EUROLITHOS European Ornamental Stone Resources

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Deliverable D3.3

Country-level atlases and a European Atlas of Ornamental Stones. Printed and digital versions

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Version: 29-10-2021

This report is part of a project that has received funding by the European Union's Horizon 2020 research and innovation programme under grant agreement number 731166.

Deliverable Data		
Deliverable number	D3.3	
Dissemination level	Public	
Deliverable name	**Country-level atlases and a European Atlas of Ornamental Stones. Printed and digital versions**	
Work package	**WP3 Atlas of European Ornamental Stones**	
Lead WP/Deliverable beneficiary	LNEG	
Deliverable status		
Submitted (Author(s))	29/10/2021	Jorge Carvalho
Verified (WP leader)	29/10/2021	Jorge Carvalho
Approved (Coordinator)	29/10/2021	Tom Heldal

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1 INTRODUCTION

The Workpackage 3 of the EUROLITHOS project aims to establish the framework and develop a first edition of an Atlas of European Ornamental Stones, integrating it in the GeoEra Information Platform, which will act as an extension to the European Geological Data Infrastructure (EGDI).

The Atlas of European Ornamental Stones is intended to be a science-based information system which will identify, collect and harmonize existing available data on the provenance of European Ornamental Stones, particularly on what respects the geology, resources, quarrying sites, and competing land uses with emphasis on those that may threaten or sterilize the resource.

Due to the constraints caused by the COVID19 pandemics, not enough emphasis was given to some of the objectives, as is the case of the location of the current and relevant old/historic ornamental stones mining sites, or they were not achieved, particularly with regard to the identification of the available resources and land use planning constraints and threats that are sterilizing ornamental stone deposits or may sterilize them.

1.1 Scope and purpose

This document is the deliverable D3.3 - "Country-level atlases and a European Atlas of Ornamental Stones". Its content is based on a close collaboration with the WP4 and WP6 teams, and tt is the final delivery of the workpackage 3.

In a previous delivery of WP3, it was presented:

- A harmonized structure of data to be collected for the characterization of the places where each stone comes from (mining spatial database);
- A harmonized structure of data to be collected for the characterization of each stone (spatial database of ornamental stone occurrences);
- A first draft of printable, country level atlases for printable purposes.

With regard to the two aforementioned database structures, they aimed at a first stage of data gathering towards the establishment of a final structure that would enable each of the partners to provide the data to the GeoEra Information Platform through the harvesting system.

Constraints of the IP platform and INSPIRE specifications made it difficult to implement a harvesting system for capturing data relating to the places of origin of the stones and data relating to each occurrence (eg. traditional/commercial name of stones, commercial name of the lithology group of each stone (the commodity code value), and provide links between directory (reports for individual unique ornamental stones) and Min4EU. Thus, it was decided to provide this information in an additional map layer. It should be updated regularly and whenever possible until the aforementioned constraints are resolved.

Indeed, some of the constraints of the INSPIRE specifications had already been identified in D3.2, which also presented a proposal for alteration in order to conveniently accommodate data related to ornamental stones.

Meanwhile, after discussions among all partners, a template for the Directory of Ornamental Stones consisting of the Identity Card (a factsheet) of each stone was presented in D4.1-2 of work package 4. This Identity Card provides information about the commercial name of the stone, its commodity type for distinguishing the main kinds of ornamental stones (i.e. granite, marble, limestone, miscellaneous, etc.), its lithology (granite, gneiss, calcitic marble, limestone, quartzite, etc.), and its typical colour picked from the Eurolithos Stone Colour list. The Identity Card provides also information about petrography, mineralogical composition, physical – mechanical properties and chemical properties of each stone.

Furthermore, anticipating the Information Platform and INSPIRE constraints, each Identity Card also includes a map concerning the geological setting of each stone origin, and data concerning its applications, uses and heritage features.

Each stone's identity card is to be linked to the the spatial data delivered by the aforementioned additional map layer.

Taking into account what was mentioned above, in addition to presenting the agreed version of the template for the printable version of the Atlas of European Ornamental Stones, this deliverable also presents the main project outputs obtained from the collaborative actions carried out by WP3 and WP6 teams, namely:

- The printable version of the Atlas of European Ornamental Stones;
- The information provided by the additional map layer

It should be noted that due to time and financial constraints, Eurolithos did not aim to list and characterize all ornamental stones and their places of origin in partner countries. The objective was to structure the databases that could support this data and, as far as possible, include the most relevant stones of each partner as first entries in the databases. For this reason, for the Directory and Atlas, most of the partners only provided data concerning a selection of stones.

The data upload system will have to remain available to partners after the end of the Eurolithos project in order to allow uploading and/or updating of data over time. Eurolithos will end as a project, but the uploading system and functionality for providing new data will continue. This will make it possible for partner countries to include more national data, and for new countries to join the archive and contribute.

2 ATLAS OF EUROPEAN ORNAMENTAL STONES – TEMPLATE FOR PRINTABLE VERSION

WP3 aimed at delivering a template for an Atlas of European Ornamental Stones at country (or region) level. This template is presented in Annex 1, and it has the following structure:

i. An introduction to the geology of the country/region
ii. An briedf description of the ornamental stone resources in the country/region and statistics about production
iii. An introduction to the use of ornamental stones in the country and associated heritage values
iv. Descriptions of ornamental stone resources: compilation of WP4 “ID cards” of each unique stone.

Each atlas should be freely distributed under the CC-BY license.

3 ATLAS OF EUROPEAN ORNAMENTAL STONES

Besides presenting a template for the European country Atlas of Ornamental Stones, WP3 aimed also at providing some examples of national atlases.

Cyprus, Emilia-Romagna Region (Italy), Greece, Italy, Norway, Portugal and Slovenia provided a first version of their national atlases (regional for the case of Emila-Romagna Region)

These atlases have been uploaded to the EGDI platform and are available at:

Cyprus	https://repository.europe-geology.eu/egdidocs/eurolithos/eurolithos atlas_cyprus.pdf
Emilia-Romagna	https://repository.europe-geology.eu/egdidocs/eurolithos/eurolithos+atlas_emrom.pdf
Greece	https://repository.europe-geology.eu/egdidocs/eurolithos/eurolithos+atlas_greece_final.pdf
Italy	https://repository.europe-geology.eu/egdidocs/eurolithos/eurolithos atlas_italy.pdf
Norway	https://repository.europe-geology.eu/egdidocs/eurolithos/eurolithos+atlas+norway.pdf
Portugal	https://repository.europe-geology.eu/egdidocs/eurolithos/eurolithos atlas portugal.pdf
Slovenia	https://repository.europe-geology.eu/egdidocs/eurolithos/eurolithos+country+atlas_slovenia.pdf

Annex 2 contains the first introductory pages of these seven atlases that were made during the EuroLithos time frame. It is expected that the remaining partners and other countries will contribute with new atlases taking advantage of the template that is now publicly available.

4 ADDITIONAL MAP LAYER

As mentioned earlier, the Eurolithos team decided to provide the information on the geographic distribution of ornamental stones occurrences from each partner country through an additional map layer (shapefile) that will be uploaded into the EGDI platform..

A view of this map is presented in Figure 1. It currently includes 1208 entries (Figure 2).

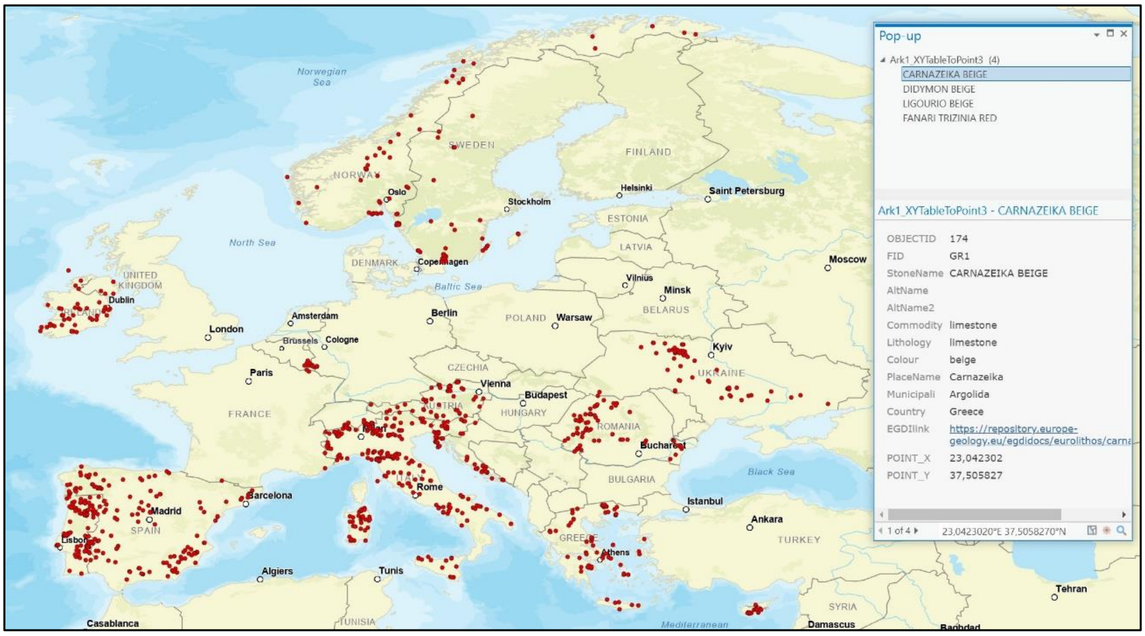

Figure 1 - Spatial distribution of ornamental stone occurrences from the Eurolithos partner countries

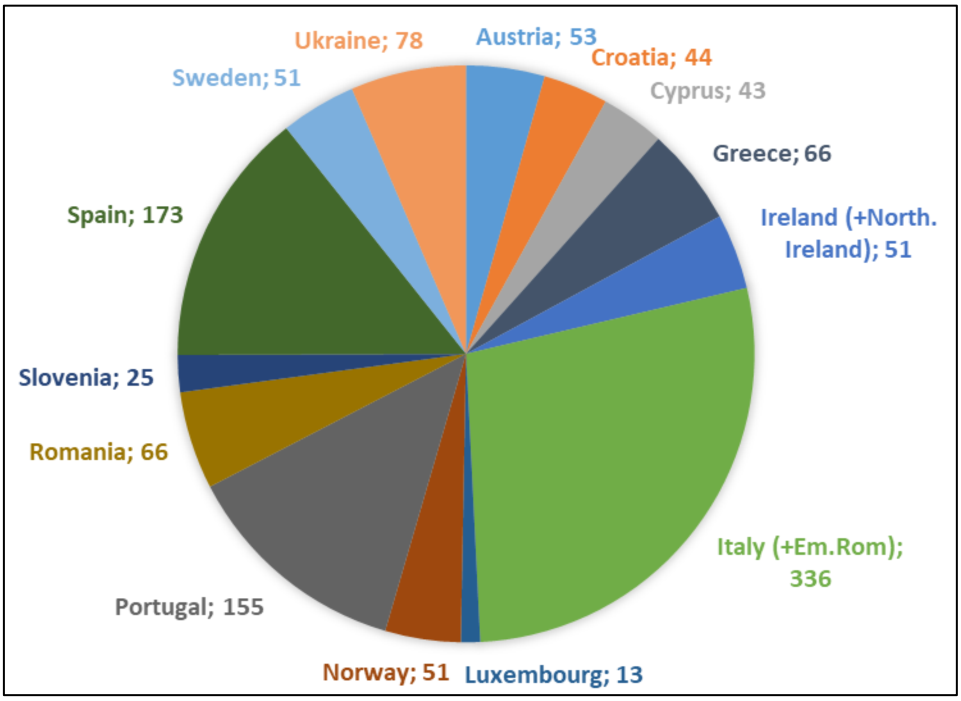

Figure 2 - Distribution of ornamental stone occurrences by country.

Table of attributes of each occurrence is given in Figure 3. It includes a link to the Directory “ID-Card” of each stone

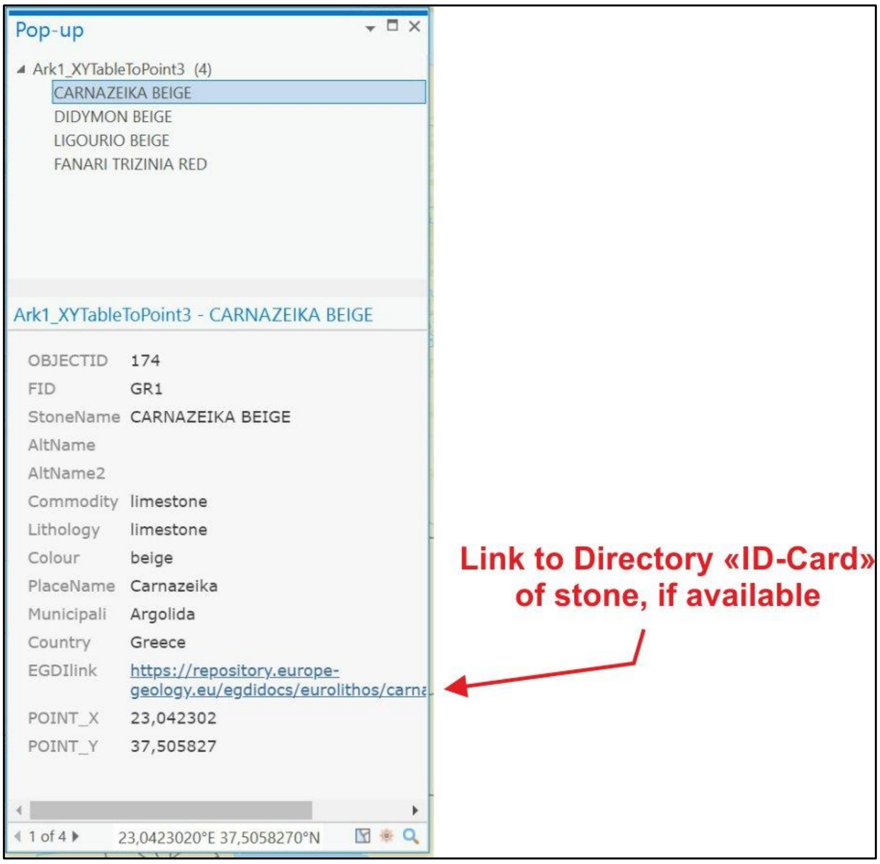

Figure 3 - Database structure given by table of attributes of an individual entry.

