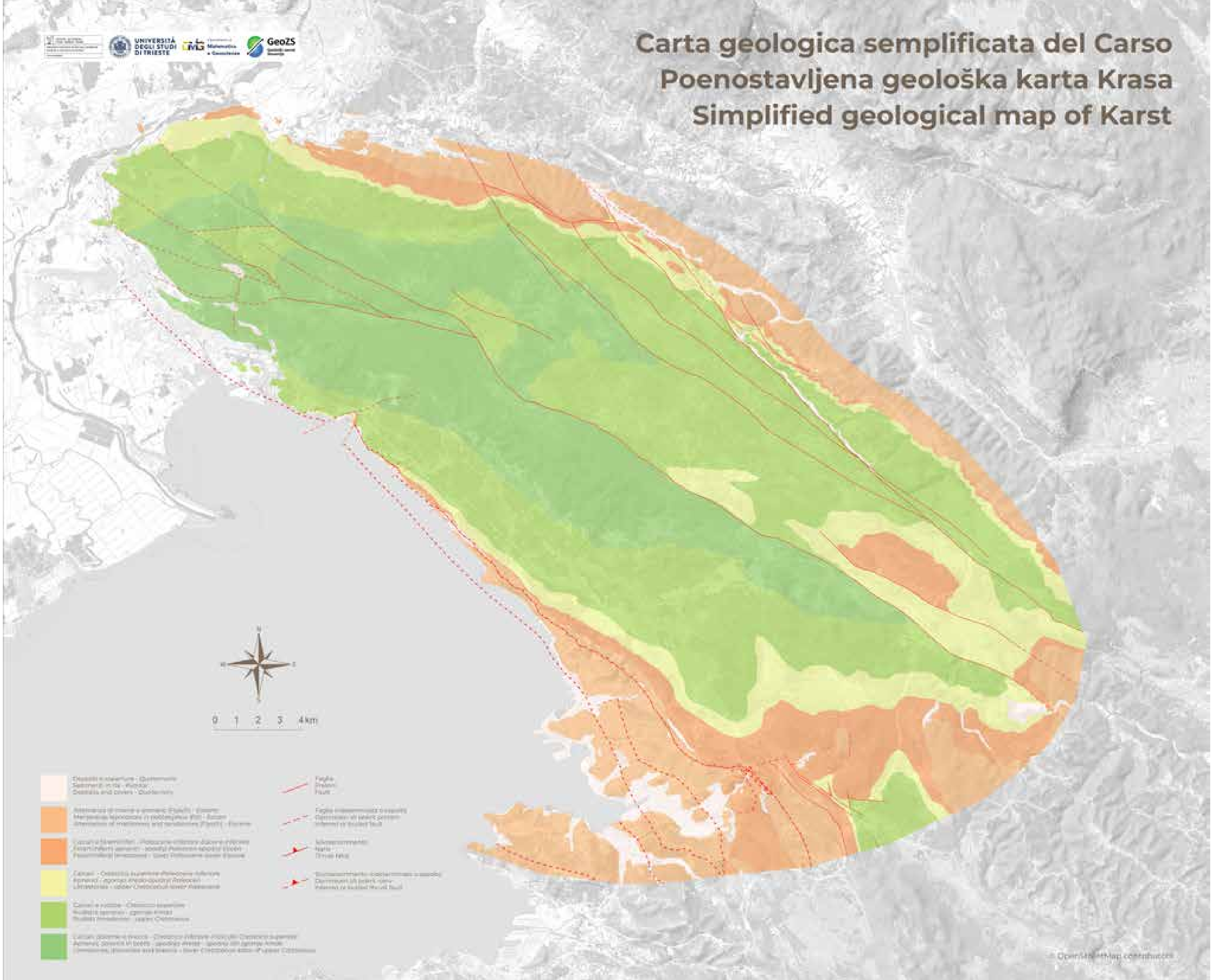
The youngest of the rocks that characterizes the Classical Karst area are completely different from those of earlier ages. Unlike the limestone that make up most of the Karst Plateau, these rocks are mainly sandstones and more or less clayey rocks (siltstone, claystone and marlstone), alternating within a sequence that is well known by the term flysch (Figure 3.3.21).

The sediments that make up these rocks derive from the erosion of older rocks and reveal the uplift of the Alps. While the mountains were growing, progressively older rocks were exposed to rain, winds and other atmospheric events. They were therefore eroded and, through rivers, brought down to the sea. At times such sands

Figure 3.3.19: Nummulitids, resembling coins, naturally isolated from weathered rock (Photo: Matevž Novak)

Figure 3.3.21: Alternation of marlstone and sandstone beds composing a flysch sequence south of Gora (Photo: Bogdan Jurkovšek)

and clays, when they were not yet lithified, slid down the continental slopes in the form of submarine landslides. Such landslides generated dense sediment-laden submarine flows called turbidity currents by geologists. After having slid into deeper parts of the seas, these currents lose velocity and therefore release their sediment load. The submarine deposits generated by a turbidity current are called turbidites. The flysch is mainly made up of turbidites, organized into thin layers. On the surfaces of some layers, traces of crawling and burrowing can be seen, mostly made by unknown animals in the former sandy seabed. Such fossil traces are called ichnofossils. Furthermore, these rocks sometimes contain abundant plant fragments, revealing the presence of extensive vegetation cover on the nearby emergent lands. In the vicinity of the Miramare Castle, some large blocks of the limestones rich in Nummulitid and Alveolinid fossils can be found. Geologists have observed that these blocks are underlain and covered by flysch, characterized by folds and deformations. This indicates that these blocks are actually parts of a large landslide that slid while flysch was still depositing. Such evidence testifies that, somewhere, the uplifting causing the rise of the Alps had brought the Cenozoic platform rocks to the surface and that they had collapsed into the sea where the turbidites of the flysch were accumulating (see Chapter 4).


Carta geologica semplificata del Carso
Poenostavljena geološka karta Krasa
Simplified geological map of Karst
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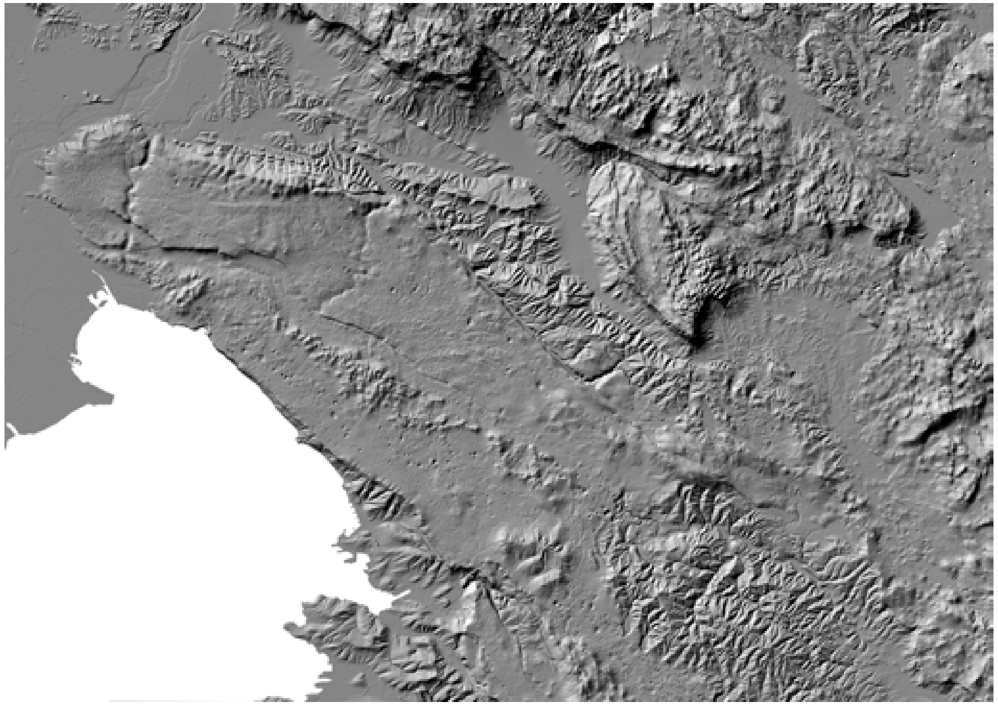


Figure 3.4.1: Shaded relief of the Classical Karst and surrounding area realised in the framewrok of HYDROKARST Interreg Italia-Slovenija 2007-2013 project

Figure 3.3.22: Simplified geological map of the Karst area, made for the geopark visitor centre at the Natural History Education Centre of Basovizza-Bazovica; the legend consider the same simplifed grouping of lithologies of the geological column in the Figure 3.3.3

3.4 Structural setting of the Classical Karst area

The present-day morphology of the Classical Karst area results from a long history of deformation that began millions of years ago. However, its structure can be summarized simply as a wide plateau with an area plunging to the southwest where the city of Trieste and the Gulf of Trieste are located (Figure 3.4.1).

This lay-of-the-land derives from the orogenic phases that involved the area over the last 70-80 million years, from the Cretaceous up to now. Orogeny is a process by which mountains are formed due to a convergence between two tectonic plates. The two plates, in this case, were the Adria, that is to say, the northernmost segment of the African plate, and the Eurasian plates (Figure 3.4.2).

3.4.1 The Dinaric orogeny

One orogenic phase produced the Dinaric chain, a mountain belt that begins at the Italian/Slovenian border and finishes where Albania ends and Greece begins (Figure 3.4.2). The Classical Karst is located in the northern sector of the Dinarides. As mentioned before, the Dinarides result from the convergence between two plates. During the Cretaceous (70-80 million years ago), these plates were separated by an ancient ocean called the Tethys. When the two plates started to converge on each other, the rocks of the oceanic floor began to subduct. Note that the oceanic crust is denser than that of the continental plates. This is why when a continental plate collides with an oceanic one, the oceanic plate dives beneath the continental one, sinking into the Earth's interior. During the evolution of this convergence, the process of creating a mountain belt reaches its apex when all the denser (oceanic) rocks have been subducted and the two equally dense continental plates collide. In geology, the subducting plate is named the lower plate, the second the upper. To describe the development of orogeny and the accretionary mechanisms of the mountains in simple terms, one can imagine the upper plate as a bulldozer or snowplow that tears away some

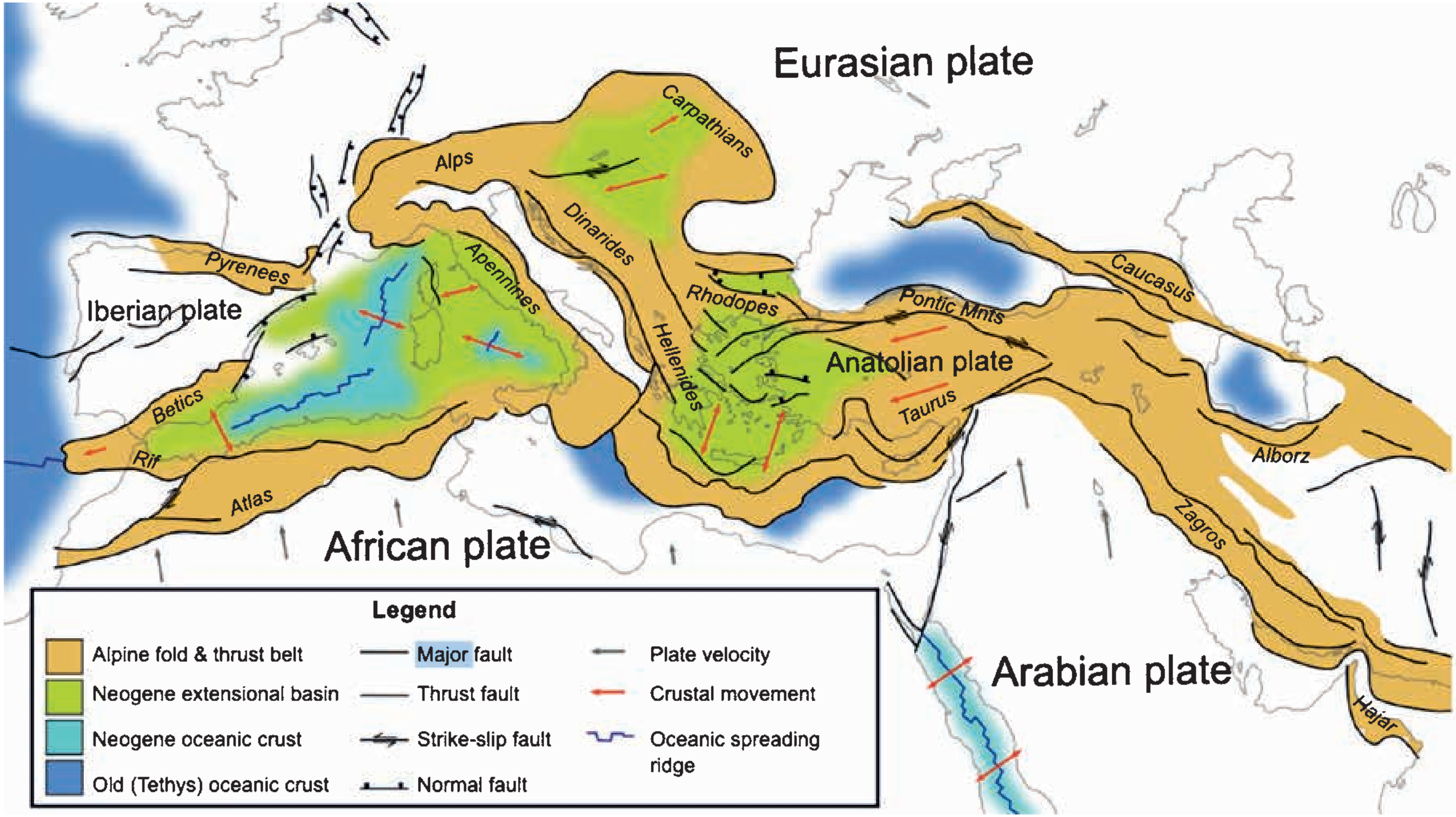


Figure 3.4.2 : Tectonic map of Europe

portions of the lower plate rock, accumulating them at its leading edge. This “front” is thicker close to the “bulldozer”, that is to say, close to the overriding, or upper plate, and thinner toward the lower plate, forming a sort of wedge. Geologists name the area where the bulldozer works as the “hinterland” with the “foreland” being the sector where the wedge is headed. Returning to the Classical Karst area, we can imagine that a bulldozer starts to compress, fold and break the rocks from northeast to southwest, creating an advancing wedge with its most external part being the Classical Karst. This natural bulldozer moved above a subducting plate at a rate of a few millimeters per year, but it worked for a million years creating the Dinaric orogenic belt. At the front of the advancing wedge, the lower plate bent due to the bulldozer’s weight, creating accommodation space for sediments that derived from the erosion of this huge

Figure 3.4.3: Simplified evolutionary sketch of the Dinaric orogeny

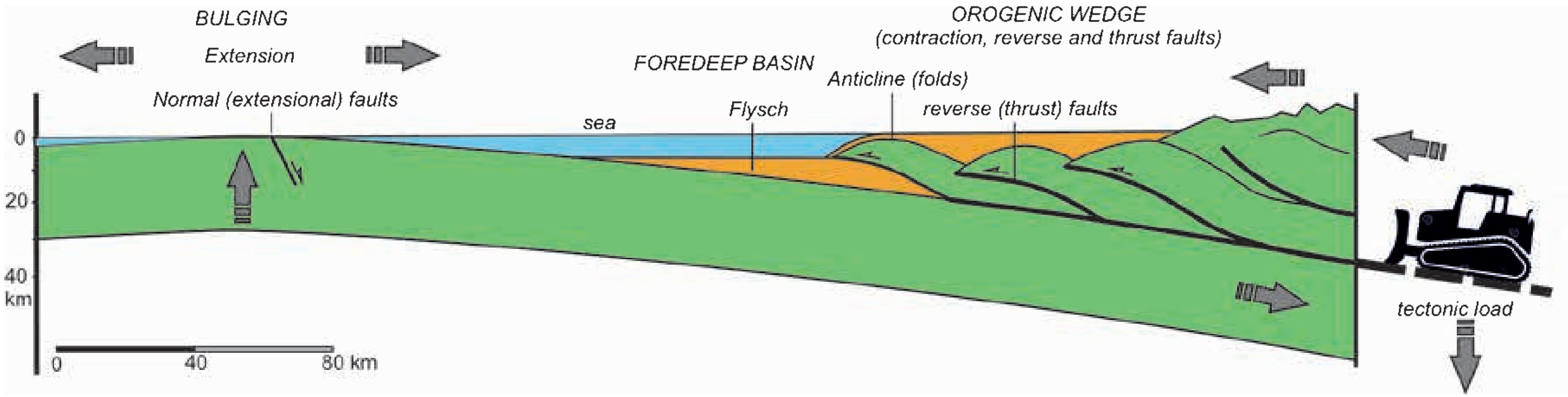
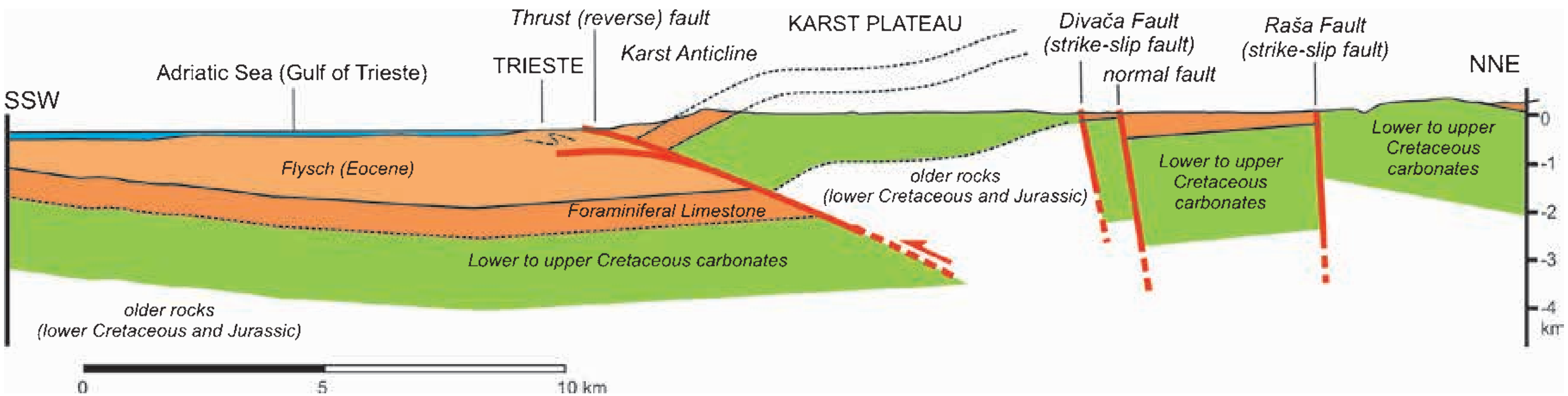


Figure 3.4.4: Geological cross-section



wedge (flysch). This process ended 20 million years ago. Hence, the geological structure of the Karst area is substantially the same today as it was 20 million years, depicting a large asymmetric fold, namely an anticline (a fold with a shape of A) with its southern limb more inclined than its northern one.

3.4.2 The structure and the history of the Classical Karst

If we imagine vertically cutting through the Karst, we would observe its internal structure, namely the Karst anticline (Figure 3.4.4).

As mentioned, this anticline is asymmetric, meaning that one limb is steeper than the other. The limb dipping toward the southwest is more inclined than the limb dipping toward the northeast. This asymmetry is because the rocks have been pushed from northeast

Figure 3.4.5: Mechanism showing the generation of a fold deforming a towel

to southwest. To understand this process, one may imagine moving a towel on a table (Figure 3.4.5). When the towel is pushed, the folds are asymmetric because the hand is pushing in one direction.

Coming back to the rocks outcropping in the Karst area today, in the center of the Karst Plateau outcrop the geological map shows the older rocks, i.e., the Lower to Upper Cretaceous rudist limestones with fossiliferous platy limestone layers (see Section 3.3; green areas in Figure 3.3.22), and moving towards the edges of the Karst the younger rocks are present (orange rocks in the geological map of Figure 3.3.22).

The geological map also shows red lines crossing the area. These red lines are the major faults. In general, faults represent fractures in the rocks that are formed as a consequence of compressional or extensional tectonic phases during the geological evolution of the area. Faults may be classified as 1) reverse faults that are surfaces in which a rock block moves up relative to another block; 2) normal (extensional) faults in which a rock block moves down with respect to another block and; 3) strike-slip faults, in which the two blocks move laterally. In the Classical Karst area, all these types of faults exist. The geological map and the cross-section show a reverse fault in the southwestern area, cutting the topographic surface in Trieste. This reverse fault is also known as a thrust fault, namely, a low-angle reverse fault, formed during the last contractional phase of the Dinaric orogeny, together with the Karst Anticline. Both these structures are derived from the contraction of the rocks. Moving northward there are two major faults: the Divača and Raša (see Chapter 4). These are strike-slip faults generated during a younger phase, during which ancient normal faults are reactivated (reactivation means that a fault changes its kinematic during the geological time, e.g., a fault that was a reverse fault due to the change of tectonic forces in the geological time may be removed as a normal fault or strike-slip fault). This means that the Divača and Raša faults at the start of their history were normal faults and then altered their movement in a horizontal mode. Note that, in general, extensional faults form when the rocks are stretched. However, only a contractional phase has been described, namely the Dinaric orogeny and the contractional structure (reverse and thrust faults).

To understand the tectonic mechanisms that generated the normal faults, it is necessary to look at the simplified sketch of Figure *3.4.3* and the bulldozer. The bulldozer creates the contractional wedge and the folds and reverse (thrust) faults. However, the thickening of the wedge increases the load on the lower plate, inducing bulging and stretching in the foreland area, hence the condition for the development of extensional (normal) faults. These normal faults are involved in the contractional wedge when the bulldozer reaches its position. Now only one question remains unsolved, namely why the Divača and Raša faults are now strike-slip faults. After the end of Dinaric orogeny's major contraction phase, the movement of the Adria plate continued, slightly changing its direction, i.e., from northeast to the north (the neo-Alpine phase). This change induced a rotation of the rocky blocks and a strike-slip reactivation of the ancient normal faults.

3.5 Geomorphology of the geopark area

The Karst is a low carbonate plateau lying between the Gulf of Trieste and the Vipava Valley at an altitude ranging from a few metres and about 500 m above sea level (a.s.l.). It is bounded to the southwest by the Gulf of Trieste and a low-lying non-carbonate flysch landscape, and to the northwest by the alluvial Friuli Plain. Flysch hills over 600 m above sea level separate the Karst from the Pivka basin. To the southeast, the Karst is well separated from the flysch areas of Brkini and the Reka Valley on one side, while on the other, more southerlyn side, it gradually merges with the karst areas of Čičarija, the Podgorski Kras and the Matarsko Podolje. The Karst Plateau stretches for 46 km southeast to the northwest and is also inclined in this direction, from Lokev at 450 m a.s.l. to Doberdò-Doberdob at 98 m a.s.l.. It is up to about 15 km wide and covers about 750 km^2.

The Classical Karst belongs to the Mediterranean area and has a Mediterranean climate, influenced by its location far to the north and the altitude. Summers are hot and dry, while winters are quite cold with a characteristic cold northeasterly wind - the *bora*. Most of the rain falls in autumn. In the central part of the Karst, in Komen, which is only ten kilometres from the sea, the average annual temperature is 12°C at an altitude of 290 metres. The amount of precipitation is relatively high, as the long-term averages range from 1,400 to 1,650 mm per year, with 1,000 mm per year on the coast.

The Classical Karst's karstification has been evolving for more than 10 million years and the original morphologies across the surface are today recognized only with difficulty. The karst surface features, just as they appear today, are the result of the predominant lithological conditionings and partially due to tectonic-structural ones.

Starting from the sea and running in a northeastly direction, it is possible to encounter different morphological units, all oriented NW-SE:

- a coastal karst between Duino-Devin and Aurisina-Nabrežina;
- a hilly alignment of the San Primo-Sv. Primož Mt. – Gurca-Gorka Mt. – Belvedere-Banovski Mt. – Calvo-Globojnar Mt.;
- the levelled landscape between Sistiana-Sesljan, Aurisina-Nabrežina and Basovizza-Bazovica;
- the hilly area which goes from Mt. Ermada-Grmada to Mt. Volnik-Lanaro as far as Mt. Tabor;
- the wide, levelled landscape between Doberdò-Doberdob, Kostanjevica na Krasu, Komen, Dutovlje and Divača on the southern side of which is a further structurally depressed area related to a range of faults between Colle Nero-Jamlje, Brestovica and Divača is present;
- the hilly northern alignment dividing the Classical Karst from the Vipava Valley.
- Separated from them are the fluviokarstic Rosandra-Glinščica Valley and northern part of levelled karstic plane of Matarsko Podolje with blind valleys on its NE edge.

As a result of the solubility of karst rocks and geological unconformities in them, the large amounts of precipitation and inflows of allogenic waters from peripheral non-carbonate rocks, a great number of characteristic surface and underground karst forms have developed here. Their study is important for understanding the geological, hydrogeological and climatic dynamics, not only of the Classical Karst, but also of the wider area.

Small-scale surface relief rocky features

The most distinctive karren fields were formed on the thick-bedded to massive Upper Cretaceous limestone in the wider Lipica, Opicina-Opčine, San Pelagio-Šempolaj and Borgo Grotta Gigante-Briščiki areas and in part of the Karst around Divača. As a rule, this type of limestone does not disintegrate as quickly on the surface and beneath soil cover as the younger, usually thinner-bedded Paleocene limestone, which is therefore more frequently reshaped as a result of karst surface processes. The larger rock masses of Cretaceous limestone have remained largely intact. However, most of the land surface has been deforested and the area around the karrens was primarily used for grazing. Karrens consist of rock masses ("stone teeth") up to 5 metres high, formed between fis-

Figure 3.5.1:
A) Karrenfeld close to the Colognatti Abyss (Photo: Furio Finocchiaro);
B) Rain flutes and solution pans have been carved out by rainwater (Repen) (Photo: Bojan Otoničar)

sures. The subcutaneous rock features that shape the rock relief of the lower parts of the karrens and, in some places, the peaks that have been reshaped under the soil, represent the oldest phases of karren/stone teeth formation. The subaerially exposed rocks have been reshaped by rainwater and thus solution flutes and runnels as well as kamenitzas cover the surface of the rocks (Figure 3.5.1 A and B). Overgrowth of the once mostly bare karst surface associated with direct exposure to rain has transformed them beneath lichens, mosses, and soil. Thus, the rock relief provides traces of the evolution of the karst surface and its use (from deforestation to grazing to re-forestation).

Medium-scale karst surface features

In detail, the Classical Karst is dissected by numerous closed karst depressions. Among them, dolines predominate, and collapse dolines, uvalas (*doli*), dry valleys and conical hills are also frequent (Figure 3.5.2). The surface is often rocky because the thin soil is not continuous and the rocky floor is not completely covered.

Dolines of a range of shapes, fills (*terra rossa*) and anthropogenic transformations (cleared with dry stone walls around them, archeological sites, vineyards, vegetable gardens or cultivated fields) (Figure 3.5.3) are very frequent in the Classical Karst. Since the soil in the Karst is often present only at the bottom of the dolines, vegetable gardens and cultivated fields are often planted. The bottoms of the dolines were levelled, while stones were removed from the slopes and buried or piled up to form dry stone walls (Figure 3.5.3). The floors of dolines were often also used for water storage (i.e., ponds or, in slovene, "*kal*") (Figure 3.5.4).

Figure 3.5.2 :
Solution doline near Padriciano-Padriče village
(Photo: Furio Finocchiaro)

Figure 3.5.3: Anthropogenically transformed doline immediately below the walls of the prehistoric settelment of Debela Griža near Volčji Grad pri Komnu (Photo: Bojan Otoničar)

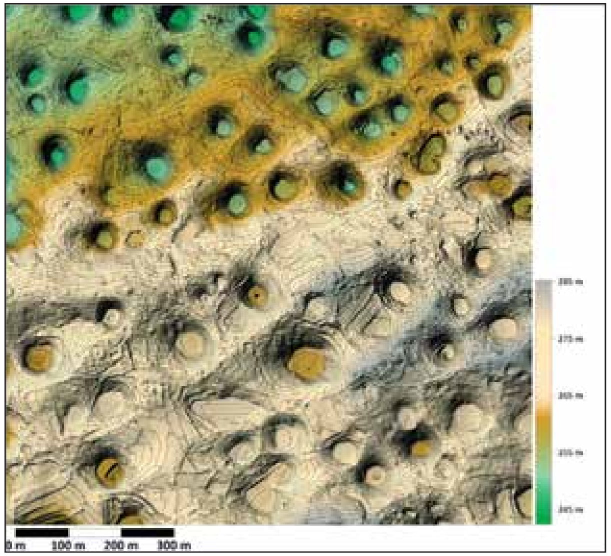


Figure 3.5.4: The pond on the bottom of the Percedol-Prčendol Doline near Opicina-Opčine (Photo: Furio Finocchiaro)

Figure 3.5.5: DEM of Lipiški Ravnik in the southeastern part of the Classical Karst is characterized by dolines with steep rocky slopes and anthropogenically flattened floors. In some dolines soil has been dug and taken to nearby villages for use in vineyards and gardens. The contour interval is 1 m. (from Mihevc & Mihevc, 2021)

More than 22,400 dolines have been identified with 5,900 on the Italian side and 16,500 on the Slovenian side of the border, covering a total area of about 20 km^2. In some areas of the Classical Karst Plateau, such around Basovizza-Bazovica, Opicina-Opčine, Divača, Borgo Grotta Gigante-Briščiki, Gorjansko, Doberdò-Doberdob and San Martino del Carso-Martinščina, the density of dolines is greater than 70 per km^2.

