GEOLOGICAL SIRMIONE
A walk through time

The history of Sirmione and Lake Garda is inevitably bound up with its geological formation over the millennia. It is fascinating because it takes you back to unknown eras, reconstructed through precise studies and meticulous research. You are especially taken back to a time when this strip of land resisted erosion from natural elements and ended up being surrounded by water, giving rise to the beautiful peninsula that today attracts tourists from all over the world.

Thanks to this remarkable initiative, visitors can now enjoy Sirmione from a different perspective. They can continue to admire the Scaliger Castle, the remains of the Grottoes of Catullus and the splendid churches found in the old town; they will always be delighted by the contrasting colours of the blue of the lake and the turquoise sky, which turn golden in the East at dawn and in the West at sunset. But now you can also identify what lies beneath the surface, from the town centre to the rock escarpment at the extreme tip of the peninsula.

Therefore I would like to warmly thank everyone who was involved in this project: the Pro Loco volunteers, who tirelessly champion any initiative that aims to promote every aspect of Sirmione, the teachers and students of Bagatta High School in Desenzano and the geologists Giovanni Fasser and Niccoló Crestana, who enthusiastically agreed to take on such a special task.

Naturally we would also like to thank the visitors to Sirmione, who will receive a copy of this booklet.

The Deputy Mayor

Luisa Lavelli

The aim of this project was to widen our knowledge of the history and evolution of our territory from a different perspective, so we enthusiastically joined the original project of getting to know Lake Garda from a geological point of view.
The etymological meaning of the term "geology" is very simple: it is the science that studies the origin, history, morphology and constitution of the Earth. This may sound like an academic exercise, devoid of substance and disconnected from everyday life. In truth, it has never before been so important to understand the areas in which we live, not only to prevent the negative effects of possible earthquakes, but also to defend ourselves from increasingly frequent catastrophic events, such as flooding.
The land on which we live is a living element, capable of welcoming us and feeding us, which in turn requires respect and care. Geology helps us in this increasingly important mission and raises awareness of how to behave responsibly regarding the environment.
We are therefore grateful to the ProLoco and the Municipal Administration of Sirmione and of course to Bagatta High School, for providing us with this opportunity.

Geologist Niccolò Crestana
Geologist Giovanni Fasser

Sirmione Pro Loco has been working for many years with the aim of promoting understanding and respect for the area in which we live. This is why we have produced this information booklet about the geology of Sirmione as part of a work-related learning project with Bagatta High School in Desenzano. Everyone involved in this project deserves a heartfelt thank you. To everyone reading this booklet, whether locals or visitors, please continue to enjoy, love and respect the beauty around you.

Luisella Baccinelli
President of Sirmione Pro Loco

The formation of **Lake Garda**

Lake Garda is the largest of the Italian lakes. It was formed by complex modifications to the earth's crust that occurred millions of years ago and has been the subject of in-depth studies by geologists, especially in recent years.

From a geological point of view, we can ideally divide Lake Garda into two different areas: Upper Garda and Lower Garda. A dividing line connects the two towns of Garda and Salò and traces an imaginary border that can be easily seen by looking at the landscape and morphology of the area.

(lower caption)

Imaginary line that divides
Upper and Lower Garda.

Upper Garda

The upper Garda area contains the older rocks formed in a geological period about 200 million years ago, between the Triassic and the Pliocene eras. This area has rocky outcrops such as Mount Baldo in the Verona area, the Tremosine-Tignale plateau and the group of Spino-Pizzoccolo mountains on the Brescia side. The predominant rock formation is the ''Dolomite'' which consists of dolostone, a double carbonate of calcium and magnesium $CaMg(Co_3)_2$. Lake Garda lies in the folds of this rock that was fractured and deformed as a result of tectonic movements (with numerous fault lines and fractures) due to the collision of plates in the process of Alpine **orogenesis**.

(lower caption)

Mount Baldo and
Upper Garda seen from Sirmione.