5 ANNEXES

5.1 Eurolithos Country Atlas Template

EuroLithos Country Atlas

[name of country]

(choose a background image)

EuroLithos Atlas

Ornamental stone resources in [name of country/region]

Thematic focus: [Country or Region]

Responsible partner(s):

Author(s):

Year: 2021

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Geology of [name of country / region]

[SHORT INTRODUCTION TO THE GENERAL GEOLOGY OF THE COUNTRY]

[SIMPLIFIED GEOLOGICAL MAP OF THE COUNTRY WITH STARS MARKING THE MAIN CURRENT PRODUCTION CENTRES OF ORNAMENTAL STONES AND, EVENTUALLY, MINING DISTRICTS]

Ornamental stone resources in [country / region]

[SHORT TEXT ABOUT THE TYPES OF PRODUCED STONES (E.G. MARBLES, GRANITES), MAKING REFERENCES TO INFORMATION PROVIDED BY THE MAP (E.G. MARBLES OCCUR IN THE NORTHERN REGION ASSOCIATED WITH THE XXXXX FORMATION OF XXXX AGE]]

Ornamental stone production

OPTIONAL [DATA ABOUT THE COUNTRY'S TOTAL PRODUCTION OF ORNAMENTAL STONES (LAST FIVE YEARS)

Use of ornamental stone and heritage values

[SHORT TEXT ABOUT THE HERITAGE VALUE OF THE COUNTRY'S ORNAMENTAL STONES, CRAFTS, TRADITION, ETC.]

Descriptions of ornamental stone resources

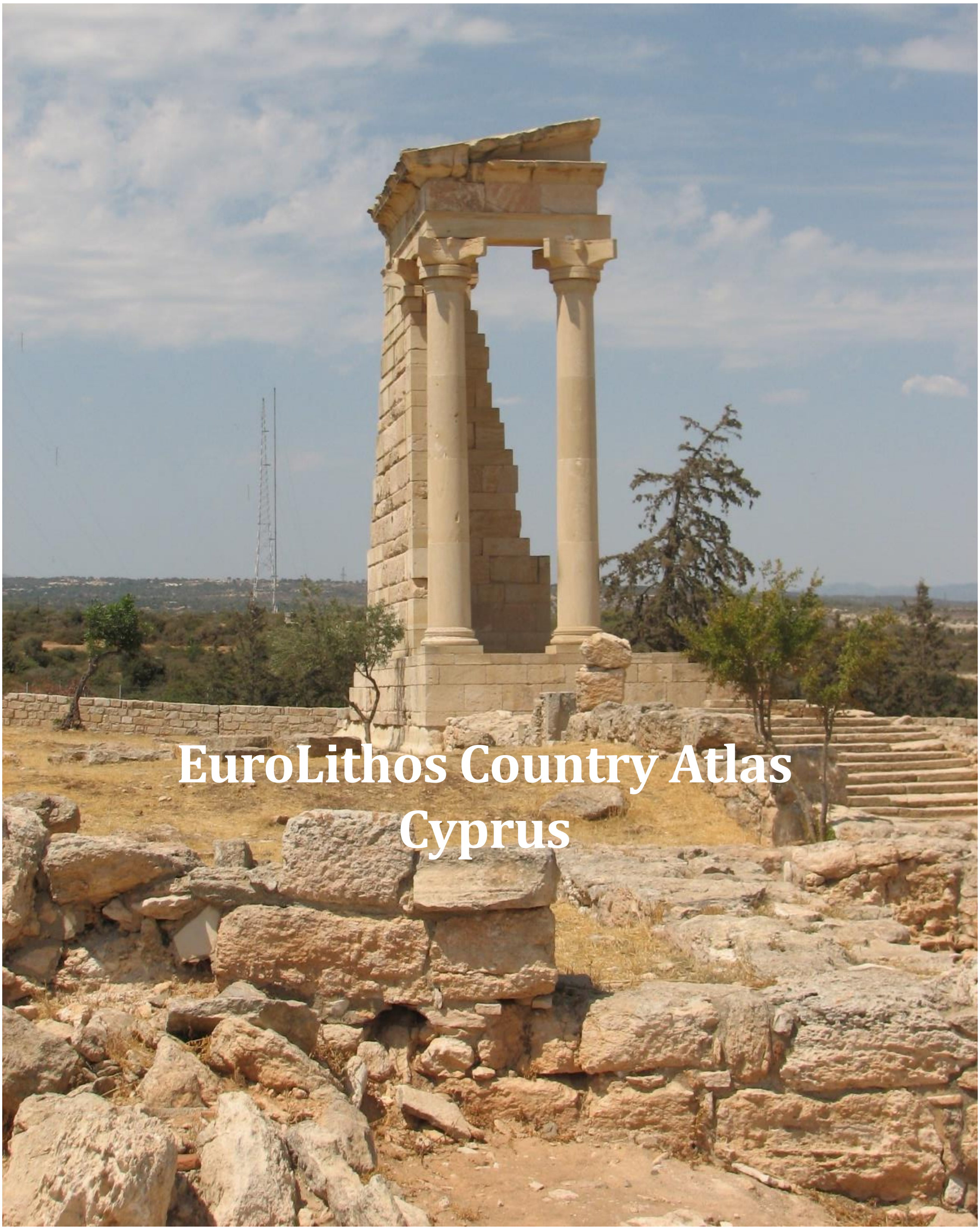
Ornamental stone resources in [COUNTRY/REGION] are described below in the order shown in Table 1.

Stone name	Commodity	Lithology

[INCLUDE IN THE FOLLOWING PAGES THE DIRECTORY FACTSHEETS OF EACH STONE]

5.2 Eurolithos Country Atlases - Introductory pages

CYPRUS



EuroLithos Country Atlas
Cyprus

EuroLithos Atlas

Ornamental stone resources in Cyprus

Thematic focus: Cyprus

Responsible partner(s): GSD

Authors: George Hadjigeorgiou, Christodoulos Hadjigeorgiou

Year: 2021

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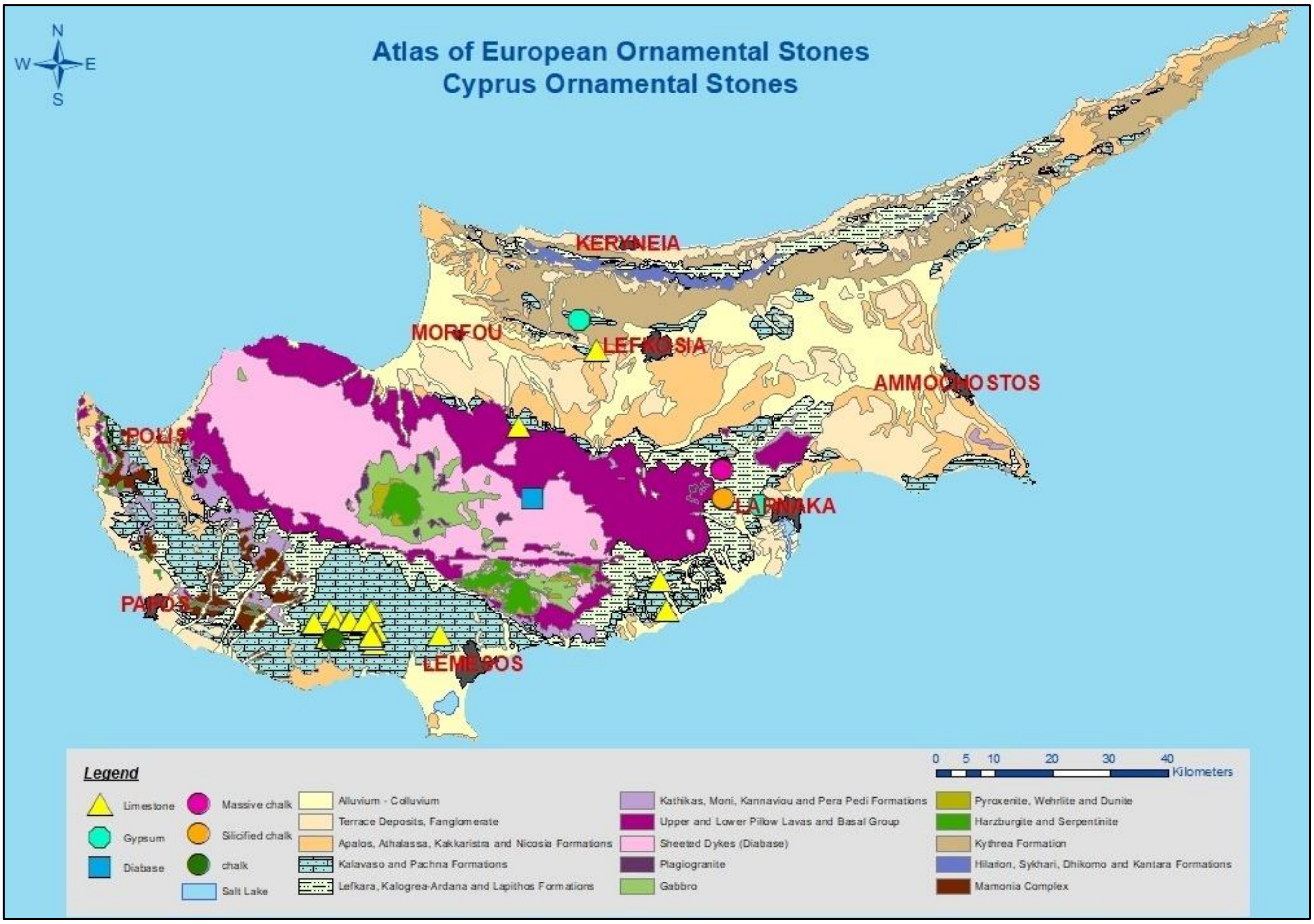
Geology of Cyprus

The genesis of the island of Cyprus was the result of a series of unique and complex geological processes, which established Cyprus as a geological model for geoscientists around the world and contributed to the understanding of the evolution of the oceans and planet Earth in general. At the top of Troodos, are outcropping rocks of the deepest layer of a fragment of oceanic crust and the Earth's upper mantle, an ophiolite complex, which was formed 92 million years ago, several kilometers below sea level. The complex geological processes in the region of Cyprus formed unique geodiversity rich in mineral resources, especially copper.

The geological structure of Cyprus

Cyprus is divided into four geological zones: (a) the Pentadaktylos (Keryneia) Zone, (b) the Troodos Zone or Troodos Ophiolite, (c) the Mamonia Zone or Complex and (d) the Zone of the autochthonous sedimentary rocks.



The Pentadaktylos (Keryneia) Zone is the northern-most geological zone of Cyprus and is considered to be the southern-most portion of the Tauro-Diranide Alpine Zone. It has an arciform disposition with an east-west direction and is characterised by southward thrusting. The base of the Zone is mostly composed of a series of allochthonous massive and recrystallised limestones, dolomites and marbles of Permian-Carboniferous to Lower Cretaceous age (350-135 Ma). These are stratigraphically followed by younger autochthonous sedimentary rocks of Upper Cretaceous to Middle Miocene age (67-15 Ma), on which the older allochthonous formations have been thrust southward.

The Troodos Zone or the Troodos Ophiolite dominates the central part of the island, constitutes the geological core of Cyprus, appears in two regions (main mass of the Troodos mountain range and in the Limassol and Akapnou Forests south of the range) and has a characteristic elongated dome structure. It was formed in the Upper Cretaceous (90 Ma) on the Neotethys sea floor, which then extended from the Pyrenees through the Alps to the Himalayas. It is regarded as the most complete and studied ophiolite in the world. It is a fragment of a fully developed oceanic crust, consisting of plutonic, intrusive and volcanic rocks and chemical sediments. The stratigraphic completeness of the ophiolite makes it unique. It was created during the complex process of oceanic spreading and formation of oceanic crust and was emerged and placed in its present position through complicated tectonic processes relating to the collision of the Eurasian plate to the north and the African plate to the south. The stratigraphy of the ophiolite shows a topographic inversion, with the lower suites of rocks outcropping on the highest points of the range, while the stratigraphically higher rocks appear on the flanks of the Troodos massif. This apparent inversion is related to the way the ophiolite was uplifted (diapirically) and then differentially eroded. The diapiric uplift of its core took place in many episodes with more intense uplift taking place in the Pleistocene (2.6 Ma).

The Mamonia Zone or Complex appears in the Pafos district in the southwestern part of the island. It constitutes a series of igneous, sedimentary and metamorphic rocks, ranging in age from Middle Triassic to Upper Cretaceous (230-75 Ma). These rocks, which are regarded as allochthonous in relation to the overlying autochthonous carbonate successions and the Troodos ophiolite rocks, were placed over and adjacent to the Troodos ophiolite during the Maastrichtian.

The Zone of the autochthonous sedimentary rocks, ranging in age from the Upper Cretaceous through the Pleistocene (67 Ma to recent years), covers the area between the Pentadaktylos and Troodos Zones (Mesaoria) as well as the southern part of the island. It consists of bentonitic clays, volcaniclastics, marls, chalks, cherts, limestones, calcarenites, evaporites and clastic sediments.

The Troodos Ophiolite

The Troodos Ophiolite consists of the following stratigraphic units, in ascending order: Plutonics (mantle sequence and cumulates), Intrusives, Volcanics and Chemical sediments.

The mantle sequence is thus termed because the rocks that form this suite are considered to be the residuals after the partial melting of the upper mantle and the formation of basaltic magma, from which the remaining rocks of the ophiolite have been derived. It is mainly composed of harzburgite and dunite with 50-80% of the original minerals altered to serpentine, and serpentinite (with or with-out concentrations of asbestos) where the alteration is almost complete.

The cumulate rocks are the products of crystallisation and concentration of the crystals at the floor of the magma chamber, beneath the zones of sea floor spreading. The main cumulate rocks include dunite with or without chromite concentrations, wehrlite, pyroxenite, gabbro and plagiogranites, which are observed in small discontinued occurrences.

The Intrusive rocks (Sheeted Dyke Complex - Diabase) have a basaltic to doleritic composition and were formed by the solidification of the magma in the channels, through which it intruded from the magma chambers at the bottom of the oceanic crust, feeding at the same time the submarine extrusion of lava on the sea floor. The Sheeted Dyke Complex is followed by a suite of volcanic rocks that consist of two series of pillow lavas and lava flows, mainly of basaltic composition. The pillow lavas have a characteristic spherical to ellipsoidal pillow shape, 30-70 cm in diameter, which were formed as a result of submarine volcanic activity. Between the intrusive rocks and the pillow lavas a transitional zone known as the Basal Group occurs. Dykes dominate the Basal Group while pillows are less common.