Most dolines, 62%, have an average diameter up to 50 m, 31.5% have a diameter between 50 and 100 m (Figure 3.5.5) with only a dozen have a diameter larger than 500 m. Their average depth is about 30 m. Larger collapse dolines in the Classical Karst are 50 to 200 m deep and as much as a few hundred metres wide, with a volume of as much as several million m^3. Collapse dolines are distributed throughout the Classical Karst area. The largest concentrations of 27 major collapse dolines are located in the Divača area, in the hinterland of the river Reka ponors, and near Sežana. They mark a path of the underground river Reka and some of the largest caves in the Classical Karst, such as the Škocjan Caves - Kačna Cave system. There are also some smaller concentrations of collapse dolines in the northern part of the Classical Karst such as those south of Kobjeglava, and in the area between Kazlje and Štorje. In the selected area of the Divača Karst (31 km^2), collapse dolines were found to account for about 4% and dolines for about 7% of the total area, but it is estimated that the total volume of collapse dolines is more than four times the total volume of dolines.

In the levelled area between Aurisina-Nabrežina and Basovizza-Basovica, the depressions exhibit a very large range in diameters and depths according to their genesis (solution or collapse) and age (evolution).

A high concentration of dolines (with a frequency greater than 40 per km^2) can be found in the wide plateau of the Gorizia-Monfalcone area. Located at an altitude of 100 - 200 m a.s.l., the plateau is characterized by a large number of dolines that are similar in size and depth, with an average diameter between 50 and 80 m.

Although the surface of the Classical Karst is densely covered with dolines (Figure 3.5.5), they account for less than 10% of the total area (excluding the hilly part of the Karst). The simple interpretation of the origin of the relief in the Classical Karst is complicated by the rather frequent occurrence of denuded caves, indicating that in some places a significant portion of the surface relief features were actually created during the transformation of underground caves.

Like denuded caves, collapse dolines could also be considered a reflection of the underground karst on the karst surface.

Apart from the already mentioned level surfaces, there are no karst forms of larger dimensions in the Karst iself, with the possible exception of the uvala near Senadolice (Figure 3.5.6). Uvala Senadolska dolina or Dol represents an elongated, closed karst depression, a little more than 5 km long and, on the perimeter over a kilometre wide, running SE-NW, at the bottom of which there are several beautifully shaped dolines. It is open only to the NW, where it turns a slight bend at Senadolice to a level area almost 100 metres lower than the SW part of the Karst.

The formation of the uvala can be attributed to the accelerated dissolution in the area of the fissure zone compared to the slower dissolution of the clayey and brecciated, crushed or broken inner zone of the Raša Fault, or it may even be a remnant of the old blind valley that drained water from an already completely eroded adjacent area of flysch.

Figure 3.5.6: Uvala Senadolski Dol near Senadolice in the southeastern part of the Classical Karst runs NW – SE direction along the Raša Fault (Photo: Bojan Otoničar)

Contact karst and dry valleys

In the Classical Karst area, the most famous sinking river is the Reka (becoming the Timavo in Italy at its re-emergence), which vanishes underground at the end of the great Vreme Valley into the Škocjan Caves (Figure 3.5.7). Some smaller streams also sink at Dane and Senožeče. The Vrhpolje Valley near Kozina can be considered a „fossil" blind valley. However, the best known and most typical are the blind valleys along the northeastern flank of Matarsko Podolje along the not clearly defined southeastern border of the Classical Karst.

Although there are a number of smaller dry valleys in the Classical Karst, often still active and more or less pronounced in relief, two stand out. Pletni Dol (Mali Dol) (Figure 3.5.8), which crosses the Classical Karst between the Branica Valley and Brestoviški Dol, and the most pronounced and largest, Vallone-Doberdobski Dol that crosses the Gorizia-Gorica-Monfalcone Karst between the Vipava Valley and Monfalcone.

The genesis of these dry valleys is still debated. Some authors believe that these valleys are what remains of ancient riverbeds, others believe they may be a trace of ancient unroofed caves which originat-

Figure 3.5.7: Blind valley of Reka River before it sinks into the Škocjan Caves. Note the levelled surface dipping slightly towards the NW of the Karst (central part of the figure) with a hilly landscape on the sides (Photo: Matej Blatnik)

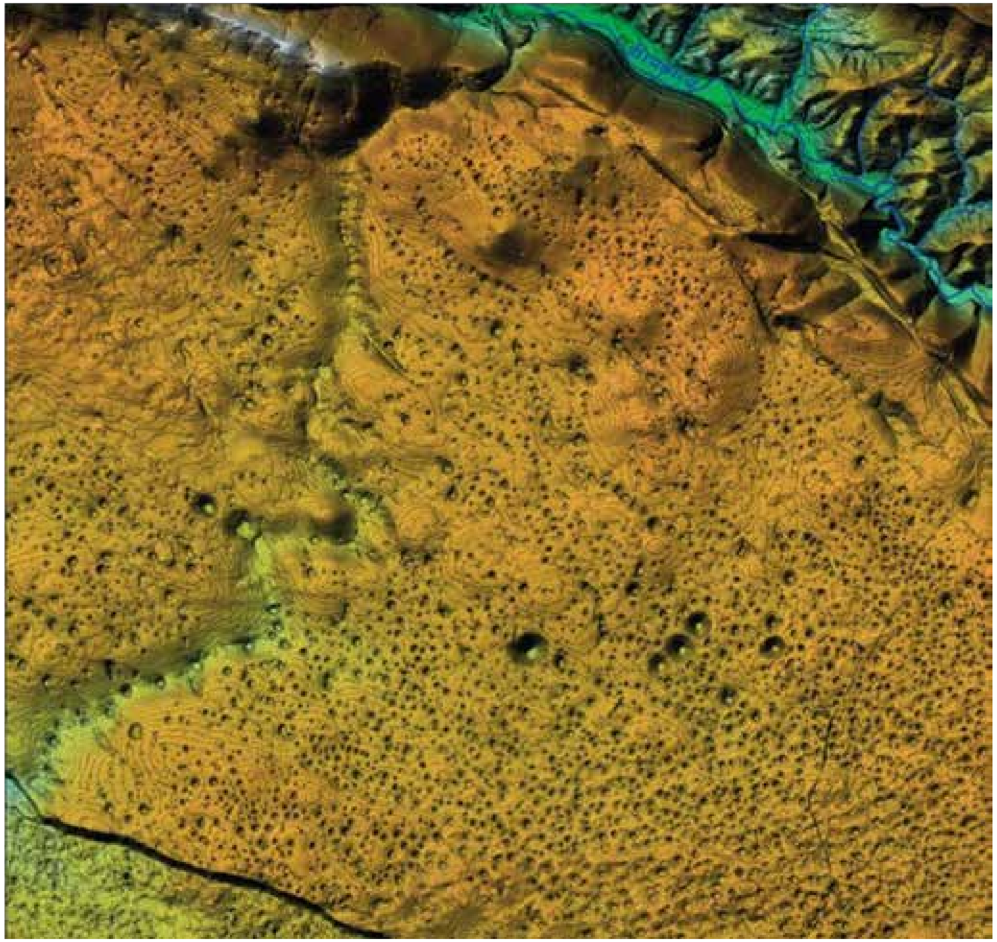


Figure 3.5.8: DEM of levelled landscape of the central part of Classical Karst with numerous dolines and Mali Dol dry valley. A doline has also formed in the dry valley. The escarpment in the lower left corner of the figure has developed along the Divača Fault. The contour interval is 5 m (from Mihevc & Mihevc, 2021)

ed by the lowering of the karst surface, others suggest the interconnection of different karst depressions such as polje, caves and uvala.

The already mentioned Brestoviški Dol (Figure 3.5.9), where the Slovenian part of the Classical Karst reaches its lowest altitude, only a few dozen metres above sea level, and where the Classical Karst region is supplied with water, is a tectonically induced depression developed along the regional Divača Fault.

Figure 3.5.9: Veliki or Brestoviški Dol in the NW part of Classical Karst is a tectonically-induced depression developed along the regional Divača Fault which is especially well reflected in the relatively steep NE flank of the depression (left side of the figure) (Photo: Matej Blatnik)

Figure 3.5.10: The Rosandra-Glinščica fluviokarst Valley (Photo: Franco Cucchi)

Fluviokarst Rosandra-Glinščica Valley

“Klinš’ca”, as the local inhabitants call it, or, simply, “Valle” as the people of Trieste call it, is at the extreme eastern side of the Classical Karst Plateau (Figure 3.5.10). It is a canyon-like valley, excavated in the Cenozoic limestone by the Rosandra-Glinščica torrent and represents a rare example of a karst river valley with surface hydrology. Its origin is mainly due to the presence of faults and overthrusts and the different predisposition to erosion between the limestone and

marls, making it a beautiful example of lithological and structural control on morphogenesis. The whole area, and in particular Mt. Stena, is characterised by surface and underground karst features. 100 caves have been surveyed, some of which are more than 100 metres long. Among them, one of the most beautiful is the Savi Cave, rich in speleothems, the growth axis of which are characterised by geochemical and physical changes (controlled by climate as well as by the dynamics of the host karst system). The Valley was also known in the past and was used to carry the salt from the coast to the inland villages. Caves with prehistoric remains, the ruins of castles and hillforts, mills, country churches, the ruins of the Roman aqueduct and abandoned quarries demonstrate the intense and ancient settlement of the area. The Rosandra-Glinščica Valley‘s peculiar climatic and geomorphological conditions and its geographical location make it a special and important habitat.

Coastal karst

Along the coastline between Aurisina-Nabrežina and the Villaggio del Pescatore-Ribiško Naselje the limestones, that outcrop widely, are rich in epigean and hypogean karst features. Marine aerosols contribute to the development of all karst features by enhancing their shape. The mixture of freshwater and seawater not

Figure 3.5.11: The Duino-Devin Cliff (Photo: Rodolfo Riccamboni)

only promotes the genesis of notches, but also of caves and springs. The moderately sloping coast up as far as Sistiana-Sesljan becomes a high cliff as far as the small port of Duino-Devin (Figure 3.5.11). The chromatic contrast of rock, sea and vegetation creates a unique and fascinating landscape in every season.

Caves

In the Classical Karst within the geopark, more than 4,000 caves have been explored, with 3,000 in Italy and almost 1,800 in Slovenia. The numerical difference is due to the fact that in Slovenia only those caves that are longer or deeper than 10 metres are recorded in the cave cadastre while in Italy smaller ones are also included. Only about ten caves are longer than 1,000 m.

The analysis carried out has highlighted that about 45% of the caves have a prevailing horizontal development, while 30% have a prevailing vertical one. About 25% have a complex shape in which shafts alternate with horizontal sections.

The basic data of caves/shafts are kept in the cave cadastre of the Slovenian Speleological Association, which is managed and directed by the Karst Research Institute ZRC SAZU, and in the Regional speleological cadastre of the Friuli Venezia Giulia Region, managed by the Geological Survey of the Autonomous Region of Friuli Venezia Giulia.

The longest cave network in the Classical Karst is the 20,200 m long cave Kačna jama while the deepest is the 378 m deep Claudio Skilan Cave.

Today in the Classical Karst there are caves that were primarily formed in the flooded or phreatic hydrological zone in different levels and zones. A special element of global value of the caves around Divača and Sežana - Opicina-Opčine, together with the Škocjan Caves, are the phreatic caves, which are found at various levels and are of exceptional importance for the study and understanding of karst hydrogeological systems and the associated geological evolution of a particular karst and karst/fluvial contact areas. The deepest karst features identifiable below the surface are the caves, the lower parts of which are still permanently or intermittently flooded. These can be intersected by ponors and collapse dolines (Škocjan Caves) or by deep stepped shafts and steep fossil epiphreatic channels (Kačna jama, Jama 1 v Kanjeducah, Brezno v Stršinkni Dolini -Jama Sežanske Reke, Trebiciano-Labodnica Abyss and the Lazzaro Jerko Cave). Shallower caves, just below the surface, and thus older, are dry, subhorizontal or slightly dipping caves, now in the vadose zone, and which represent fossil or relict phreatic channels which in the past drained a significant proportion of karst groundwater to springs. Caves of this sort include the Divaška jama, Vilenica, Jakofčičeva jama, Gustinčičeva jama v Blažčevi dolini, Lp2 (at Lipica), Lipiška jama, Škamprlova jama, Grotta Claudio Skilan, Grotta di Padriciano, Grotta Impossibile, Grotta Lindner, Grotta Gigante-Briška jama, Grotta Torri di Slivia-Pejca v Lascu and the Grotta Noè-Pečina v Rubijah. These caves are often accessible through vertical shafts or are so close to the surface that karst denudation has opened the cave ceilings (Figure 3.5.12).

Figure 3.5.12:
The denuded cave entrance of the Grotta Azzurra-Zidaričeva pejca Cave (Photo: Furio Finocchiaro)

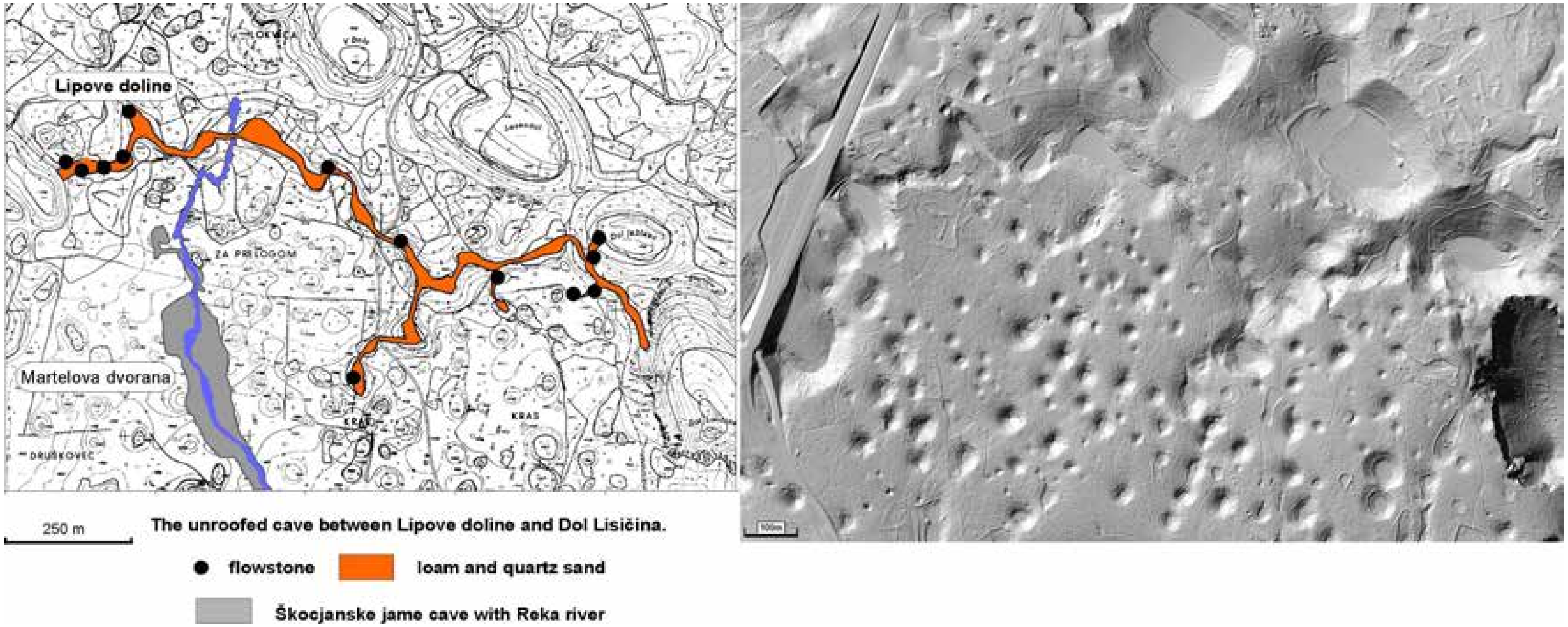


Figure 3.5.13: Topographic map with location of the denuded cave at Lipove Doline above Škocjan Caves (left) (from Mihevc 2001) and a Lidar DEM (Slovenian Environment Agency) of the same area (right)

The related relative raising of the territory or lowering of the erosion base and simultaneous lowering of the karst surface due to denudation is confirmed by the numerous denuded caves or caves without ceilings (e.g. the denuded cave with stalagmite in the Lipova dolina above Škocjan Caves (Figure 3.5.13), a large denuded cave near Povirje, various denuded caves near Sežana, and a denuded cave with stalagmites in Borgo Grotta Gigante-Briščiki). Today, these caves are part of the karst surface, but their form is basically a relic of the phreatic/epiphreatic underground karst, which was later transformed into a vadose hydrogeological zone, and subsequently even on the karst surface and subject to surface processes. The denuded caves and the caves observed today in the vadose zone may have been formed at the same time and be of the same age, separated only by a later different location according to the morphology of the surface. The oldest caves in the Classical Karst today are those closest to the karst surface, including the caves in the area of Tabor, Monte Lanaro-Volnik Hills and Mount Ermada-Grmada where the Grofova jama Cave, with a sedimentary fill at least 10 million years old, is particularly interesting and important.

Cave shafts are numerous in the Classical Karst and represent vertical channels that can be independent or represent entrances to horizontal caves. Here it is worth mentioning the entrance to the longest cave in the Classical Karst, the Kačna jama Cave, the Abisso della Volpe Shaft and the independent shaft of Lipiško brezno. The entrance to the Kačna Jama is located in a large doline at the bottom of which opens a 186 m deep system of parallel shafts, the Abisso della Volpe is 181 m deep, while the Lipiško brezno shaft is an independent cave feature and, at 210 m, probably represents the deepest known single vertical shaft in the Classical Karst.

The origin of large shafts in the Classical Karst is not yet fully understood, since it is not clear whether they are shafts that originated in the vadose zone, created by percolating water from the surface or whether they are actually subvertical phreatic or epiphreatic channels.

3.6 Hydrogeology of the geopark area

The Classical Karst aquifer

Every time you walk along the Karst Plateau you will be amazed by the uniqueness and variety of landscapes that surround you. Sometimes just a few steps are enough to pass from forest to arid, stony ground, from spires and hums to chasms and depressions, from soft meadows to impervious *karrenfelds*. Everything tells a story lasting millions of years, in which water, as a tireless sculptor, has modeled every rocky outcrop, making it original and unique. Water, however, only stays on the surface for short periods of time. The extensive network of discontinuities (layers, fractures, faults, ...), enlarged and expanded by karst phenomena, allows for the easy infiltration and a rapid accumulation of water below the surface, creating one of the most important and productive aquifers of the entire Mediterranean area. (An aquifer is a body of rock and/or sediment that contains water and releases it in appreciable amounts). The symbol of this aquifer are the Timavo Springs, that, with their average flow rate of 30 m^3/s, represent the most important source in the area of the geopark.

But where does all this water come from? And why does it come out at this particular place?

To answer this question, we need to turn to geology.

As we have already described in the previous chapters on the Classical Karst there are two different lithologies: carbonate rocks (limestone and, in part, dolomite) and siliciclastic rocks, here represented by flysch (an alternation of marl and sandstone in which the silicatic component prevails over the carbonate one). These two geological units have different hydrogeological characteristics and influence the recharge and outflow in the aquifer. In fact, the former are extremely karstified and facilitate infiltration and underground flow (high permeability), while the latter are not karstified at all, favouring surface runoff and representing a barrier to underground flow (low permeability).

When observing the Hydrogeological Map (Figure 3.6.1), note how the flysch is present in an almost continuous fashion, both in

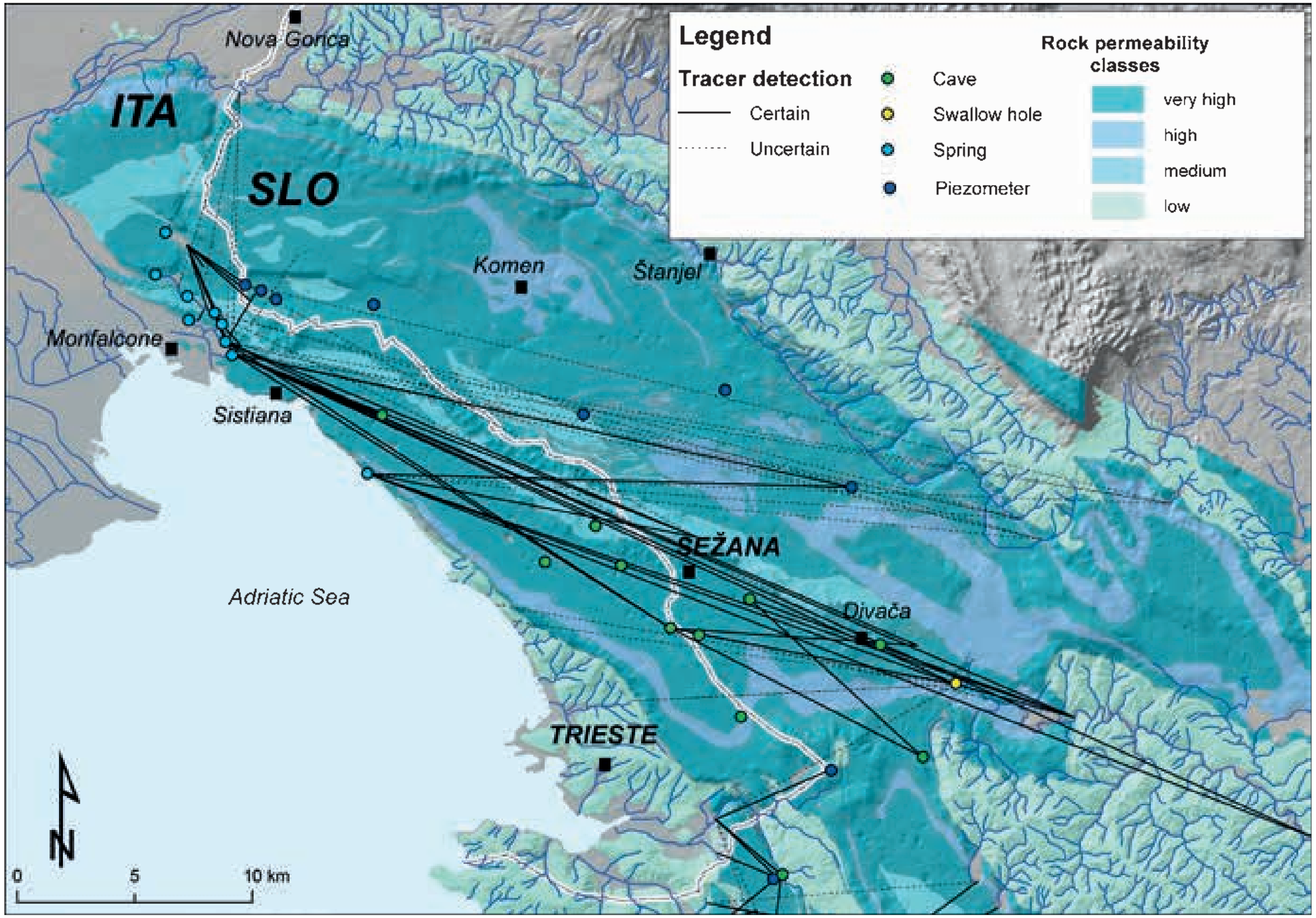


Figure 3.6.1: The hydrogeological map of the Classical Karst (modified from Zini et al., 2022)

the northern and eastern sector of the Classical Karst, nearly surrounding it. Its presence is a hydrogeological barrier that favours the accumulation of water in the limestone and the groundwater flow towards the north-west, up to the sector in correspondence of the area between Aurisina-Nabrežina and Monfalcone where the barrier is lacking and the groundwater can re-emerge in numerous springs.

The aquifer recharge

The aquifer is recharged by three distinct contributions: rainfall, water from the Reka and Raša Rivers, and inflows from the Isonzo Plain aquifer (Figure 3.6.2).

Given the extension of the Karst Plateau and the heavy rainfall in this region, precipitation represents the main contribution to the re-

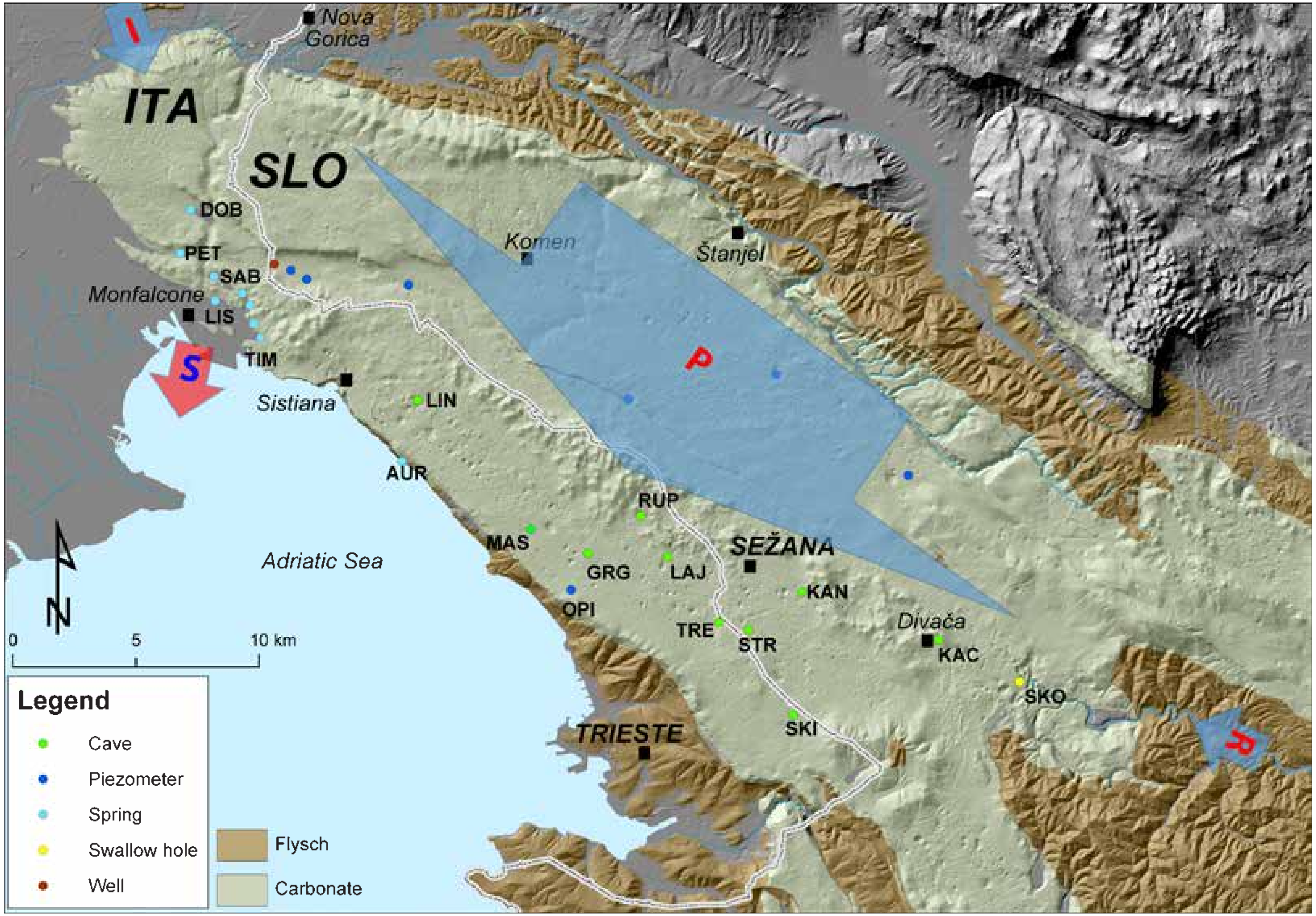


Figure 3.6.2: The hydrostructure of the Classical Karst with the main water points: SKO Škocjan Caves, KAC Kačna jama-Abisso dei Serpenti Cave, KAN Jama 1 v Kanjaducah Cave, SKI Claudio Skilan Cave, STR Brezno v Stršinkni dolini - Jama Sežanske Reke Cave, TRE Trebiciano-Labodnica Cave, LAJ Lazzaro Jerko Cave, GRG Grotta Gigante - Briška jama Cave, RUP Rupingrande Abyss, OPI Opicina piezometer, MAS Massimo Abyss, LIN Lindner cave, AUR Aurisina Springs, TIM Timavo Springs, LIS Lisert Springs SAB Sablici Lake, PET Pietrarossa Lake and DOB Doberdò Lake. The blue arrows identify the various contributions to feeding the aquifer and the red arrow the average flow values of the various springs (modified from Zini et al., 2022)

Figure 3.6.3: Vreme's swallow hole. Tracing test using a fluorescent green dye (uranine) (Photo: archive of the Department of Mathematics and Geosiences - University of Trieste)

charge of the Classical Karst aquifer, which is located in a transition area between the Mediterranean and continental climate, where the average rainfall varies from about 1000 mm/year along the coast to 1800 mm/year inland and to values over 2000 mm/year in the Reka basin. Due to the intense and widespread karstification of the rock mass, the low vegetation cover and often the negligible amount of soil, there is no hydrographic network on the surface, but rainwater quickly infiltrates, recharging the groundwaters.

An important contribution can be observed in the north-western sector of the Karst between the towns of Merna and Sagrado where the waters of the Isonzo-Soča and Vipacco-Vipava Rivers are in direct contact with the limestone. In this area a series of swallow holes activates the transfer of surface and groundwater towards the karst aquifer. The water infiltrates at numerous points and in this way has created a complex karst network that brings the waters towards the springs between Mucille-Močile and the Timavo Springs themselves.