The "Theory of plate tectonics" explains that the lithosphere is divided into 22 plates, which are in constant movement and consequently cause seismic and volcanic activity. The origin of mountain ranges is also closely linked to plate movement, as in the case of the Alps, formed by the collision between the African and the Eurasian plates.

During the Triassic period these two plates became fragmented and separated by the formation of the Tethys Ocean basin and gave rise to high and low structural zones (high or low seabed) developing an environment characterized by emergent areas, islands and coral reefs, alternating with areas of deeper basins, including abyssal plains. Specifically Lake Garda is located between a deep sea area (Lombardy area) and the Veneto platform.

(blue box)

OROGENESIS:
From Ancient Greek OROS (mountain) + GENESIS (origin); indicates the process by which any high ground is formed.

(upper caption)

The different fault lines of the Garda area.

(lower caption)

Computer reconstruction of the Tethys Ocean.

To explain the fluvial origins of Lake Garda, clearly visible in the Upper Garda area, we must take a look at the "**Messinian salinity crisis**", dating back to about 6-7 million years ago and caused by the repeated closure of the Strait of Gibraltar, which resulted in a partial desiccation of the Mediterranean Sea (what was left of the Tethys Ocean). The partial desiccation of the sea not only allowed the deposition of evaporites (salt, gypsum, etc.), but also caused the coastlines to recede and increased the erosive capacity of the rivers in the Alpine watersheds, forcing them to dig deeper to reach the level of the sea. Erosion has therefore deeply carved the rock, creating the river valleys on which the great lakes of Lombardy now sit.

(brown box)

MESSINIAN SALINITY CRISIS:
Geological event of the last part of the Miocene (5 MLN years ago) during which the Mediterranean almost completely evaporated due to the closure of the Strait of Gibraltar.

(lower caption)

Example of the erosive power of water.

Lower **Garda**

The Southern end of Lake Garda, on the other hand, began to form 2 million years ago, when the Garda valley began to undergo massive climate changes, characterized by periods of glaciation with intervening warmer periods.

These periods of climatic cooling coincided with the advance of enormous glacier tongues that occupied the valley previously eroded by the rivers.

Recent geological studies have shown five distinct stages of glaciation, in which each stage tends to cancel out the previous one, depositing new sediment, caused by the melting of the glacier that deposited previously.

- Stage I (known as Ciliverghe): the first glacier advancement is the most impressive and remains have been found in the area of Ciliverghe and Calvagese. Although it is not possible to establish the movement of the glacial front with certainty, it can be assumed that its advance was influenced by the morphology of the rocky substratum and then contained to the north-west by the slopes of the Prealps and to the south-east by the structural tectonic rise that still exists between Garda and the tip of Sirmione peninsula.
- Stage II (known as Mount Faita): with the second advance of the glacier, it moved slightly eastwards and its sediment formed the hills of Gavardo.
- Stage III (known as Carpenedolo): after the glacier melted it deposited moraine to form the hills of Medole and the hill of Villa Cortine in Sirmione.

- Stage IV (known as Sedena): the fourth glaciation left little effect on the territory; it consisted mainly of the alignment of the hills to the west of Lonato and the higher ground around Bardolino. During this extremely important stage the glacier covered, for the first time, the structural tectonic uplift caused by the “Punta San Vigilio- Sirmione- Rivoltella” fault line.
- Stage V (known as Solferino): the last glaciation created ridges of morainic hills with very steep slopes in the Lower West Garda area. In the east, on the other hand, the sediments created hills of lower altitude and gentler slopes. Finally, in the South, the moraine left by the end of the glacier formed the amphitheatre of the Garda morainic hills as we know them today.

(upper caption)

The 5 glaciation stages

It is interesting to note that in the Sirmione area the deposits are made up of shallow sediments and ground moraine characterized by silty-clay deposits.

A study of the different phases makes it clear that the five glacial tongues underwent a progressive eastward rotation. This shift is due to the tectonic movement of the faults that caused the hill ridges in the west and forced the glacier to rotate eastwards.

(upper caption)

On the left
The five glaciation stages
showing the rotation towards the East.

(lower caption)

Garda: showing the different depths of water due to its geological origins.