The Pera Pedhi Formation is composed of umber (chemical sediment), radiolarites and radiolaritic shales. These were the first sediments to be deposited over the ophiolite rocks as a result of hydrothermal activity (hot solutions rich in Fe and Mn) and sedimentation on the sea floor.

The Autochthonous Sedimentary Rocks

The sedimentation in the geological history of Cyprus started 80 Ma in a deep sea which becomes gradually shallower. The sedimentation begins with the deposition of the **Kannaviou Formation** (bentonitic clays, volcaniclastics), followed by the deposition of the **Moni and Kathikas Formations**. Carbonate sedimentation begins 65 Ma with the deposition of the **Lefkara Formation**, which includes pelagic marls and chalks with characteristic white colour, with or without cherts. The Lefkara Formation is followed by the **Pakhna Formation** 22 Ma, which consists mainly of yellowish marls and chalks. The colour of the rocks, the presence of calcarenitic layers and the occasional development of conglomerates are characteristics that differentiate the Pakhna from the Lefkara Formation. Sedimentation of the Pakhna Formation began and terminated in shallow-water environment with the development of reefal limestones (Terra Member at the base and Koronia Member at the top of the Formation).

The deposition of the evaporites of the **Kalavasos Formation** (6 Ma), was the result of the isolation of the Mediterranean Sea from the Atlantic Ocean and the subsequent evaporation of its waters. The Formation is composed of gypsum and gypsiferous marls that cover extensive areas.

Upon the reopening of the Gibraltar Strait and the reconnection of the Mediterranean Sea with the Atlantic Ocean, a new cycle of sedimentation began (5 - 2 Ma). The **Nicosia Formation** was deposited first and contains grey and yellow siltstones and layers of calcarenites and marls. Upwards it consists of calcarenites interlayered with sandy marls **(Athalassa Member)**. They follow the **Apalos and Fanglomerate Formations**, which consist of clastic river deposits (gravels, sand and silt).

The Mamonia Zone

The Mamonia Zone is named after the village of Mamonia in Pafos, where classic outcrops of the Zone occur. It consists of a series of allochthonous volcanic, sedimentary and in smaller proportion metamorphic rocks that were formed 230-75 Ma and it includes the following:

I. Volcanic (lavas) and sedimentary rocks (recrystallised limestones) of the Diarizos Group.

II. Pelagic sedimentary rocks (limestones, mudstones and quartzitic sandstones) of the Agios Photios Group.

III. Metamorphic rocks (schists and marbles) of the Agia Varvara Formation. These rocks were derived from the metamorphism of the Diarizos Group.

The rocks of the Mamonia Zone have been intensely deformed and mixed with large fragments of the Troodos ophiolite rocks foming extensive zones of melange.

The Pentadaktylos Zone

The three main geological formations aged between 250 and 135 Ma are the **Dhikomo, Sykhari and Hilarion Formations**, which form the main carbonate masses of the Kyrenia Range. The Dhikomo Formation consists of deformed thinly bedded limestones with layers of grey and green phyllites. The Sykhari Formation is composed of massive to thickly bedded dolomitic limestones. The Hilarion Formation consists of medium-bedded to massive limestones, which were subjected to a very low degree of metamorphism. These formations were placed southward over the younger autochthonous marine sediments, which are known as the Lapithos, Kalogrea-Ardana (Belapais) and Kythrea Formations. Impressive and continuous outcrops of limestones occur in the central part of the range, whereas in the eastern part they occur in the form of olistholiths over the younger sediments. These limestones (olistholiths) are referred to as the **Kantara Formation** aged between 350 and 250 Ma.

The geological evolution of Cyprus

The genesis of Cyprus took place through a series of complex tectonic processes in the broader context of the subduction of the African plate under the Eurasian plate. Thus, about 90 Ma, a new oceanic crust was created, part of which was cut off and later formed the Troodos ophiolite. About 75 Ma, older rocks (230 to 75 Ma) of the African plate have been thrusted onto the ophiolite and are currently found mainly in the southwestern part of the island. Then a period of relative tectonic inactivity followed that lasted up to 10 Ma, resulting to the deposition of a sequence of carbonate sediments, in progressively uplifted area.

About 6 Ma, a series of allochthonous limestones, aged between 350 to 135 Ma were thrusted over the northernmost flanks of the Troodos Ophiolite, forming the Pentadaktylos range. At the same time, the Mediterranean Sea was isolated from the Atlantic Ocean resulting to intense evaporation, drastic sea level drop and salinity increase resulting in gypsum and salt deposition throughout the Mediterranean region, with thickness of up to 3 km. These rocks form today the impermeable layer (trap), beneath of which the hydrocarbon reserves of the eastern Mediterranean are found.

The reopening of the Gibraltar Strait, reconnected the Mediterranean Sea with the Atlantic Ocean, 5,3 Ma, and caused its flooding and the quick rise of the sea level, thus resulting in the deposition of marls and calcarenites. During the last 2,6 Ma, there was an abrupt uplift of the Cyprus area where in this period the Troodos and Pentadaktylos ranges were gradually uplifted to their current position. The abrupt uplift, combined with intense rainfall, resulted in extensive erosion of the ranges, particularly that of Troodos, and the transportation of large quantities of clastic sediments that were deposited in river valleys developing the most important aquifers of Cyprus.

Ornamental stone resources in Cyprus

Cyprus has ornamental stones which have been used since prehistoric period. These stones are considered as commercial limestone, such as the limestones (calcarenites) originated from the Geological Formation of Pachna (end of the Oligocene/ 22 million years ago) and from Athalassa member of the geological formation of Nicosia (Beginning of the Pliocene / about 5 million years ago). Additionally, reef limestone from Koronia Member (Messinia - Upper Miocene / 7,2- 5,3 million years ago) originated from the Geological Formation of Pachna and also limestone (chalk) from the Geological Formation of Lefkara (Upper Maastrichtian / 67 million years) until the end of the Oligocene (22 million years). Cyprus also has miscellaneous dimension stones, such as chert (silicified chalk) originated from the Geological Formation of Lefkara (22 million years), gypsum from the Geological Formation of Kalavassos (Messinia - Upper Miocene) / 7-5 million years ago). Finally, some other stones such as basalt, which is diabase (sheeted dyke complex) and some other rocks from Troodos Ophiolite (92 Ma) are considered as commercial.

Ornamental stone production

Ornamental stone Production in Cyprus for the last five years, are described below in the order shown in Table 1.

Stone name	**Commodity**	**Lithology**	**Production in tones for the last 5 Years**
Petra Pachnas (Petra Pachnas)	Limestone	Limestone	14.045
Petra Pachnas (Petra Kyvidon)	Limestone	Limestone	114.520
Petra Pachnas (Klimara)	Limestone	Limestone	No data
Petra Pachnas (Petra Anogyras)	Limestone	Limestone	45.254
Petra Pachnas (Petra Prastio Avdimou)	Limestone	Limestone	6.516

Klimara Agias Annas (Petra Agias Annas)	Silicified chalk	Silicified chalk	125
Petra Lympion	Massive chalk	Massive chalk	6.250
Plakes Avdimou (Klimara)	Chalk	Chalk	No data
Gypsomarmaro	Gypsum (Laminated)	Gypsum	No data
Petra Yerolakkou	Limestone	Limestone	No data
Petra Troodous	Basalt	Diabase	1.560.833
Petra Mitserou	Limestone	Limestone	1.500.000

Use of ornamental stone and heritage values

The decorative stone of Cyprus has been used since prehistoric period (13th century BC, the famous ancient port and settlement of Kition). From the beginning of the 1st century AD (Roman period) until the 4th century AD, ancient theatres of large capacity of spectators, were built from limestone rocks from several geological formations, based on the proximity to the archaeological sites. Throughout the Middle Ages, castles and other were built using the same type of rocks. During the 19th century, many buildings (schools, museums, etc.) were built using limestone from Yerolakkos area as a building material. Today the various types of Cyprus limestone, gypsum, silicified chalk, massive chalk, diabase and other ultramafic and mafic rocks are used for the construction for decoration of walls and floor pavement. Additionally, Cyprus limestone are used for the restoration of older buildings and ancient monuments. The various types of rocks that were used are: From all types of ornamental stone that were used two were the predominant: The calcarenites from the Geological Formation of Pachna and that of the Athalassa member of the geological formation of Nicosia.

EMILIA - ROMAGNA


1


2

EuroLithos Country Atlas

Emilia-Romagna Region, Italy


3


4

Photos and references

1,https://www.eurocavesnc.com/foto/cave/canala/big/f_06.jpg;2,https://www.arenariadicarnigliaagazzi.it/fotoalbum.php;
3, http://www.lapietradicassio.it/cava.html; 4, https://www.trekkingtaroceno.it/la-valle-di-pietra-bedonia-e-le-cave-di-carniglia/ Reference: arch. Emanuele Mazzadi

EuroLithos Atlas

Ornamental stone resources in Emilia-Romagna, Italy

Thematic focus: Country, Region

Responsible partner(s): Regione Emilia-Romagna, Servizio Geologico, Sismico e dei Suoli, SGSS

Author(s): Maria Teresa De Nardo

Year: 2021

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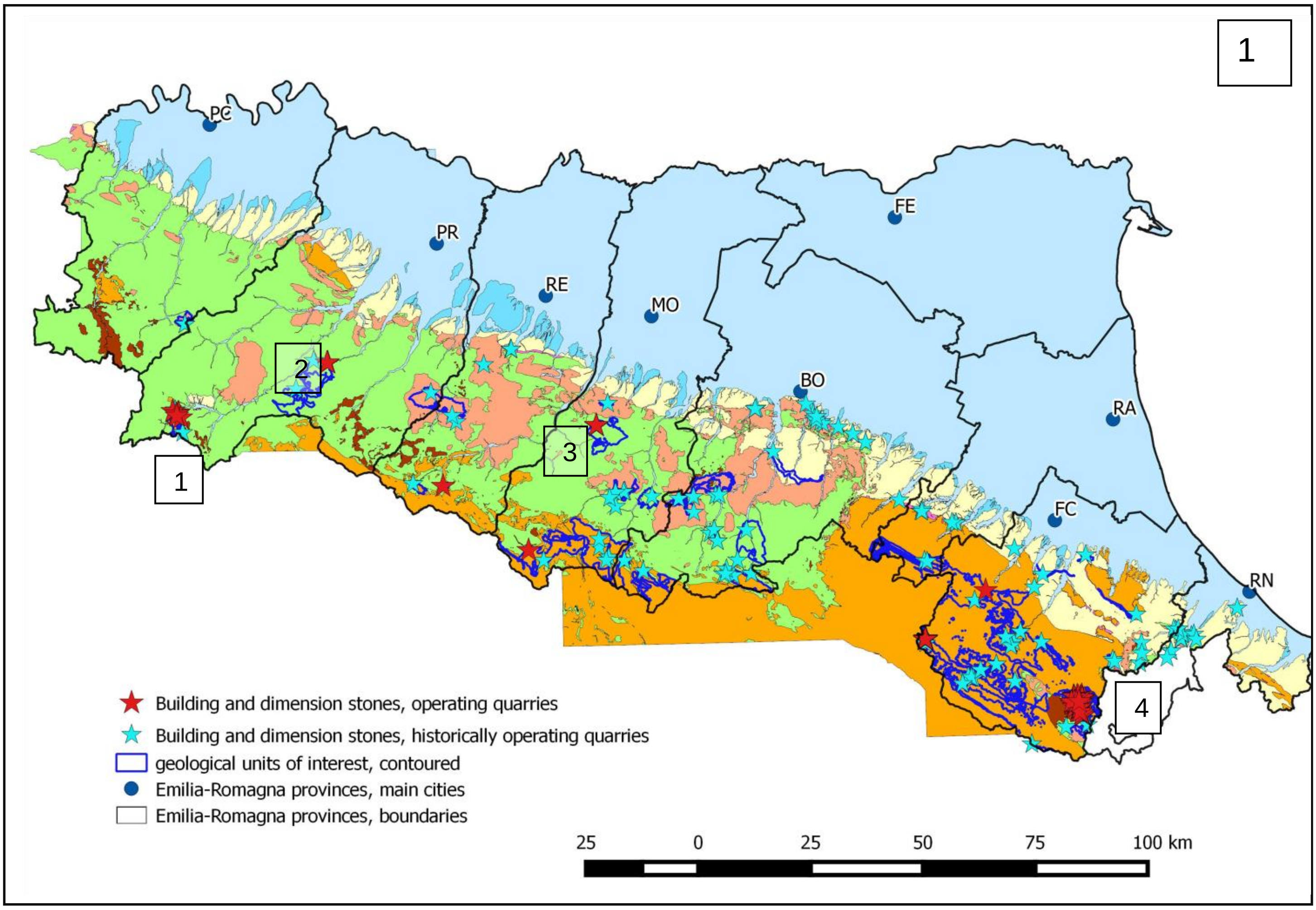
Geology of Emilia-Romagna Region

Figure 1 – location of the Emilia-Romagna region (1a) and simplified geological map (1b), building and dimension stones quarries (centroids) are symbolized by stars, geological units of interest in blue contours. Explanations in the text



Emilia-Romagna is an Italian region located in the northern part of the country, South of the Po River course (figure 1a); figure 1b shows a simplified geological map. The territory is made up of a southern mountain and hilly sector (40% of total surface), geologically pertaining the Northern Apennines, and a northern alluvial plain (light-blue area in figure 1b) related to the deposits of the Po River and Apennine river-courses, which are either tributaries of the Po River or flow into the Adriatic Sea to the East. In the figure 1b, sub-regional, province boundaries and main cities are symbolized as well: Piacenza (PC), Parma (PR), Reggio-Emilia (RE), Modena (MO), Bologna (BO), Ferrara (FE), Ravenna (RA), Forlì-Cesena (FC), Rimini (RN)

The Emilia-Romagna Apennines are characterized by NE-verging, WNW-ESE oriented tectonic structures (thrust-faults and folds, mainly), either outcropping in the chain or buried beneath the alluvial plain, expression of the compressional stresses related to Alpine orogenetic phases. NE-SW oriented transverse faults interrupt the main structures laterally. In the Emilia-Romagna Apennines, geological units are mainly made up of clastic, sedimentary rocks, except some peculiar ophiolitic bodies of magmatic origin.