The contribution of the Raša and Notranjska Reka (Upper Timavo) Rivers to the aquifer is the most interesting from a hydrodynamic point of view. These watercourses flow on the surface as long as they pass over the flysch, but when they reach the limestones, a series of sinkholes drain their waters at depth. The Raša discharges are relatively modest and even for long periods the riverbed remains dry, while those of Reka are decidedly greater, and represent on average more than a quarter of the recharge of the entire karst aquifer.

The Reka/Timavo aquifer system

The *Notranjska Reka* River, named the *Timavo Superiore* in Italian, originates on the slopes of Mt. Dletvo on the border between Slovenia and Croatia. It flows for more than 50 km on flysch until it enters onto the limestone about 7 km upstream of the Škocjan Caves. In this part of the river the karst process is active and the Reka loses part of its water. This phenomenon is particularly evident near Gornje Vreme where during low flow periods all the Reka waters are swallowed and downstream the riverbed is dry (Figure 3.6.3).

When the flow rate is higher than about 1 m^3/s the Vreme swallowhole is unable to capture all the water which continues its flow towards Škocjan Caves. The Reka enters the Škocjan Caves, which are more than 6 kilometres long, at an altitude of 317 meters above sea level (a.s.l.), crosses some very deep collapse dolines (the Mala dolina is 120 metres deep and the Velika dolina is more than 165 metres deep) and after having covered about 3.5 kilometres of a gigantic gorge, 10 to 60 metres wide and over 100 metres deep, it disappears into the siphon of the Dead Lake at 212 metres a.s.l.

The *Notranjska Reka* has an extremely variable flow rate, ranging from over 380 m^3/s during floods to 0.18 m^3/s in dry periods. The flow rates can be so high that sometimes the underground conduits cannot drain all the water. The groundwater rises abruptly, flooding sections of caves that are usually inactive. The air in the cavities is expelled abruptly giving rise to what, in 1800s, were referred to using the German term "*luftloch*" (blow-hole) (Figure 3.6.4). Using these points speleologists discovered and explored the caves, reaching the Timavo's underground conduits including the Kanjaduce Cave (Jama 1 v Kanjaducah), the Abyss at the Stršinkna dolina-Jama Sesanke Reke, the Trebiciano-Labodnica Abyss and the Grotta meravigliosa di Lazzaro Jerko (Wonderful Cave of Lazzaro Jerko). Furthermore, the Timavo can also be reached in the cave system of Brezno treh generacij (Three Generations Abyss, B3G) - Kačna jama (Snake Cave, KAC).

Kačna jama is an enormous hypogeous complex that developed in Cretaceous limestone about 1 km west of the village of Divača and about 800 m west of the Dead Lake. The abyss opens at an altitude of 435 metres a.s.l. and has an access shaft 186 metres deep, leading to a larger system of conduits distributed on two levels reaching a depth of 280 metres.

The upper level is hydrogeologically inactive but richly concreted. The lower level, which is accessed from the upper one through a series of shafts and conduits, develops sub-horizontally and consists of a complex system of conduits. Here, in low water conditions, the Reka/Timavo flows freely up to a siphon located at 156 metres a.s.l. The siphon can drain a maximum flow rate of 15 m^3/s. With higher flow rates the water level in the cave rises and a series of overflow conduits are activated, and drain flow rates up to 130-150 m^3/s. For higher flow rates the water level increases further still and even the gorge of the Škocjan Caves begins to flood.

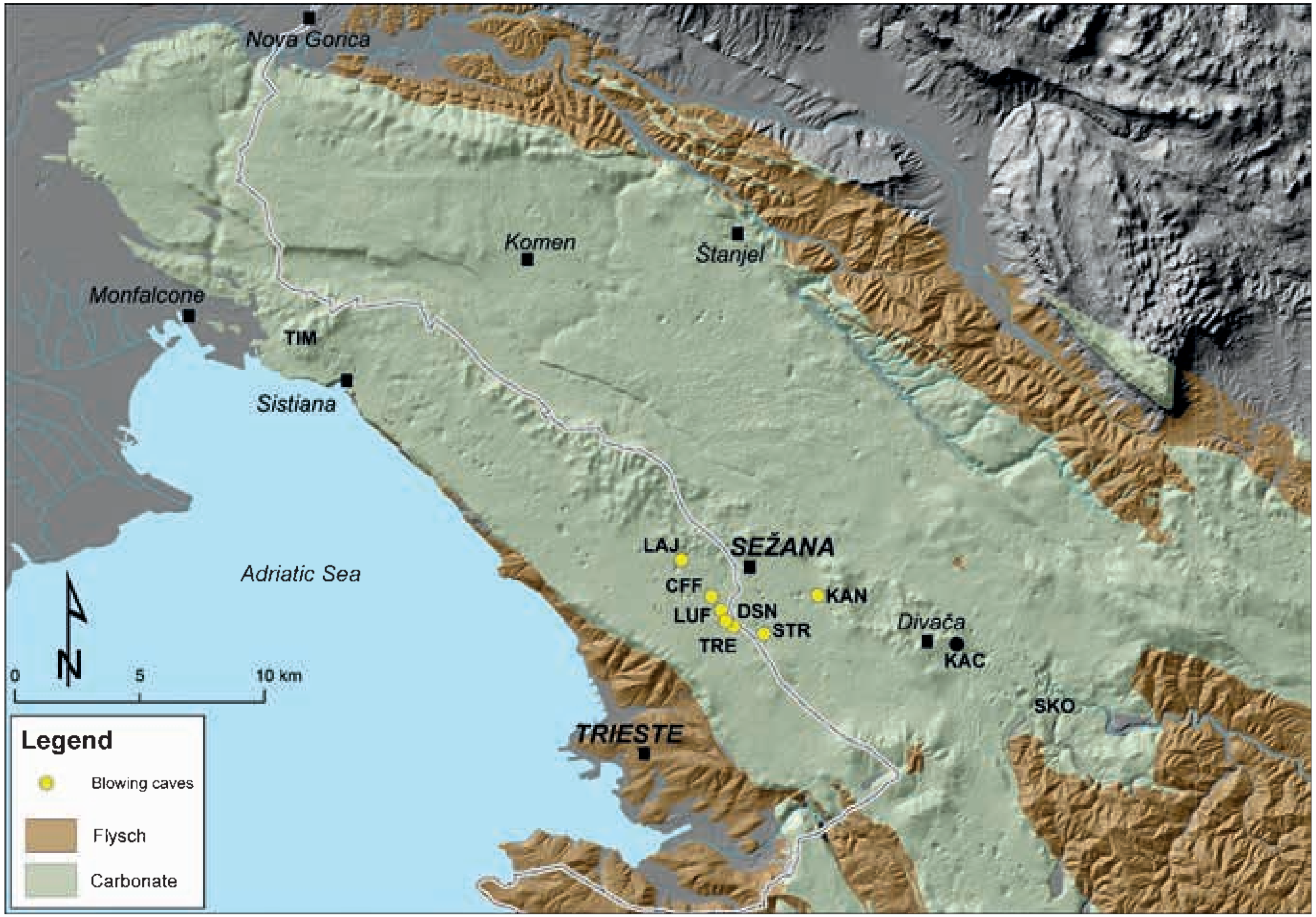


Figure 3.6.4: The "Luftloch" or blowing holes. SKO Škocjan Caves, KAC Kačna jama-Abisso dei Serpenti Cave, KAN Jama 1 v Kanjaducah Cave, STR Brezno v Stršinkni dolini – Jama Sežanske Reke Cave, TRE Trebiciano-Labodnica Cave, DSN Sette Nani Doline, LUF Luftloch Cave, CFF Pozzo presso il Casello ferroviario di Fernetti–Grotta Decapitata-Abisso Nagasaki Cave, LAJ Lazzaro Jerko Cave

In 2010, the Brezno treh generacij Abyss was discovered. It is connected with the new galleries of the Kačna jama Cave and forms an underground system of more than 20 km in length. It owes its name to the fact that during the explorations speleologists found traces of old excavation works, probably created at the end of the 19th century.

Five kilometes downstream of the Kačna jama Cave is the Kanjaduce Cave (Jama 1 v Kanjaducah). This is a 330 metre deep cave with a development of 1.5 km. At the bottom of the cave, at an altitude of about 20 metres a.s.l, there is a large conduit (600 metres long, 50 metres wide and 60 metres high) through which Reka/Timavo water flows. After a further 2.6 km we reach the underground system, the Jama Sežanske Reke - Brezno v Stršinkni Dolini, at the bottom of which the waters of the Reka/Timavo flow at about 15 m above

Figure 3.6.5: Reka/Timavo at the bottom of the Trebiciano-Labodnica Abyss (Photo: Alberto Maizan)

sea level along a wide tunnel. The cave has two separate entrances: the first, Jama Sežanske Reke, opens at 354 m a.s.l, and leads to the entrance siphon, while the second, Brezno v Stršinkni Dolini (344 m a.s.l.), leads to the exit siphon. The entrance siphon was explored by cave divers to a depth of 60 metres. From this cave, through a series of siphons, some of which are still unknown, you can reach the Trebiciano-Labodnica Abyss. This is the best known cave on the Karst and played an important role in karst hydrogeology research. Explored in 1841, for over eighty years it was the deepest cave in the world. Today it has a total planimetric development of more than, 2,400 m and a depth of 370 m (Figure 3.6.5). Recent cave-diving explorations have ascertained the presence of large flooded conduits that reach 40 m in depth, well below sea level, and several hundred metres in length.

One more cave that intercepts Timavo waters is the Grotta Meravigliosa of Lazzaro Jerko Cave, which opens in Col in Monrupino-Repentabor at an elevation of 302 m above sea level and 3.5 km north of the Trebiciano-Labodnica Abyss. The cave is mainly vertical, with numerous shafts that lead to two large halls, on the bottom of which water flows at an altitude of about 4 metres a.s.l.

Lazzaro Jerko is the last known cave in which it is possible to observe the Reka/Timavo directly. This is probably due to the fact that downstream the Timavo conduits are completely flooded and below sea level. The connection between all these caves with the Aurisina-Nabrežina, Timavo and Sardos Springs was confirmed by a series of tracer tests made with a range of tracers on several occasions.

During floods, however, and in concomitance with the increase in flow rates at the Škocjan sinkhole, the groundwater level can rise by tens of metres (up to over 100 m), flooding the deepest sections of some caves such as the Rupingrande and Massimo Abysses, the Claudio Skilan and Federico Lindner Caves, Dolenca jama and the Drča jama Caves.

The springs

Along the coastline from Aurisina-Nabrežina to the town of Monfalcone, where the limestone/flysch contact is at topographically low altitudes and often below sea level, the presence of numerous

springs draining the waters of the Classical Karst aquifer can be observed. Starting from the south-east, the first spring zone to be found is the Aurisina-Nabrežina Springs (Figure 3.6.6). These total 9 springs, which develop on a front of about 350 m, located near the limestone/flysch contact zone, which in this area is found on the beach. The waters today are collected in an artificial drainage trench which is parallel to the coastline, and which served as the aqueduct of the city of Trieste from 1857 to 1971.

From Aurisina-Nabrežina to Villaggio del Pescatore-Ribiško naselje there are other numerous outflows, often below sea level and not always permanent, with an estimated average total flow of 0.5-1 m^3/s and an extremely variable outflow depending on the regime. The largest springs are located below sea level to the west of the Bay of Sistiana-Sesljan.

In the westernmost area, between Doberdò-Doberdob and Monfalcone, a complex system of springs, karst lakes, and sinkholes can be observed, giving rise to a unique hydrogeological system and ecosystem (Figure 3.6.7).

Lake Doberdò-Doberdob is the northernmost of this series of karst lakes that also includes Mucille-Močile, Pietrarossa-Prelosno, and Sablici-Sabeljsko. These depressions, the bottom of which is located at altitudes between 1 and 5 m a.s.l., bring light to the waters of the karst aquifer. In each of the lakes there are permanent spring areas and sinkholes that regulate the water regime. During the periods of spate, the flow rate of the springs increases quickly and the sinkholes sometimes fail to drain all the water that pours into the lakes, making the level rise to over 10 m in a few hours.

This behavior characterized the whole area until the 1960s. The later construction of drainage canals in Pietrarossa-Prelosno and Sablici-Sabeljsko modified the hydrodynamics of this area, limiting the increase in water levels.

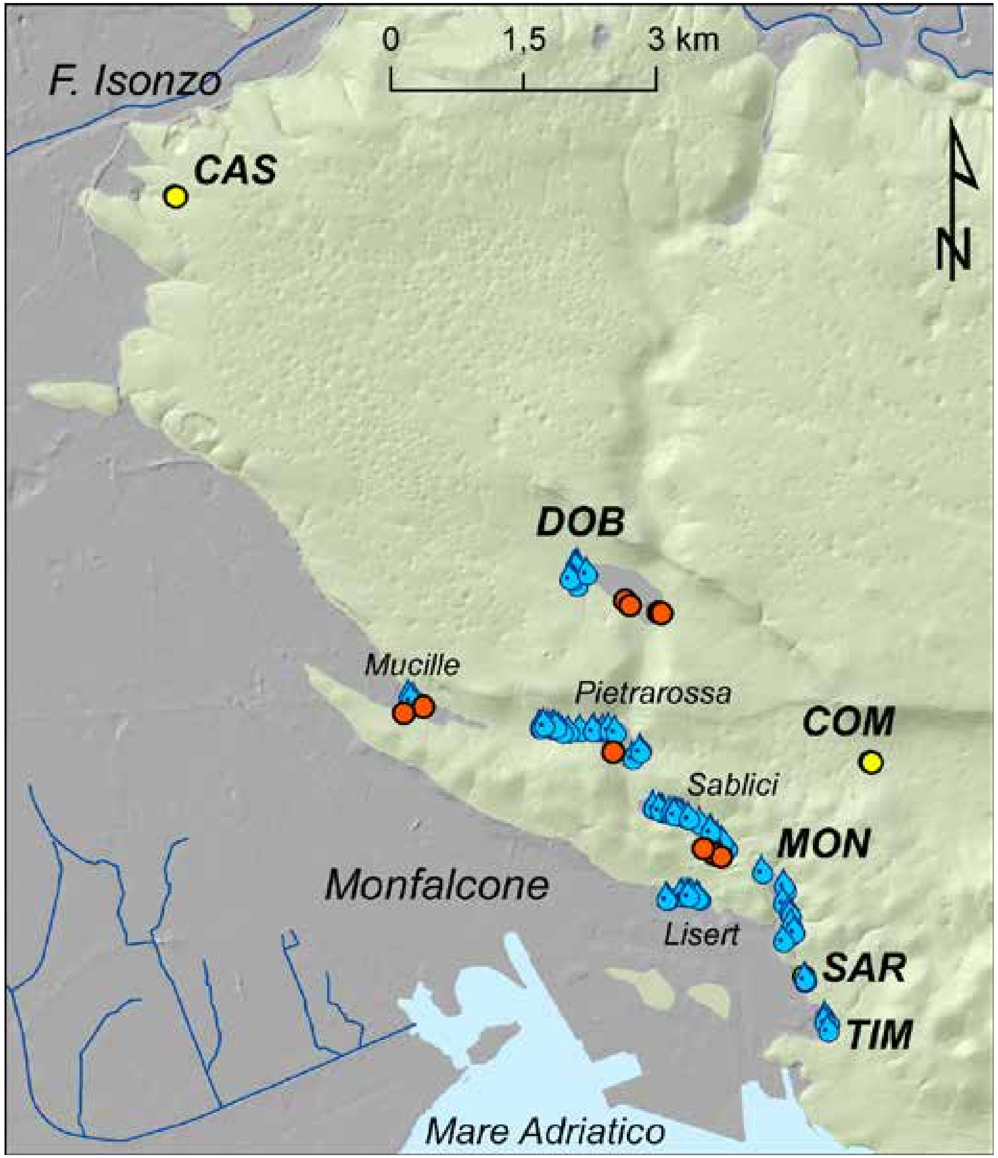


Figure 3.6.7: Springs and water points of the western sector of the Classical Karst.

Figure 3.6.6: Aurisina-Nabrežina Springs in flood condition: note the muddy waters that flow through the beach (Photo: archive of the DMG- Department of Mathematics and Geosciences - University of Trieste)

In San Giovanni di Duino-Štivan there are the Timavo Springs, which represent the main emergence of the Classical Karst. The sources consist of four springs collected in three branches that flow into a single channel that after 3 kilometres flows into the sea in the Gulf of Monfalcone. From the three branches of the springs there is a complex and articulated network of wide conduits that reach a depth of 83 m below sea level and a development of over 1500 metres.

In addition to the Timavo springs, the area also includes the Sardos Springs (Figure 3.6.8) and since 1929 the whole area is tapped for the water supply of the city of Trieste.

The hydrodynamics of the aquifer

The Timavo Springs represent the central junction of the hydrogeology of the whole Classical Karst, as they drain most of the waters that feed the aquifer. At this point the waters of the Reka, the waters coming from the Isonzo and Vipacco Rivers, and the waters linked to the precipitations of the whole Classical Karst flow together with different regimes.

Each flood, however, has a unique behaviour, since the flow of water within the aquifer is related not only to the amount of rainfall, but also to the hydrogeological conditions prior to the single event (low water conditions, flood,...) and the distribution of rainfall over the entire area.

The waters of the Reka River - swallowed at Škocjan Caves - affect the entire eastern sector of the Karst up to the area of Duino-Devin. In their subterranean course they mix with the waters of the precipitation that infiltrates the plateau and finally emerges in all the coastal springs from Aurisina-Nabrežina to San Giovanni di Duino - Štivan (Figure 3.6.9).

During the most intense flooding events some overflow conduits are activated, which causes this water to also flow from the Sardos Spring. However, the waters of the Reka/Timavo cannot reach the westernmost sector of the Karst (the Isonzo Karst) where other contributions prevail.

Figure 3.6.8: Sardos Springs (Photo: Luca Zini)

Figure 3.6.9: Timavo Springs during flood (Photo: Luca Zini)

The waters that flow in the Isonzo Karst, in fact, are basically fed by two contributions, with the waters dispersed by the Isonzo-Soča and Vipacco-Vipava Rivers and the precipitation that infiltrates in this area. The waters of the Isonzo-Vipava system are the main source of supply in this sector of the Classical Karst and sustain the flow rates of all the springs from the Mucille-Močile to the Moschenizza-Moščenice Canal. During dry periods, when the flows of the Reka in Slovenia are very low (a few hundred litres per second), the Timavo Springs are also largely fed by this source.

In this framework, the Sardos Spring represents the point of contact between the western system fed by the Isonzo/Vipava system and the eastern one linked to the Reka/Timavo, and according to the different hydrogeological regimes we observe the prevalence of one contribution over another or their mixing.

GEODIVERSITY IN PICTURES: GEOLOGICAL ATTRACTIONS OF THE GEOPARK

4.1 Introduction: the geodiversity and the geosites of the geopark

In the same way as biodiversity, geodiversity is defined as the diversity of non-living elements of nature - including its minerals, rocks, sediments, fossils, soils, landforms, topography, geological and morphogenetic processes, and hydrological forms. Geodiversity, besides having its own values, supports life in the Karst and thus it has a great influence on biodiversity and its evolution. From microscopic to macroscopic life, geodiversity is always present. Nowadays, the concepts of geodiversity and biodiversity lead to better conservation management and tourism improvement. Highlighted in the seventh point of the Declaration of the Rights of the Memory of the Earth, signed at Digne (France) in 1991, is the phrase: "we have always been aware of the need to preserve our memories – our cultural heritage. Now the time has come to protect our natural heritage. The past of the Earth is no less important than that of Man. It is time for us to learn to protect this Earth heritage, and by doing so learn about the past of the Earth, to learn to read this 'book', the record in the rocks and the landscape, which was mostly written before our advent".

There is therefore a geological heritage represented by those places having a scientific interest which allows an understanding of the history or evolution of an area. These places, called geosites, are worthy of conservation and enhancement, and are part of what we call "natural heritage", which is that set of biotic and abiotic aspects distinguishing an area.

Figure 4.1.1: The geosite Doberdò-Doberdob Lake. The area of the Nature reserve of Doberdò-Doberdob and Pietrarossa-Prelosno Lakes is characterized by a high level of geo and bio diversity (Photo: Roberto Valenti)

The natural variety of minerals and rocks, together with the geological, geomorphological, pedological and climatic processes, create the necessary conditions for the development of life and its variety. With this in mind, there is no doubt that the geodiversity of the Karst/Carso/Kras geopark is unique, so much so as to be recognized as a universal symbol of karst phenomena typical of temperate climates.

In this area, characterized by all kinds of superficial and underground karst features, by a particular hydrogeological network, and rare fossils, 61 geosites have been selected from the long lists of geologically and geomorphologically valuable natural features, officially listed in the Italian and Slovenian registers. These geosites are thus the icon sites to describe the geodiversity of the Classical Karst and its scientific value for the understanding of karst phenomena and the geological processes which created them.

In Italy, the geosites have been cataloged and described in the Geosites Inventory of the Friuli Venezia Giulia Region. Similarly, in Slovenia, such valuable natural features are designated a nature conservation status in a register maintained by the Institute of the Republic of Slovenia for Nature Conservation and are protected by the Nature Conservation Act.

Based on scientific criteria and depending on their importance and uniqueness, the geosites have been classified as being of international, national, regional or local interest. This classification is then associated with the prevailing geological characteristic, so that a geosite can be further described as being of geomorphological (GM), geological (G), paleontological (P), hydrogeological (H), or other interest.

The map and list of all geosites with a brief description can be found in the Annex I.

4.2 Geodiversity in pictures

Among all the recognized geosites in the Classical Karst, below are briefly described the most representative of the karst landscape, not only for their particular scientific interest, but also from a geotouristic perspective. The order of description is merely geographical, from NW to SE.

4.2.1 The karst lakes (geosite n. 3)

The southern part of the Isonzo Classical Karst sector is affected by a number of tectonic lines, trending WNW-SE, that give rise to elongated depressions (*polje*) occupied by four lakes directly fed by the waters of the Classical Karst aquifer. The northernmost and largest *polje* is the Doberdò-Doberdob Lake; to the south, two modest hills separate it from the Pietrarossa-Prelosno Lake and the Mucille-Močile and Sablici-Sabliči Lakes, located west and south-east of Pietrarossa-Prelosno, respectively. The *poljes* open up in the limestones, dolomites and breccias of the Lower Cretaceous-Upper Cretaceous, in which the gently sloping SE-bounded bedrock is locally conditioned by faults having a predominantly transcurrent character. Doberdò-Doberdob Lake *polje* lies between the Colle Nero Fault (Jamlje Fault) and a minor fault connected to the Brestovica Fault, the other three lakes are conditioned by minor faults and one of the lineaments connected to the Palmanova Line, the tectonic line of regional character along which the Karst Platform is overlain by flysch turbidites.

The lakes are the expression of the complex system of springs, karstic lakes and swallow-holes, which give life to the hydrogeological spring system characterizing the north-western sector of the Classical Karst. The waters flowing in the Isonzo Classical Karst sector have a dual recharge: the waters deriving from the influent character of the Soča-Isonzo and Vipava-Vipacco Rivers and the effective infiltrations occurring in the area. The former act as the main recharge in this sector of the area, sustaining the flow rates of all the springs from the Mucille-Močile to the Moschenizza-Moščenice Channel. During low water periods, when Notranjska Reka flow rates in Slovenia are very low (a few hundred litres per second), Timavo Springs are also largely fed by this resource. During floods, a greater influence of karst waters on the Soča-Isonzo component is instead observed. This influence is due to the increase in the piezometric levels in the karst sector which inhibits the recharge from the Soča-Isonzo.

Figure 4.2.1: February 2017, panoramic view of the Doberdò-Doberdob temporary Lake in a dry period. In the background, on the right, Mt. Castellazzo with a scarp due to the Colle Nero Fault (Jamlje Fault) (Photo: Chiara Calligaris)

Doberdò-Doberdob Lake, the bottom of which lies between 4 and 5 m a.s.l., is home to the karst water table, usually located at 4.8 m a.s.l. The water level is regulated by a few springs and several swallow-holes. During floods, the flow rate of the springs quickly increases and the swallow-holes are unable to drain all the waters, which causes a rise in the water level. During exceptional floods this can reach about 6 metres in a few hours. The speed with which the depression fills and empties means that the bottom of the lake is often free of water. Thus Doberdò-Doberdob is therefore considered an intermittent lake (Figure 4.2.1).

Permanent spring areas and swallow-holes regulating the water regime are also present at the Mucille-Močile. Their average level is at an altitude of 4.60 m a.s.l. and rises about 3.5 m during exceptional floods. Two spring belts of about fifteen and twenty points respectively with flow rates varying from a few litres per minute to several tens of litres per second recharge the Pietrarossa-Prelosno and Sablici-Sabliči Lakes. Until the 1960s, the hydrogeological behaviour of these lakes was entirely similar to that of Doberdò-Doberdob. Following a series of drainage works and the construction of two drainage canals which cut the natural thresholds present between Pietrarossa-Prelosno and Sablici-Sabliči Lakes and between the latter and the Moschenizza-Moščenice Canal, the hydrodynamics of this area was radically altered. However, the drainage network of this area is complex and articulated with numerous underground paths bringing groundwaters to feed a spring system now obliterated by the Monfalcone urban fabric.

In order to better understand the origin and groundwater flow of these waters, researchers have used different approaches over the years, and are still working on this topic. One of the used methods is the water monitoring through the evaluation of electrical conductivity as natural tracer. In addition to the data obtained with this approach, tracer tests with artificial dyes have been carried out since 2018 from some of the swallow-holes in the Doberdò-Doberdob Lake. The results showed that, unexpectedly, most of the tracer flows to the Timavo Springs. The Pietrarossa-Prelosno Lake springs, on the other hand, although geographically closest, are only marginally affected by Doberdò-Doberdob waters.

4.2.2 The "Villaggio del Pescatore" geosite (geosite n. 6)

The Villaggio del Pescatore geosite, located in the Duino-Aurisina – Devin-Nabrežina Municipality, is particularly relevant because, since the late nineties, two complete and exceptionally preserved fossils of a new genus of dinosaur, named *Tethyshadros insularis* have been excavated there. The two skeletons, that are still articulated, with almost all the bones in anatomical connection, were nicknamed Antonio and Bruno and are now displayed at the *Museo Civico di Storia Naturale* of Trieste. Other fossils belonging to the same genus has been found in the Villaggio del Pescatore site as well as animals such as crocodiles, teleost fishes and invertebrates, including decapod crustaceans. The geosite corresponds to an old stone quarry cut into limestone the layers of which are almost vertical and therefore exposed in a natural cross section. The stratigraphic organization of the rocks of the geosite is complex, but two main rock types can be recognized. One is composed of gray limestones that can be referred to the typical Upper Cretaceous rudist limestone and contain fossils fragments of rudist bivalves (bivalve molluscs that became extinct at the end of the Upper Cretaceous like dinosaurs). The other rock type is made up of finely laminated limestones. The thin laminae may be dark or greyish-white and are often characterized by a complex folding that testifies to the deformations which occurred when the sediment was freshly deposited and still not completely lithified (turned into a rock). The dinosaur fossils were found within these thinly-laminated limestones. Most notably, the skeleton of Bruno itself has been involved in the folding as can be spectacularly seen in the display at the museum (Figure 4.2.2).

Figure 4.2.2: Bruno, as it is displayed at the Civic Museum of Natural History of Trieste (Photo: Marino Ierman, Trieste Municipality - Fototeca Civici Musei di Storia ed Arte, Museo Civico di Storia Naturale di Trieste)

Bruno is the only dinosaur in the word lying on a fold of the rock that curves its skeleton by 180 degrees. Paleontological investigations have allowed the dating of these rocks to the Upper Cretaceous (Santonian-Campanian) and sedimentological and geochemical data suggest that the laminated limestone deposited in a confined marine environment, close to the emergent land and influenced by fresh water, conditions that may be approaching the blue holes (water-filled cavities near the sea that appear as blue holes) found in modern tropical carbonate platforms.

4.2.3 The olistoliths of Miramare Castle (geosite n. 27)

Miramare Castle is located on a promontory that stretches southwest into the Gulf of Trieste. In the vicinity of the Castle, scattered within the park surrounding it and also along the shore, the visitor can clearly see large blocks of whitish limestone. In total, approximately a hundred calcareous blocks with volumes ranging from about 500,000 m^3 to 1,300,000 m^3 have been identified. The blocks are made of rocks belonging to the foraminiferal limestones. Two blocks are particularly notable. One is located nearby the little port of Grignano. There, the limestone block on its northeastern side is clearly in contact with the well layered sandstone of the flysch. The sandstone close to the block, appears deformed by complex folds as if the limestone block has pushed against them. Historical photographs of the site, made prior to the building of the stone wall that is now below the limestone block, testify that flysch is found also beneath it and adjacent to its southwestern flank (Figure 4.2.3).

Figure 4.2.3: Miramare Castle olistolith pictured from the Grignano harbor (historical photo by Collezione Tomè, XIX – XX century)

The other large and notable limestone block is located between the stables and the Castle itself, along the road that leads to the southeastern gate. Nearby the entrance of a tunnel, adjacent to the block, is a clayey, marly breccia with limestone fragments containing sparse nummulitids. This rock, completely different from the limestone, also testifies strong deformation occurring in the vicinity of the block. Both at Grignano harbor and nearby the castle stables the rocks surrounding the blocks display evidence of deformation. A final important clue about the origin of the Miramare limestone boulder is that mapping has revealed that the flysch deposits are also found above the blocks. This means that they are found *within* the flysch deposits. The clear evidence of deformation adjacent to the blocks has allowed them to be interpreted as *olistoliths*. Olistolith is a term used by geologists to indicate large rock boulders that are part of a landslide body. The sliding of the blocks within as yet incompletely consolidated sediments explains why the latter are deformed in complex ways. The whole Miramare promontory is likely made by the deposits of a large such submarine landslide that slid into the sea basin where the flysch sandstones were in the process of depositing, between 40 and 48 million years ago. The fact that the Miramare olistoliths are made of limestone belonging to the Foraminiferal limestones testifies that the carbonate platform deposits were also involved in the event although the mechanisms of emplacement and the provenance of the ancient landslide are still unclear and currently under investigation.