(upper caption)

The Grottoes of Catullus promontory

GEOLOGICAL SIRMIONE

A long walk through millions of years

6-Grotte di Catullo = Grottoes of Catullus

5-Fonte Bojola = The Bojola Spring

4-Lido delle Bionde = Lido delle Bionde beach

3-Collina Cortine = Cortine hill

2-Passeggiata delle Muse = Passeggiata delle Muse walk

1-Castello Scaligero = Scaliger Castle

If you want to view Sirmione from a geological point of view, enter the old town past the Scaliger Castle, then turn right along the castle moat and turn left into Via Dante, continuing behind the church of Santa Maria della Neve. This is where your journey through time begins.

1- BELVEDERE “SPIAGGIA DELLE MUSE” BEACH

From this vantage point you can admire Lake Garda in its entirety. It is interesting to observe the different morphology of the lake and you easily distinguish the northern end of the lake and the southern end, divided by a hypothetical line from Garda to Salò. To the north-east you can see the immensity of Mount Baldo and to the north-west Mount Pizzoccolo and the rock formations of the west coast. The constituent rock is Dolomite. This morphology, dominated by a steep coastline overhanging the lake, is caused by the fluvial genesis of the lake itself (partial desiccation of the Mediterranean Sea, strong increase in river erosion in the Alpine valley furrows) subsequently shaped by glaciers, whose deposits have produced the hills of the Benaco moraine amphitheatre, with gentler slopes (Bardolino-Lazise-Peschiera) to the south east.

2- BEGINNING OF THE “PASSEGGIATA DELLE MUSE” WALK

Walking beside the lake on the Passeggiata delle Muse, to your left you can see the Cortine promontory formed by the so-called "Sirmione Conglomerate". These are non-stratified conglomerates, with predominantly calcareous pebbles, recently dated by isotopic methods to the Lower Pleistocene. We can observe that the conglomerate is formed by rounded pebbles (due to their long journey), cemented into the rock by the pressure of the glacial masses present during the Quaternary. The pebbles have different consistencies according to their age. This rock formation can be seen along almost nearly all of the Passeggiata della Muse walk up to the pier of Hotel Villa Cortine, where there is a sharp change.

3- VILLA CORTINE PIER

This is where the geology of Sirmione changes. Behind the bar you can see another type of rock, which is part of a formation called the Scaglia Lombarda, made up of sedimentary limestone and marl, with very evident stratification planes, predominantly pink, red and gray in alternation. The same type of rock can also be seen on the lake bottom. The presence of this formation is due to the San Vigilio-Sirmione-Rivoltella fault that is found in depth at this point. The compressive tectonic movement of this fault caused the aforementioned rock formation, which was hundreds of metres deep, to push to the surface. This rock formation (Scaglia Rossa) dates back to the Cretaceous period, in other words about 80 million years ago!

4- LIDO DELLE BIONDE PIER

As you continue to Lido delle Bionde beach, at the pier, to the north, you can see the Grottoes of Catullus promontory, made up entirely of “Scaglia Rossa” marl and limestone. Looking at the rock in front of you, you can see how the rock layers run in a W-NW direction, with inclinations of 6° and 10°, in a NE-SW direction. This trend remains constant throughout the rocky escarpment, as we shall see later. The Bojola spring can also be found in this area, at about 200 metres from the lake shore, in a place where the thermal water reaches the aforementioned fault and finds its way to the surface.

Near the beach there is one of the wells dug to exploit the hot spring.

5- PIAZZALE ORTI MANARA

Piazzale Orti Manara is outside the entrance to the Grottoes of Catullus: from this panoramic position you can observe once again the different morphology of Upper and Lower Garda. South of the Gulf of Salò the landscape is gentler, mostly hilly, with the exception of the Rocca di Manerba, which is an older formation. The origin of the Rocca is attributable to compressive tectonic movements along the numerous faults present in that area. The hills south of the Rocca, which distinguish the south-west coast of the lake, are instead of glacial origin and formed by moraine deposits, mainly silty-clay, deposited when the glaciers retreated in the various phases that shaped the lower end of the lake. To the right of the Rocca di Manerba you can see the largest of Garda's islands: the Isola del Garda, also known as Isola Borghese.