The structurally lowermost geological units are mainly represented by several hundreds of metres thick, foredeep arenitic and pelitic turbidites (orange areas in figure 1b); their age ranges from Late Oligocene to Middle Miocene. They widely outcrop in the Romagna Apennines (Formazione Marnoso-Arenacea in the Ravenna, Forlì-Cesena and Rimini Apennines) or make up the ridge of the Emilia Apennines ("Tuscan Units", Parma, Reggio Emilia, Modena and Bologna provinces) or outcrop within tectonic windows (Piacenza and Parma Apennines mainly). During the orogenetic phases, they were overridden by deformed terrains pertaining the Ligurian Domain, corresponding to original stratigraphic sequences deposited in the Tethys Ocean (as testified by the ophiolitic slabs), dating back to the Jurassic to Middle Eocene. Ligurian Units (green areas in figure 1b) are made of shaly chaotic units and of preserved, locally very thick, turbiditic sequences: among them, the Late Cretaceous and Paleocene-Middle Eocene Helminthoid or Tertiary Ligurian flysches. The so-called Subligurian Units (Late Cretaceous- Oligocene age, brown areas in figure 1b) are tectonically interposed between the Ligurian and the underlying Tuscan Units.

During the orogenetic phases, the translation of the Ligurian, overriding the Subligurian Units and towards the foredeep turbiditic basins was accompanied by the sedimentation of the clastic formations of the Epiligurian Sequence (pink areas in figure 1b), unconformably deposited on the deformed Ligurian Units during the Early Eocene- Middle Miocene period Nearby the Apennine foothills, Messinian gypsum outcrops. Late Messinian and Pliocene to Early Pleistocene, mainly clayey, formations (whitish areas in figure 1b) seal older, displaced geological units.

Ornamental stone resources in Emilia-Romagna

In the simplified geological map in figure 1b, quarries of building and dimension stones (centroids of corresponding polygons) are subdivided into two classes: operating or planned (red stars) and historical ones (light-blue stars). Data derive from the Servizio Difesa del Suolo, della Costa e Bonifica of the Regione Emilia-Romagna; several data on historical, nowadays abandoned, quarries derive from bibliography as well.

In the Emilia-Romagna region, operating or planned dimension stones quarries are almost residual, with respect to the past, that is till the 1950s-1970s.

Blue contours in figure 1b indicate geological units, mainly arenitic, of interest. In historical times lithologies other than arenites were quarried ad employed as ornamental stones: gypsum (known as "selenite"), coloured limestones, ophiolites; nowadays they are no more of economic interest, local historical quarries may thus become a matter of interest for geo-turistic itineraries.

As a synthesis, nowadays dimension stone quarries are to be found in the following geological settings, according to figure 1b:

- 1, Parma province, Late Oligocene-Early Miocene arenaceous turbidites outcropping in the Monte Zuccone tectonic window
- 2, Parma province, Cretaceous arenitic turbidites in a slab within the Ligurian Units
- 3, Modena province, Late Cretaceous arenitic and marly-calcareous turbidites in a slab of Helminthoid Flysch within the Ligurian Units
- 4, Forlì-Cesena province, Middle Miocene foredeep arenite turbidites (Formazione Marnoso-arenacea)

Use of ornamental stone and heritage values

As aforesaid, dimension stone quarries in the Emilia-Romagna Apennines are not widespread nowadays. Thus, this makes them even more interesting, both because of the remarkable natural quality of rock-types (mainly, arenites) and for the local significance of this resource. In fact, the use of autochthonous dimension stones (according to planning and regulation measures at provincial extent, after the 17/1991 Regional Law) is preferable, to avoid incongruous remediation interventions on public and rural buildings.

The Emilia-Romagna dimension stones are mostly sandstones, or better, arenites, as clasts may present a variable petrographic composition with respect to end members as feldspar or quartz grains; metamorphic, volcanic and carbonate lithic grains and carbonate intraclasts. The cement is mostly calcareous.

These arenites are well-cemented, compact and resistant to atmospheric agents, resilient to ice and freezing. They are very suitable for coverings and flooring, for outdoor paving and façades, balconies, portals; compact, fine-grained arenites with ornamental, sedimentary laminae are employed indoor as well, for decorative coverings, bathroom and kitchen tops.

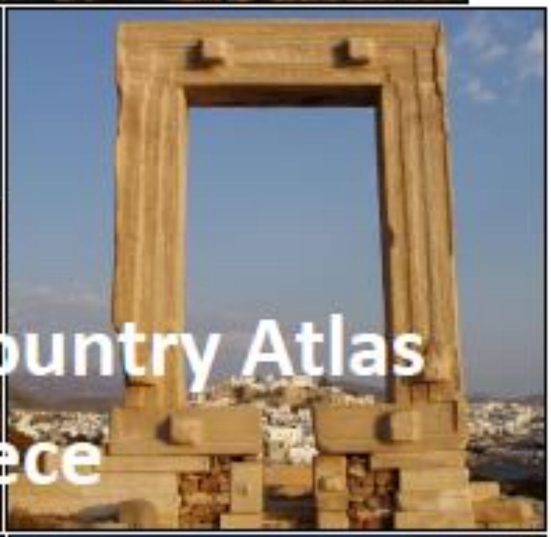
Grey, in different tones, is the the most common color; light-grey to whitish color is more distinctive of “Alberese” fine-grained arenites or limestones.

Historically, the use of most of these arenites was widespread, as testified by villages and churches or remarkable buildings. Some examples are given in the Parma Apennines, along the so called «Via Francigena», the main road used by pilgrims walking from Canterbury to Rome in the Middle Ages. In the Reggio Emilia and Modena Apennines, several romanic parish churches (some of them built up in the Early Middle Ages by order of Matilde, countess of Canossa) were built using local calcareous arenites or the siliciclastic ones known as “Macigno”, though the location of original quarries is often unknown. In the Bologna Apennines, the surroundings of the Riola village host fairly recent examples of artistic buildings in local arenites, among them a church by the Finnish architect Alvar Aalto. In the Forlì-Cesena Apennines, the extraction of “Pietra serena” and “Alberese” is still active; these lithotypes are typical of Tuscan architecture as well.

Some historical dimension stones were rare and typical to the region and they are no longer in use: translucent selenite gypsum (employed in Bologna during the Roman Age and in the Middle Ages), red or grey limestones, green ophiolitic rocks and travertines.

GREECE

EUROLITHOS European Ornamental Stone Resources



EuroLithosCountry Atlas Greece

EuroLithosAtlas

Ornamental stone resources in Greece

Thematic focus: Greece
Responsible partner: HSGME
Authors: Laskaridis Konstantinos, Arapakou Angeliki
Year: 2021

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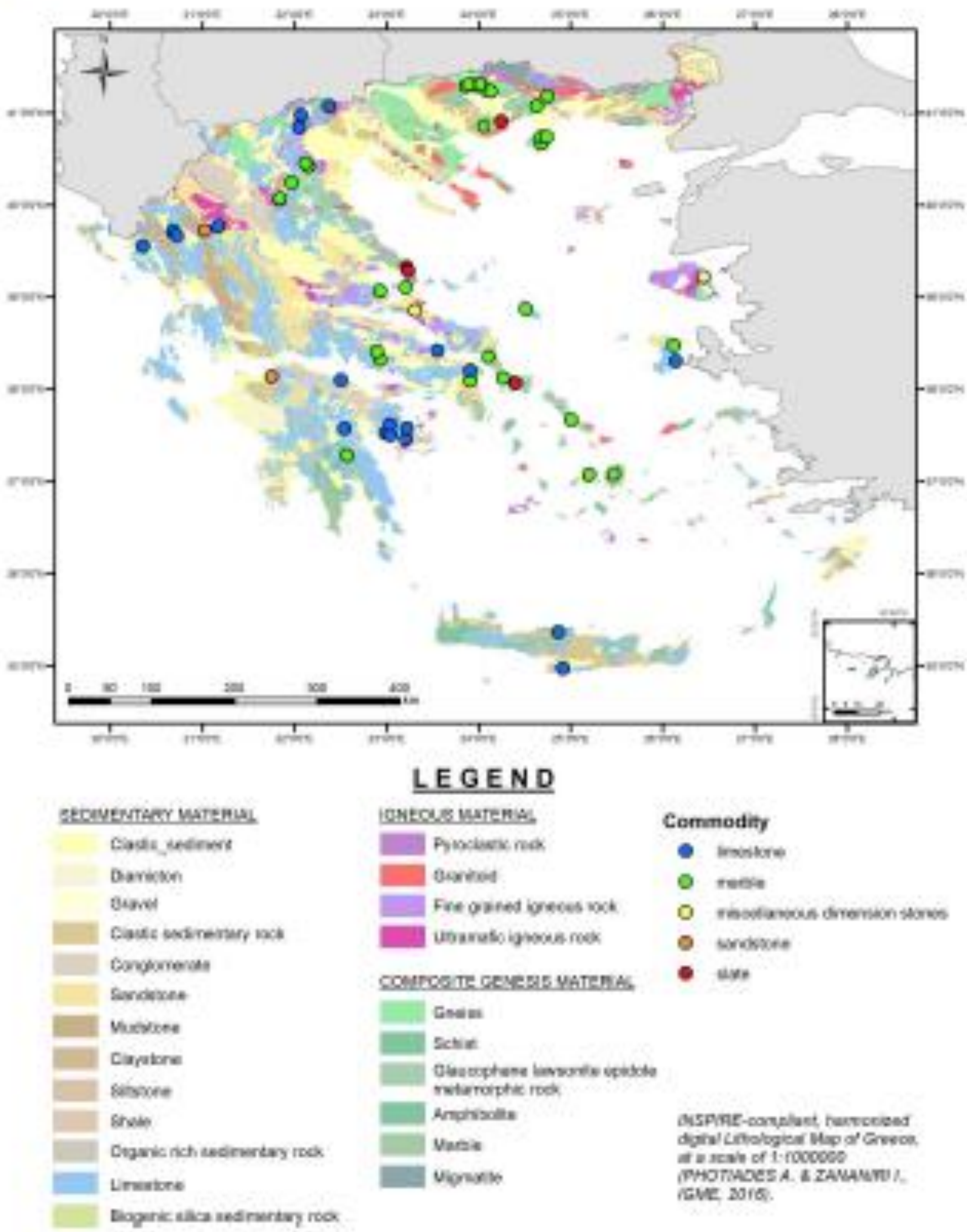
Geology of Greece

Greece comprises a wide variety of geotectonic units, widely known as the Hellenides, which belong to the Alpine-Himalayan orogenetic system. They consist of two major groups of geotectonic units, the so-called Internal and External Hellenides. The External Hellenides, occupy the largest part of Western and Central Greece, and are dominated by Mesozoic sedimentary rocks (mostly limestones, dolomites, etc.). In contrast, the external Hellenides dominate the Eastern and Northern parts of Greece and are characterized by more complex geodynamic evolution reflected in their lithological variety. Ophiolitic rocks occur throughout Greece, with their most prominent outcrops located in NW Greece. Metamorphic and magmatic rocks occur mainly in the northern part as well as in the Aegean area, in the Rhodope and Attic-Cycladic Massifs, respectively.



Ornamental stone resources in Greece

Ornamental stones deposits are scattered throughout the country. Marbles are the most important ornamental stones of Greece, which occur in a large number of deposits, many of them being known from ancient times (e.g. Pentelikon Mountain, Paros island, Thasos island, etc.). The Greek marbles are characterized by various types in respect to their grain-size, colours, textures, etc. The marble deposits are mostly located in the east and north part of mainland Greece and some of the Aegean islands.

Another group of frequently exploited ornamental stones in Greece, comprises various types of limestones, which also display a large morphological variety. The main production centres are located in NW Greece, the Peloponnese prefecture, and the islands of Evia, Crete and Chios. Slates (a term used to describe rocks of sedimentary and metamorphic origin, i.e. various types of schists) are produced in a few localities, e.g. Northern Greece, Pelion Mountain, and the northern part of Evia island.

Finally, other ornamental stones with limited production include miscellaneous dimension stones and clastic stones (commonly sandstone) extracted from a few localities in Greece.

Ornamental stone production

Greece, having a long tradition in quarrying various types of ornamental stones, has managed, today, to be among the 10 most important producing and exporting countries in the world despite increased competition. Stone quarrying takes place all over Greece, new reserves are gradually exploited and ornamental stones have become widely applicable industrial products. According to 2019 relevant data, annual production is in the order of $10^6 m^3$, from which 27% is exported. The majority of Greek marble exports is absorbed by China (about 50%-60% of the total marble exports). Marble and stone exports represent around 2% of the annual revenues of overall Greek exports (data refer to the period 2012-2019).

Calcitic marbles are mainly located in Attica, Central Greece and Aegean islands, dolomitic marbles in Eastern Macedonia and Thrace, limestones in Epirus, Western and Central Macedonia, Peloponnese and Crete, travertines in Attica, Peloponnese and Central Macedonia, sandstones in Epirus, schists and slates in Central Greece and Thessaly.

Use of ornamental stone and heritage values

Ornamental stone quarrying in Greece has started since ancient times. During the 5th century BC, intensive quarrying has been reported in large exploitation centers, such as: Penteli and Aghia Marina (Attica), Naxos, Paros and Thassos islands, all well-known for their white marbles; Tinos island and Hassabali (Larissa), for their green marbles; Styra and Karystos (Euboea), for "cipollino marbles"; Krokees (Peloponnese), famous for the greenish "krokeatis lithos"; and Skyros island, for multi coloured marbles. The first monuments of Greek sculpture appeared as early as 630 BC. Characteristic monuments are the temple of Zeus in Olympia and the temple of Apollo in Delphi (marble of Paros in the façade and porous-stone for the rest part of the construction). White "Pentelikon" marble is famous for being employed in the construction of historic monuments of art, such as the Parthenon on Athens Acropolis.The Erechtheum, the temple of Olympius Zeus, the statues of Aphrodite of Milos, Hermes of (the sculptor) Praxitelis, Niki of Samothraki etc. are also significant creations using Greek ornamental stones during the classic period. In the early 20th century, Greek stones became well known abroad, exported in Western Europe. The abrupt development of construction in urban centres and the high standard of living increased the demand in marble extraction. Consequently, new reserves all over Greece were exploited and ornamental stones became widely applicable industrial products.

Descriptions of ornamental stone resources

Ornamental stone resources in Greece are described below in the order shown in Tables 1, 2 and 3 based on their commodity and lithology.