4.2.4 *Borgo Grotta Gigante – Briščiki karrenfeld (geosite n. 28)*

West of Borgo Grotta Gigante - Briščiki, beyond the railway line, between the station to the north and Prosecco-Prosek sports centre to the south, there is an area representative of the Classical Karst landscape developing on pure limestones, with sub-horizontal or poorly dipping layers, characterized by different thicknesses (Figure 4.2.4). The outcrops are rudist limestones where intact shells or fragments of rudists bivalve fossils are frequent.

On a sub-trapezoidal surface of just under a square kilometre there are three large and about twenty smaller dolines, the widest and most complete *karrenfeld* of the Trieste Karst. The most evident and rare example of roofless cave is also found, along with the entrances of a few dozen caves, including a cave that has returned hundreds of artifacts dating back to prehistoric times. Close to it is the *Grotta Gigante - Briška jama* (2/2VG), a cave with the world's largest hall in a show cave (Figure 4.2.5).

Figure 4.2.4: Karrenfeld at Borgo Grotta Gigante - Briščiki (Photo: Chiara Calligaris)

Figure 4.2.5: Panoramic view of the great hall and the Ruggero stalagmite (Photo: Grotta Gigante Archive)

Two of the three dolines, Koprivnik and Školudnjek, have the typical depressed sub-circular shape, a diameter of about 250 metres, a depth of 40 m, very steep flanks and a flat bottom.

The third, however, the northernmost called Murnjak, is elliptical, 450 m along its longest axis and running NNE-SSW, about 250 m wide and 30 m deep, with the eastern flank much more steep than the western one. Along the SW and NE margins of the Školudnjek, with particular abundance and variety on vast areas of outcropping limestone, rainwater has carved all the typical karst solution features including solution flutes, linear or meandering solution grooves, deep crevasses crossed by small rock bridges, grikes, covered karst and hums follow one another with continuity. But the

main characteristic of these *karrenfelds* lies in the size and frequency of the solution pans or kamenitzas (škavnice in Slovene) (Figure 4.2.6). Overall, in the area between the two circular dolines, almost 200 have been observed, of which about thirty have an axis greater than 1 metre and a basin close to or greater than one square metre. So much so that many of them have been adapted over time as drinking troughs for animals.

The alternation in the sedimentary succession of thick and thin layers generates successive decametric bands of covered karst or sparse outcropping teeth and intensely karstified rock, meadows, *grize* and *karrenfelds*, interrupted by large and small dolines which give rise to a unique and fascinating landscape.

On the SE edge of the Koprivnik there is a sort of natural trench, a few metres deep, about ten metres wide and about seventy metres long, of what remains of an ancient tunnel, which is a sub-horizontal cave whose ceiling has been slowly removed by surface karst corrosion, a *roofless cave* (Figure 4.2.7).

Near the railway line, near at edge of a small sinkhole, a small cave, Grotta della Tartaruga (1688/4530VG) had been obstructed by debris and earth up to the ceiling. The un-obstruction led to the opening of some small halls where concretions on the ceiling, thick columns and a basin of about 20 cm in diameter collecting the dripwater are present. The excavations brought to light multiple levels of occupation from the Mesolithic to the Bronze Age. Of particular importance is the D level, attributed to the Neolithic, in which abundant remains of vases, numerous tools and artifacts not retouched in flint, two axe blades and 2 axe-chisels in polished stone were found.

*Figure 4.2.6: One of the great solution pans (*kamenitza*) in the Borgo Grotta Gigante-Briščiki area (Photo: Furio Finocchiaro)*

Figure 4.2.7: The entrance of the roofless cave at Borgo Grotta Gigante-Briščiki (Photo: Chiara Calligaris)

4.2.5 Archeological caves

Among the many archaeologically important caves in the Slovene Karst, we should mention at least two, each of which is of particular importance not only at the national level, but also beyond. The Bestažovca Cave (geosite n. 43), 280 metres long and 43 metres deep, located in the Tabor hills which is on one of the highest lying caves above sea-level in the Slovenian Karst, and contains, among other geological and geomorphological attractions, many prehistoric archeological remains, including prehistoric drawings dating back at least 7,000 years, is a unique site for Slovenia.

Another archaeologically significant cave is Jama na Prevali 2 or Mušja jama (geosite n. 54), located southwest of the village of Matavun - in the hinterland of the Škocjan Caves - below the Prevala peak. An entrance shaft with three relatively small entrances divided by submerged blocks leads into 200 m long and 90 m deep horizontal cave. Below the shaft, in the entrance hall is a large cone of gravel, in which archaeologists have found a charcoal layer with burnt animal bones and hundreds of mostly bronze and also iron artefacts, i.e. offensive and defensive weapons (swords, spearheads, helmets), tools (axes, sickles, knives), parts of costumes (needles, fibulae, collars, bracelets, earrings) and metal utensils (kettles, buckets). These findings show the extraordinary influence that the Škocjan Caves and the surroundings had as a sacred place amongst European and Mediterranean cultures in the Late Bronze Age, around 1000 B.C.

On the Italian side, the Pocala-Pečina pod kalom Cavern (173/91VG), geosite n. 23, is one of the most interesting paleontological sites in Friuli Venezia Giulia Region. It is a protected cave in which abundant Pleistocene animal remains have been found, in particular the bones of cave bears (*Ursus spelaeus*). It extends for just over a hundred metres and is 20 to 40 m wide. The entrance (protected by a gate) opens into an elongated doline, remains of a roofless cave as revealed by concretions on the walls. It consists of a single sloping gallery with an uneven floor of fill and collapse deposits on which there are some concretions. First explored in 1893 by Ludwig Karl Moser and Giovanni Andrea Perko, it became famous for the extremely high number of cave bear finds discovered in numerous excavation campaigns. Between 1903 and 1929, important protagonists of archeological research of the time such as L. K. Moser, Carlo Marchesetti, Eugenio Neumann and Raffaello Battaglia excavated in the cave. Since 1998, the Civic Museum of Natural History of Trieste has undertaken new excavations, with the opening of a trench under the supervision of Ruggero Calligaris, the Museum's curator at the time, and Gernot Rabeder, from the University of Vienna, reaching the unexcavated layers that were thought to be impossible to find. Since the faunal composition in the cave is 97.5% cave bear remains, the Pocala-Pečina pod kalom Cavern can be defined as a 'bear cave' although the bones of other animals have also been found. The cave lion (*Panthera leo spelaea*) is the second most rep-

Figure 4.2.8: The cavern and deposits inside the Pocala-Pečina pod kalom Cavern (Photo: Luciano Gaudenzio and Sandro Sedran - Civic Museum of Natural History of Trieste archive)

resented animal (0.75% of the remains), followed by goats and sheep (*Capra hircus* and *Ovis aries*), aurochs (*Bos taurus*), wolf (*Canis lupus*) and deer (*Cervus elaphus*). In addition to animal remains, numerous Mousterian flint artefacts, i.e. from the Neanderthal culture, were also found. The fauna of the Pocala-Pečina pod kalom Cavern, from the Upper Pleistocene, has been dated to around 60,000 years ago based on the study of the cave bear teeth. Recently, some finds have been dated using the radiocarbon method. Of these, four are older than 45,000 years, which is the limit of the dating method (i.e. they are older than 45,000 years, but it is not known by how much) and one sample is dated 36,500-34,500 years ago. The finds from the Pocala-Pečina pod kalom Cavern are now on display at the Civic Museum of Natural History in Trieste.

4.2.6 *Fossiliferous Tomaj Limestone (geosite n. 34)*

The abandoned Kazlje Quarry in the Tomaj Limestone is one of the most important sites for fossil vertebrates, invertebrates and plants from the Late Cretaceous in the northern part of the former Adriatic-Dinaric carbonate platform. The paleontological findings from this site have been published in a number of scientific publications.

The Kazlje geosite is located in a forested area about 400 m southeast of the centre of the village of Kazlje. Tomaj Limestone is a thin-bedded to platy limestone, once used as roofing and flooring material. It occurs as individual horizons within the thick-bedded Upper Cretaceous rudist limestones and forms vertical walls up to 4 m high in the abandoned quarry. The limestone is dark colored and laminated. In the limestone layers nodules and lenses of chert occur, a hard, dense rock composed of microcrystalline quartz. The presence of pelagic fossils together with terrestrial plant fossils shows a good connection between the open sea and the lagoon where this limestone was formed about 84 million years ago. A large number and variety of well-preserved fossils, including plants, ammonites, fish, turtles, sea urchins, brittle stars, planktonic organisms and even imprints of soft-bodied jellyfish have been found in the Tomaj Limestone in the wider area and described in the scientific literature (Figure 4.2.9 and Figure 4.2.10).

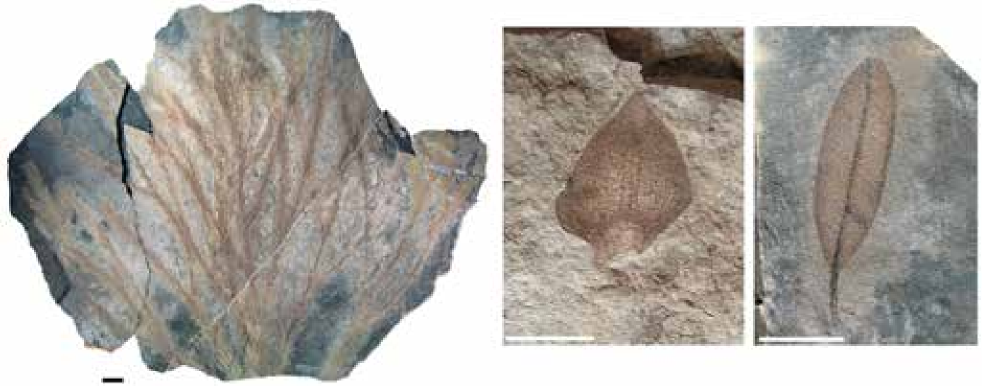


Figure 4.2.9: Plant fossils, found in Tomaj Limestone (from left to right: conifers Brachyphyllum *and* Araucarites, *and* Magnoliaphyllum*). Scale bar 1 cm (Photo: Bogdan Jurkovšek)*

Figure 4.2.10: Animal fossils of Tomaj Limestone (from left to right: fish Chirocentrites *and* Enchonodus, *turtle, ophiuroid brittle star, and ammonite). Scale bar 1 cm (Photo: Bogdan Jurkovšek)*

4.2.7 The Lipica rudist limestone quarry (geosite n. 45)

The Lipica Limestone, one of the Upper Cretaceous rudist limestone types, contains numerous varieties of limestone that differ both in structure and colour. This limestone represents the most commercially valuable rock in the Classical Karst area (Figure 4.2.11). Both the names of the limestone and the natural stone are derived from the village of Lipica.

Near the western edge of the quarry, younger and softer Upper Cretaceous-Lower Paleocene limestone beds overlay the Lipica Limestone. As a result, the terrain towards Lipica is less karstified and coal layers are frequently found between the limestone beds. Coal was mined in the 19th and early 20th century in this area.

Figure 4.2.11: The Lipica 1 Quarry lies northeast of the well-known Lipica Stud Farm. In this quarry, large blocks of massive Cretaceous limestone are exploited. The quarry is situated in the most economically promising part of the Lipica Limestone in the north wing of the Lipica syncline, a large bowl-shaped fold with an axis slightly plunging towards the southeast (Photo: Matevž Novak)

Rocks of the Lipica Formation were formed about 85 million years ago in the immediate vicinity of thickets of rudist bivalves that were the inhabitants of the shallow marine carbonate platforms and marginal areas of the Tethys Ocean during the Cretaceous period.

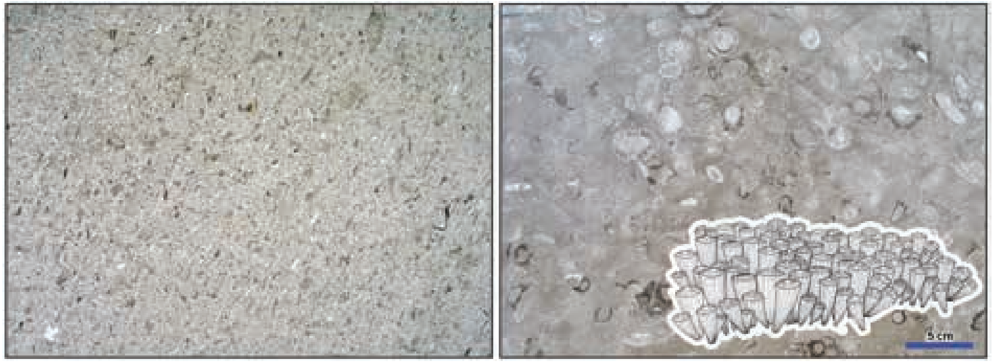


Figure 4.2.12: Today, two types of limestone are obtained in the Lipica 1 Quarry. The first is a light olive-grey, homogeneous, fine- or coarse-grained uniform ('unito') type with fossils or fossil fragments of only a few millimetres big (left). The other type is composed of a more fine-grained groundmass that contains mainly rudist shells and other fossil remains of different size. Due to their flower-like cross-sections this limestone is named the Lipica rosy ('fiorito') type (right). Besides rudists, both types of limestone often contain foraminifera, sponges and skeletal parts of other inhabitants of the warm, well-ventilated shallow marine environment of the former Adriatic-Dinaric carbonate platform (Photo and drawing: Bogdan Jurkovšek)

4.2.8 The Aurisina-Nabrežina roman Quarry (geosite n. 24)

In the broad, ancient mining basin known as Ivere, just inside the Karst ridge close to Aurisina-Nabrežina, a number of pit quarries (Figure 4.2.13) have been in operation since Roman times. The entire area is characterised by massive limestones from which large blocks are obtained. These are very pure, homogenous limestones with a light grey ground colour. The distinctions between the different varieties quarried depend on the size, classification, quantity and distribution of the fossils. The latter, almost always in fragments, are mainly thick-shelled lamellibranchs, mainly rudists with remains of different sizes and, subordinately, foraminifera, algal remains and rare bryozoans. Along the high, smooth walls, one can observe not only the different sedimentary structures, but also the traces of rudimentary ancient excavations and the evolution of excavation techniques over times. The layered strata, with an orientation running NNW-SSE and an inclination of 20°- 30° towards SSE, encouraged quarrymen to extract material even using tunnels inclined towards the sea.

4.2.9 Rosandra-Glinščica Valley (geosite n. 58)

At the southern border of the Italian Classical Karst there is the only example of a karst valley with surface hydrography of the area around Trieste: the Rosandra-Glinščica Valley (Figure 4.2.14).

The valley is deeply carved in Cenozoic limestone, marlstone and sandstone, with a morphology and hydrography largely conditioned by tectonics as well as by its lithology, i.e. folds, faults and different rock types, on which erosion and karst corrosion have created a particular hydrostructure. It is one of the few karst river valleys in Italy and is a complex geosite of international value. It also contains within it numerous other elements of geological interest such as limestone outcrops particularly rich in Alveolinid and Nummulitid foraminifera, intraformational marlstones and claystones, alluvial deposits and debris, sometimes cemented, short-range folds in the flysch, an important fault mirror (the Crinale Fault), a waterfall and a gorge with potholes and recessed meanders, a paleo-landslide and a landslide body with large boulders, a kilometre-scale cave system on the right side (inside Mt. Stena) and a cave rich in prehistoric animal remains on the left one, the Bukovec Spring and the Antro di Bagnoli-Jama karst springs.

Figure 4.2.13: The Aurisina-Nabrežina Roman Quarry (Photo: Chiara Calligaris)

Figure 4.2.14: The Rosandra-Glinščica Valley from the top of Mt. Stena (Photo: Furio Finocchiaro). In the background the Gulf of Trieste.

Privileged views of the Valley include those from the *Vedetta di Moccò* and *Vedetta di San Lorenzo*. From both the slopes overhanging the Rosandra-Glinščica stream are visible, those on the right of Mt. Stena enlivened by escarpments and rocky cliffs, spires, debris fans and large mobilized blocks, those on the left set on the side of the Mt. Carso anticline and the Crinale Fault, all expressions of a diverse lithology, of complex tectonics and remarkable geodynamics.

From the *Vedetta di San Lorenzo* you can also see the ancient, meandering Salt route and the church of Santa Maria di Siaris-Sveta Marija na Pečah, located in correspondence to the crown of the translational landslide along the northern flank of Mt. Carso-Griža/Mali Kras. The latter rapresents, the morphological expression of an anticline fold that towards the plain evolves into a knee fold and in a thrust fault on the turbidites of the flysch.

But the valley is characterized by the Rosandra-Glinščica stream, whose waters, initially supported by marls, after Bottazzo-Botač, fall down a suggestive 30 m waterfall highlighting the transition from flysch to limestone (Figure 4.2.15). Downstream of the waterfall, the stream carves a deep gorge, full of rapids, potholes, waterfalls, recessed meanders and tanks. The riverbed often changes direction following the main fracturing systems present in the rock mass up to the small town of Bagnoli-Boljunec. Along the stretch in the gorge the watercourse is fed by numerous small karst springs.

The valley is also hypogean karst, with Mt. Stena being a very special example with more than a hundred explored caves. The Fessura del vento Cave (930/4139VG), with its 143 m of difference in altitude is the deepest. The Gualtiero Savi Cave (5080/5730VG), with its 4,180 m in length, is the one with the longest development. These two caves, together with the Grotta delle Gallerie Cave (290/420VG) and the Martina Cucchi Cave (4910/5640VG) are part of a single vast and articulated complex of over 7 km of development, the result of an ancient karst evolution.

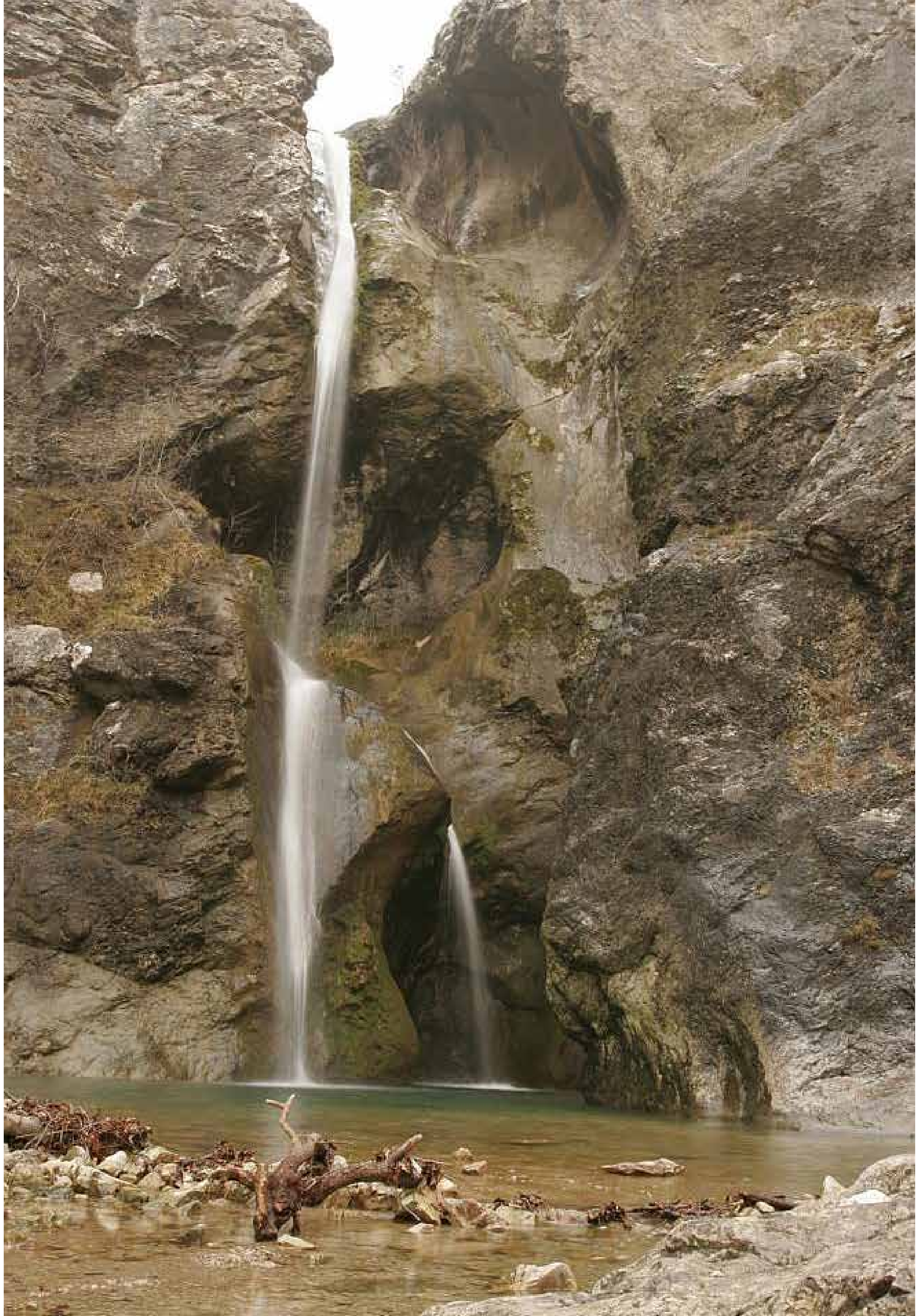
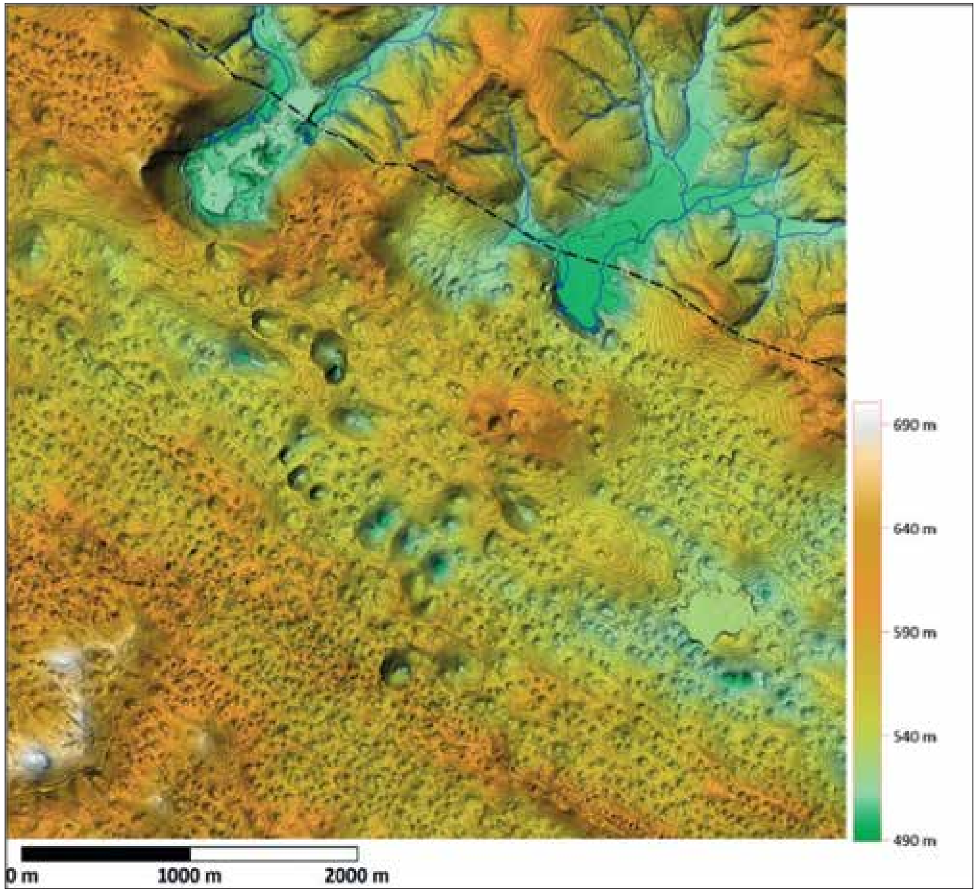


Figure 4.2.15: The Rosandra-Glinščica waterfall in low flow conditions (Photo: Franco Cucchi)



The valley is also home to unusual quaternary deposits. In front of the CAI refuge, to the hydrographic right of the Rosandra-Glinščica stream, rises a sub-vertical wall, a dozen of metres high, consisting of torrential alluvial and slope deposits, more or less cemented, which represents the only outcrop of ancient alluvial deposits in the karst environment of the Trieste area. The alternation of sediments with different genesis and grain size and their subsequent incision by the torrent witness the complexity of the geological evolution of the area, linked both to tectonics and to Plio-Quaternary climate changes.

A few hundred metres from the valley exit, at the bottom of Mt. Carso-Griža/Mali Kras, from an oblique fracture, waters flow out. This is the Antro di Bagnoli-Jama Spring, a cave which drains the karst waters of Mt. Carso-Griža/Mali Kras and Socerb-San Servolo Plateau.

4.2.10 Blind valleys of Matarsko Podolje (Odolina blind valey) (geosite n. 61)

Apart from the unique blind valley of the Notranjska Reka river sinking into the Škocjan Caves, the most characteristic and geologically interesting contact karst features are the blind valleys of Matarsko Podolje on the SE border of the geopark (Figure 4.2.16 and Figure 4.2.17).

Figure 4.2.16: Contact karst with typical blind valleys. Surface streams flow from the impermeable flysch region of the Brkini Hills (NE) and sink into the levelled karstic surface of Matarsko Podolje (archive of IZRK ZRC SAZU)

Figure 4.2.17: The Brezovica blind valley is the most north-western and thus the shallowest blind valley of Matarsko podolje. Left figure: view to the NE towards the Brkini hills with a surface drainage system (Photo: Matej Blatnik); right figure: view to the SW over the karstified Matarsko podolje levelled surface. (Photo: Matej Blatnik)

This is a system of 17 parallel surface streams that form a surface drainage system on the siliclastic flysch of the Brkini Hills that sinks near the contact with the carbonate rock under the 20 km long and 2 to 5 km wide levelled karst surface of Matarsko Podolje. Since the valleys are cut into the karst edge due to the uneven uplift of the area, the deeper valleys are on the SE part of Matarsko Podolje. The shallowest blind valley, Brezovica in the NW part of Matarsko Podolje, is cut only 50 m deep, while the deepest Brdanska Dana is cut 250 m deep into the limestone hills and its floor is 120 m below the levelled surface of Matarsko Podolje. At present, the karst water level is deep below the floors of the blind valleys even during floods. The recent gradient in the karst is so high that the old deposits are washed from the surface into the karst by suffosion processes.

Odolina (Figure 4.2.18) is a typical blind valley of Matarsko Podolje and one of the three located on the Slovenian side of the geopark area. The Odolina sinking stream drains an area of 4.3 km^2. Near the

Figure 4.2.18: The bottom of the Odolina blind valley is covered with coarse-grained siliclastic sediments of Quaternary age, derived from flysch. The stream on the left side sinks as a waterfall into originally phreatic 117 m deep ponor cave at high water flows (Photo: Matej Blatnik)

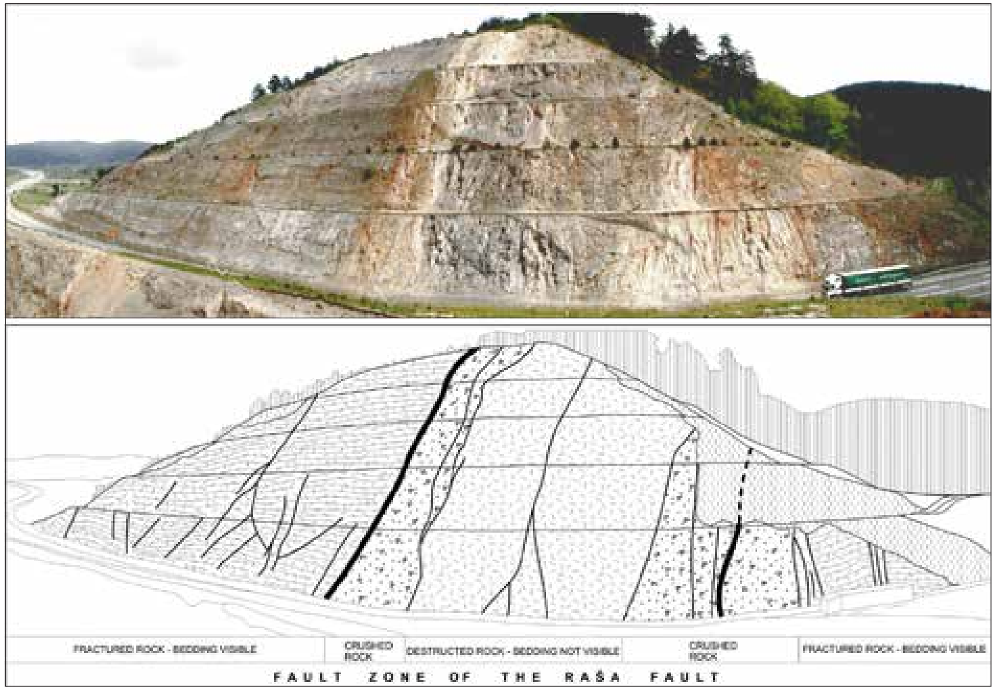


Figure 4.2.19: On the Zajčica section of the highway near Senožeče, we can see a cross-section of the almost 100-metre-wide fault zone. From the vantage point on the other side of the highway, where there is an explanatory board, we can see the typical zoning of rock deformation within the inner and outer fault zones. In the inner fault zone, we see crushed rock followed by the destructed rock in which the bedding is not preserved. In the fractured rock of the outer fault zone, the original bedding of the limestone is still visible. The northeastern tectonic block (left) consists of layered limestone of the Upper Cretaceous rudist limestone, and the southwestern block (right) consists of layered Upper Cretaceous-Lower Paleocene limestones.
(Photo: Ladislav Placer, Bogomir Celarc. Drawing: Ladislav Placer)

transition of the stream into the limestone, the narrow river valley widens and forms a blind valley 1 km long and 300 m wide, cut 60 m into the karst plain at its end. At normal water levels, the stream sinks into the riverbed immediately upon reaching the limestone, while during heavy rains the water sinks into the 117 m deep originally phreatic ponor caves. The bottom of the blind valley is covered with coarse-grained siliclastic Quaternary sediments derived from flysch. In the ponor cave of the Jezerina blind valley, for example, no significant deposits of clastic sediments have been recorded for the last 12 ka, as flowstone has begun to grow on alluvial sediments. These alluvial sediments are presently cut by river erosion, and alluvial dolines and sinkholes up to 25 m deep have formed on the floor of the Odolina blind valley.