6- THE WALK BACK INTO TOWN

While returning to the town centre, along via Catullo, you can once again see the limestone and calcareous marl of the Cretaceous (Scaglia Rossa) period until you reach Piazzale Piatti. Continuing along via Piana, the "Sirmione conglomerate" can be seen again behind houses and hotels. The area of Sirmione peninsula that does not have any rock is mainly formed by gravel deposits of lake origin and glacial deposits, mainly silt-clay, linked to the various glacial phases of the Quaternary.

The geology of **Sirmione**

As we have seen when discussing the origin of Lake Garda, the territory of Sirmione consists mainly of fine-grained deposits of a silt-clay nature, in other words, of material deposited by the glaciers that formed the southern end of the lake.

The tip of the peninsula, which extends into the lake, is different. We can in fact identify the presence of outcropping rock: the promontory of the "Grottoes of Catullus" formed by marl and red limestone, in flakes (Cretaceous = 80 million years ago) and the promontory of the Cortine hill, constituted by the "Sirmione Conglomerate", composed of stratified conglomerates with mainly calcareous pebbles (Early Pleistocene = about 1 million years ago).

The origin of these two rock formations, belonging to different eras, surfacing only at the tip of the peninsula, is due to a tectonic phenomenon. In fact this area is intersected by the "Punta San Vigilio - Sirmione - Rivoltella" **reverse fault** that cut the northern part of the peninsula in two and caused the rise of the rocky substrate, which should be deeper.

To summarise, what is unusual about the territory of Sirmione is the coexistence of various types of rocks attributable to epochs and geological phenomena that are extremely different from one another and that cannot be attributable to other structures nearby from a geographical point of view.

(blue box)

REVERSE FAULT:
a fault in which one part is pushed up higher than the other.
Reverse faults can lead to movements where older rocks overlap more recent rocks.

(upper caption)

The Sirmione Conglomerate.

(lower caption)

The San Vigilio – Sirmione – Rivoltella fault.

The **BOJOLA** spring

It is not uncommon to find hot springs along different kinds of tectonic fault lines. In the case of Sirmione the "San Vigilio - Sirmione -Rivoltella" fault has allowed the thermal water to reach the surface as the Bojola spring, which flows about 200 metres from the shore, at a depth of 18 metres, with a temperature of 70° Celsius.

This thermal water begins its journey in the area of the small Dolomites (Mount Baldo and the Lessini mountains) where the meteoric waters infiltrate, due to carsism, into the rock fractures and cavities and descend to a depth of about 4 km, flowing over a solid waterproof crystalline baserock. During its journey, the water is enriched with chemical components that give it a sulphurous-salsobromoiodic character i.e. enriched with sulphur, in the form of hydrogen sulphide, sodium, bromine and iodine) and, due to the geothermal gradient, its temperature increases. The presence of gas (water vapour) also creates

(lower caption)

Bojola thermal water.

an increase in pressure, which causes the water to rise along fractures or fault lines. The first information about the existence of the spring dates back to 1546, but it was only in 1891, thanks to more precise studies made by the science professor at Bagatta high school, Don Angelo Piatti and the ingenuity of Giuseppe Piana, that they were able to channel the thermal water to the surface. Since then the exploitation of the spring has become an economic and tourist opportunity for Sirmione. To date, three wells have been dug to access the water, all on the fault line mentioned above.

(upper caption)

The tip of Sirmione peninsula with its geological features.
MAP

Hot water source

KEY

Depositi del tardo pleistocene/olocene = Late Pleistocene / Holocene deposits

Conglomerato di Sirmione (SIR2) = Sirmione conglomerate (SIR2)

Conglomerato di Sirmione (SIR1) = Sirmione conglomerate (SIR1)

Calcari marnosi del tardo cretaceo = Late Cretaceous marl limestone

Calcari marnosi del tardo cretaceo = Late Cretaceous marl limestone

Piattaforma di abrasione = Abrasion platform

Affioramenti = Outcrops

Faglie = Fault lines

Giacitura di strato = strata sequence

Seismicity of the territory

Earthquakes are phenomena caused by tectonic movement along a fault line and they generate energy transmitted through elastic waves that make the earth vibrate. The point of origin of an earthquake is called its hypocenter and is located on the fault line; its surface projection point is called the epicentre.