ITALY


Eurolithos Country Atlas
Italy

EuroLithos Atlas

Ornamental stone resources in Italy

Thematic focus: Country

Responsible partner(s): ISPRA

Author(s): Mauro Lucarini, Fiorenzo Fumanti

Year: 2021

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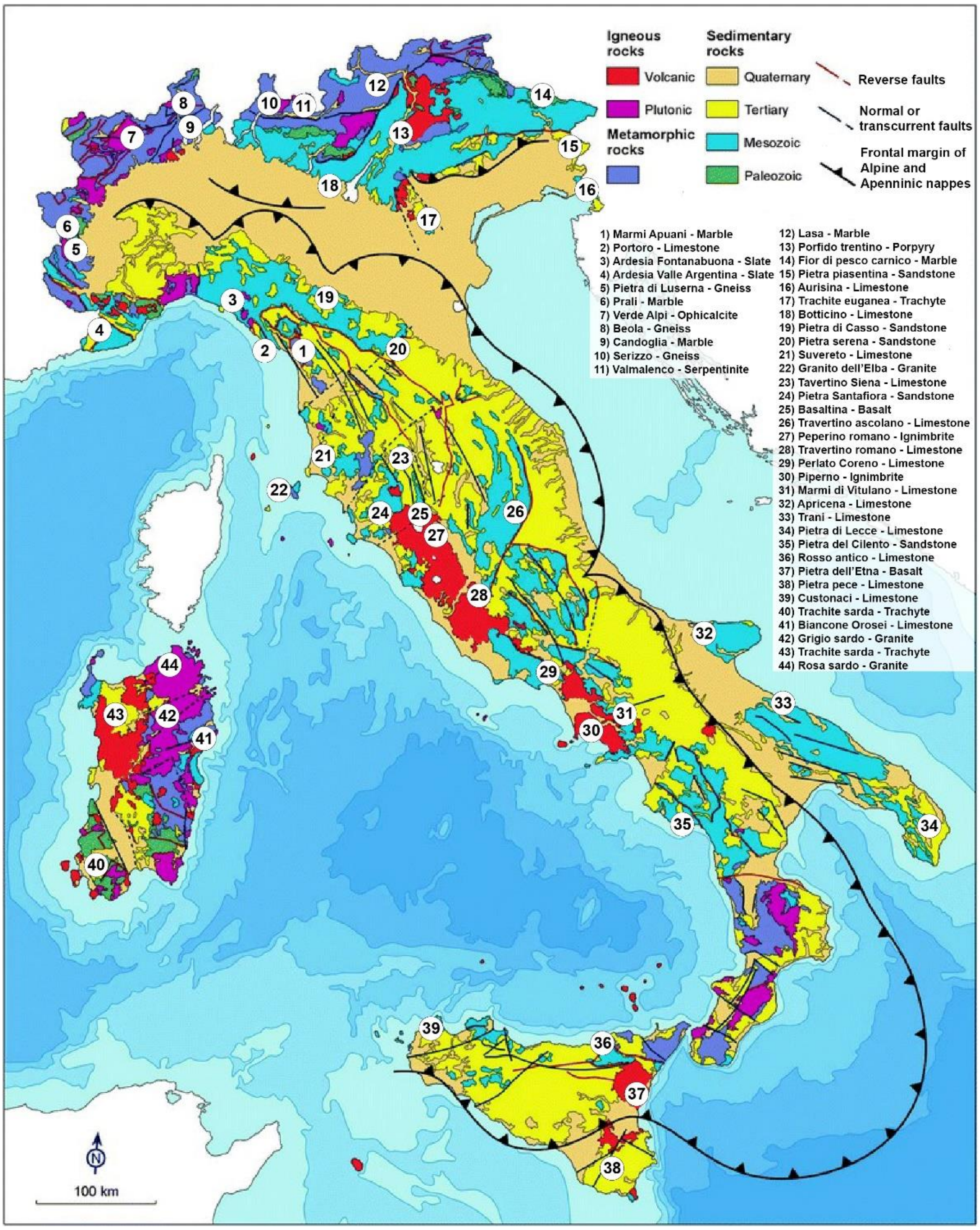
Geology of Italy

The Italian peninsula is an extremely active region from the geodynamic point of view as witnessed by the presence of active volcanoes (Vesuvius, Campi Flegrei, Stromboli, Vulcano, Etna) and by frequent earthquakes, as well as witnessed by land and coasts instability. As a matter of fact, Italy, being situated in the middle of the Mediterranean, is subject to the same geological evolution which characterizes this entire region, controlled by the progressive approaching of two megaplates, Eurasia to the north and Africa to the south.



The geology of Italy and its related tectonic setting are therefore the result of this collision, the most evident expression of which is represented by the two main mountain ranges that make up its backbone: the Alps to the north and the Apennines from the center to the south, along the peninsula.

The present geology of Italy, including the two major islands, Sicily and Sardinia, is remarkably varied and contains rock series from all eras and periods (Fig. 1). The Italian territory can be subdivided into seven specific sectors, i.e. The Alpine chain proper, the Po Plain, the Apennines, the Apulia foreland, the Calabrian-Peloritan arc, Sicily and Sardinia.

Fig. 1 – Simplified Geological Map of Italy (Bosellini, 2017, modif.). Location of the main extractive sites (including the historical ones) of ornamental stones in Italy.

Ornamental stone resources in Italy

From a production point of view, the rocks are divided into: Marbles, Granites and Stones.

The term Marble refers to all rocks of a predominantly carbonate nature suitable of polishing, regardless of their origin; this category therefore groups both real marbles (metamorphosed carbonate rocks) such as the Tuscan ones of the Apuan Alps and limestones such as Chiampo, Botticino, Trani, Perlato di Sicilia and others.
Often the term Marble is also extended to ornamental rocks of a non-carbonate nature such as the Green Stones (Verde Aver, Verde Issorie, Verde Imperiale excavated in Val d'Aosta), perfectly polishable and mainly made up of mineral serpentine derived from the metamorphism of igneous rocks basic and ultra-basic.
The term Granite groups all the igneous rocks both intrusive and hypoabyssal and also the metamorphic rocks as long as silicate in nature and in any case polishable (gneiss such as Beole and Serizzi of the Ossola Valley). We thus pass indiscriminately from real granites such as the Sardinian ones, to syenites (Syenite of Balma or Granite of Biella), diorites, anorthosites (Labradorite) an gabbri, rocks, the latter, with basic chemism.
The Stones represent perhaps the most heterogeneous group characterized by rocks of various origins and mineralogical nature, with poor mechanical resistance, easy to work and therefore generally not polishable. As an example we remember the Ceppo della Lombardia, the Ligurian slate, the Peperino Lazio, the Tuscan Pietra Serena, the Venetian Pietra Piacentina and others.

Ornamental stone production

A fairly modest downward trend in production, trading and consumption has continued to characterise the ltalian stone sector reflecting the overall trend. Nonetheless, the critical situation has not prevented the sector from showing some positive signs which are worthy of note including a slight recovery in the importation of raw materials far domestic processing, and above all the resistance of the leading average price previously assigned to exports of the finished product.
In the final balance of 2019, exports registered a quantitative decrease of 4.5% (aver five times more than the overall world one). This added to the decreases of the previous years. going down to 2.5 million tons as against an historic maximum of 3.6 recorded in far-off 2000. Specifically, the decrease was less significant in raw materials. where it stopped at 33%, while for finished products it increased to 5.8% with a further drop in added value, also confirmed by its impact on the total amounts exported, which went down to 47.5%, but with a major share for raw materials which began to expand its volumes. while its values held relatively fast.
In the short term too there were decreases in ali the product types an d in 2019 there was also a more accentuated decrease in value. Exports abroad of rough blocks and slabs continue to favour calcareous stone, particularly marbles and travertines, which maintained a quantity of 1.2 million tons in absolute figures, while for siliceous stone (more in demand at a world level but not easily available in ltaly) the final balance was for only just over 100,000 tons. For finished products added value was the most requested type, leaving an overall share of about 10 % for simple finished and slate products, which is halved in the overall calculation.
Over a 20-year period the share of exported products has lost 20% wholly in favour of raw materials. Specifically, the exportation of raw materials confirmed China as the main buyer. in terms of both quantity and values, with 51 .2% of the specific turnover, while in the next positions we find India and Egypt.
The average value of rough material exports showed it was holding up fairly well, with 352 dollars per ton, confirming the 350 of the previous year, with over 1500 for sales on the US market. Exportation of the finished product maintains its traditional characteristics as regards ali the main destinations. The United States and Germany are in first and second position, with very different average prices in favour of the former, which maintain a 27.8% share, with a general decrease of 13% as compared to 2016.
The distribution remains fairly differentiated. with three countries (Switzerland. France and United Kingdom) which each purchased ltalian finished products for over 50 million dollars. As for the average price, it may be said that it remains a strong point in ltalian export in the sector, having a value per unit of product of over 75 dollars per square metre equivalent (with the standard thickness of 2 cm). This is a 3% decrease, but it remains decidedly at the top of the world market, which shows moments of particular excellence for the United States but also for Russia, Canada, United Kingdom and France, all over 100 dollars per metre (with the minimum of 41 for China).
Looking finally at importations, after a long series of annual regressions (8 in one decade) they showed a recovery of 4.9%. In absolute figures, this means an increase of over 40 thousand tons recorded in 2019, as compared with a total of 940.000 and a difference regarding siliceous materials, the main component of foreign purchases, which over the long term shows significant decreases above all for those from India, unlike the situation in the rest of the world; while materials from Africa

and Brazil obtained relatively better results. Nonetheless, it should be remembered that while the growth in raw materials stopped at 4.4%, for the finished product it was 6.3%, placing on the home market 237 tons of products which at the aforesaid thickness are the equivalent of approx. 4.4 million square metres. An amount which gives cause for reflection in the current Italian situation (Montani, 2020).

Use of ornamental stone and heritage values

Italy is, as is well known, a country of ancient mining traditions in the sector of cutting stone in the western Mediterranean. These traditions, which date back to the Greek-Roman world, have been maintained and renewed over the centuries thanks to a great cultural flow that through the Middle Ages and the Renaissance has strongly conditioned art and therefore urban architecture. In recent times the stone industry has reached global importance in Italy; such production, about 8.5 million tons per year overall, places the Country at the top placed in the world with particular reference to marble, limestone and travertine, while for the granites other countries hold the record of production. Domestic production is no longer sufficient to supply processing companies that they import materials from all over the world; some marbles, however, internationally famous (i.e. the "Carrara Marble" or the "Roman Travertine"), continue to represent an important voice in the production of Italian stone.

Ornamental stones have been exploited in Italy since ancient times for the construction of numerous buildings and monuments many of which represent the current national heritage. From the Colosseum (i.e. Travertine) to the Florence Cathedral (i.e. Carrara Marble), from the St. Peter Basilica (i.e.Broccatello Marble) to the Milan Cathedral (i.e. Candoglia Marble), passing though countless monuments and buildings in almost every city, town or village of the Peninsula, ornamental stones have characterized places with varoius styles and in different times.

NORWAY


EuroLithos country
atlas: Norway

EuroLithos Atlas
Ornamental stone resources in Norway

Thematic focus: Country

Responsible partner(s): NGU

Author(s): Tom Heldal

Year: 2021

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GEOLOGY OF NORWAY

Norway's bedrock reflects a long history, that extends nearly 3 billion years. In the rocks, we find traces of ancient mountain ranges that had risen and have eroded down to sediments as Earth has undergone changes.

Norway is part of the *Fennoscandian shield* that constitutes the Precambrian bedrock of Scandinavia. The oldest rocks in Norway date back 3 billion years and can be found far north, in Finnmark and along the coast in Troms and Vesterålen. These rocks include various igneous rocks and gneisses. On top of these are several successions of volcanic and sedimentary rocks, including banded iron formations, ranging in age from 2800 – 2000 Ma (**Feil! Fant ikke referansekilden.**).

Moving south and west the Precambrian bedrock becomes gradually younger. In southwest Norway, along the Swedish border, are *Mesoproterozoic magmatic and sedimentary rocks*. Most of the Precambrian terrains in south Norway do, however, belong to a broad range of magmatic, volcanic and sedimentary rocks of the *Sveco-Norwegian* orogeny (1200-950 Ma. These units also carry remains from a continental arc formation around 1500 Ma.

In the far north, in East Finnmark, there are autochtonous sedimentary rocks, showing little impact from the Caledonian orogeny. The range in age from Neoproterozoic to Silurian. In the northern part of the area, they gradually turn into folded successions, influenced by the Timanian orogeny (1000-500 Ma).

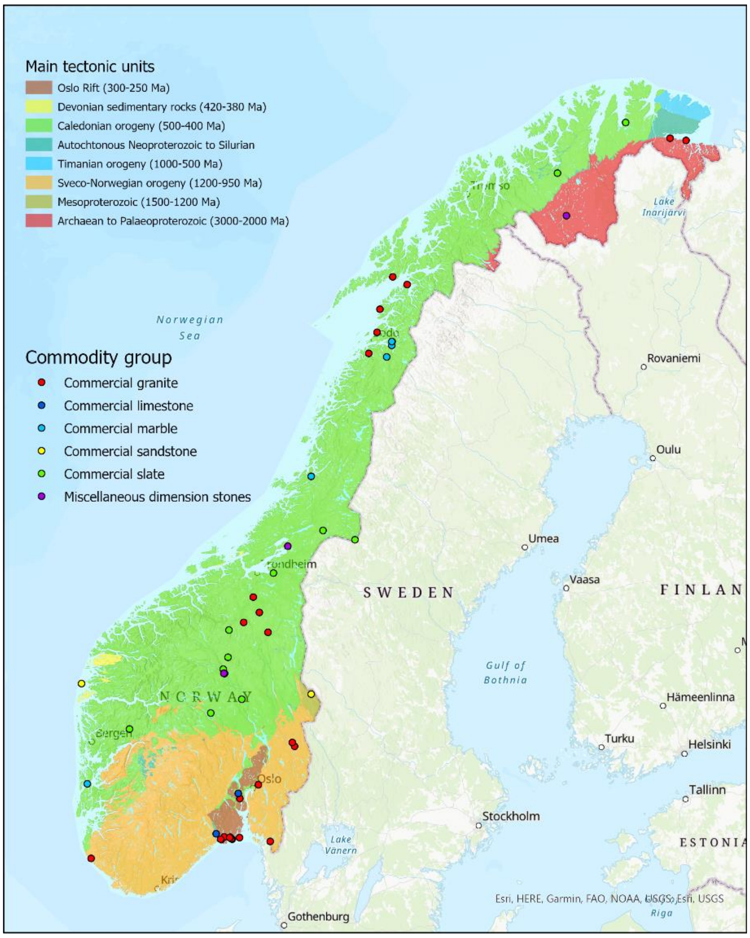


Figure 4. Main tectonic units in Norway and a selection of ornamental stone resources.