4.2.11 The Raša Fault zone (geosite n. 38)

Several long, regional faults run through the Outer Dinarides in southwestern Slovenia in a NW-SE direction, which were formed in past geological periods. One of them is the Raša Fault (Figure 4.2.19), named after the Raša River on the edge of the Classical Karst Plateau. The Raša Fault runs almost in a straight line from the edge of the Southern Alps near Gemona to Ilirska Bistrica and further to the southeast, probably across the Velebit. It is one of the faults along which the North Adriatic Block is laterally displaced and thrust under the Southern Alps. Based on the location of the seismic foci, it is assumed that the Raša Fault is seismically active today southeast of Mt. Vremščica, while seismic activity along this fault in the Classical Karst and Friuli area is less reliable.

4.2.12 Caves of the Classical Karst

The geological evolution of the geopark is best reflected in the karst caves formed in the Reka/Timavo hydrogeological system. One of the largest cave spaces has been formed here, not only in Europe but also in the world.

The Škocjan Caves (geosite n. 53) are a 6,550 m long and 223 m deep cave system consisting of eleven karst caves, four of which have separate entrances on the surface (Figure 4.2.20).

These active and relict or fossil speleological objects are connected to the karst surface through the Mala and Velika dolina collapse dolines. Most of the caves were formed in the Cretaceous thick-bedded limestone and only a small part in Paleocene bedded limestone. Although Škocjan Caves can be defined as a water cave formed by the sinking Notranjska Reka River, the main cave is generally divided into a water part (Šumeča jama) and a dry part (Tiha jama). The river first sinks into the Mariničeva and Mahorčičeva Caves, 80 m below Škocjan Village at an altitude of 317 m above sea level. It then flows on the surface in the Mala dolina, crosses under the natural bridge

Figure 4.2.20: The Notranjska Reka river sinks into Škocjan Caves below Škocjan and Matavun Villages. Before disappearing into the underworld for the last time the Reka appears in Mala and Velika dolina collapse dolines (Photo: Matej Blatnik)

(called Okno) and finally sinks into a major part of the Škocjan Caves below the viewpoint in the 160 m deep Velika dolina at 269 m above sea level. In the central part of the Škocjan Caves, the Notranjska Reka River flows through several halls, and further into the Hanke Channel, which is the longest single cave channel in the caves, with a length of about one kilometre, a width of 10-15 m, and a height of up to 90 m, the largest underground canyon in Europe (Figure 4.2.21).

The Hanke Channel is followed by two large halls, the second of which, the Martel Hall, is the largest known underground hall in Slovenia and second largest in Europe. It is 308 m long, 89 m wide on average, 123 m at its maximum, 106 m high on average and 146 m high at the highest point. The volume of the hall is 2,550,000 m^3. At the end of the Martel Hall, in the Martel Lake, the lowest point of the cave is located at 214 m a.s.l. The Martel Hall (Figure 4.2.22) is followed by a 1.5 m high and 9 m long passage to the Marchesetti Hall. Behind the siphon of the Marchesetti Lake, another 680 m of passages have been discovered in the last twenty years. Under the ceiling of Martel Hall, a fossil tunnel about 350 m long was discovered in 2020, which cavers reached through an entrance dug directly from the surface.

The Tiha jama is a dry fossil channel of the Škocjan Caves. Due to difficult access from the direction of the Šumeča jama (70 metres steep wall), it was discovered relatively late compared to the other passages of the Škocjan Caves. The Tiha jama is 525 metres long and lies between 340 and 350 metres a.s.l. Today, access to the Tiha jama is through an artificially dug tunnel from the collapse doline Globočak, while the Tiha jama and Šumeča jama are connected over the Hanke Channel gorge with the Hanke Bridge.

Some 800 metres of undiscovered passage separate the Škocjan Caves from Kačna Cave (geosite n. 49), a cave west of Divača, with an entrance at an altitude of 435 metres (Figure 4.2.23). It is 280 metres deep and consists of a network of channels about 20.5 km long, located between 154 m and 290 m a.s.l. This currently makes it the third longest cave in Slovenia after the Migovec Cave system and the Postojna Cave system.

Figure 4.2.21: Up to 90 m high, the Hanke Channel - the largest underground canyon in Europe with the Hanke Bridge (Photo: Matej Blatnik)

Figure 4.2.22:
With a volume of over 2.5 million m³ the Martel Hall is the largest known underground hall in Slovenia and second largest in Europe (Photo: Matej Blatnik)

Figure 4.2.23:
The 186 metres deep entrance shaft of the Kačna Cave widens into 60-metre-high entrance hall in the lower part (Photo: Matej Blatnik)

The first explorations of the cave were related to the search for water resources for the supply of Trieste and the search for the underground course of the Reka/Timavo River. The bottom of the entrance shaft was reached in 1891 by A. Hanke with the help of local people. In 1895, under the direction of J. Marinitsch, the locals built a path through the entrance shaft to facilitate access to the cave.

The entrance to the cave is a large doline, at the bottom of which opens a 186 m deep system of parallel shafts. These all eventually come together and end at the ceiling of the 60-metre-high entrance hall. The Kačna Cave has two distinct levels in terms of the position of the galleries which also differ in orientation. The river appears at normal water level in a siphon near the Risnik collapse doline at an altitude of about 200 metres a.s.l. and disappears in a drainage siphon at an altitude of 154 metres. Depending on the hydrological characteristics, the cave can be divided into three parts: 1) the active channels, which have gravitational profiles, 2) the high water channels with the highest permeability and 3) other channels

Figure 4.2.24: Vilenica, the oldest show cave of Europe. Tourists have been able to admire its beauties since the 17th century (Photo: Peter Gedei, Jamarsko društvo Sežana archive)

that discharge flood waters formed in different directions following different geological structures. During floods, the water level in the cave rises about 126 metres.

The question why the development of Škocjan Caves channels compared to the Kačna Cave channels experienced completely different development still remains open. The Škocjan Caves have a single, wide, oval channel that winds and splits, forming a canyon up to 90 m deep, while the Kačna Cave is characterized by two levels of main channels that develop at different heights.

All the caves where the Reka/Timavo River watercourse is encountered are extremely important from a scientific point of view, because they allow us to see and study the karst aquifer "in situ", which is often considered a "black box". In this way, we can directly verify the characteristics of the aquifer itself, which we can normally only determine using data from springs and/or sinkholes and precipitation.

For the study of the geological (tectonic) and geomorphological evolution of the area, the relict or fossil and roofless caves are of particular importance. They are older and lying higher in the vadose hydrogeological zone than the previously described caves, which still actively discharge groundwater. Between Divača and Sežana there are several rather large relict/fossil caves, which represent the former main drainage paths of the Karst aquifer formed in the flooded, i.e. phreatic, hydrogeological zone. During the later tectonic uplift of the Karst, they "hung" in a vadose hydrological zone and could be defined to some extent as the former, now abandoned underground riverbed of the Reka/Timavo River. A characteristic cave of this type is Vilenica (geosite n. 24) (Figure 4.2.24), one of the longest (841 m) and deepest caves in the Classical Karst. It is located in the Sežana Karst and with its current depth of 190 m and its location between Kačna Cave and the newly discovered water caves (Jama 1 v Kanjaducah, Brezno v Stršinkni dolini-Jama Sežanske Reke) it is perhaps still connected with the Reka/Timavo River in its lower part. The cave channels in the part of the cave that is arranged for tourist visits are spacious and decorated with beautiful flowstone.

Vilenica is considered to be the oldest tourist cave in Europe and probably in the world. The data show that the owner of the land, Count Petači, began to receive income from entrance fees as early as 1633 when he started to share it with the church of St. Mihael *in Lokva*. The cave was well visited during the tourist boom until the middle of the 19th century and was known as the most beautiful and largest cave in the Karst. Since 1980, literary evenings have been held in the cave, and since 1986, the Vilenica International Literary Festival - a meeting of poets and writers from all over Europe – when also Vilenica Prize is given to a Central European author for outstanding achievements in the field of literature and essay writing.

The Claudio Skilan Cave (5070/5720VG) (geosite n. 48) opens up near Basovizza-Bazovica and, with its depth of 378 m and total length of 6,400 m, is the deepest explored cave in the Classical Karst. Opened in 1990 and explored in the following years by the "Carlo Debeljak" Cave Group, which equipped the first shafts with ladders, it has two levels of sub-horizontal conduits. The former is located at a depth of about 40 m and is small, while the latter, at about 180 m of depth, consists of a series of large tunnels with diameters ranging from 20 to 40 m that run for more than 2 km in a NW-SE direction. Some of the galleries are richly concreted with impressive gour and stalagmite groups. It has a complex path with several large, deep pits which intercept groundwaters during floods.

Figure 4.2.25: The Skilan Cave, crystals in the terminal part of the Brena Branch (Photo: Sandro Sedran S-Team)

Figure 4.2.26: Lindner Hall, on the bottom of the Trebiciano-Labodnica Abyss during a flood in 2011 (Photo: Alberto Maizan)

In the sphere of speleology, the Trebiciano-Labodnica Abyss (3/17VG) (geosite n. 5) is certainly one of the best known caves in the world.

The development of trade that led to the city of Trieste becoming the busiest port in the Mediterranean in the 19th century brought about a rapid increase in population, which tripled within a few years.

The city authorities were forced to impose strict measures to ration the water available in times of drought. Various initiatives were then undertaken to find an alternative source. On the Karst Plateau, so-called "blow-holes" were identified (see Chapter 3.6) and in the most promising one, near the village of Trebiciano-Trebče, excavations were begun in 1840. Five months after starting the digging and at a depth of over 300 m, the quarryman Luca Kral and the miner Antonio Arich (Arič), coordinated by Antonio Federico Lindner, reached a large cavern, at the bottom of which the waters of the Timavo River flowed. For the period, this was such an extraordinary feat that for over eighty years the Trebiciano-Labodnica Abyss was the deepest explored cave in the world. A year after the discovery, fixed ladders were placed that allowed easy access to the cave and enabled the study and monitoring of the waters' hydrodynamics. The cave became a point of attraction for speleologists and scholars from all over the world. Even today, part of the wooden staircase that was last renovated in the early 1900s can still be seen in the access pit to the large terminal cavern, which was named after Lindner. Cave explorations did not end with the discovery of flowing water, but continued over time. In the early 1950s, the first cave-diving explorations were carried out by Walter Maucci and Stefano Bartoli. This was an epic feat achieved with rudimentary equipment and gear that led to the exploration of more than 60 metres of flooded conduits and halls, allowing the reaching of a flooded hall called Lake Boegan in honour of the illustrious Timavo researcher. For the period, it represented a world record for the length of the siphon explored. In the years that followed, further cave-diving explorations were undertaken by numerous other groups until the current expeditions, led by a team of French cave-divers from the *Fédération Française d'Études et de Sports Sous-marins* (FFESMM) in Marseille, in collaboration with the *Società Adriatica di Speleologia* (SAS). In the summer of 2022 this led to the discovery of the exit siphon and the identification of a large new cavern (160 m long, 50 m wide and 60 m high) below the 7 Nani doline blow-hole near Trebiciano-Trebče (Figure 4.2.27).

Figure 4.2.27: Newly discovered cave in the summer 2022 (Photo: Patrice Cabanel)

Figure 4.2.28: The entrance to the Lindner Cave (Photo: Franco Cucchi)

The A.F. Lindner Cave (829/3988VG) (geosite n. 22) opens up near San Pelagio - Šempolaj at an altitude of 179 m a.s.l. and has a depth of 176 m for a total length of 825 m. The entrance is on the northern edge of the vast geosite called Karrenfeld at San Pelagio-Šempolaj and Lindner Cave, in an elongated doline, the relict of a cave section brought to light by surface levelling, part collapse doline, part roofless cave (Figure 4.2.28). The cave consists of a large main tunnel inclined at 40° to the SW, richly concreted, which is occasionally inundated during floods, in close connection to the Timavo Springs, less than 7 km away (Figure 4.2.29).

At first glance, quite insignificant, but scientifically one of the most important caves in the Classical Karst is the rather small 226 m long and 46 m deep cave Grofova jama Cave (geosite n.11) or Brezno na Gr-

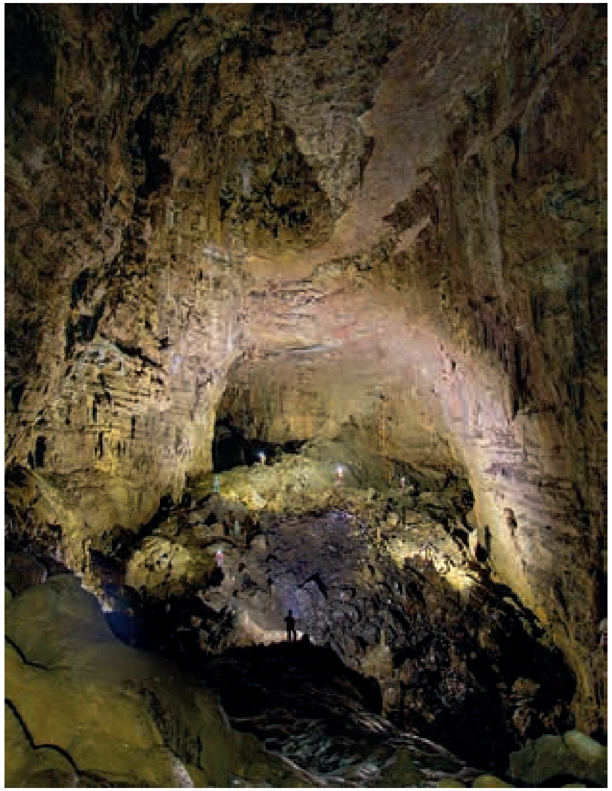


Figure 4.2.29: The broad conduit in the Lindner Cave (Photo: Sandro Sedran S-Team)

Figure 4.2.30: Grofova jama Cave was converted into a shelter and a field hospital during World War I. However, the special value of the cave is the section of the cave sediments consisting mainly of the clay mineral montmorillonite. (Photo: Bojan Otoničar)

madi (Figure 4.2.30). It is located on the northern slope of Mt. Grmada on the NW edge of the Classical Karst above Brestovica pri Komnu in the immediate vicinity of the state border with Italy at an altitude of 275 m, about 150 m above the flat surface of the plateau.

The special value of the cave is the profile of the clay cave sediments, several metres high, consisting mainly of the mineral montmorillonite. Recent research has shown that these are the oldest known cave sediments in south-western Slovenia. The montmorillonite fill derived from volcanic ash that had previously weathered on the surface, most likely from one of the eruptions of the Smrekovec volcano in northern Slovenia, but perhaps also from one of the volcanoes in the wider Mediterranean region. According to various dating methods, the montmorillonite clay was most likely deposited in the cave about 10 million years ago.

4.2.13 The Duino-Devin Cliff (geosite n. 9)

Between Sistiana-Sesljan Bay and the ancient fortress of Duino-Devin, sub-vertical limestone layers give a stretch of coastline a characteristic overhang. On a small scale, the cliffs offer elements of great interest such as surface karst features of rare beauty and development. It is also characterised by an outcrop of richly fossiliferous and petrographically distinctive rocks. Among the latter, special attention should be paid to the unusual condensed Lower Cretaceous-Paleocene lithostratigraphic succession. Discontinuous lenses of pinkish to brown calcareous breccia, bauxites and very rare vadose pisolites and concretised gour deposits of a Cretaceous paleocave precede the Cretaceous Paleogene transition by a few metres. The cliff reaches a height of 90 m and its edge can be closely followed along the Rilke Path, the walk that German poet Rainer Maria Rilke used to take during his stay at Duino Castle (1911-12) as a guest of Princess Maria della Torre e Tasso (*Thurn und Taxis*). Along the path, from which there is a wide panoramic view stretching from the Gulf of Trieste to Koper-Capodistria and the Istrian coast, to the Grado Lagoon and the outlet of the Soča-Isonzo River, one can observe all kinds of epigean karst morphologies, the whiteness of which stands out when set against the colour of the sea and that of the varied vegetation.

4.2.14 Timavo Springs (geosite n. 5)

The Timavo Springs at San Giovanni di Duino-Štivan consist of four outlets collected in three 'branches' from which most of the water infiltrating the Classical Karst emerges with an average output of 30 m^3/s, a minimum of 7.4 m^3/s and a maximum of 158 m^3/s. A complex system of flooded caves called the 'Timavo Complex' extends upstream, connecting the springs with the Timavo Cave (1844/4583VG) and the Pozzo dei Colombi Cave (215/227VG). Cave-diving explorations carried out over the years (in particular the 'Timavo' and 'Timavo System Exploration' projects) have reached a depth of 82 m below sea level and detected more than 1,500 metres of tunnels. Technical and logistical difficulties due to the turbidity of the water, with poor visibility (just over a metre in good conditions) and the depth and the speed of the current have prevented further exploration, but the underground course of the Timavo System is likely to have a total development of several tens of kilometres. The course of the river then continues for less than 2 km until it flows into the Gulf of Panzano in the Adriatic.

Near the first branch is the Church of San Giovanni in Tuba, built on early Christian foundations, while a short distance away is the archeological site of a cave that is the site of a Mithraic temple, the Grotta del Dio Mithra Cave (1255/4202VG), a place of worship in Roman times, while just over a kilometre away are the thermal springs at Monfalcone (geosite n. 4).

Figure 4.2.31: The central section of the cliff pictured from the sea (Photo: Luca Zini)

Figure 4.2.32: Timavo Springs, 1st branch (Photo: Luca Zini)

KARST AND MAN

5.1 Classical Karst stones

Limestone rocks are generally excellent building stones. The stratification also isolates large blocks that can be easily extracted, while the diagenesis ensures good geomechanical properties and the variety of colours allow diversity in architecture. Walls, churches, simple or impressive buildings, towers, bridges and paving stones are therefore scattered throughout the villages. This compactness, homogeneity and workability allow artists and craftsmen to create simple or magnificent works of art that decorate the houses and squares.

Figure 5.1.2: The Cava Romana of Aurisina-Nabrežina Quarry: on the left the excavations on the slope, on the right the excavations in the tunnel (no longer active) (Photo: Giancarlo Massari)

In some areas of the Classical Karst, sedimentary and diagenetic processes have favoured the formation of particularly compact, homogeneous and poorly divided horizons from which large blocks suitable for use as architraves, load-bearing columns, doorposts, window frames, and blocks from which statues, sculptures and urns can be made. This type of limestone is often called "marble of the Karst" (Figure 5.1.2).

Figure 5.1.1: People have always worked with stone in the Karst. Over the course time this ancient knowledge was in danger of vanishing, but it has been revitalized through the commitment of enthusiasts and experts passing on this ancient knowledge and the cross-border Partnership of Karst dry stone construction which started within the UNESCO program Man and Biosphere. The Kamenton action in autumn 2022 at Basovizza-Bazovica (Photo: Sara Bensi).

The stones of the Karst are not "marbles" in the geological sense, that is, they have not undergone metamorphic processes that have modified their original petrographic and mineralogical properties. They are limestones, carbonate organogenic sedimentary rocks. The chemical composition has a $CaCO_3$ content of over 98% and a $MgCO_3$ content of less than 1% with insoluble residues in traces. The imbibition coefficient is very low, the values of resistance to compression, flexion, impact and wear are excellent, and the thermal expansion coefficient is insignificant.

In short, from the commercial point of view all the stones are an excellent "marble", that is, a lithotype with a Mohs hardness of 3-4,

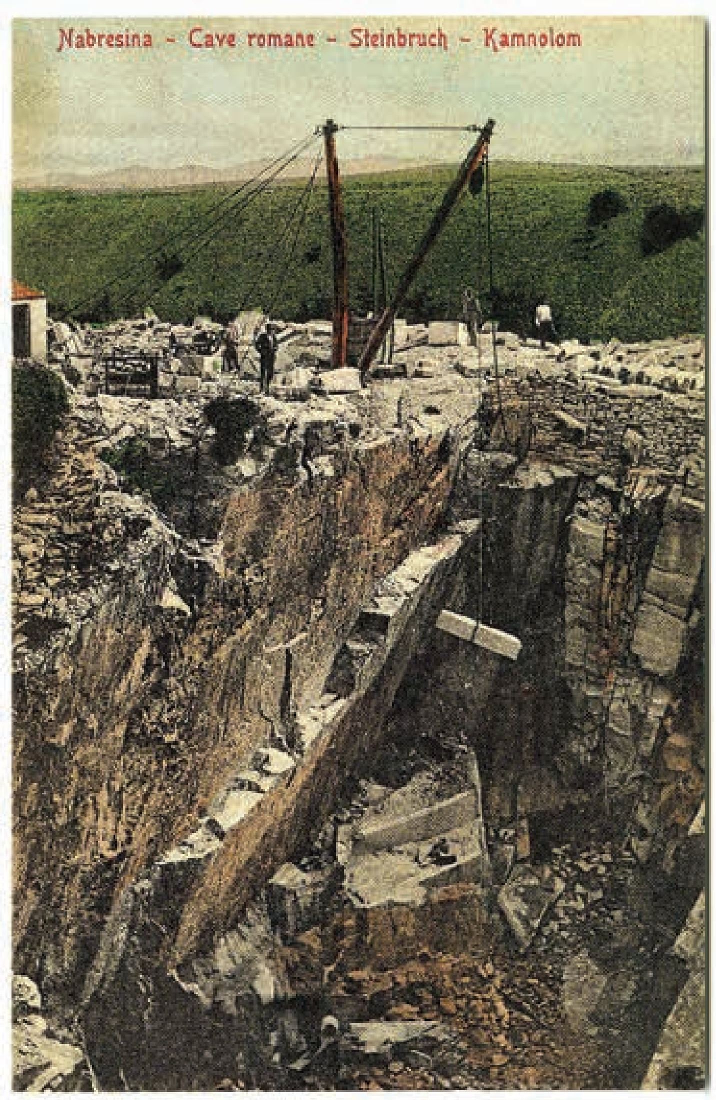


Figure 5.1.3: Photograph of Aurisina-Nabrežina Cava Romana on a period postcard

which can be polished and is suitable for decoration and usable in various fields of construction and furniture production.

Given the variability of the sedimentary environments that characterized the Adriatic-Dinaric carbonate platform in the Cretaceous, there are currently several types of ''Karst marbles'' on the market: *Aurisina Chiara, Aurisina Fiorita, Aurisina Granitello, Roman Stone, Fior di Mare, Repen Classico Chiaro, Repen Classico Zolla, Lipica unito, Lipica fiorito* and *Kopriva*. Besides the types still in production today, the Komen platy limestone (Figure 5.1.6), the colorful Karst breccia, the red or yellow flowstone and the black Gabria were all quarried.

The Aurisina varieties were widely used in Roman times, and the Repen and Lipica were used over time for domestic purposes given their substantial impermeability.

From the material traces and also from the written sources or oral tradition, it is clear that in the 18th and 19th centuries there were more than 400 limestone quarries on the Classical Karst. The oldest traces of stone extraction can be found in the Aurisina-Nabrežina basin in the upper part of the walls of the *Cava Romana* (Figures 5.1.2 and 5.1.3).

In addition to the large quarries used since ancient times, where the morphological and lithological conditions favoured the extraction of blocks, people opened small quarries from which were extracted the useful material for the construction of houses, sacral and public buildings, walls and roofs. Apart from the convenience of having the production sites close to places of use, the choice of materials had to take into account the chromaticity, uniformity, decorativeness, and the technical and physical-mechanical characteristics in line with the intended use: external or interior, ornament or structure, workability or hardness..

Since the earliest settlements, almost the entire population was involved in some way in the process of stone extraction. The local population specialized in the work in quarries or in stone cutting, organizing themselves into several stonemasonry workshops. Until the beginning of the 20th century, in this area practically every family had at least one member involved in one of the activities and gained modest income from it.

The process of stone extraction has changed over the centuries. In roman times, the work was done both in open pits and underground. Stone blocks were cut by digging grooves with picks and chisels, detaching them with wooden wedges, later with wet or iron wedges, before being beaten or forced with long iron levers. This was followed by a process outside the quarry with pointed chisels from large to fine and bush-hammers or hammers with teeth from large to fine, until blocks or suitable boulders were obtained. To move the stones, cylindrical rods, the *curuli*, were used, while to lift them *capre* using a pulley, the *trochlea*, and the *machinae tractoriae* (with several pulleys) were used. Transfers of stone over a distance saw winches employed, the *sucule*, while to hook the blocks, in addition to simply placing them in a sling (but the rope hindered the placing), the ropes were tied to nuts or studs placed on the side faces, or *ferrei forfices* were used. These were iron scissors or multi-element *olivelle* introduced into lateral holes or in the centre of the upper face.

From the second half of the 1800s, explosives and gunpowder were used. In the early 1900s drills using compressed air and the helical wire came into use and employed extensively in Karst until the early 1980s. In recent decades, the most modern techniques require the use of a diamond wire or a diamond chain cutting machine.

Depending on the type of quarry, on a slope or in a pit or well, the way the blocks are handled has changed considerably over time. In the first type, the blocks were transported by inclined paths and winches. In the second type, the movement of the blocks (but also of the waste) could only be done with the help of powerful lifting equipment (derrick cranes), which until recently were indispensable in quarry operations. Nowadays, the lifting of block is carried out by powerful mechanical shovels.

Figure 5.1.4: Mausoleum of Theodoric in Ravenna with a roof, made of a single block of Aurisina-Nabrežina limestone (Photo: Franco Cucchi)

The first to appreciate the limestone were, of course, the inhabitants of the *castellieri*, the fortified villages built on the hilltops. Apart from its use for the construction of ordinary houses, the use of Karst stone for larger and more important buildings began with the expansion of the Roman city of Aquileia and its port in 100 C.E.

At the beginning of the first millennium, the presence of Karst stone in *the X Augustean Region Venetia et Histria* was mainly related to sepulchral use, with urns sealed with lids, epigraphs, stelae and altars distributed along the two main routes, the *Via Julia Augusta* and the *Via Postumia*. Then Aquileia gradually gained strategic and economic importance, so the construction of temples, forums, theatres and other buildings began. The stone blocks arrived at the stonemasonry workshops in Aquileia, were worked on site and then distributed within the city and the surrounding area. The greatest distribution of Karst stone took place between the 1st and 3rd centuries C.E. The blocks were quarried in the Aurisina-Nabrežina area and sent to Aquileia or *Tergeste*, across the Adriatic Sea from the Sistiana-Sesljan Bay. In *Tergeste*, on the *Capitolium*, there were numerous monumental buildings made of karst stone, which allowed considerable savings compared to imported stone materials, but still guaranteed solidity and magnificence.

Among the blocks quarried in the quarry of Aurisina-Nabrežina, the most famous is the *ingens saxum*, the monolithic roof of the Mausoleum of Theodoric in Ravenna (Figure 5.1.4), which since 1996 has been a UNESCO World Heritage Site. It is circular, with a diameter of 10.76 meters and a thickness of 3.09 meters, which means almost 300 tons of rock! It is still a mystery how the block was ex-

Figure 5.1.5: Most valuable Karst stones are Lipica fiorito (top left) and Lipica unito (bottom left) from the Lipica Quarry (which correspond to the Aurisina Fiorita and Aurisina Chiara types from Aurisina-Nabrežina Quarry), then Repen (top right) and Kopriva (bottom right) types of limestone from the Doline Quarry (corresponding to Repen Classico Zolla and Repen Classico Chiaro in Italy and the boutique dark Kazlje limestone (Photo: Bogdan Jurkovšek)

cavated, how it was transported to Ravenna and how it was placed (around 520 C.E.) on the decagonal - circular structure of the mausoleum at a height of fifteen metres.

There is little evidence of the use of Karst stones in important constructions from the Middle Ages and until 1700s, when Trieste and its surroundings gained importance as a free port of the Habsburg Empire. After the construction of the Southern Railway, the line that connected Vienna with Trieste (1857), the period of greatest wealth began for the Karst quarries. The use of the Karst stone quickly spread throughout the entire territory of the Empire and beyond. Aurisina-Nabrežina became the most important processing and distribution centre for stone from the entire area of the Karst and also from the Istrian region. The Aurisina-Nabrežina quarry provided the stone for several famous monuments, including several representative buildings in Trieste (the Greek Orthodox Church, the Stock Market, Miramare Castle), in Vienna (Burgtheater, National Opera, Hofburg and Parliament), the railway station in Milan (1930), Budapest and other European cities, as well as the entrance to the Suez Canal.