There are different types of plate boundary movements that can generate earthquakes:

- Convergent (two plates slide toward each other and collide).
- Divergent (two plates slide apart from each other),
- Transform (two plates slide or grind past each other).

(upper image)
Scarpata di faglia = Fault escarpment

EPICENTRO = EPICENTRE

IPOCENTRO = HYPOCENTRE

Faglia = Fault

(blue line)

Faglia trascorrente = Transform fault

Faglia normale = Normal fault

Faglia inversa = Reverse fault

The seismograph is an instrument that traces seismic waves in the form of a seismogram. The "magnitude" is determined by the maximum height of the seismic wave. However magnitude is not the only way of measuring the effects of an earthquake. Local seismic amplification phenomena are also crucial, linked to the characteristics of the land on which the buildings are constructed: a clay soil with low consistency amplifies the effects of the seismic shock, whereas in the presence of a rocky substrate there are no such effects. Furthermore, coseismic effects linked to an earthquake can cause serious damage to buildings located in areas at risk, such as slopes subject to landslides.

(blue box)

GEOGNOSTIC SURVEY:
A survey based on analysis of the ground, its strata and its geological characteristics. From "GEOGNOSIA", in ancient Greek GEO (LAND) + GNOSIA (KNOWLEDGE).

A Seismic Hazard Map created by the INGV establishes the basic seismic dangers of the Italian territory through parameters that indicate expected seismic activity. It has been used to subdivide the national territory into seismic zones by establishing different levels of danger, decreasing from 1 to 4. Sirmione and the lower end of Lake Garda are classified in seismic zone 2, but more detailed studies (Seismic Microzonation) of the town, based on **geognostic ground surveys** and geophysical surveys, have noted the heterogeneity of the terrain and the different areas based on the possible phenomena of local seismic amplification. For this reason Sirmione has been mapped by subdividing it into micro-zones that take into account the different nature, and therefore the different response, of the ground to seismic waves. The detailed analysis of the territory, through seismic microzonation, therefore provides the tools to draw up a Territorial Government Plan that takes into account the seismic risk,

(upper image)

SISMOGRAMMI = SEISMOGRAM

ROCCIA = ROCK

TERRENI SOFFICI = SOFT GROUND

RILIEVO IN ROCCIA = ROCKY HIGH GROUND

ONDE SISMICHE = SEISMIC WAVES

Key

Terreni di copertura = Ground coverage

CLlc - Silty clay with faintly gravelly stretches ranging from consistent to very consistent, of a lakebed nature

CLti - Silty clay with fairly gravelly stretches, from slightly consistent to consistent, of till

GMfl - Silty and clayey gravel and sands from moderately thick to thick, of glacial lakebed nature

GMlc - Gravel with pebbles and silty - clayey sands from moderately thick to thick, of a lakebed nature

MLlc - Sandy silt with fragments of rock, from scarcely to moderately thick, of a lakebed nature

Substrato geologico = Geological substrate

LPS - Lapideo stratificato = stratified rock

GR - Granulare cementato = Cemented granular ground

Elementi tettonico strutturali = Structural tectonic elements

Faglia inversa potenzialmente attiva e capace (certa) =

Potentially active reverse fault (certain)

Faglia inversa potenzialmente attiva e capace (incerta)

Potentially active reverse fault (uncertain)

Giacitura di strato = strata sequence

(lower caption)

Mappa di microzonazione del territorio = Microzonation map of the territory

a fundamental tool for informed planning of infrastructures and buildings in strict compliance with seismic regulations. This tool was also used to update the municipal Emergency and Civil Protection Plan, again based on seismic risk.

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