Most of the Norwegian mainland is covered by rocks involved in the *Caledonian* orogeny (500-400 Ma), including fragments of older basement rocks. The mountain range, once of Himalayan size, is long gone, but in its ruins a vast diversity of igneous, volcanic and sedimentary rocks are found, most of them metamorphosed under greenschist to amphibolite phasis conditions.

The erosion of the mountain range, that took place immediately after its formation, are represented by thick units of conglomerate and sandstone deposited in the *Devonian* period (420-380 Ma).

The youngest rocks to be found in mainland Norway, are in the *Oslo Rift* (300-250 Ma). This was a continental rift system similar to the Rift Valley in Africa, that for some reason never evolved to form a new ocean. A variety of plutonic and volcanic rocks are the main constituents. The rift was formed in older rocks (Cambro-silurian sedimentary rocks) that belonged to a foreland to the Caledonian orogeny.

ORNAMENTAL STONE RESOURCES IN NORWAY

Ornamental stone resources are present in all the main tectonic units in Norway (**Feil! Fant ikke referansekilden.**). The Archean and Palaeoproterozoic rocks of the far north contain ornamental stone deposits of migmatite gneiss and green quartzites. In the south of Norway, both sandstone and gabbro deposits are included in the Mesoproterozoic successions.

The Sveco-Norwegian orogeny contributed with some of the best quality granite resources in Norway, and in addition anorthosites with blue play of colours. The *Caledonian mountain range* is composed of thrust sheets and fold belts of a diversity of predominantly metamorphic rocks, including schist, slate, marble and soapstone. There are also various plutonic rocks (mostly granite) related to island arc formation, and sandstone and conglomerate deposited during Devonian erosion of the massive mountain range.

The Oslo Rift hosts perhaps the most valuable of the Norwegian ornamental stones, Larvikite. This is a plutonic rock formed beneath the continental rift, known for its blue play of colours. The rift also include syenite and granite, mostly used for domestic purposes.

ORNAMENTAL STONE PRODUCTION

The production value of ornamental stone in Norway has shown a slight increase during the last five years, around 1 billion NOK (100 mill. Euro). The most important activity is the production of larvikite, most of the production exported as raw blocks. Such export also occurs in less quantity from anorthosite and granite resources. The production of schist is different, processing factories are usually situated close to the quarries. Thus, only finished products are sold, much of which for export.

There are two interesting and innovative trends in Norwegian ornamental stone production in recent years. One is the reduction of waste from raw block production. This includes the use of waste for coastal protection blocks, production of drywall-stone and paving stone, production of rock aggregate, and even the employment of sawing dust for agricultural purposes.

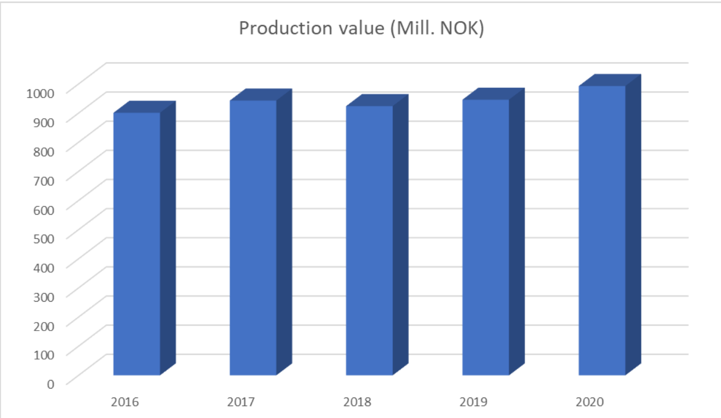


Figure 5. Total production value Norwegian Ornamental stone

The other line of innovation is the development of new products in the schist industry. From being solely focused on extracting only the stone usable for roofing slate, there is now a wide range of products, from sawed and honed slabs from schist blocks not applicable for splitting, to drywall-stone. This has created a much better utilisation of the resources, less waste and more valuable products.

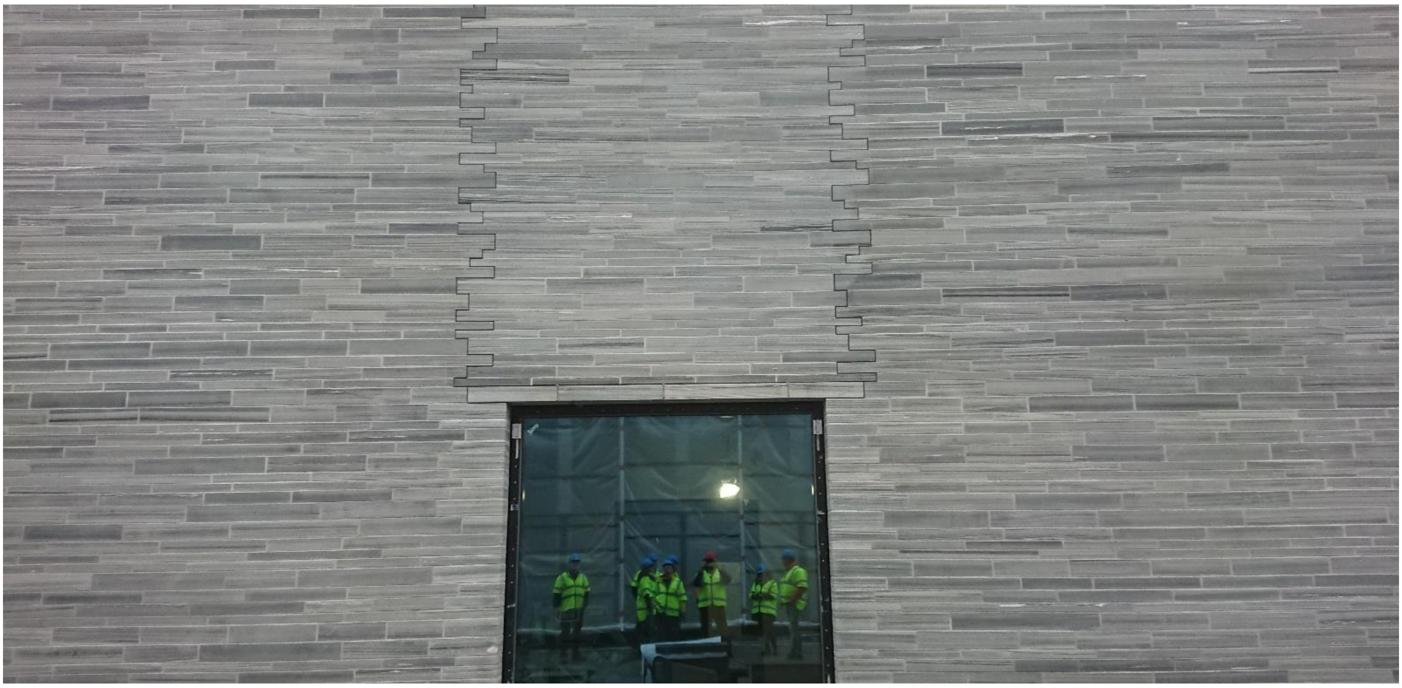


Figure 6. The use of sawn and sandblasted, cross-schistosity cuts of the Oppdal schist in the facade of the new Norwegian National Art Museum (to open in 2022) crossed an innovation barrier.

USE OF ORNAMENTAL STONE AND HERITAGE VALUES

In Norwegian context, the use of ornamental stone became an issue shortly after the Viking period. Christianity brought demands for stone buildings (churches and monasteries), and during the 12th century, many foreign stone masons found their way to Norway for helping the locals finding and using stones for the holy constructions. The Nidaros Cathedral (Figure 4) is the most prominent example from this period, with extensive use of soapstone and marble. However, there are many other buildings, applying the best possible, nearby resource of stone; soapstone, marble, granite, monzonite, greenstone.

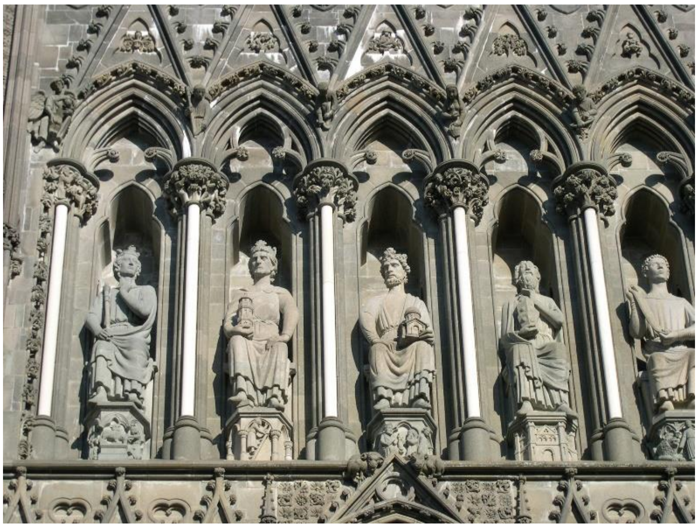


Figure 7. Soapstone and white marble in the Nidaros Cathedral, Trondheim.

After the plague in 1348-50, much of the acquired knowledge of stone construction was lost. After the Reformation in 1537, many of the medieval buildings were nothing but quarries for people in power. The Norwegian stone industries did not recover until the 18th century, when the Danish king wanted “rare and beautiful stones”, and marble production started in southern Norway. Most of the marble were brought to Copenhagen, where we still can find it in royal castles and the infamous Marble Church.

In Norway, not so much marble was used, but rather schist. The Caledonian orogeny transformed sandstone and claystone to schist, readily available most part of the country and easy to exploit and use for building. Most likely was the roof of the King Håkons Hall in Bergen (1261) covered with roofing slate. Over the years to come, schist became used much in traditional architecture, particularly in the rural areas.

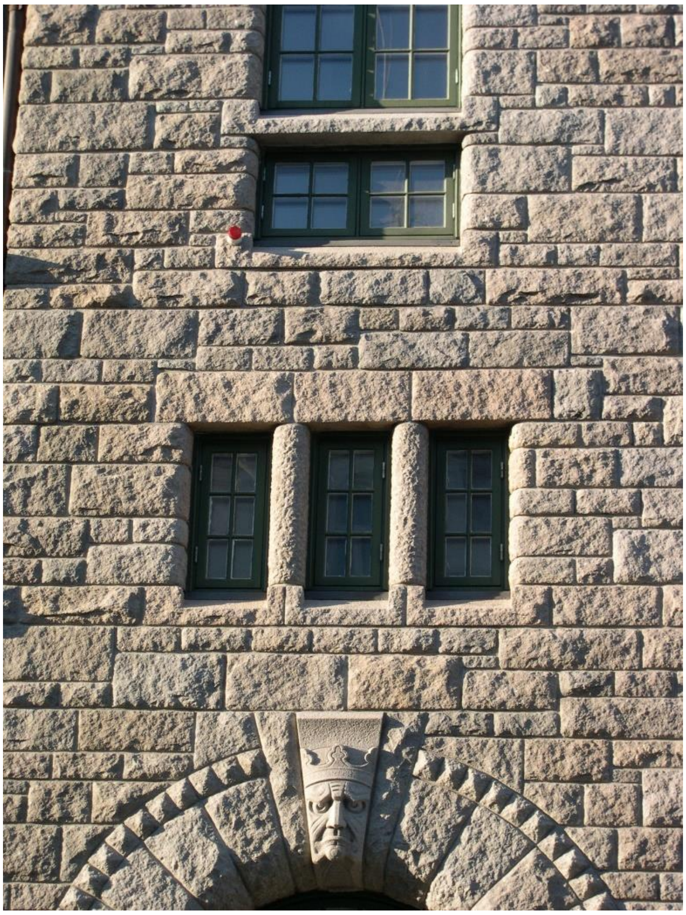


Figure 8. "Scottish Rubble" facade, Iddefjord granite, Trondheim (early 20th century).

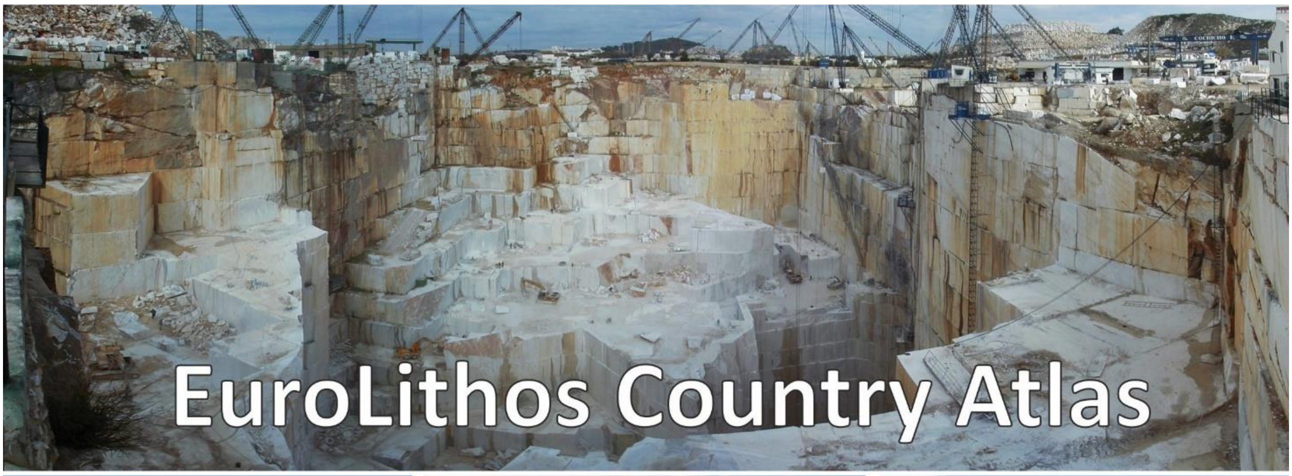
With the industrial revolution came new technology and need for building materials. The modern stone industry in Norway was born between 1820 and 1870, and towards the end of the 19th century, thousands of people were employed in granite, gneiss, schist, marble and soapstone quarries all over the country. Early 20th century public buildings were made of stone, and the streets were covered with paving stone. Much of the production was exported to other countries as far as Argentina.

After WW2, the use of stone was rather limited except for roofing slate and funerary monuments. During the late 20th century things changed, and ornamental stone became again important building material. Recent large building projects have often included innovative ways of using ornamental stone, i.e. the Oslo Opera House and the new National Museum.

