THE FIRST 55 IUGS HERITAGE STONES

International Union of Geological Sciences

GEOHERITAGE IUGS INTERNATIONAL COMMISSION ON GEOHERITAGE

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International Union of Geological Sciences
International Commission on Geoheritage
Subcommission on Heritage Stones

This publication is dedicated to the memory of Barry Cooper (1948-2023) who was instrumental in the establishment of the IUGS Heritage Stones Subcommission and for the promotion of geological and architectural heritage materials, and history.

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Subcommission on Heritage Stones

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[all maps are redrawn based on maps by the authors
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Messages

It is a pleasure to introduce this volume of the First 55 IUGS Heritage Stones. These have been chosen by peer-review and represent only part of the collection of heritage stones that will be recognised by the International Union of Geological Sciences (IUGS) over the coming years. The teams involved in these selections not only study the petrography, geological setting, and the geographic occurrence, but also the architectural and cultural impact of the stone. Indeed, some of the stones are essential in building economic value others have enormous artistic value – of note might be the Carrara Marble used by Renaissance artists. The specimens span six continents and multiple millennia in their use.

This book is one that you pick up from time to time from a convenient table, while sipping a beverage and discover the importance of stones in our civilisation. Some localities will immediately be evident as they may also be important in national heritage, others might be more obtuse as to why they are included, but they will be equally fascinating.

If you are not a geologist, I expect you will be bemused by the names we give to rocks. These are mainly based on the localities from which the type specimens were described and can be quite poetic; the Jaisalmer Golden Limestone or the Turkish Denizli Travertine, migmatites and charnockites and many more!

I thank all of those involved in developing the IUGS Heritage Stones volume.

Please enjoy the read.

Professor John Ludden CBE

President of the International Union of Geological Sciences (IUGS)

Stone carvings and artworks of the Paleolithic are among the earliest expressions of human creativity and ritual. The emergence of sophisticated stone shelters during the Neolithic marked significant technological and cultural advancements, reflecting humans' evolving relationship with their environment and growing architectural skills. The use of stone with favorable characteristics in architecture and art followed the growth and evolution of societies and cultures. These special stones are an essential part of our heritage and show the important role of geological sciences along human history. Many cities and iconic monuments across the world are strongly influenced by a specific stone. Geologists have long appreciated these heritage stones not only for their qualities, but also for their geological meaning. The IUGS Subcommission on Heritage Stones aims to give recognition to those stones that are linked to the evolution of human culture. The first 55 are here presented for the appreciation of those who take interest in the history and nature of human stone use.

Stan Finney
Secretary General
of the International Union
of Geological Sciences (IUGS)

Asier Hilario
Chair of the International Commission
on Geoheritage of the IUGS
Basque Coast UNESCO Global Geopark

About the Heritage Stone Subcommission (HSS)

The International Commission on Geoheritage (ICG) of the International Union of Geological Sciences identifies, recognises, and designates significant geological heritage sites, stones, and collections (https://iugs-geoheritage.org/). The International Commission on Geoheritage (ICG), established in 2016 during the 35th International Geological Congress held in Cape Town, South Africa, has grown significantly and now includes three dedicated subcommissions: the Subcommission on Geosites, the Subcommission on Heritage Stones, and the Subcommission on GeoCollections. These subcommissions operate under revised uniform terms of reference as of 2022.

The initiative "Global Heritage Stone Resource", along with IAEG Commission C-10 on Building Stones and Ornamental Rocks, established the framework for the Heritage Stone Subcommission during the 33rd International Geological Congress in Oslo, Norway in 2008. This project was elevated to an IUGS-Heritage Stone Task Group for a four-year period during the 34th IGC in Brisbane, Australia in 2012. Finally, at the 35th IGC in Cape Town, South Africa, in 2016, the Heritage Stone Subcommission was officially founded as part of the ICG. In the year 2020, the rejuvenated International Commission on Geoheritage consolidated the programme of designation of 'IUGS Heritage Stone' by identifying, recognizing and designating natural stones that have played significant roles in major architectural works worldwide, reflecting cultural heritage. The IUGS Heritage Stone designation aims to promote the geological knowledge, usage, and conservation of these culturally, architecturally, and historically significant natural stones. It also serves as an excellent outreach activity, raising public awareness about geological heritage and encouraging its protection and celebration (https://iugs-geoheritage.org/).

The designation process involves meeting specific criteria, giving the recognized stones a distinct identity and value on an international level. The criteria for recognizing heritage stones include significant cultural relevance based on historical and archaeological use, reflecting its importance in cultural evolution, and use in the past. It also involves consideration of traditional and indigenous beliefs and cultural practices related to the stone. Stone built heritage sites must be iconic monuments synonymous with cultural identity. A description of stone's location and geology is mandatory which includes its geological age, petrographic name, stratigraphic name, comprehensive petrographic and technical description. Documentation of known active and historical quarries, along with information on the ongoing availability of material for quarrying, including historical quarries that are no longer active but preserved also form part of the criteria for the designation of 'IUGS Heritage Stone'.

Documenting Heritage Stones holds significant societal relevance, including the preservation of local traditions and the enhancement of the area's cultural and social heritage. Scientifically, it offers valuable benefits through research and knowledge that can aid restorers and architects in using the same Heritage Stone for building restoration. The most important outcome is increasing awareness and highlighting the importance of geological heritage among the population. This book outlines fifty-five stones from various parts of the world which have been designated as 'IUGS Heritage Stone'.