Nowadays, in the Slovenian part of Karst only two companies own the concessions for limestone extraction. The first company quarries stone blocks in several locations including Kopriva (*Kopriva Limestone*), Doline (*Repen* and *Kopriva Limestones*) and Lipica (*Lipica unito* and *Lipica fiorito Limestones*) (Figure 5.1.5) (see also Chapter 4). The other small company has a quarry in Debela Griža pri Povirju (*Repen Limestone*).

As far as the Italian part of the Karst is concerned, in the Aurisina basin there is a small company and a consortium which includes some concerns that exploit several quarries. The quarried material is purely local: Aurisina chiara, Roman stone, Aurisina fiorito and Aurisina granitello. In the Zolla and Rupingrande area a third company quarries the Repen and Fior di Mare varieties.

The quarries in the Karst area were important, and must be preserved, because quarrying is part of the tradition and identity of the area. Nevertheless, it is necessary to take into account the aesthetic and the environmental vulnerability of the area. Abandoned quarries are often an impressive element of the cultural landscape, especially where quarrying and stonemasonry were the main economic activity of an entire area. They are perceived as "wounds" in the natural environment, but today they offer other possible uses. In all operating quarries and in potentially interesting deposits of dimension and technical stone, quarrying should be possible only if high environmental standards are met. Smaller quarries should be preserved to allow limited extraction of those karst (Figure 5.1.6) stone varieties suitable for restoration of authentic karst architecture.

Figure 5.1.6: Abandoned surface extraction of the Komen platy limestone in Gabrovica (Slovenia), used for roofing and paving (Photo: Bogdan Jurkovšek)

5.2 The Karst / Kras / Carso as a cultural landscape

Stone is the undisputed protagonist of the Karst cultural landscape, from prehistoric times down to the present day. It was this stone that enabled cultures to erect constructions in both urban and rural areas from prehistory, right up until the 20th century saw it give way to concrete. This centuries-old practice created a specific Karst landscape composed of a network of countless dry-stone walls and a variety of stone buildings – shepherds' shelters, houses and villages, hillforts and castles, churches and chapels. The same stone has been collected, cut, erected and used for civil, military and religious purposes for generations. The traces we can still find today are evidence of an uninterrupted will and ability to exploit this distinctive material of the Karst: its limestone.

The *castellieri/kaštelir/gradišče*

The oldest buildings in the Karst are its hillfort settlements *(*called *castellieri*, *kaštelir, gradišče)* dating back to the Bronze and Iron Ages, these were small villages, built on hilltops and fortified for defensive purposes. They are made up of stones placed one on top of the other, often erected dry and surrounded by one or more concentric walls of a fairly massive circular or elliptical shape, within which the inhabited area was laid out, and the perimeter of which could be usually up to one kilometer in length (Figure 5.2.1).

These settlements were generally located on hills or in dominant positions, following the natural configuration of the land. There are hundreds of them, in a range of shapes and sizes, depending on their age and the site's local morphological characteristics. The *castellieri/ gradišča,* which first arose as temporary camps for shepherds, later became permanent settlements and remained so for more than a millennium, from the 15th to the 3rd century B.C.E. They lost their residential function with the arrival of the Romans, when they were transformed into military garrisons and largely reduced to ruins during conquests. On the basis of the archaeological material found in these ruins, it has been possible to reconstruct the living conditions, uses and customs of the communities in the area of the Karst from the Iron Age through to the first Roman settlements. With the arrival of the Romans new urban patterns were introduced, creating commercial, administrative, and religious centres. New settlements were built in the plains below the forts, in the most favourable locations close to farmland, where in most cases they still stand today.

Figure 5.2.1: The prehistoric lowland hillfort settlement Debela griža near Volčji Grad (Photo: Roberto Valenti)

In the tumultuous time of Late Antiquity, when the foundations of the Roman state began to crumble in these places, the focus of settlement again moved to more remote and difficult to access places. Some hillfort settlements were re-fortified and used until the decline of the Roman Empire, while others have survived until the present day. This dual pattern - with settlements in the plain and hillforts above - characterises the Karst's cultural landscape to this day. In the Middle Ages, fortresses *(rocca/tabor)* as well as castles were built on the sites of former fortifications.

The Gradec at Rupinpiccolo-Repnič is a good exaple of a hillfort where the original walls were preserved enough to be partly reconstructed and presented to the visitor. On a low hill, in addition to the remains of the walls, you can see the gates of the *castellieri* from the early Iron Age.

Another important fortress is that of *Tabor* or *Rocca* of Monrupino-Repentabor (Figure 5.2.2). This place features the stratification of buildings from different periods, on a hill in a strategic position that on one side dominates the Karst of Trieste and, on the other, the Slovenian sector. It was initially a prehistoric hillfort, then a fortified Roman *castellum*, and finally a defensive fortress against the enemies. The hillfort of Monrupino-Repentabor, whose stone walls can be admired halfway up the hill, is the largest in the area, covering 1,600 square metres and one of the best equipped. It is the best-preserved *tabor* in the Karst. Tabors are fortified settlements, usually with a church, which served as refuges during Turkish invasions and are present throughout Slovenia. At that time, from the top of the Tabor they signaled the approach of a threat by lighting bonfires.

buildings built of dry stone walls confirm that the hill was intensively inhabited in the first half of the 1st millennium BC, in the Early Iron Age. The remains of Roman architecture and numerous Roman finds on the Štanjel hill reveal that this was an important Roman settlement and a late Roman outpost. In the late Roman period, a fortress or tower stood on top of the hill and was used by the soldiers to control the passage to the Vipava Valley. The area of Gledanica provides good visual communication with the mountain pass on Hrušica (*Ad Pirum*), through which the main Roman road ran from Italy (Aquileia) to the Ljubljana basin (*Emona*) and further toward Pannonia. The remains of a ruins on top of the hill is most likely a remnant of a tower from the 13th or 14th century. A village settlement was formed below the tower, which gradually transformed into a fortified *tabor*.

Also worth mentioning is the Slivia-Slivno hillfort, the remains of the wall and the ramparts can still be seen. It was built in the Middle Bronze Age, and was inhabited for almost the entire Iron Age. It is one of the most significant *castellieri* in the Italian part of the Karst and is known for its very rich archeological remains.

Vahta pri Kazljah is one of the largest and better-preserved *gradišče* in the Slovenian part of the Karst. This prehistoric site of extraordinary dimensions has a double ring of defensive stone walls, which are almost completely preserved. Of same importance and well preserved is the hillfort called Debela griža at Volčji grad. Hillforts in Brestovica, Sveto pri Komnu, Lipovnik nad Škrbino, Temnica,

Figure 5.2.2: Community house of Rocca di Monrupino-Tabor (Photo: Sara Bensi)

A prehistoric settlement also occupied the whole upper part of the Štanjel hill located at the edge of a Karst Plateau. It controlled the better part of the Komen Karst as well as the passages through the Raša and Branica River valleys. According to the finds of an archaeological investigation, the beginnings of the settlement date back to the Bronze Age but most of the finds date back to the Iron Age. The rich layers of the settlement and the remains of prehistoric

Figure 5.2.3: Dry stone wall (left) and hiška (right) are characteristic cultural landscape elements of Karst (Photo: Sara Bensi)

Kobdilji, Škocjan pri Divači, Povir, Tomaj, Rodik and elsewhere have also been preserved.

Typical remains of architectures of the late Middle Ages are, in addition to the Rocca di Monrupino the preserved towers in Dolenja vas and Lokev. However, perhaps the most eminent example of medieval defensive architecture is the castle of Duino-Devin.

Dry stone walls *and hiške*

The local stone, already used in the Bronze Age for the construction of *castellieri/gradišča,* was also used as a building material for the dry-stone walls; a technique that it made possible to reclaim agricultural land, protecting soil and plants from the powerful, cold bora wind, and at the same time divide up properties. The low walls have become a characteristic feature of the landscape of the Karst Plateau, characterized by water scarcity and a shallow, rocky soil that, largely unsuitable for agricultural activities, is mostly used for grazing.

Outside the settlements, usually on the edges of the fields and next to the dry-stone walls, special circular, walled structures and a corbelled roof were built. These are called *hiške* and are primitive shelters used by shepherds or farmers who worked in the fields far from the villages (Figure 5.2.3). In almost all cases, they are simple architectural structures with a single room, sometimes using the large limestone blocks available in nature. The *hiška* is built with overlapping stone slates that once they reach the desired height, converge towards the center, forming a pseudo-dome. The average area of each is about 2 square metres (varying from a minimum of 0.8 to a maximum of 4.9 m^2) and the average interior height about 1.6 m. They are mostly cylindrical and prismatic in shape. The door opens into a shelter, facing away from the east - north-east direction, from where the bora blows.

The Karst house *(kraška hiša)*

The houses are usually small and single unit, sometimes with an additional, often separate kitchen *(spahnjenca)*; or slightly larger structures with a second floor and an external staircase, usually representing the residential part of a homestead with a walled courtyard *(borjač)*. The traditional Karst house is built of raw or semi-processed stone obtained sometimes also from the clearing of fields and pastures. The roof is constructed of wood (oak), while the roofing, initially of straw in the first phase, later saw stone slabs used and, much later, tiles. Together with lime and wood, the use of stone gave the inhabitants of Kras-Carso complete autonomy in the construction of their houses.

In Repen there is a Karst house, nowadays a museum, where you can discover the characteristic Karst architecture in all its facets and see furnishings, utensils and household items inside. It is a complex consisting of a closed courtyard *(borjač)* and stone gate portal *(kaluna)*. The house has a roof made of platy limestone, square windows with railings, doors with triangular and rectangular crosspieces and a set of stone stairs to reach the wooden balcony *(gank)* (Figure 5.2.4, left). Inside is the stone-paved kitchen with a bread oven, an open fireplace and a niche for the water tub. The buildings that overlook the courtyard include a stable, chicken coop, a manure pile, barn and a tool shed. Every two years at the end of August, the museum hosts a Karst Wedding (see Chapter 5.3), an important ethnographic event for local people (Figure 5.2.4, right).

The Karst House in Štanjel has also been renovated into a museum with an ethnological collection. There is a commercial part on the ground floor, and a living part on the first floor. Rainwater from the roof covered with stone slabs is channeled through the stone gutters into the monumental public well next to it, which testifies to the importance of water for the Karst. The house reflects the architectural peculiarities of the original karst houses built in the Romanesque and Gothic periods.

The Škrateljnova homestead in Divača is an impressive Karst homestead, that dates back to the 17th century, where the residential part was represented by the Skrateljnova hiša, a typical two-story karst house and a kitchen, added later. (Figure 5.2.4

and Figure 5.2.5). The facade of the building is very dynamic with steeply sloping roofs covered with tabular limestone slabs, while the roof covering the balcony is covered with brick tiles. The auxiliary buildings, including the hayloft and the stable, as well as the fenced pigsty and the wine cellar, have tiled roofs. The entire complex now houses the Museum of Slovenian Film Actors with a permanent exhibition in honour of the film actress Ita Rina, born in the town in 1907.

Figure 5.2.4:
Left - the Karst house in Repen (Photo: Roberto Valenti); right - a detail of the hause during the Karst Wedding in 2022 (Photo: Sara Bensi)

Figure 5.2.5:
The Škrateljnova hiša in Divača (Photo: Mitja Guštin)

Figure 5.2.6:
A fortified village of Štanjel
(Photo: Jošt Gantar)

Villages

Over time, the shape of the villages has changed, stringing together houses and other buildings. In this way, long streets called *gase* were formed, so characteristic of Karst settlements in the Medieval period. Later, the houses were arranged around courtyards (*borjač*), with high stone walls, and a passage with a stone portal (*kaluna*). The buildings in the villages resemble each other in appearance and size. Even the architecture of the churches or fortresses does not differ too much from that of the houses. Limestone is the predominant material used in buildings and artefacts. Everything conceivable for domestic use that could be was made of stone, such as the linings of the wells, the guttering, the containers for lard and the feeding troughs for the animals.

Many villages, as a whole or at least in their centres, have preserved a Medieval design, with a network of streets connecting the individual homesteads. One of the most important showpiece of Karst architecture and culture is Štanjel (Figure 5.2.6). The compact village spreads out along alleys on the slope of the hill within defensive walls. On the eastern side the village gives way to the characterful Ferrari Garden from the period between the two world wars, designed by the important Slovenian architect Maks Fabiani. Below the entrance to the village stands a castle and a church, which together form a larger square with a fountain.

Sacral architecture

Almost every village in the *Kras-Carso* has its own church or at least a chapel, which are an all-important part of the harmonious Karst landscape. The Church of Our Lady of the Assumption in Šmarje pri Sežani is among those best-preserved (Figure 5.2.7), with an original Gothic style featuring a steep stone roof and a bell-gable above the entrance. The Church of St. Giles in Sveto near Komen is classified among the most important monuments of sacral architecture in Slovenia. The church has a unique octagonal nave, covered by an umbrella-shaped roof that is supported by a single, formerly wooden pillar. The Sanctuary of Monrupino-Repentabor preserves the 16th century structure of the buildings and walls, with the central body of the building resting on the internal shelf of the tabor, while the apse rests directly on the external cliff. In Rosandra-Glinščica Valley the ancient church of Santa Maria in Siaris - Sveta Marija na Pečah, built on a steep rocky spur, dates back to the 13th century. For a long time, it has been a destination for pilgrimages.

The castles

Above all, in the northern sector of the Karst stand the remains of castles, forts and fortresses of Medieval and modern foundation. The most notable is perhaps the Habsburg residence of Miramare Castle (Figure 5.2.8), overlooking the sea. To reach it, Maximilian of Habsburg had the railway station built in the mid-19th century along the historic Wien-Trieste railway line.

In the southernmost section of the Karst there are ruins of Medieval military buildings, which were built to protect the traffic connections and trade routes to Istra and Ljubljana, such as the castle of Moccò (*Muhov grad*) in Rosandra – Glinščica Valley.

The first railway

To connect the city of Wien with the southern part of the Habsburg Empire, and the port of Trieste, the "Südbahn" or "Southern Railway" was opened in 1857. To obviate the difference in height between Divača and Trieste, the railways had to be laid out amidst dolines and other Karst features, thus becoming an important component of this part of the Karst. For the same reason, between Trieste and Monfalcone, in 1928 a new Trieste coastal road was opened (the *Strada Costiera Trieste*), which crosses the Karst slopes just before a natural tunnel (Crepa Magna) up to Sistiana-Sesljan and offers wonderful views of the intertwining of rocky layers, across the bay, on the high slopes, on the cliffs below and across to Duino Castle on one side, and Miramare Castle and the city of Trieste on the other.

Figure 5.2.7: Church of Our Lady of the Assumption in Šmarje pri Sežani (Photo: Fabiana Pieri)

Figure 5.2.8: Miramare Castle in the Gulf of Trieste (Photo: Giancarlo Massari)

Military arcitecture

The numerous testimonies of the World War I and II left on the ground are 'open-air museums' where you can visit trenches, forts, tunnels, mule tracks and military shelters in a good state of conservation.

5.3 Agriculture, traditions and geoproducts of the geopark

The Karst is an area with a millennia-long history, which can still be read in both the material and abstract culture. Agriculture has always shaped the landscape and is reflected in its agri-food production, cuisine and popular festivals.

The area of the geopark is a distinctive place with a range of natural characteristics. These affect human activities, in particular agriculture and subsequently the local cuisine and related traditions, that have developed over time, and are still kept alive today. There are many local products, customs, and habits, often differing from one village to another. This chapter presents the most typical and important ones that represent the backbone for the sustainable tourism offer of the geopark.

5.3.1 Agriculture

Taking into consideration the geographical and historical context and adding all the natural characteristics of the geopark area (geological, hydrological, botanical, climatic and so forth) we can see that the area it covers is more or less a rural one, with small settlements where agricultural activities have been the main source of survival for centuries.

Traces of prehistoric land use and field division in the Karst suggest that the main activities were the breeding of cattle, small and large, as well as farming. The natural vegetation was forest that was extensively cleared, mainly for grazing, the production of hay and for cultivation. Deforestation accelerated water and wind erosion, which gradually transformed the Karst into a barren landscape over the last millennium. In the 19th century, systematic reforestation began, first unsuccessfully with oaks (*Quercus spp.*) and later, with greater success, using black pine (*Pinus nigra*). Economic changes and the development of the non-agricultural economy sectors in the second half of the 20th century contributed much to reduce the active farming population. The abandonment of agriculture led to intense natural vegetational succession of agricultural land, a process that is still ongoing. Another reason for the abandonment of fields and meadows is the unsuitability of Karst land for mechanized cultivation.

Figure 5.3.1: Grazing is a form of counteracting the loss of biodiversity due to natural reforestation (Photo: Roberto Valenti)

Throughout history the Karst and the neighbouring Brkini region have been a rural hinterland of Trieste. They supplied the city with foodstuffs, firewood, handicrafts and other products as well as ice. The latter was cut from *kal* (shallow Karst ponds with standing water) in the winter and stored in ice caves-*denice* - either natural or man-made. The temperature in them was constant, so the ice was preserved for a large part of the year. In the summer, they cut the ice, both exporting it and selling it in Trieste.

Climatic and edaphic (soil) conditions enabled the development of viticulture and fruit growing which are important branches of agriculture with a long tradition in the Karst. Fruit commonly grown in orchards include cherries, plums, peaches, and walnuts, and are usually for domestic use and not sold. Fruit growing is especially important in the south-eastern part of the area covered by the geopark, in Brkini. Here the conditions are more suitable and from the crops, they also produce dried fruit and brew and distil spirits. Other activities that also take place here include agricultural tourism, olive oil manufacturing, dairy farming, and cheese-making.

Viticulture is probably one of the most renowned local branches of agriculture and a major source of income. Despite the fact, that the Karst soil is rocky and barren, the area is a recognized wine-growing region with using major international grape varieties, but especially important are the autochthonous ones including Glera, Vitovska, Malvasia, Refosco, and Terrano (Figure 5.3.2).

5.3.2 Geoproducts

The geological nature of the area influences local production and in particular agro-food production, which are outlined in this section.

Teran (Terrano)

Terrano (Slovene *Teran*) is a Slovenian and Italian wine variety (not to be confused with a completely different grape variety also called Teran, which is indigenous to the Croatian part of the Istrian peninsula), bearing the mark of the recognized traditional denomination. It has been cultivated since antiquity, mentioned in Roman and Greek sources, as well as medieval German ones, and in the "Glory of the Duchy of Carniola," by the Slovenian natural historian and polymath Valvasor from the 17th century. It is a member of the Refosco family of grape varieties, but it gets its distinctive taste and colour from the Karst soil, known as the *terra rossa*. As such, it is inextricably linked to the specific carbonate bed-

Figure 5.3.2:
Karst vineyard landscape
(Photo: Bogdan Jurkovšek)

rock and is undoubtedly one of the most typical geoproducts. *Terrano* wine is produced solely on the Karst Plateau, both on the Slovene and Italian sides and is the principal red wine grape in this area.

Kraški pršut (Karst prosciutto)

Kraški pršut belongs to the group of Mediterranean air-cured hams and has an EU-protected geographical indication (PGI). The protection of the *Kraški pršut* comes from the natural and climatic characteristics of the Karst region, from the tradition and the transfer of knowledge of the locals to today's generation, from its long-standing reputation, and above all from its distinctive quality. It is a pig hind leg or thigh, dry-cured for a minimum of 9 months according to the traditional recipe which, together with the special Karst climate with the bora wind, develops the typical texture, colour, smell, and taste of *Kraški pršut*. The Karst climate is also reflected in other dry-cured meat products that are typical for the area: *zašink* (pork neck), pancetta, salami and so forth.

Brinjevec (Karst Gin)

Brinjevec (or *Brinovec*) is a strong alcoholic drink (between 40% and 50% alcohol), also produced within the geopark area. It is distilled from the ground and fermented Juniper (*Juniperus communis*, Slovene *brin*) berries only, and it differs from similar drinks that have different alcohol bases with added juniper flavour (compound Gin, Slovak *Borovička*, Dutch *Jenever*, Serbian *Klekovača*, etc.).

Brkinski slivovec (Brkini plum brandy)

This is a plum brandy made from local autochthonous plums. *Brkinski slivovec* is made in special copper pots solely in the south-eastern part of the geopark area and is a protected drink with a geographical indication (GI) under Slovenian regulations.

Karst honey

As a result of its geographical position and climate conditions, the Karst has a unique floral composition of grasses, clover, herbs, forest, and shrubs that offer varied foraging for bees, rich in aromatic substances, which is reflected in the specific, full, and lively aroma and intense colour of the honey produced.

In Slovenia, beekeeping has a long and rich tradition, and honey is produced under strict regulation and only by a nationally protected bee subspecies – the Carniolan honey bee (*Apis mellifera carnica*). Therefore, Slovenian honey (PGI), including Karst honey (PDO), is protected under national and EU legislation.

About a hundred beekeepers are active on the Italian side of the geopark, mostly small or medium-sized businesses, for a total of about a thousand beehives in the area. A special mention is merited for the Marasca cherry honey PAT, so-called "morello cherry" honey derives from the nectar of the Dog cherry or St. Lucia cherry (Prunus mahaleb), a shrub that typically grows on the carbonate substrates of the Karst.

Karst cheese

As it was mentioned above, the area covered by the geopark has a long tradition of dairy farming as well as a specific floral composition with lot of herb species. This results in a rich, distinctive aroma and taste of cheese, even without any additions to it. A specialty of the area is the cheese, made by a local farmer near Aurisina - Nabrežina, with a unique ripening process that makes it one-of-a-kind. Maturation takes place for the most part in a 70-metre-deep Karst cave and is also called *Jamar* (the Slovene term for speleologist or caver) for that reason. There is also a wine cellar in Komen, that ages indigenous Karst cheese under controlled temperature and humidity in an old štirna, a traditional Karst well, six metres below ground.

Tergeste olive oil

Tergeste extra virgin olive oil (PDO) is produced in the Italian part of the Karst, from Duino - Devin to San Dorligo - Dolina, and obtained from the *Belica Bianchera* olive varieties, which must make up at least 20% of the groves, combined with other common varieties. *Tergeste* oil is golden-green in colour with a fruity aroma and a light to mild piquant taste. With its rather delicate flavour, Tergeste is perfect for salads, vegetable-based cream soups, pasta, rice or fish dishes (Figure 5.3.3).

5.3.3 Cuisine

Karst cuisine, like its cultural landscape, is an intertwining of Mediterranean, Germanic, Romanesque and Slavic influences, especially distinguished by its commitment to local, preferably home-grown, ingredients. Karst cuisine is frugal and without unnecessary expense.

In the past dishes were simple, the food they prepared was very much tied to the season and to what they grew at home. The main role was played by vegetables: cabbage, potatoes, beets, beans, peas and corn. They ate various stews 2 to 3 times a week, most with frequently *polenta* – maize meal, and buckwheat. Sweet dishes, desserts and white bread were not on the menu on an ordinary day, they were a special treat on Easter, Christmas and other holidays.

As the Karst was a rural environment, they bred pigs in almost every homestead. In winter, normally in December,

Figure 5.3.3:
Olive growing has become increasingly popular in recent years, with the production of quality oil recognised in the supra-regional sphere (Photo: Cesare Grazioli)


SAMATORCA
TERNOVA ALTA
PRAPROT
PREPOTTO

they butchered them and processed all the parts of the pig. This was a family feast, as it filled their larder for the whole year. They made *prosciutto*, *zašink*, *pancetta*, sausages and *salami* that were then dried and cured in the bora wind. These are very typical for the area and are often served to visitors as a welcome. Fresh dishes were also made, including blood sausages, crackling, brawn and fresh meat. Offal, such as the liver, heart, and brain were prepared as a snack for the butchers.

The Karst's forests and meadows represent a botanical paradise in the spring and summer months. Wild asparagus, savory, nettle, dandelion, yarrow, plantain, sage, mint and lemon balm are just a few of the ingredients that can be incorporated into many traditional dishes such as minestrone, *frtalje*, risottos or a meat offering as well as some contemporary dishes such as cheese spreads and cream soups.

Before going into detail about the main dishes of the local cuisine, it is useful to introduce a typical public eating place in this area, where one can enjoy typical dishes: the so-called "*Osmice*".

Osmica (pl. *osmice*) (osmiza) is a traditional form of selling wine and other homemade products from home, which only lasted eight days a year. Now it lasts longer in some places, but osem means "eight" in Slovene, hence the name osmica, meaning eight days. Written sources report that the right to open an *osmica* dates back to the time of Emperor Charlemagne, renewed over the centuries by successive ruling authorities. With this decree, winegrowers were given permission to sell their wine at home for eight days a year. Today, this local specialty is a popular form of tasting local delicacies and socializing on farms. Karst *osmice*, which some farms open twice a year, serve excellent wines and typical Karst dishes. They are recognizable by a wooden sign and a bunch of ivy that stays fresh for approximately eight days (Figure 5.3.4).

Figure 5.3.4:
(a,b) The osmice are a place for socialising and meeting the local gastronomic culture. (Photo: Rodolfo Riccamboni, FOTODAMJ@N);
(c) „Frasco", a branch of ivy indicating the presence of an open osmiza (Photo: FOTODAMJ@N)

Some of the most typical Karst dishes are:

Jota - perhaps the most famous Karst dish. Beans and sauerkraut or turnip are cooked together with a piece of dried meat (pancetta, *pršut*, sausage...), potatoes, cumin, garlic and bay leaves to create a stew or thick soup that is perfect for staving off the cold bora wind in the winter.

Mineštra - a thick soup or a stew made with vegetables, often with the addition of pasta or rice. There is no set recipe for it since it can usually be made out of whatever vegetables and herbs are

Figure 5.3.5: The tradition of preparation in tablecloths of cooked štruklji is passed on from generation to generation (Photo: Jože Požrl - Sežana Municipality Archive)

available. It can be vegetarian, contain meat, or contain an animal bone-based stock (such as chicken stock). A special variety is barley minestrone with pork meat (Slovene *Ječmenova mineštra s svinjskim mesom*). It is a recognizable and highly appreciated dish by Karst people, made of barley, potatoes, beans and pork.

Frtalja (from the Venetian word fritaia, which means "fried") - an egg omelette, especially common in the springtime, as at that time there are many plants and vegetables available such as wild asparagus, wild hops, herbs such as fennel, mint and chicory, tomatoes and young garlic sprouts as well as spices. They are added to egg and some other ingredients (small bits of stale bread, *prosciutto*, mushrooms, wine). The quantity of ingredients is never exactly defined however, the main part being herbs and vegetables, with eggs and flour only there for binding them together.

Štruklji - a type of strudel, a traditional Slovene dish, composed of dough and various types of filling (cottage cheese, walnut, tarragon, dried fruit...) in the form of a roll. With many variations throughout the country, and there are also some that are typical of the Karst. They are traditionally cooked in white cloth, but if they don't have any filling, they are called ˝deaf˝ štruklji and cooked without using a cloth (Figure 5.3.5).

Krompir v zevenci - from the vats in which cabbage has been soured, they take the remaining liquid, called *zevnca,* add some garlic, pepper, and sometimes a piece of pork. In this mixture, they then cooked peeled potatoes and dress them with cracknels or onions.

Žouca - this is a type of offal, a mandatory dish every Easter. Pork legs, ears, tail, tongue, or some better pieces of meat are well washed and put in cold water. They are slowly and evenly cooked for seven to nine hours (these are "magic" numbers) until the meat starts to come away from the bone. While cooking, the water boils down to three quarters. The pieces of pork are taken out of the broth. Then it is strained and cooled to remove the excess fat that accumulates

Figure 5.3.6: An overview on Karst tastes
(Photo: Jože Požrl - Sežana Municipality Archive)




on the surface. The cooled bits of pork are cleaned and shaped into even pieces and distributed in a deep dish and the broth poured over them. Slices of hard-boiled eggs, black peppercorns, and bay leaf are added and cooled for several hours.

Supe - This is prepared from bread a few days old, that is cut into 2 slices, 3 centimetres thick. These slices are soaked in milk and whisked eggs with a pinch of salt. They are fried in hot oil and, while still warm, sprinkled with sugar. It is no wonder that this rich dish is still a favourite with children today.

Fancli z dušo - a type of fried dough, that has a special salty filling or "soul" (Slovene *duša*), made of salted anchovies. These are a typical dish on Shrovetide.

Figure 5.3.4: (d, e) In the osmica you can get to taste really local products and the typical Karst wine, Teran or Terrano, while enjoying the marvelous landscapes that the Karst offers (Photo: FOTODAMJ@N, Fiorella Bieker)

5.3.4 Events and traditions

Local communities keep alive customs that have been preserved in all Karst villages and reflect their Slovenian, Italian, German and Istro-Venetian origins. Many *šagra* or *opasilo* (celebrations) and traditional holidays are held in the Karst, especially in spring and summer. There are also some events that are more recent in origin, but have been accepted and are growing in importance.

Tourist promotion websites offer an exhaustive overview of the events promoted throughout the calendar year, but here we highlight some of the most important and characteristic ones, which best describe the local culture.

Pust (Shrovetide)

The celebration of *Pust - Pustovanje* (Carnival) is very widespread and important on the Karst. It is among the first festivals in the calendar year, it is supposed to drive away winter and is a harbinger of spring. People dress up in a range of characters - called *šeme* - to form a procession. The procession then goes around the village and visits homesteads, where they get treats such as *fancle*, *štraube (crostoli)*, wine, eggs, sausages and money.

First of May celebrations

In most places in Slovenia, including the villages in geopark, this celebration is associated with the installation of the *Mlaj*, tall trees, usually a pine or a poplar, with peeled trunks, green tops and decorative wreaths on which are hung fruit (oranges, apples) and a fluttering flag on top. The *Mlaj* is set up the eve of May 1st. In some places, it is accompanied by bonfires.