The most important heritage of stone in Norway are buildings. In particular, the group of medieval stone buildings (churches, monasteries and some profane buildings) is important, but also a large group of buildings between 1870 and 1930. However, many of the quarries and quarry landscapes left behind from extensive exploitation are important; both as heritage in themselves or as sources for future material for restoration and new constructions.

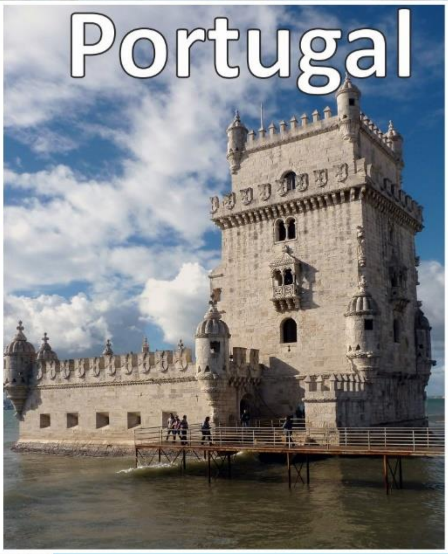
PORTUGAL

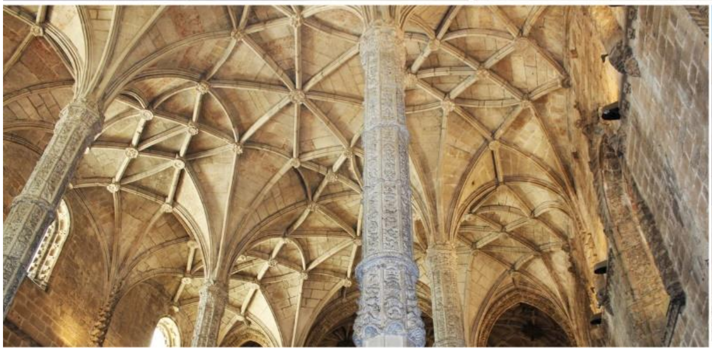
EUROLITHOS European Ornamental Stone Resources



EuroLithos Country Atlas

Portugal





EuroLithos Atlas

Ornamental stone resources in Portugal

Thematic focus: Country

Responsible partner: LNEG

Author(s): Jorge Carvalho, Cristina Carvalho, Vitor Lisboa

Year: 2021

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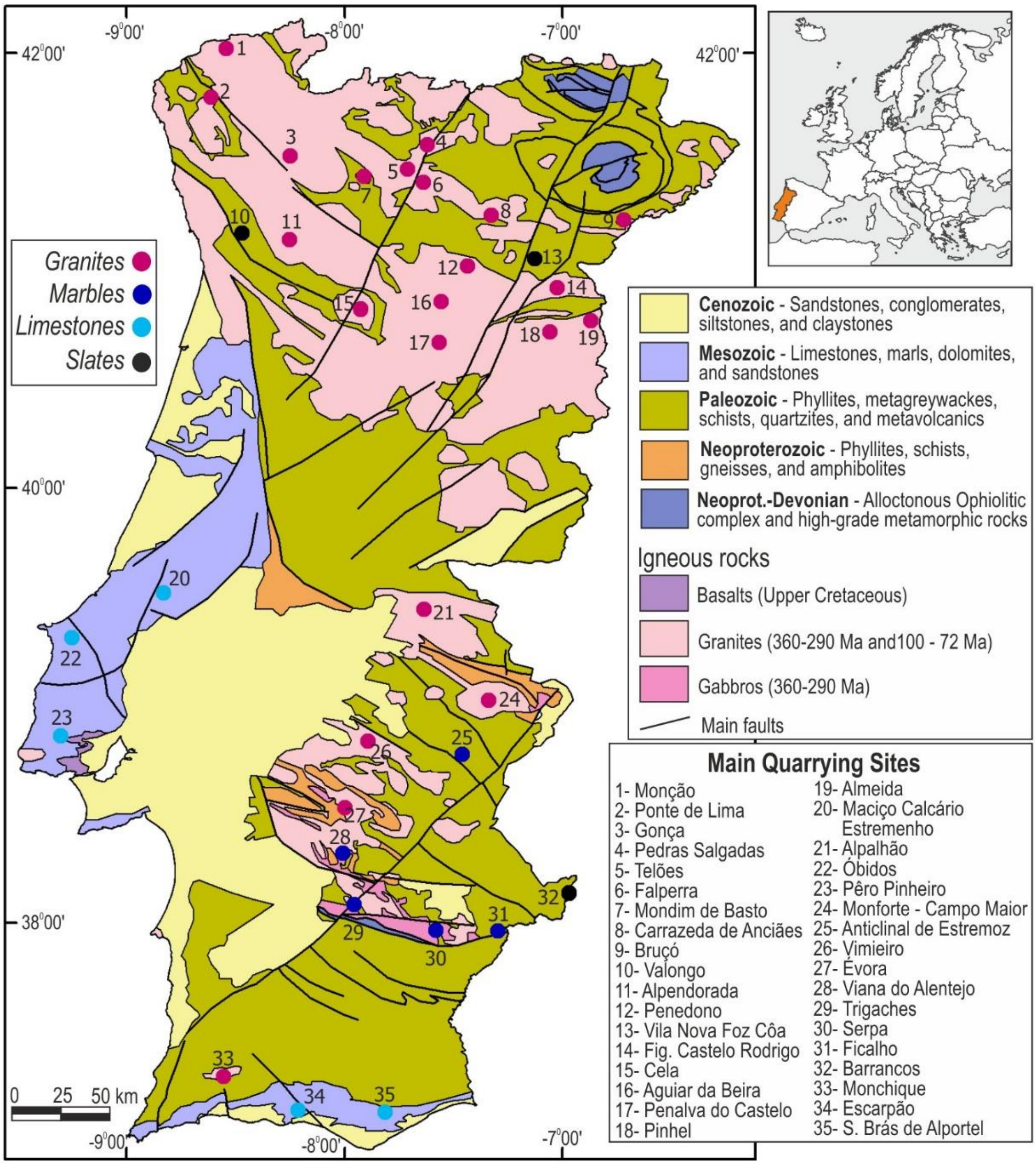
Geology of Portugal

Mainland Portugal is subdivided into the so-called Iberian Massif, the western and southern Meso-Cenozoic borders, and the basins of the Tagus and Sado Rivers. The Iberian Massif integrates Neoproterozoic and Paleozoic metamorphic (flysch-type metasedimentary sequences, quartzites, metavolcanics and marbles) and igneous plutonic rocks. The Meso-Cenozoic borders are mainly composed of clayey siliciclastic sediments, marls and limestones. In the Cenozoic Tagus and Sado basins, sandstones, conglomerates, and argillites predominate, being mostly of Pliocene age.



The Iberian Massif, particularly affected by the Variscan Orogeny, consists of four tectono-stratigraphic units. The Central Iberian Zone corresponds to the central and northern regions where Paleozoic metassediments are extensively intruded by granitic rocks. An ophiolitic complex and high-grade metamorphic rocks integrate the Galicia-Trás os Montes Zone in the north-eastern region. The Ossa Morena Zone, in the central-south region, comprises Neoproterozoic to Paleozoic metassediments, as well as gabbro and granitic intrusions. The southern region of the Iberian Massif makes up the South Portuguese Zone: a low-grade metamorphic sequence of flysch-type sediments with important VMS deposits.

Ornamental stone resources in Portugal

Portugal has a great diversity of ornamental stones distributed by the granite, marble, limestone and slate commercial groups. Quarrying of granite takes place in tardi-tectonic variscan plutons in the northern and central regions of Portugal mainland. Portuguese ornamental granites are fine to coarse grained, having colours ranging from dark grey to pink and yellow, the latter corresponding to weathered granites. The most important quarrying sites are located in the north of Portugal: *Monção* (light-pink granite, coarse grain), *Pedras Salgadas* (light-grey biotitic granite, fine to medium grain), *Falperra* (yellowish granite, fine to medium grain), and *Alpendorada* (grey granite, medium grained). Still, it is worth noting that a few granitic stones are also quarried at the south of Portugal, particularly a variety extracted in the Algarve region that corresponds to a medium to coarse grained syenite having a grey background colour, but with reddish-brown punctuations due to the presence of nepheline.

Most of the Portuguese limestones are quarried at the *Maciço Calcário Estremenho*, a morphostructural unit of the Lusitanian Basin. They are fine to coarse grain limestones (grainstones and rudstones) having light beige colour. Depending on how the blocks are cut to obtain the slabs, these may present a textural pattern marked by sedimentary laminations or not. In the Pero Pinheiro region, near Lisbon, limestones with a high heritage value are exploited. They are reef limestones in which the presence of large fossils of Rudists and the white, yellow or red colour gives them particular aesthetics characteristics.

The variscan *Estremoz* Anticline, eastwards of Lisbon, is the most important mining district of marbles in Portugal. Quarrying takes places in dozens of quarries grouped in five main exploitation centres. Predominantly, these fine to medium grain marbles have a white or pink colour, with shade variations, but dark grey varieties also occur. They have a wide variety of textures, with narrow stripes of darker colours being common. The marbles exploited at *Viana do Alentejo* and *Serpa* are also worth noting due to their greenish colour and coarse grain, and those from *Trigaches*, which have grey colour and very coarse grain.

Concerning slates, there are only a few quarrying sites. The most important ones are located in *Valongo*, where the extraction takes place underground, and *Vila Nova de Foz Côa*.

Ornamental stone production

Quarrying ornamental stones has a long tradition in Portugal and, despite the increased competition, Portugal is one of the most important worldwide producers and exporters. The extraction of ornamental stones occurs all over the country, but the main production centres are located in the northern region, where granites are extracted, and in specific places of the central region of the country, where limestones and marbles are quarried, respectively in the *Maciço Calcário Estremenho* and Estremoz Anticline.

Total production of ornamental stones in Portugal for the year of 2019 reached 3.6 million tons, broken down as follows: granites 2 261 553 t, limestones 1 127 233 t, marbles 165 535 t, and slates 61974 t. About 62% of this total was exported, but unevenly distributed accordin to the type of stone. Only 28% of the total production of granites was exported, meaning that the production was largely absorbed by the domestic market. On the contrary, of the total production of limestones and marbles together, 85% was exported, mainly to China. Provisional data for 2020 production are similar, meaning that COVID-19 pandemic did not affect production. However, exports decreased by 19%.

Use of ornamental stone and heritage values

Ornamental stones have been exploited in Portugal at least since the occupation of the Iberian Peninsula by the Roman Empire, particularly the marbles of the Estremoz Anticline, which can be found in ancient Roman buildings, epigraphs or sculptures in Portugal and abroad. The Roman temple of Évora and the Roman Theatre of Mérida (Spain) are iconic examples of the use of marble from the Estremoz Anticline during this period. Other stones have been used in antiquity, as a Roman quarry in the region to the north of Lisbon testifies. Limestones of the Lioz variety were extracte and used for the construction of buildings in *Olisipo* (the Roman city of Lisbon). These same variety was the main building material used for the reconstruction of Lisbon after the big earthquake of 1755 and it is still used today, not as a structural construction material, but for wall and floor cladding. In the granitic regions of Portugal, there are also testimonies of the use of granite since the Roman Empire, but the main current testimonies date from the period between the 9th and 13th centuries, during which several castles and other types of fortifications were built.

SLOVENIA

EUROLITHOS European Ornamental Stone Resources

EuroLithos Country Atlas
SLOVENIA

EuroLithos Atlas

Ornamental stone resources in Slovenia

Thematic focus: Slovenia

Responsible partner(s): Geological Survey of Slovenia (GeoZS)

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Year: 2021

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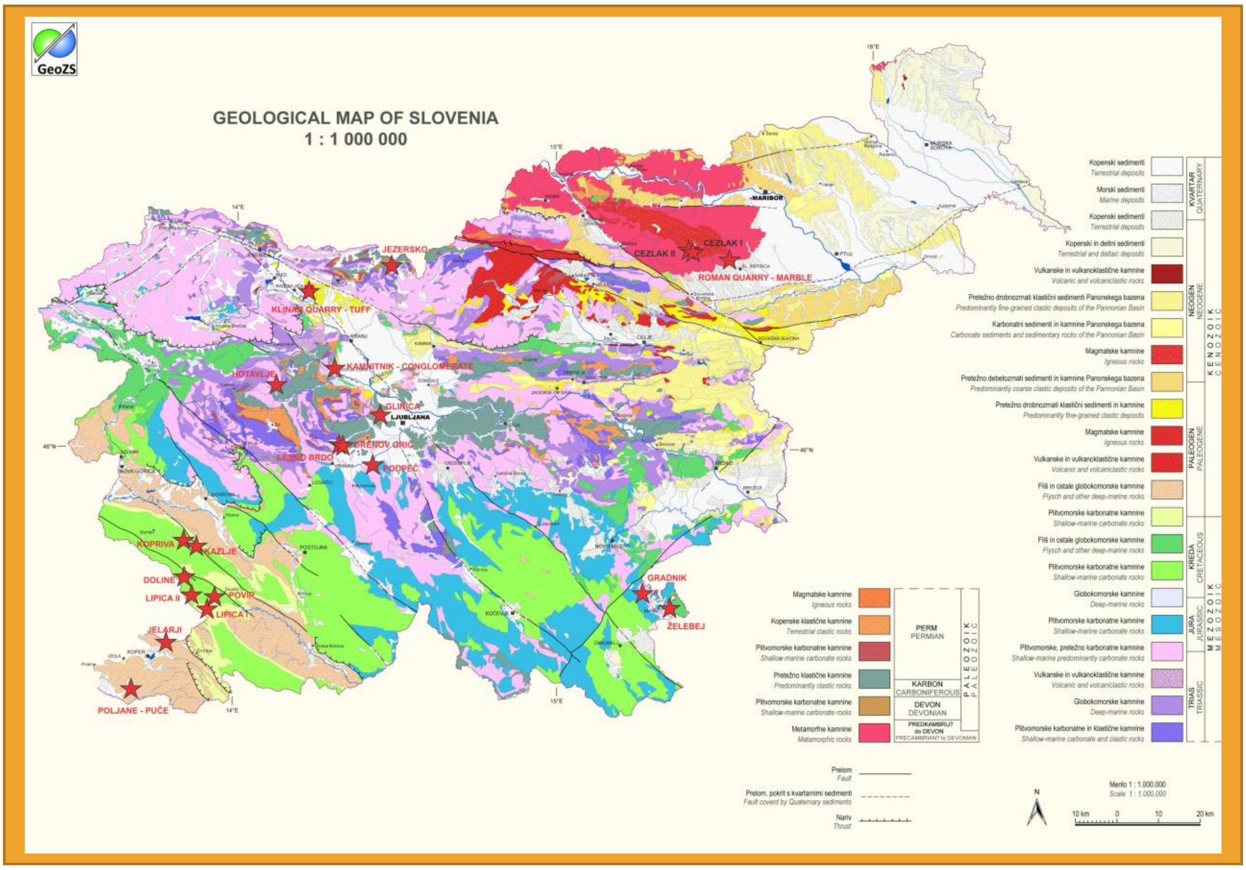
Geology of Slovenia

The territory of Slovenia spans the junction between four major Alpine structural units, each with an independent palaeographic and tectonic history: 1) the Dinarides, 2) the Southern Alps, 3) the Eastern Alps and 4) the Pannonian Basin. The present-day assemblage and geological structure of these structural units was mainly formed during the last 20 Ma, in Neogene. Tectonic processes related to the Alpine collision are still active. Paleographically, the structural units of Slovenia belong to the Adriatic continental microplate (Adria). Prior to the Mesozoic, the Adriatic fragment was attached to the African plate. Tertiary collision of Adria with Eurasia produced the Alpine orogenic chain and was the tectonic driving force that shaped the present-day structure of the Slovenian territory. The complex paleogeography of the Tethys Ocean domain and its margins that formerly existed between the African and Eurasian plate were largely obscured by subsequent subduction and collisional processes.