Majenca

One of the most characteristic festivals is the Majenca: it is held at the beginning of May in Dolina (a hamlet of San Dorligo della Valle-Dolina) and consists of music and dances. A celebration with ancient origins, it has been held every first Sunday of May in the very heart of the village. For the occasion, the so-called "*maj*" is raised (a fir trunk about fifteen metres high on which a cherry tree is placed), and the unmarried village boys invite single girls to dance under the tree to celebrate spring. This is a festival where the whole community takes part, including cultural and other associations, the Municipality, local winemakers and olive growers (Figure 5.3.7).

Figure 5.3.7: The Majenca*, an example of a traditional ancient Karst spring festival (Photo: FOTODAMJ@N)*

Teran and Kraški pršut festival

On the Slovenian side of the geopark, Praznik terana in pršuta (Terrano and Karst ham Festival) in August is the most important festival of the Karst people and all lovers of Karst cuisine and customs. With its rich gastronomical, oenological, cultural, sports, ethnological and entertainment-social programs, it attracts visitors from home and abroad to the Karst. At several events that connect the destination, several local providers present themselves, with a hospitality offer that includes the famous culinary specialties of the Karst and Brkini regions, but especially Teran and Kraški pršut.

St. Martin's day celebrations (Martinovanje) on the Karst

When the smoke-tree turns red, the other colours of the Karst also take on a special hue. These are the colours of love, the coherence of the people of Karst with nature and their devotion. In Autumn, the tastes are mature so the locals organize *Martinovanje* party (St. Martin's day is November 11th) in several locations throughout the geopark and provide culinary treats and a tasting of Karst wines.

Karst pre-wedding traditions

An interesting custom also takes place a day or two before a wedding for the newlyweds. This custom has been preserved in the Karst with small variations from one village to another to this day. Two days before the wedding, young, unmarried boys and girls, create a "*koluna*" for the newlyweds, which means that they put up two *Mlaj* trees (usually peeled pine trunks with a green top) in front of the entrance to the family homestead, and decorate them with juniper and ivy branches and stolen flowers. They hang up a sign between the two *Mlaj* trees, wishing all the best to the newlyweds.

Kraška ohcet (Traditional Karst wedding)

Every two years, the *Kraška ohcet* takes place in Monrupino - Repentabor. This a folklore event lasting several days, reviving a 19th -century wedding. It starts on a Thursday evening dedicated to single boys and girls and ends on Sunday when the wedding takes place in a stone church in Tabor, followed by a wedding lunch with typical dishes and dancing until late in the evening. The event is particularly spectacular also thanks to the spontaneous participation of numerous, more than 500 local inhabitants dressed in the traditional costumes of the Karst (Figure 5.3.8).

Figure 5.3.8: The Kraška ohcet *- Traditional Karst wedding in Repen (Photo: FOTODAMJ@N, Igor Grilanc)*

BIOLOGICAL PECULIARITIES OF THE CLASSICAL KARST

6.1 Introduction - the geodiversity and biodiversity of the area

The Classical Karst is an area where abiotic and biotic features work hand in hand to develop a unique landscape. Due to the area's natural resources (geographical position, rocks, climate) and centuries-old traditional human activities (mowing, grazing, burning, building dry stone walls) the Karst is a remarkably diverse landscape and a varied mosaic of habitats with extremely rich flora and fauna. Here there are many endangered species of plants and animals, many of which are rare and endemic. Among the latter, the cave species stand out. The area is of great scientific importance for the study of various plant and animal groups, with a focus on caves. High biodiversity also means a better quality of human living environment. The interdependence of the abiotic and biotic parts of nature are clearly visible and spread across the entire area of the Classical Karst. Iconic examples include the Škocjan Caves, Doberdò-Doberdob and Pietrarossa-Prelosno Lakes, the valley of the Rosandra-Glinščica and the Duino-Devin Cliffs, where a diverse flora and fauna develops on geologically and geomorphologically different elements.

Figure 6.1.1: Illyrian iris (Iris cengialti subsp. illyrica) *on the edge of the Rosandra-Glinščica Valley (Photo: Roberto Valenti)*

The Karst region is an area rich in biodiversity. The main factors that over time have favoured the development of this richness of life are, on the one hand, the border area between three important biogeographical regions, i.e. the Mediterranean, the Continental and the Alpine and, on the other, a lively, harsh and often bumpy geomorphology, not very suitable for intensive use by humankind, which has favoured the natural evolution and conservation of ecosystems.

The convergence of three biogeographical areas is a remarkable reason for the cross-contamination, mutation and selection of new species, for which the Karst is also recognized, along with the richness of its habitats and the species of important conservation value. Proof of this is the fact that more than half of this territory is fully included in the Natura 2000 network, which protects the habitats and species of greatest conservation value at a European level.

The presence of rocky environments, unsuitable for agriculture, is a multiplying factor in facilitating the conservation of biodiversity and natural selection. In particular, the underground karst environments constitute genuinely extreme environmental contexts, in which flora and fauna of exceptional rarity and ecosystemic value find space.

In quantitative terms, the Classical Karst has:

- 23 habitats, of which 5 are recognized as priorities by the European Habitats Directive on the Italian side and 16 habitats, of which 10 are recognized as priorities on the Slovenian side;
- More than 200 species of birds, of which 72 are included in Annex I of the European Birds Directive (2009/147/EC);
- 27 animal species among mammals, reptiles, amphibians, fish and invertebrates protected by the Habitats Directive (92/43/EEC), of which 4 are priority;

- over 500 species of butterflies;
- several endemic species of flora and fauna.

Prior to the introduction of the most representative and the most peculiar flora and fauna species which the visitor to the Karst may come across during a geo-excursion, it is appropriate to present the main habitats of the Karst. The most representative six of them are: woods and scrub, karst dry grassland, calcareous thermophilic scree habitats, cliffs, water bodies and underground environments.

At the Carsiana Botanical Garden in Sgonico-Zgonik it is possible to experience the most representative habitats of the Karst.

Woods and scrub

In ancient times the Karst was covered by oak forests which, following deforestation and grazing for thousands of years, were progressively destroyed. Today only a few fragments of these ancient woods still exist.

The Karst scrub is the most represented environment on the Karst Plateau. It quickly established itself after World War II with the abandonment of grazing. This formation is the degradation product of the ancient Karst forests. Its composition reflects the geological and environmental characteristics present in most of the Karst where the residual soil layer and the permeability of the rocky substrate are some of the factors that determine the development of a sparse tree cover, mostly characterized by specimens that are shrubby rather than arboreal, with little standing timber. The tree layer is in fact represented by elements with a slender stem and reduced vertical development.

Karstic dry grassland

It is where the wood gives way to ancient pastures that one of the most peculiar environments of the area has been created: Karst grassland. This zoogenic formation occupies a recognizable part of the geopark's surface. It was generated by the pressure of grazing animals, mostly cattle, sheep and goats, which, over the millennia, have selected a grass cover resistant to trampling and grazing (as well as to the usual aridity and poverty of the soil).

Calcareous thermophilic scree habitats

Very localized, but extremely interesting, are the perialpine calcareous thermophilic scree habitats. These represent an environment in which plant colonization is made difficult, both by dryness as well as the instability of the substrate and constant exposure to atmospheric factors. They therefore host a peculiar plant community, mostly limited to a low herbaceous layer.

Cliffs

In the coastal area of Trieste, the Karst reaches the sea, forming high cliffs, characterized by vertical rock faces, rocky towers and scree that are subject to strong insolation, wind and salinity. This environment relegates the vegetation to sparse shrub and herbaceous strips formed by communities typical of Mediterranean scrub.

Water bodies

One of the peculiarities of the Karst environment is an almost total absence of surface water. This condition is mainly due to the permeability of the heavily fractured bedrock. The water therefore flows preferentially along underground channels, leaving the surface free of aquatic environments.

The main exceptions on the Italian side of the Classical Karst are the Pietrarossa-Prelosno and Doberdò-Doberdob lakes, in the Isonzo-Soča karst, and the Rosandra-Glinščica stream in the province of Trieste. The ponds, small depressions in the ground where the collection of rainwater was facilitated with the addition of clayey material, were used for watering domestic animals and as a water supply for local populations. They are rapidly disappearing due to lack of maintenance.

Figure 6.1.2: The Karst cornflower (Centaurea kartschiana) *endemic to the Duino-Devin Cliffs (Photo: Roberto Valenti)*

Underground environments

We cannot speak of Karst without pointing out the richness of its underground environments. The various systems of sinkholes, vertical wells, caves and caverns, hidden in the subsoil, provide the biocenoses with another type of habitat. The flora colonizes it by responding to the gradients of brightness, and to the variations of humidity and temperature, which lead to an ordered succession between phanerogams, ferns, bryophytes / liverworts, and finally, chloro- and cyanophytes.

6.2 Flora

The area of Classical Karst is floristically very rich. It belongs to the sub-Mediterranean phytogeographical province. The predominant primary vegetation was once forest. Humans reduced the forest areas through logging and burning. On deeper soils, farmers established meadows and maintained them by regular mowing. On areas with sparse soil and on rockier areas, on the other hand, they grazed. Grazing, erosional processes and occasional fires transformed the pastures into rocky areas, especially on the slopes. In the middle of the 19th century, afforestation of the degraded karst soils began. A few decades ago, however, the scrubbing over of the pastures and meadows came about due to less use.

The most widespread forest communities are the sub-Mediterranean thermophilic forests of hop hornbeam and flowering ash (*Ostryo-Quercetum pubescentis*). In the past, sub-Mediterranean forests of oaks and autumn moor-grass (*Seslerio autumnalis-Quercetum petreae*) thrived in the Karst, but these have been largely cleared. Today, hop hornbeam and autumn moor grass (*Seslerio Autumnalis-Ostryetum*) can also be found in the Karst, while beech forests (*Hacquetio-Fagetum*) thrive on shady slopes in the foothills. A large part of the Karst is covered by secondary stands of black pine (*Pinus nigra*), which was used to reforest bare areas in the 19th century. An important habitat in the Karst is dry grassland (mainly *Carici humilis-Centaureetum rupestris*) (Figure 6.2.1). This is one of the most colourful and floristically rich grassland communities in Europe.

*Figure 6.2.1: Amethyst eryngo (*Eryngium amethystinum*) and rock knapweed (*Centaurea rupestris*) (next page, with spotted fritillary (*Melitaea didyma*)) are typical plants for karst dry grassland (Photo: Roberto Valenti, Tina Klanjšček)*

A special feature of this area are endemic species such as the Justin's bellflower (*Campanula justiniana*) and Karst cornflower (*Centaurea kartschiana*) (Figure 6.1.2). Some species have a classic habitat in this area, such as the *Pedicularis friderici-augusti*. In the Škocjan Caves and in the Velika dolina there is an interesting occurrence of glacial relicts growing in the colder air at the bottom of the collapse dolines, with auricula (*Primula auricula*), silver saxifrage (*Saxifraga crustata*), Alpine yellow or two-flowered violet (*Viola biflora*) and rock scurvy grass (*Kernera saxatilis*). In addition, there are thermophilic relicts, remnants from the interglacial period including southern maidenhair fern (*Adiantum capillus-veneris*), spiny asparagus (*Asparagus acutifolius*), prickly juniper (*Juniperus oxycedrus*) and yellow crisp-moss *Tortella flavovirens*. The latter survive the winter because of the warm air that rises from the cave in winter. The simultaneous occurrence of plants with such different ecological requirements is a rarity in nature.

Among the most iconic floristic elements of Karst are certain shrubs. In autumn, smoke-bush (*Cotinus coggygria*) (Figure 6.2.2), common dogwood (*Cornus sanguinea*), Cornelian cherry (*Cornus mas*), and blackthorn (*Prunus spinosa*) dress the dry rocky karst landscape in warm colours.

Some of the species are threatened with extinction and are listed in the IUCN Red List of Threatened Species, such as ragged-robin (*Lichnis flos-cuculi*) due to the overgrowth and human encroachment on nature and the marsh plants due to pond abandonment. However, some species are protected even though locally they register healthy populations, because of a risk of extinction at European level.

Figure 6.2.2: Smoke bush (Cotinus coggygria) *dresses in autumn the landscape of Karst in reddish and yellowish colours (Photo: Roberto Valenti)*

6.3 Fauna

The geopark also has an extraordinary variety of animal groups, both on the surface and underground. Numerous caves in the Karst area form the habitat of a large number of animal species, making it a hotspot of biodiversity in cave fauna. A branch of biology - speleobiology - is concerned with the study of the cave fauna, which is very diverse in this area. The underground has specific ecological characteristics, for example an absence of natural light, dependence on food from external ecosystems (limited food intake), a connection with external ecosystems through water, and stable conditions due to low variations in chemical and physical parameters. In the course of evolution, animals have developed adaptative mechanisms to the cave environment, such as slow reproduction, a longer life cycle, fewer offspring, elongated limbs and tentacles, an increased sense of smell, touch and taste, the absence of eyes and a lack of of pigment. Because of these adaptations, many subterranean organisms are endemic, with some are limited to very small areas. Subterranean organisms are highly endangered because habitat destruction or pollution can spell the end for a species. The most important caves that contain rich fauna and are significant from the point of preserving the underground fauna in the Karst region are the Škocjan Caves, Dimnice, Dolenca, Belinca, Kačna Cave, Grotta Gigante-Briška jama Cave, Grotta di Trebiciano-Labodnica Cave, Dio Mithra Cave, Azzurra-Zidaričeva pejca Cave, Gallerie Cave, Noè-Pečina v Rubijah Cave, and Regina del Carso-Kraljica Krasa Cave.

Animal species that are strictly bound to underground habitats are called troglobionts. One of the most recognizable representatives, and a symbol of the Dinaric Karst natural heritage, is the proteus (*Proteus anguinus*), also called the olm, European cave salamander, or locally, in Slovenian – because of its pale skin – "the human fish" (Figure 6.3.1). It was the first specialized cave animal in scientific literature, already described in 1768. However, not all cave-dwelling species are troglobionts. Animal species that are not completely adapted to cave life also live in caves or at their entrances, e.g. bats, and they are called troglophiles.

Figure 6.3.1: Olm or European cave salamander (Proteus anguinus) *is adapted to life in caves. The eyes visible in this juvenile individual, are completely atrophied in the adult stage (Photo: Jurij Hajna)*

Figure 6.3.2: The cave cricket (Troglophilus neglectus) *(Photo: Luca Dorigo)*

Both terrestrial and aquatic fauna are found in Karst caves. The aquatic fauna includes crustaceans, for example, amphipod *Niphargus*, the cave shrimp *Troglocaris*, the copepods *Cyclopoida* and *Harpacticoida*, the isopod *Titanethes dahli*, and others. The terrestrial fauna includes cave crickets (*Troglophilus neglectus*) (Figure 6.3.2), spiders and beetles, as well as many species of snails. Among the most important species is the endangered slenderneck beetle (*Leptodirus hochenwartii*) (Figure 6.3.3), the first ever scientifically described cave animal (in 1832), which has since been recorded in more than 13 caves in the Karst. The largest cave animal in the area and worldwide is the proteus. It is the only European amphibian that lives in the underground watercourses of the Dinaric karst. Its geographic range includes north-eastern Italy, southern Slovenia, Croatia and Bosnia and Herzegovina. It is completely adapted to life in the dark, has no eyes and no skin pigmentation. It also retains the external gills and other larval features into adulthood (neoteny). Proteus has been found in several caves with active water currents. The slenderneck beetle and the proteus are listed as species of European conservation concern in the EU Habitats Directive and in the IUCN Red List of Threatened Species. The Speleovivarium of Trieste is a caving museum in an underground environment where it is possible to see many species of fauna and flora from the Karst caves.

More than twenty bat species have been recorded in the Karst, including the greater horseshoe bat (*Rhinolophus ferrumequinum*), the lesser horseshoe bat (*R. hipposideros*) (Figure 6.3.4), the common bent-wing bat (*Miniopterus schreibersii*), the long-fingered bat (*Myotis capaccinii*), and the greater mouse-eared bat (*M. myotis*). Bats occur in larger numbers in several areas of the Classical Karst.

Figure 6.3.3: The endangered slenderneck beetle (Leptodirus hochenwartii) *(Photo: Slavko Polak)*

One of the largest habitats for bats is in the Škocjan Caves, where they are most numerous, with several thousand individuals. In the caves the bats also have their offspring and hibernate in winter.

The second underground habitat in the Karst is epikarst. This is the uppermost layer of rock beneath the soil, through which water seeps from the surface. The study of epikarst fauna is relatively new, so this type of fauna has not been studied extensively. The fauna has been studied so far in the Classical Karst area within the extensive Natura 2000 area on both sides of the border and due to

Figure 6.3.4: The lesser horseshoe bat (Rhinolophus hipposideros) *in the Fessura del vento Cave in Rosandra-Glinščica Valley (Photo: Luca Dorigo)*

the presence of previously protected natural areas. In the Škocjan Caves, for example, 12 species of true subterranean epikarst animals have been discovered from the drops of infiltrated water, of which as many as five are new species of small copepod crustaceans. The species *Elaphoidella karstica* is endemic of the Škocjan Caves - only one individual from a single stream of infiltrating water was found.

Insects are abundant in the Karst region, including endangered European beetle species for which the Natura 2000 site is designated, including the aforementioned slenderneck beetle (*Leptodirus hochenwartii*), the European stag beetle (*Lucanus cervus*) and the beech longhorn beetle (*Morimus asper funereus*). In all probability a Natura 2000 site will also be designated for the great capricorn beetle (*Cerambyx cerdo*). Also characteristic are the predatory bush cricket (*Saga pedo*) (Figure 6.3.5) and the endemic eastern stone grasshopper (*Prionotropis hystrix hystrix*).

*Figure 6.3.5: Predatory bush cricket (*Saga pedo*) - a species protected by the "Habitats" Directive, it is among the largest arthropods in Europe (Photo: Roberto Valenti)*

Butterflies stand out in terms of the number of species in the Karst. The karst area is extremely diverse, with over 500 species of butterflies and moths. Of the endemic species and subspecies, three have been reported: a subspecies of Assman's fritillary *Mellicta britomartis* ssp. *michieli*, and two moths, *Nyssia graecarius* and *Dyscia raunaria*. Of the endangered European species in the Karst, four species have been included in the Natura 2000 network: the eastern eggar (*Eriogaster catax*), the Anker moth *Erannis ankeraria*, the marsh fritillary (*Euphydryas aurinia*) and the false ringlet (*Coenonympha oedippus*) (Figure 6.3.6).

*Figure 6.3.6: The false ringlet (*Coenonympha oedippus*) is protected by the Natura 2000 network (Photo: Tatjana Čelik)*

Natura 2000 sites have already been designated for many bird species (e.g. the woodlark (*Lullula arborea*), the European nightjar (*Caprimulgus europaeus*), the Eurasian hoopoe (*Upupa epops*) (Figure 6.3.7), the European honey-buzzard (*Pernis apivorus*), the Eurasian eagle-owl (*Bubo bubo*) and the Eurasian scops owl (*Otus scops*), as relatively high densities of European nesting sites have been found in the Karst.

Species, threatened with extinction, and protected species linked to aquatic habitats are found in the geopark including the European freshwater crayfish (*Austropotamobius pallipes*), the alborella (*Alburnus alborella*), a fish native to the Rosandra-Glinščica torrent, and among amphibians the Italian crested newt (*Triturus carnifex*), the yellow-bellied toad (*Bombina variegata*) and others can be found.

Figure 6.3.7:
The Eurasian hoopoe (Upupa epops)
(Photo: Roberto Valenti)

Figure 6.3.8: The horn-nosed viper (Vipera ammodytes) *(Photo: Roberto Valenti)*

Figure 6.3.9: The golden jackal (Canis aureus) *in the Rosandra-Glinščica Valley Natural reserve (Photo: Roberto Valenti)*

Dry karstic grasslands are an excellent habitat for a variety of reptiles. Among snakes, a black colour form of the western whip snake (*Hierophis viridiflavus carbonarius*), the Aesculpian snake (*Zamenis longissimus*), cat snake (*Telescopus fallax*) and horn-nosed viper (*Vipera ammodytes*) (Figure 6.3.8) all occur. Among lizards, European green lizard (*Lacerta viridis*) is very common, while the Dalmatian wall lizard or "Karst lizard" (*Podarcis melisellensis*), Italian wall lizard (*P. sicula*) and Dalmatian algiroydes (*Algiroydes nigropunctatus*) are less frequent.

The Karst area is also a habitat for carnivores; wild cat (*Felis silvestris*), lynx (*Lynx lynx*), golden jackal (*Canis aureus*) (Figure 6.3.9), wolf (*Canis lupus*), and brown bear (*Ursus arctos*) have all been recorded.

NATURE CONSERVATION

7.1 The geopark's protected areas. Protection of natural and cultural heritage

The value and the sensitivity of the Classical Karst is reflected in the numerous living species, natural sites and objects of cultural heritage, protected on the basis of the various laws, regulations or other legal acts at Slovenian and Italian state or local levels. These include the international conventions and regulations of the European Union, such as the Convention on Biological Diversity, the Convention on the Conservation of European Wildlife and Natural Habitats (Berne Convention), the Convention on the Conservation of Migratory Species of Wild Animals (Bonn Convention), the Ramsar Convention on Wetlands, the *Natura 2000* network covered in the Decree on Special Protection Areas, and others. These protected areas overlap in some parts, and the rules of conduct complement each other. While the named regulations focus more on the protection of biodiversity, habitat types, and individual animal and plant species that are rare or endangered, that is to say the biotic/living natural values, the special attention of geoparks is paid to the conservation of abiotic/non-living nature. Their intention is to emphasize that the environment is not of uniform importance to humans, but based on current knowledge and human values, with certain parts of nature being perceived as being more valuable than others. These are areas that are exceptional, rare, typical, well preserved, exemplar, or important for scientific research. Depending on their significance, they are designated as being of local, national or international/global importance.

Figure 7.1.1: Dry karstic grassland - The Val Rosandra-Dolina Glinščice Natural Reserve (Photo: Roberto Valenti)

The largest protected area of Classical Karst is the Škocjan Caves Regional Park, appearing on the UNESCO List of World Heritage Sites since 1986. In 1999, large parts of the park also became a Wetland of International Importance under the Ramsar Convention, in recognition of the outstanding value of these underground wetlands. A much larger landscape unit was designated as a Karst Biosphere Reserve under UNESCO's Man and Biosphere Programme in 2004. The Miramare Marine Nature Reserve is partially included in the area of the geopark and is also a UNESCO MAB site.

The area of geopark features 7 ecologically important areas, 72 natural monuments, 1,052 Karst caves and 164 other valuable natural features in Slovenian territory and 6 Natural Regional Reserves, 1 Biotope protected area and more than 3,400 Karst caves within Italy. Almost the entire area is also part of the *Natura 2000* network (Fiugure 7.1.2).

Since geoparks are informal protection categories that do not impose additional strict protection measures, the latter are determined by existing laws and regulations. The protection of the Classical Karst area thus follows the systems of protection of nature and culture in Slovenia and Italy respectively.

In Slovenia, the measures for biodiversity conservation and preservation of valuable natural features are defined by the Nature Conservation Act. Statutory regulations – The Rules of Defining and Protection of Valuable Natural Features and Decrees on Types of Valuable Natural Features – determine the national or local importance of these features, as well as the conduction and protection for various activities. Underground caves are further protected by the Underground Caves Protection Act. On the Italian side the main Laws and Regulations regarding nature protection are set at two levels: National and Regional. The Italian State adopted a framework law on protected areas in 1991 (LN 394/91), which has been amended several times over the years. The Friuli Venezia Giulia Region has its own legislation on protected areas which sets out in detail the implementation of the National Law at a local level with a Regional Law (LR 42/96). The regional legislation on nature conservation was also integrated in 2016 with the law for the protection of geodiversity (LR 15/2016), which represents a unique case in this field in the two countries.

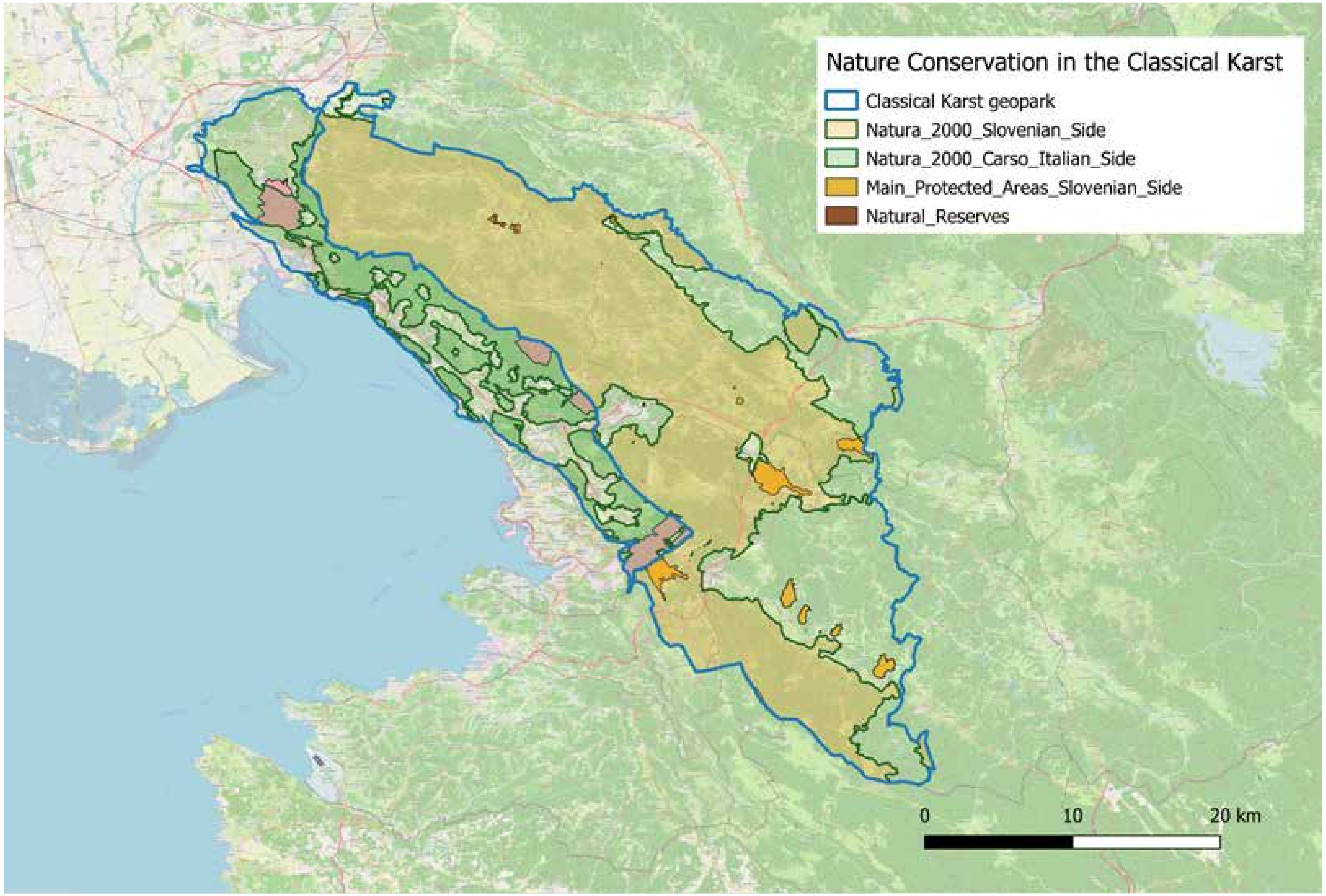
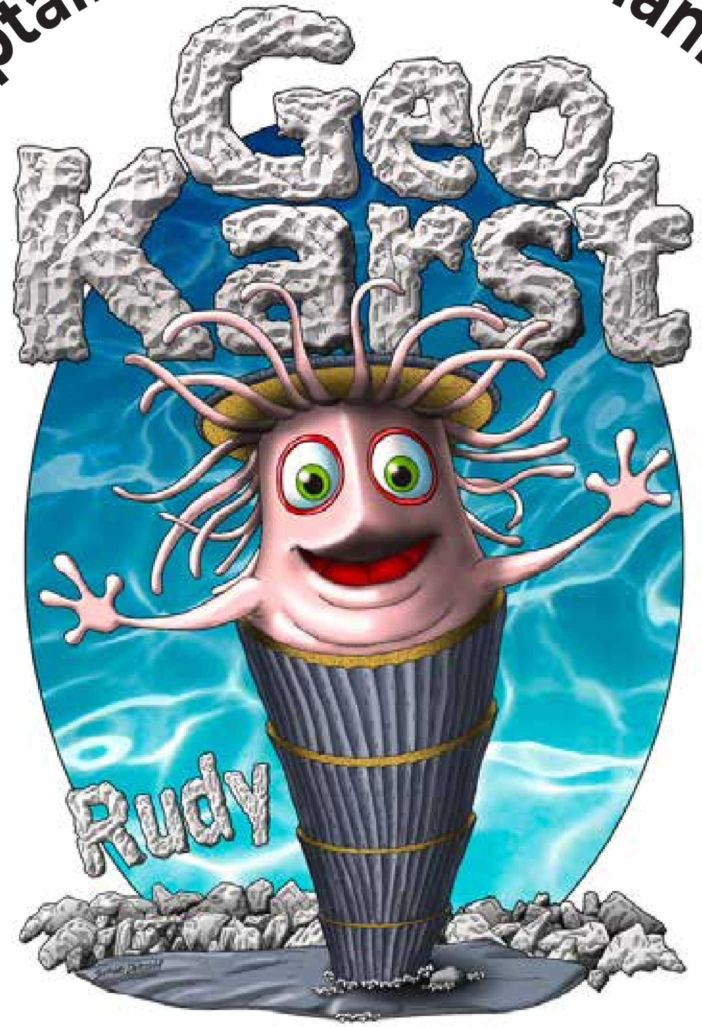


Figure 7.1.2: Legislative nature conservation areas in the Classical Karst (eco&eco , © OpenSteetMap contributors)

In addition to the protection of nature, as natural heritage is of fundamental importance to the existence of humanity, it is useful to take into account cultural diversity and heritage, which, in the Karst, are also impressive. Numerous archaeological sites, exquisite religious, public and vernacular architecture, World War I sites, protected landscapes, monumental trees and traditional crafts are protected as cultural heritage. In Karst, the characteristic cultural landscape is inextricably linked with stone as a traditional building material. Its quarrying, carving and its use is designated as an intangible cultural heritage. The skill of drywall construction; knowledge and techniques, which include the Karst drywall construction, was inscribed on the Unesco list of the Intangible Cultural Heritage of Humanity in 2018. Cultural heritage is also protected at national levels: in Slovenia by the Cultural Heritage Protection Act; in Italy by the Code of Cultural Heritage and Landscape (Legislative Decree 42/2004).