The lithologic composition of Slovenian territory is heterogeneous due to the complex geological past. Many deposits with variegated kinds of stone can be found in the area. Intensive tectonic activity and movement in the Earth's crust caused many fractures and faults in the rock beds. Consequently, it is very difficult to extract large stone slabs in the quarries. (Vrabec et al., 2009).



Simplified geological map of Slovenia with stars marking the main quarries (active and abandoned) of ornamental stones (Geological map of Slovenia 1:1 000 000, Bavec et al, 2013, https://egeologija.si/geonetwork/srv/slv/catalog.search#/metadata/ce9bd14b-5c46-4b20-8242-08c4b9b3b371)

Ornamental stone resources in Slovenia

In Slovenia, the types of stone are subdivided according to how it is used: ornamental (decorative) natural stone – stone for decoration and art, and building stone – stone used in building. The data on exploitation, production and use of ornamental and building stone are managed jointly under the term "natural stone".

The Karst region is one of the most interesting and promising areas with stone reserves of in Slovenia. Different types of limestones from Karst are used in building industry as well as in art. This region has been associated with the quarrying and manufacturing of stone for over two thousand years. The second interesting region of stone resource is the Pohorje range with granodiorite and various metamorphic rocks. Deposits of gray and variegated carbonaceous rocks and shales are known in central Slovenia. Calcareous tufa and breccia are known in the Karavanke mountains and sandstone is known at the coast. Deposits of different types of limestone can also be found in other regions. Important tuff deposits are located in a part of Gorenjska region and the Savinja valley.

The stone deposits depend on the geological composition of the regions. Characteristics of the regions are determined according to the geographical potential.

Nine territories of stone resources can be found in Slovenia and the following criteria was used for their determination: distribution of interesting and/or promising deposits of stones and potential of once abandoned quarries and deposits, which were reactivated and are still active today. Territories are also defined according to the tradition of stone quarrying.

Regions of stone deposits are:

- the coastal region which includes the Slovenian Adriatic coast and the Slovenian part of Istria,
- the Kras (Karst) area between the Brkini, the Vipava valley and the Italian border,
- Central Slovenia with foothills of the Alps, the margins of the Ljubljana basin, the Poljane valley, The Selce valley and the Idrija area,
- the Pohorje range between the rivers Drava, Mislinja and Dravinja, and the Drava River plain,
- the Karavanke mountains from Podkoren to Črna na Koroškem (Carinthia),
- Bela Krajina between the Kolpa river, the Gorjanci range and Kočevski Rog massif,
- the Tolmin area between the Šentvid plateau, the Julian Alps and the Italian border,
- the Dolenjska and Notranjska (Lower/Inner Carniola) karst from Nanos over the Bloke plateau and Suha Krajina to the Krško basin,
- the southern part of Slovenian Styria and the Posavje hills.

Slovenia is composed mostly of sedimentary rocks. The most common of them is limestone. Furthermore, some igneous and metamorphic rocks are exposed in the northern and central part of the country. All of them can be used as ornamental and building stones. On the other hand, certain soft rocks and the rocks with low adhesion from the north-eastern part of Slovenia cannot be used for this purpose.

Regarding the lithological varieties in Slovenia, the following types of rocks can be used as ornamental and building stones: granodiorite, gabbro, calcareous breccia, calcareous conglomerate, calcareous and quartz sandstone, clay shale, tuff, limestone, dolomitised limestone of various degrees of recrystallization, calcareous tufa, flowstone, mica schist and other types of schistose rocks, gneiss, marble, amphibolite, eclogite, serpentinite (Mirtič et al., 1999).

Ornamental stone production

Of all the above-mentioned promising rocks, only limestone, granodiorite, sandstone, and temporarily gabbro are actually quarried. The quarrying of variegated calcareous breccia, conglomerate, flowstone, marble, tuff, calcareous tufa and clay shales was abandoned during the last thirty years. Serpentinite, amphibolite and eclogite have not yet been quarried to a great extent. Various types of metamorphic rocks were once used in the Pohorje range for roof tiles and especially for wall and floor paving. Nowadays, mica schist is again used for roof tiles (Mirtič et al., 1999).

In the last five years, the production of "natural stone" in Slovenia decreased from more than 136,000 tonnes in 2014 to less than 97,000 tonnes in 2019 (see figure below).

GeoZS Geološki zavod Slovenije

PRODUCTION OF MINERAL COMMODITIES IN SLOVENIA
(in metric tons)

		2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
Bentonite		140	130	130	160	104	135	168	98	143	199	232	182	147	113	99
Calcite		164.752	271.509	273.745	348.152	405.467	459.926	458.800	474.152	555.663	646.542	268.677	255.709	220.771	204.914	221.767
Kaolin																
Chalk																
Quartz sand		254.195	278.041	295.667	289.529	215.065	253.866	230.908	219.481	224.387	207.381	343.455	338.080	359.476	343.683	311.954
Tuff		95.126	88.013	90.319	109.949	58.062	39.401	24.639	23.732	19.171	8.872	9.116	8.840	9.144	8.633	9.133
Industrial dolomite		279.555	294.645	299.177	177.715	146.214	156.179	154.721	119.317	136.516	177.338	172.697	150.545	172.656	129.821	102.619
Chert		19.445	15.445	16.745	21.648	16.695	16.114	18.907	9.960	11.530	15.340	21.041	20.272	15.525	20.436	20.773
Ceramic clay		78.683	86.443	78.221	32.200	9.478	12.279	10.103	5.295	3.479	7.461	7.574		5.478	42.052	6.412
Industrial minerals and rocks		**891.896**	**1.034.226**	**1.054.004**	**979.353**	**851.085**	**937.900**	**898.246**	**852.035**	**950.889**	**1.063.133**	**822.792**	**773.628**	**783.197**	**749.652**	**672.757**
Brick clay		730.670	638.329	706.866	420.360	235.348	296.118	374.020	159.746	180.748	154.944	194.852	202.540	167.898	159.615	180.088
Natural stone	limestone	102.635	52.459	47.983	71.260	73.156	55.045	25.109	21.006	21.158	79.005	99.541	101.991	107.630	91.231	69.155
	tonalite	36.488	56.587	65.715	67.400	39.787	36.855	45.930	23.374	41.016	23.749	26.995	26.746	28.544	41.793	25.078
	other	29.741	24.392	27.124	21.959	21.573	19.724	11.896	11.526	8.332	9.917	9.790	7.690	6.151	3.615	2.660
Natural stone		168.864	133.438	140.822	160.619	134.516	111.624	82.935	55.906	70.506	112.671	136.326	136.427	142.325	136.639	96.893
Raw materials for lime		1.691.696	2.089.495	2.082.593	1.631.391	1.221.197	1.260.446	1.103.163	896.241	860.890	919.528	1.103.283	1.046.293	1.174.038	1.212.883	1.186.037
Raw materials for cement		1.306.889	1.324.803	1.489.625	1.684.258	1.188.493	982.653	883.573	952.758	1.138.560	1.325.907	1.190.807	1.149.065	1.318.832	1.405.518	1.551.728
Materials for construction industry		**3.898.119**	**4.186.065**	**4.419.906**	**3.896.628**	**2.779.554**	**2.650.841**	**2.443.691**	**2.064.651**	**2.250.704**	**2.513.050**	**2.625.268**	**2.534.325**	**2.803.093**	**2.914.655**	**3.014.746**
Crushed stone	limestone	5.926.378	7.242.777	7.134.305	7.541.043	6.284.804	5.773.480	4.034.597	3.264.404	2.813.266	3.060.104	3.486.409	3.164.109	3.824.938	4.757.905	4.557.967
	dolomite	6.197.589	6.712.996	6.909.947	7.291.259	7.175.362	6.143.336	5.440.918	4.223.692	4.127.357	4.901.721	4.427.094	4.280.306	4.808.753	5.516.316	4.984.010
	other	99.215	257.546	235.002	150.258	149.562	155.716	151.276	69.335	127.272	161.762	194.610	26.018	9.190	7.781	8.662
Crushed stone		12.223.182	14.213.319	14.279.254	14.982.560	13.609.728	12.072.532	9.626.791	7.557.431	7.067.895	8.123.587	8.108.113	7.470.433	8.642.881	10.282.002	9.550.639
Sand and gravel		3.750.707	6.871.519	8.549.960	4.506.076	3.001.291	2.422.771	1.899.770	1.707.455	2.143.013	2.799.006	2.943.870	1.833.732	2.047.403	1.810.666	1.437.101
Construction materials – aggregates		**15.973.889**	**21.084.838**	**22.829.214**	**19.488.636**	**16.611.019**	**14.495.303**	**11.526.561**	**9.264.886**	**9.210.908**	**10.922.593**	**11.051.983**	**9.304.165**	**10.690.284**	**12.092.668**	**10.987.740**
TOTAL		**20.763.904**	**26.305.129**	**28.303.124**	**24.364.617**	**20.241.658**	**18.084.044**	**14.868.498**	**12.181.572**	**12.412.501**	**14.498.776**	**14.500.043**	**12.612.118**	**14.276.574**	**15.756.975**	**14.675.243**
brown coal		594.456	587.912	483.417	488.828	510.769	419.466	435.800	314.262							
lignite		3.945.100	3.932.842	4.037.766	4.008.442	3.921.746	4.010.930	4.066.278	3.967.064	3.721.188	3.108.203	3.168.001	3.348.889	3.355.664	3.216.735	3.218.696
coal		4.539.556	4.520.754	4.521.183	4.497.270	4.432.515	4.430.396	4.502.078	4.281.326	3.721.188	3.108.203	3.168.001	3.348.889	3.355.664	3.216.735	3.218.696
oil		303	284	344	174	138	233	263	279	298	366	261	229	241	270	267
gas condensate		196	154	167	104	105	207	131	60	114	95	98	150	240	499	223
gas		4.913	3.751	3.078	2.348	2.317	6.006	2.095	1.454	2.698	2.463	3.109	4.331	7.554	14.423	6.225
oil and gas*		**5.412**	**4.189**	**3.589**	**2.626**	**2.560**	**6.446**	**2.489**	**1.793**	**3.110**	**2.924**	**3.468**	**4.710**	**8.035**	**15.192**	**6.715**
sea salt		803	1.624	3.029	535	2.924	59	4.291	5.684	3.360	0	2.191	2.417	2.335	2.018	1.437

Production of mineral commodities in Slovenia – production of "natural stone" is marked with a red rectangle (Source: Bulletin Mineral Resources in Slovenia, year 2020 (https://www.geo-zs.si/PDF/PeriodicnePublikacije/bilten_ms_eng/Bilten_2020.pdf)

Use of ornamental stone and heritage values

Use of stone in Slovenia has a long tradition. Our ancestors used all stone found in their vicinity. The oldest preserved products made from Slovenian stone are various stone tools from Early and Late Stone Ages. The oldest monuments are the Roman tombstones and inscribed stone which were found in north-eastern and central Slovenia. One such example is the Roman tombstone walled-in on the south part of St. Leonard's church in Spodnje Gameljne. It is reposited at the National Museum in Ljubljana. The Roman tombstone is made from Podutik limestone called "gliničan" which was commonly used during the Roman times. Romans also used it for building the city of Emona about two thousand years ago.

The necropolis made of Pohorje marble is one of the most important stone monuments in Slovenia. It is located in Šempeter in the Savinja valley, and it is a perfect case of stone manufacturing from the Roman age.

The Orpheus monument at Ptuj is also a Roman tombstone made of Pohorje marble, all in one piece. It is 5 m high and the largest known monolithic example in Central Europe.

Later on, stone marks such as contagious signs, crosses and chapels were built from stone as well. The oldest known sign is from the 14th century. The stone marks were used as direction indicators, boundary stones, monuments in cemeteries, etc.

Two periods are especially marked with the use of stone in Slovenia, baroque and mid-20th century. In baroque times, the finest statues, fountains and entrance portals were carved of stone, mostly by Venetian sculptors (Mirtič et al., 1999).

Just this year, in July, the selected works of architect Jože Plečnik were inscribed on the UNESCO World Heritage List. Between World War I and World War II his work carried in Ljubljana present an example of a human centred urban design that successively changed the identity of the city from a provincial city into the symbolic capital of the people of Slovenia. The architect Jože Plečnik contributed to this transformation with a series of public spaces (squares, parks, streets, promenades, bridges) and public institutions (national library, churches, markets, funerary complex) that were sensitively integrated into the pre-existing urban, natural and cultural context. This highly contextual and human-scale urbanistic approach, as well as Plečnik's distinctive architectural idiom, characterised also by the extensive use (and re-use) of stone stand apart from the other predominant modernist principles of his time.

With the discovery of the Portland cement in the beginning of 20th century, cheap concrete products supplement the stone. Today stone is still used for the same purposes as it was used in the past, although the import of stone is considerable, changing the Slovenian cultural landscape. This is especially inconvenient in the regions with a long tradition of use of stone. It is therefore important to preserve the use of the Slovenian autochthonous types of stones and its resources – quarries. Which stone will be used for certain purposes depends mainly on the appearance, manufacturing properties, proximity of the quarry, possibility of purchase, transport and price (Mirtič et al., 1999).