Captain Rudist says "Thanks!"



Captain Rudist is the geopark mascot. Created by Sergio Derossi, it represents the most common fossil in the Karst - the rudist bivalve that lived in the Cretaceous period and became extinct along with the dinosaurs. The limestones of the Karst are crammed full of rudist fossils.

7.2 Code of ethics for geopark visitors

All geoparks are committed to protecting their natural and cultural heritage, with special attention to the preservation of important geosites. They take steps to educate visitors about the value of geosites and raise awareness of the need to protect geodiversity.

All geopark visitors should follow both the lists of permitted activities and restrictions as well as the simple Code of Conduct for their own safety and to minimize impacts on the natural environment.

RESPECT NATURE.

✦ ***Learn about non-living nature and contribute to its conservation by following the rules of geoethics.*** Obtain information on geological and geomorphological values and protected areas. Do not damage rocks and do not extract or collect rocks, minerals, or fossils. In caves, never break, damage, or take speleothems (dripstones, crystals, cave pearls) or other anything else from the cave inventory. Collect geological material only where it is allowed and regulated. If you suspect that you have made a geological find of significance, you should report your discovery to the visitor centre.

✦ ***Learn about living nature and contribute to its preservation.*** Obtain information on protected animals, plants and habitats. Refrain from picking plants or hunting and gathering animals. Do not encroach on dens, nests, nesting sites, or feeding areas. Do not introduce non-native animal and plant species. Pick plants, mushrooms, and wild fruits only where allowed and regulated.

✦ ***Do not disturb animals.*** Warn the animals of your presence by speaking, so that they can retreat. Do not approach or feed livestock or wild animals. Keep your dog under strict control or on a leash. Do not make unnecessary noise.

✦ ***Use trails.*** Use hiking trails to minimize your impact on nature and to ensure your own safety. Respect barriers. If you must cross cultivated land, stick to the edges.

- ***Enter caves according to regulations.*** Enter tourist caves or open caves with controlled access only when accompanied by an official, qualified guide. Visit caves in a manner that does not endanger the cave, the cave inventory, or any living creatures.
- ***Leave no trace.*** Take all your waste with you and dispose of it in designated litter bins or at municipal collection sites. Do not light fires on the Karst, given the high risk of fire and the absence of surface water necessary to extinguish them.

RESPECT YOURSELF AND OTHERS.

- ***Know your capabilities and take them into account.*** Plan your visit in advance and adapt it to the weather conditions, your skills and abilities. Take the proper footwear, clothing and other equipment, and make sure you have enough food and drink, together with some reserves.
- ***Be considerate of other visitors.*** Give priority to those weaker than you on trails. Hikers have priority over cyclists and cyclists have priority over motorists.
- ***Take care of safety.*** Look out for your own safety and the safety of others. Keep away from rock faces. According to your knowledge, your assessment of the circumstances, and the way you react to them, try to help others to the best of your ability without jeopardizing your own safety. In the event of an accident, call 112 and follow instructions.
- ***Drive and ride only along designated roads.*** Drive your motor vehicle or ride your bicycle only on designated roads and trails. By doing so, be aware that driving in a natural environment is restricted.
- ***Park in parking places.*** Park your vehicle only in designated parking areas and in a manner that does not obstruct trails or gates. Be a role model for others.

RESPECT PROPERTY.

- ***Do not violate property rights.*** Do not walk across cultivated fields, growing crops, vineyards, orchards, or near beehives. Do not pick fruit, agricultural products, or firewood without the owner’s permission. Close the gates of any pasture fences you open.
- ***Avoid worksites.*** Avoid sites where forestry work is being undertaken. Visiting operating quarries or mines (whether operating or idle) is allowed only with the permission of the operators and under the conditions they specify.

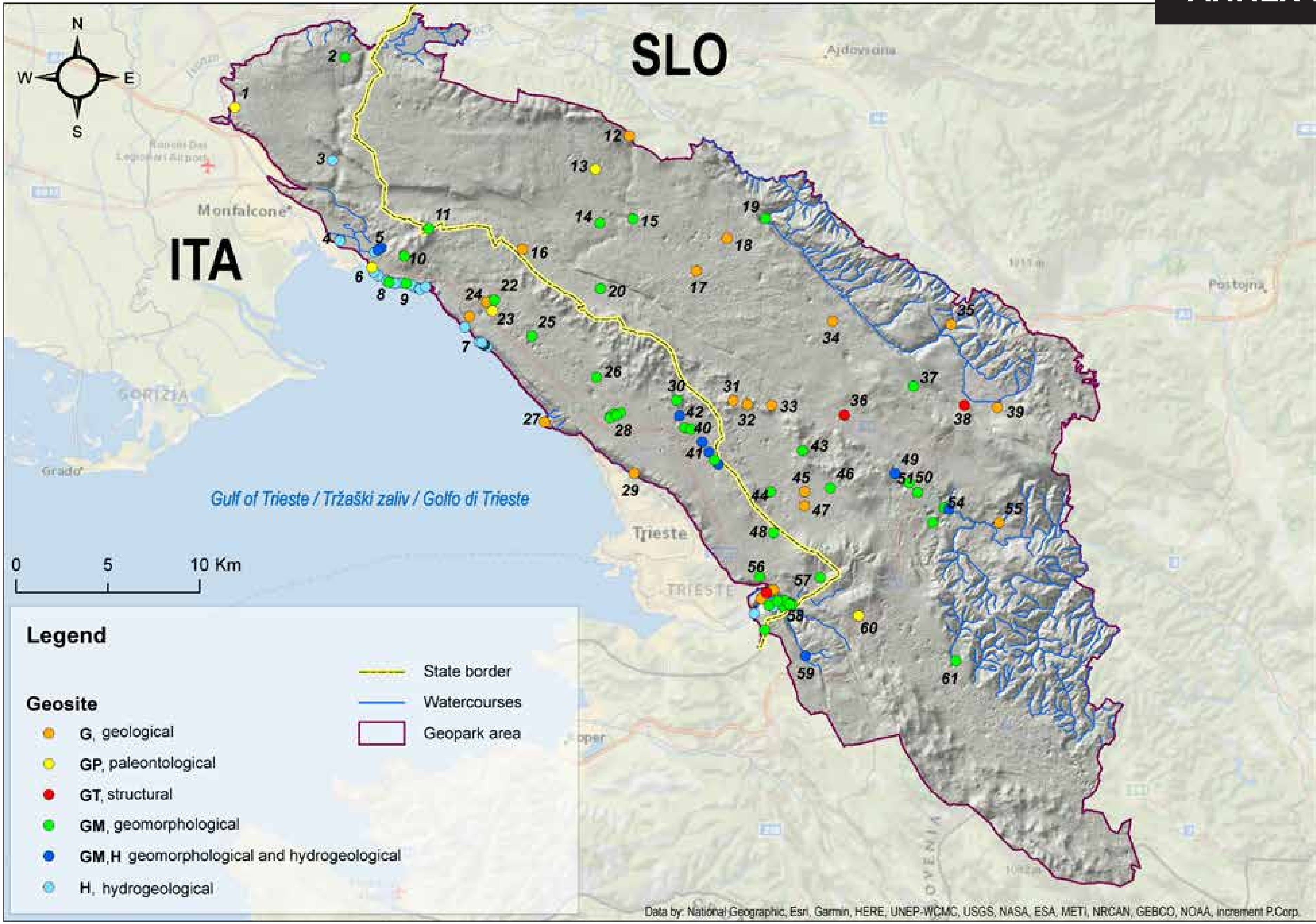
RESPECT THE LOCAL COMMUNITY.

- ***Learn about and respect local customs.*** During your visit, learn about local customs. Observe, enjoy and respect them and support the local community by buying local products and using local services. In this way, contribute to the preservation of the cultural landscape and nature.

In short, you should follow two simple rules: Do not take anything from the geopark except your impressions and your photos, and do not leave any traces of your visit.

SELECTED GEOSITES IN THE CLASSICAL KARST GEOPARK

ANNEX 1



ID del GEOSITO	GEOSITE	NATION	TYPE	DESCRIPTION
1	Paleontological excavation near Polazzo	ITA	GP	Greenish-grey platy limestones characterised by the presence of abundant reef fish fossils and, to a lesser extent, terrestrial plant and reptile fossils.
2	Regina del Carso-Kraljica Krasa Cave (2328/4760VG)	ITA	GM	This is the largest cave in the north-western sector of the Karst. Rich in concretions, it develops in a S-N direction with an almost constant inclination.
3	Doberdò-Doberdob Lake	ITA	H	Doberdò-Doberdob Lake is one of the few karstic lakes in Italy. It occupies the bottom of a polje and is set in an exceptional karstic environment, characterised by the presence of a series of estavelles. Together with the nearby Pietrarossa Lake, it represents a landscape that changes with the height of the water table.
4	Thermal spring of Monfalcone: SPA	ITA	H	Hot water (today around 40° C) from limestone reservoir rocks found at a considerable depth comes to the surface through faults and karst conduits. Already used by the Romans, who adapted them as thermal baths, after alternating periods of abandonment and reutilization, they have been back in use since 2014.
	Thermal spring of Monfalcone: Pozzo del Lisert Cave (4808/5608VG)	ITA	H	Non-accessible cave beside the spa at the bottom of which hot water is found.
5	Timavo - Timavo Springs	ITA	H	The Timavo Springs are part of the extensive spring area of the Classical Karst. After an underground journey of 30-40 km beginning at the Škocjan Caves swallow hole, the waters come to light with four springs, just over 2 km from the Adriatic Sea, creating a fascinating environment that has been eulogised since ancient times.
	Timavo - Grotta del Timavo Cave (1844/4583VG)	ITA	GM, H	This is part of the so-called 'Timavo Springs Complex', the system of largely flooded caves explored by cave divers from the largest of the spring mouths.
	Timavo - Pozzo dei colombi di Duino Cave (215/VG227)	ITA	GM, H	A window on the Timavo Springs Complex that provides access to flooded conduits down to a depth of 82 m below sea level.
	Timavo - Grotta meravigliosa di Lazzaro Jerko Cave (2305/4737VG (LAJ))	ITA	GM, H	Evidence of a direct connection with the groundwater table became a 'window' onto the underground Timavo.
	Timavo - Abisso di Trebiciano - Labodnica Cave (3/17VG)	ITA	GM, H	Evidence of a direct connection with the groundwater table became a 'window' onto the underground Timavo.
6	Dinosaurs of the Villaggio del Pescatore-Ribiško naselje	ITA	GP	Exceptional complete hadrosaur skeletons have been found in a former quarry. These are some of the very few complete dinosaur skeletons found in Italy and are unique worldwide for the exceptional nature of their preservation and the fact that they were found in anatomical connection.
7	Coastal karst springs	ITA	H	Small freshwater outflows at sea level near Villaggio del Pescatore-Ribiško Naselje and Aurisina-Nabrežina coast. The latter used in the past as freshwater resource for the Trieste water supply.
8	Underwater karst springs	ITA	H	Freshwater outflows below sea level in the stretch between Villaggio del Pescatore and Sistiana-Sesljan and others close to Aurisina-Nabrežina.
9	Duino-Devin Cliff	ITA	GM	The cliffs reach a height of 90 m and stretch from the Bay of Sistiana-Sesljan to the small harbour of Duino-Devin, for a length of about 1,500 metres. Differential erosion and corrosion have shaped pinnacles and towers, creating a fascinating landscape.
	Notch near Duino-Devin cliff	ITA	GM	Between Duino-Devin and Sistiana-Sesljan, the submerged notch lies at a depth of between 2.5 m and 1.3 m.
10	Dolina del principe - Dol Doline	ITA	GM	Large sub-circular doline opening on the side of a relief (Mt. Cocco - Mt. Ermada Ridge).
11	Grofova Jama Cave-Brezno na Grmadi Abyss	SLO	GM	Grofova Jama Cave is scientifically one of the most important caves of the Karst. The montmorillonite clay (weathered volcanic ash) found in it is the oldest dated cave sediment in southwestern Slovenia, deposited in the cave about 10 million years ago.
12	Paleokarst features and paleosoils of Trsteljska Brda Hills	SLO	G	Although the paleokarst and paleosoil phenomena of the Trsteljska Brda Hills are relatively indistinct, they are important for understanding the geotectonic processes and the evolution of the Adriatic Carbonate Platform at the end of the Cretaceous.
13	Komen-Škrbina - Komen Limestone with fossil vertebrates	SLO	GP	An important and internationally known locality of numerous fossil vertebrates in the Komen platy limestone.
14	Doline at Debela Griža - Volčji Grad prehistoric settlement	SLO	GM	Besides its geomorphological significance, the doline beneath the ramparts of the prehistoric settlement of Debela Griža with its dry stone walls and terraces shows traces of repeated modifications since prehistoric times.
15	Mali Dol dry valley	SLO	GM	Mali Dol is a dry valley that represents a relict form of fluvial relief on the karst surface, formed in the geological past by a small river that crossed the gradually uplifting area of the Karst.
16	Abandoned quarry of flowstone Rusa jama at Gorjansko	SLO	G	The abandoned flowstone quarry Rusa jama. Part of the interior of the Slovenian Parliament building is also decorated with this rare natural stone.
17	Outcrop of Komen Limestone at Skopo	SLO	G	Outcrop with the clearly visible structural features of the Komen platy limestone, also known for the finds of fossil fish and plants.

ID del GEOSITO	GEOSITE	NATION	TYPE	DESCRIPTION
18	Kopriva Quarry of rudist limestone	SLO	G	A quarry of the prized natural stone of the Kopriva type, important for understanding the global sea-level rise at the beginning of the Upper Cretaceous.
19	Raša Valley with its tributaries	SLO	GM	The mostly dry valley of the Raša with its tributaries, which represents one of the most prominent landforms in the Karst or its surroundings, could be defined as a fracture or crush zone of the Raša fault emptied by erosion.
20	Veliki (Brestoviški) Dol	SLO	GM	Veliki (Brestoviški) Dol represents a tectonic depression formed in the Divača Fault zone.
21	Slivia-Slivno's breccia quarry	ITA	G	No longer active quarry in which a polychromic limestone breccia is found.
22	Karrenfeld at San Pelagio-Šempolaj and Lindner Cave (829/3988VG)	ITA	GM	Alternating bands of karst stony ground (grize) and limestone banks on which are visible all the small surface corrosion features, favoured by the purity of the limestones and the slightly inclined stratification.
23	Palaeontological site of the Caverna Pocala-Pečina Pod kalom Cave (173/91VG)	ITA	GP	Protected cave in which abundant Pleistocene animal remains have been found, including many bones of Ursus speleus, alongside a few artefacts.
24	Aurisina-Nabrežina's Cava Romana	ITA	G	Pit and tunnel quarries for the extraction of particularly compact and aesthetically valuable horizons, commercially referred to as 'marble', were already active in Roman times.
25	Sinkhole of the Noè-Pečina v Rubijah Cave (23/90VG)	ITA	GM	Large sub-circular opening in the ceiling of a prevailing sub-horizontal cave.
26	Baratro dei cavalli Doline	ITA	GM	A collapse doline, asymmetrical, with steep edges and vertical rocky walls.
27	Olistoliths of Miramare Castle	ITA	G	An olistostroma consisting of limestone blocks (olistolites) chaotically embedded in the arenites and pelites of the flysch.
28	Karst at Borgo Grotta Gigante-Briščiki	ITA	GM	An emblematic area for the surface and underground geomorphology of the Italian Karst sector, this is a cave of well above average size, several large and deep dolines, vast karrenfelds, roofless caves and caves used by humans during prehistory.
	Karst at Borgo Grotta Gigante-Briščiki - Grotta Gigante-Briška jama Cave (2/2VG)	ITA	GM	This is the largest show-cave in the world: with a volumetric capacity of 600,000 m3, it is 130 m long, 110 m high and 65 m wide.
	Karst at Borgo Grotta Gigante-Briščiki - Karrenfeld	ITA	GM	Extensive limestone outcrop along the eastern and northern edges of the Školudnjek doline where small karst features such as kamenitze, Karren of all types, karst crevasses, and dissolution holes abound.
	Karst at Borgo Grotta Gigante-Briščiki - Grotta della Tartaruga Cave (1688/4530VG)	ITA	GM	Cave in which remains attributable to the Upper Paleolithic have been found.
	Karst at Borgo Grotta Gigante-Briščiki - Roofless cave	ITA	GM	A serpentine section of a very ancient cave with a predominantly sub-horizontal development (conduit) that came to light through progressive dissolution and lowering of the surface.
29	Drowning of the Cenozoic Carbonate Platform: the conglomerates	ITA	G	Multiple beds of carbonate conglomerate mark the top of the Nummulitid and Alveolinid Limestone carbonate platform. They are followed by marls and clayey limestone that testify a sharp deepening of the depositional environment and the drowning of the carbonate platform.
30	Monrupino-Repentabor residual blocks (hum)	ITA	GM	Unusual isolated features, mute witnesses to the ancient karst surface.
31	Repen limestones at Dolina quarry	SLO	G	A very beautiful profile through the productive zone of the Repen limestone, one of the most prized natural stones from the Karst, rich in rudist shells.
32	Upper Cretaceous stratigraphic section along the Sežana-Vrhovlje road	SLO	G	A long stratigraphic section, important for understanding the evolution of the Adriatic-Dinaric carbonate platform in the Upper Cretaceous.
33	Phantom Karst' (i.e., dedolomite) in the Povir Formation near Sežana	SLO	G	In the surroundings of Sežana, typical brownish coloured calcite bands from metres to tens of metres in size occur in the Lower to Upper Cretaceous limestones, dolostones and breccias, as the result of dedolomitization phenomena.
34	Kazlje Quarry of Tomaj Platy Limestone	SLO	G	An abandoned quarry of the Tomaj platy limestone, one of the most important sites for fossil vertebrates, invertebrates and plants of the northern part of the Adriatic-Dinaric carbonate platform.

ID del GEOSITO	GEOSITE	NATION	TYPE	DESCRIPTION
35	Cretaceous/Paleogene Boundary section Dolenja vas at Senožeče	SLO	G	A well-studied and internationally known stratigraphic section that crosses the Cretaceous-Paleogene boundary, marked by one of the most severe mass extinction events in geological history.
36	Fault zone of Divača Fault	SLO	GT	A zone of tectonized rocks a few tens of metres wide along the Divača regional fault.
37	Uvala Senadolski Dol	SLO	GM	The Senadol Valley represents an elongated karst depression (uvala) running along the fault zone of the Raša Fault, the formation of which is due to accelerated dissolution in the area of the fracture zone of the Raša Fault. It may also be a remnant of an ancient blind valley.
38	Fault zone of Raša Fault	SLO	GT	A cross-section, almost 100 metres wide, of the fault zone of the Raša fault, exposing the typical zoning of rock deformation within the inner and outer fault zones.
39	Rudist patch-reef at Senožeče-Gabrče	SLO	G	Fossil marine reef, built of rudist shells in a road section.
40	Timavo - Blow-holes: Pozzo presso il Casello ferroviario di Fernetti Cave (104/87VG (CFF))	ITA	GM, H	Evidence for a direct connection with the karst groundwater table.
	Timavo - Blow-holes: Luftloch (7477/6442VG (LUF)) Cave	ITA	GM, H	Evidence for a direct connection with the karst groundwater table.
	Timavo - Blow-holes: Dolina dei sette nani (DSN) Doline	ITA	H	Evidence for a direct connection with the karst groundwater table.
41	Karrenfeld and Karren at Percedol-Prčendol	ITA	GM	To the east of the Percedol Basin, kamenitze, karren and karst crevasses develop in quantity and in a variety of shapes on sub-horizontal strata.
42	Abisso della volpe Abyss (100/155VG)	ITA	GM	Single shaft, about 10 metres wide and 181 metres deep.
43	Bestažovca Cave	SLO	GM	This relatively small cave in the Tabor Hills houses, among other geological and geomorphological attractions, numerous prehistoric archeological remains, including drawings that are at least 7,000 years old and unique in Slovenia.
44	Small-size relief rocky features along the "Living Karst Museum" path	SLO	GM	Along the thematic "Living Karst Museum" path, the whole range of both surface and subsurface small-scale karst features can be observed.
45	Lipica 1 Quarry of rudist limestone	SLO	G	A quarry of Lipica limestone, widely used in architecture, both in Slovenia and abroad. Known in literature for its rich rudist bivalve fauna.
46	Vilenica Cave	SLO	GM	Vilenica is a typical example of a relict cave. It is considered the oldest tourist cave in Europe and probably in the world, since entrance fees were charged as early as 1633. Since 1986, the cave has hosted the Vilenica International Literary Festival, which honours outstanding achievements of Central European authors in the field of literature and essayism.
47	Mines of black coal at Lipica	SLO	G	Abandoned black-coal mines and fossil deposits.
48	Claudio Skilan Cave (5070/5720VG)	ITA	GM	One of the largest and deepest and complex cave systems in the Trieste Karst.
49	Kačna jama Cave	SLO	GM, H	With a length of more than 20 km and a depth of 280 m, Kačna Jama Cave is the longest cave in the Karst and the third longest cave in Slovenia. It is also of great importance from a scientific point of view, because together with the other caves that reach the Reka, it offers the possibility to see and study the karst aquifer "in situ".
50	Risnik Collapse Doline	SLO	GM	Risnik is a beautiful example of a depression with a series of forms indicating the stages of its development and thus that of the entire Divača Karst.
51	Denuded (roofless) cave at the Lipove Doline	SLO	GM	The denuded cave at the Lipove Doline is one of the most educative and beautifully designed denuded caves and thus also a special phenomenon for understanding the geomorphological and geological development of karst areas.
52	Reka blind valley and collapse dolines at Škocjan Caves	SLO	GM	The Reka blind valley and the collapse dolines of Škocjan are part of the Regional Park and Natura 2000. They have been inscribed on the UNESCO World Heritage List, declared a Karst Biosphere Reserve (MAB) by UNESCO and included on the Ramsar List as an underground wetland.
53	Škocjan Caves	SLO	GM, H	The Škocjan Caves, together with the surrounding karst phenomena, represent a geomorphological unicum, suitable for studying the geomorphological and geological/geotectonic evolution of a larger area, as well as other geologically similar areas around the world. They have been a UNESCO World Heritage Site since 1986.
54	Jama na Prevali 2 Cave (Mušja Jama Cave)	SLO	GM	Numerous objects from the Bronze and Iron Ages, which were ritually thrown into the Mušja jama, indicate the extraordinary importance that the cave, as well as the surroundings of the Škocjan Caves, had as a sacred place during the European and Mediterranean cultures in the Late Bronze Age around 1000 BCE.
55	Stratigraphic section at Vremski Britof	SLO	G	An internationally known stratigraphic section of the youngest part of the Cretaceous foraminiferal limestones of the Liburnian Formation.

ID del GEOSITO	GEOSITE	NATION	TYPE	DESCRIPTION
56	Črbenjak doline near San Lorenzo-Jezero	ITA	GM	Large solution doline with gentle slopes located near the karstic ridge.
57	Blind Valley of Grozzana-Gročana	ITA	GM	Between the villages of Grozzana-Gročana and Pesek there is a blind valley with a cultivated floor
58	Rosandra-Glinščica Valley	ITA	GM	The Rosandra-Glinščica Valley is a complex geosite due to the variability of the geological and geomorphological phenomena recognisable within it, including a karst fluvial valley with a deep gorge the slope morphology of which is strongly influenced by tectonics and lithological variations, containing an complex and active cave system on several levels. It represents a unique example of surface hydrography in karst territory.
	Rosandra-Glinščica Valley - Drowning of the Cenozoic carbonate platform: the marls	ITA	G	Widespread outcrops of limestone marls and marly limestones, also known as 'Fucoid Marls', which lie between the flysch and the Alveoline and Nummulite limestones.
	Rosandra-Glinščica Valley - Mt. Stena Cave system - Fessura del Vento Cave (930/4139VG)	ITA	GM	A cave of about 2.6 km in length within the Mt. Stena relief.
	Rosandra-Glinščica Valley - Mt. Stena Cave system - Grotta delle Gallerie Cave (290/420VG)	ITA	GM	A cave which develops within the limestone relief of Mt. Stena, on the orographic right of the Rosandra Torrent. It is an important archeological site.
	Rosandra-Glinščica Valley - Mt. Stena Cave system - Grotta Gualtiero Savi Cave (5080/5730VG)	ITA	GM	A cave of about 4 km in length within the Mt. Stena relief.
	Rosandra-Glinščica Valley - Mt. Stena Cave system - Grotta dei Pipistrelli Cave (527/2686VG)	ITA	GM	A small cave which develops within the limestone relief of Mt. Stena.
	Rosandra-Glinščica Valley - Mt. Stena Cave system - Grotta Martina Cucchi Cave (4910/5640VG)	ITA	GM	A cave of about 1 km in length within the Mt. Stena relief.
	Rosandra-Glinščica Valley - Mt. Stena Cave system - Grotta Ferroviaria Cave (1435/4352VG)	ITA	GM	A small cave which develops within the limestone relief of Mt. Stena.
	Rosandra-Glinščica Valley - Rosandra-Glinščica torrent waterfall	ITA	GM	Waterfall set on a sub-vertical fault about 30 metres high immediately downstream of the contact between the turbiditic rocks and the limestones.
	Rosandra-Glinščica Valley - Paleolandslide	ITA	GM	Landslide involving a limestone block about 40 metres thick, about 200 metres wide and 250 metres high.
	Rosandra-Glinščica Valley - Rosandra-Glinščica Torrent Gorge	ITA	GM	A deep valley stretchingfor some 1,300 metres where the stream flows through deep meanders and potholes.
	Rosandra-Glinščica Valley - Bukovec Spring	ITA	H	A small spring originating from condensation phenomena within the overlying debris.
	Rosandra-Glinščica Valley - Crinale Fault	ITA	GT	Fault conditioning the morphology of the northern side of Mt. Carso.
	Rosandra-Glinščica Valley - Alluvial and debris deposits	ITA	G	Alluvial deposits interdigitated with slope debris, evidence of the complex evolution of the valley, linked to climate change.
	Rosandra-Glinščica Valley - Bagnoli-Boljunec Springs - Antro di Bagnoli-Jama (76/105VG)	ITA	H	Karst spring, in sub-vertical layers of Alveoline and Numulitide limestones at the contact with flysch.
	Rosandra-Glinščica Valley - Caverna degli Orsi-Medvedja jama Cave (5075/5725VG)	ITA	GM	Modest protected cave in which bone remains of the Ursus spelaus have been found.
59	Beka-Ocizla cave System	SLO	GM, H	This system of sinkholes, natural bridges and caves represents a special example of contact karst, which is completely different from the contact karst of the Matarsko Podolje, because the streams do not sink at the end of blind valleys, but laterally in the valley of the Rosandra/Glinščica stream, which forms here at the contact between flysch and limestone.
60	Paleokarst pit with fossil remains of vertebrates (dinosaurs and crocodiles) near Kozina	SLO	GP	This is the first and so far one of only two known dinosaur sites in Slovenia and also one of the two sites in the Karst, which is also rich in remains of crocodile teeth. The site is of international importance for understanding the evolution in particular of hadrosaurs and of regional importance for reconstructing the paleogeographic and paleobiogeographic evolution of the area between the Adriatic and Eurasian geotectonic plates.
61	Matarsko podolje (Brezovica, Odolina) blind valleys	SLO	GM	Brezovica and Odolina are typical blind valleys of Matarsko Podolje and represent a "textbook" example of blind valleys as the most expressive phenomenon of contact karst.

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SHORT PRESENTATION:

Geoparks that adhere to the UNESCO Global Geoparks Network (GGN) traditionally present themselves to the community with a publication that illustrates their distinguishing features, which have enabled them to become a UNESCO Geopark.

This informative publication on the Classical Karst geopark is the business card with which this territory and its community present themselves to UNESCO GGN, visitors and citizens in general.

This is not the first work to illustrate the unique geology and geodiversity of this area, the natural environment and the rich cultural heritage of this border area between Italy and Slovenia. For several centuries the geology of the Classical Karst has been the subject of scientific studies and speleological explorations, which have enriched our knowledge of Karst and the specific environment of the area. This is, however, the first publication to consider the geological and territorial resources present across the entire area of the Classical Karst, from the point of view of geoparks, as an element encapsulating identity for the local community and as a tool for sustainable development.

It is an editorial work created within the framework of the Italy-Slovenia Interreg cross-border cooperation project "GeoKarst" and as part of the policy for the enhancement of geodiversity and geoparks promoted by the Autonomous Region of Friuli Venezia Giulia.

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GeoKarst

Progetto standard co-finanziato dal Fondo europeo di sviluppo regionale
Standardni projekt sofinancira Evropski sklad za regionalni razvoj

https://www.ita-slo.eu/en/geokarst