Gurmeet Kaur

Chair of the ICG Subcommission on Heritage Stones

THE FIRST 55 IUGS HERITAGE STONES

Introduction

JoAnn Cassar
(L-Università ta' Malta)

In this first-of-a-kind book, "The First 55 IUGS Heritage Stones", we celebrate building stones, decorative stones and stones used for statuary, which embody human ingenuity and skill and are testimony to cultures and societies, which have appeared - and disappeared - over time. Stone has the ability to merge the tangible with the intangible and thus bears testimony to rituals, traditions, religion, ceremonies and human resilience, as well as past technologies, manual skills and even interconnectivity across space and time. Recognition that the stone which surrounds us can be extracted, cut, carved and shaped has been here since the dawn of time, with the first such activities directly linked to day-to-day survival: to provide food and shelter. The very first stone tools were used by Homo Erectus and then passed on to Homo Sapiens, perhaps 2 million years ago. Later, in the Palaeolithic, a desire to embellish the immediate surroundings emerged, represented by the extraordinarily life-like first cave drawings in limestone caves (e.g. Lascaux and Altamira). During the Neolithic, more defined and refined stone weapons and implements, figurines, and also simple jewellery emerged, and temples and other buildings started appearing; available clay resources were exploited to make sun-dried brick and, later, fired brick and pottery. Practical use of available geological resources grew.

As greater and lesser civilizations flourished, the use of these materials developed and became practically ubiquitous - reflecting their availability and workability, and the skill and resourcefulness of the people who learned how to manipulate them. Taking a journey around the world, we find that in the prehistoric Mediterranean, the Neolithic peoples of Malta built their complex Megalithic Temples in limestone, and in Sardenia, nuraghi, dolmen and menhir were erected in granite. However, even in these distant times, stones were also being transported over great distances - take Egypt where, together with the use of local limestone, granite was also used, transported over long distances from Aswan to the Giza plateau to be used mostly for facing; and in Great Britain bluestone was transported from Wales for use in Stonehenge, together with the local stone. Other examples from around the world include the monolithic churches of Lalibela, Ethiopia, carved out of the surrounding volcanic scoria (ignimbrite), and the Longmen Grottoes, in China, with their impressive limestone statues, representing the high point of Chinese stone carving. Fast-forward to the Greco-Roman world, expressions of power and might are embedded in stone temples and statuary, created in white (but often painted) Parian Marble (Greece) whilst also finding the Romans extracting and transporting coloured marbles all around the Mediterranean and beyond.

Early use of stone in the Americas found the Olmecs, Mayans, the Incas and Aztec Empires constructing superb buildings, including pyramids, in the local stones (limestone, sandstone, granite, volcanic tuff). Who has not heard of, and possibly also visited, Machu Picchu in Peru (granite) and Teotihuacan in Mexico (using the local Tezontle)? But even in this region, "poorer" materials were also used when readily available, one example being the magnificent Chan Chan (Peru) built of earthen materials.

Reflecting the abundant, readily available and easy to use earthen materials, there was widespread and resourceful use of sun-dried and later also fired brick in Asia. Cultures which used such materials included the Harappan culture in the Indus Valley (e.g. Mohenjo-daro, in modern day Pakistan), and the Sumerian and Babylonian Kingdoms in Mesopotamia. Here too, over time, great and elaborate use of stone developed - take Angor Wat in Cambodia (laterite and sandstone), Borobudur in Java (andesite and basalt), and Kailasanathar Temple in India (sandstone and granite).

These are the stones this book celebrates: magmatic (granites, basalts, tuffs, and other), metamorphic (marble, gneiss, slate, charnockite), and sedimentary (limestones, sandstones, breccias, laterite).

This richly illustrated and informative book thus explores, over time and geographies, the art and architecture carved out of stone, and is a tribute to the creativity of the human mind, the awe-inspiring manual skills and an eternal wish to not only grace the present, but also the future, in the perennial "durable" material which we are celebrating: Heritage Stone. From the quarrying of available materials - be they limestone, marble, granite, gneiss or slate - selected for aesthetic considerations and/or intrinsic properties, to the transport, cutting, carving and finishing of these timeless materials, we today can only marvel at how the great stone monuments of the world were created, and the materials used. Thus, we find that it is information on the stones themselves that allows us to have a complete understanding of these artistic and architectural marvels. This information is however usually not readily available, and it is this great lacuna that this book seeks to address.

We have thus prepared a book - an opus - which presents to the reader a close interaction between the original location of the stone (geological setting, quarries), what the stone is (petrography, mineralogy) and the diverse uses of the material over the millennia (heritage issues, social and cultural impact). The examples come from Asia, Africa, Europe, the Americas and Australia. From Europe we have examples in the porous and easily carved Globigerina Limestone of Malta, a stone used for UNESCO recognised sites such as the capital city of Valletta; the iconic green Connemara Marble from Ireland, used expertly in buildings such as the Museum Building of Trinity College in Dublin; Lede Stone from Belgium, a sandy limestone used in several UNESCO listed buildings in Belgium and France; Villamayor Stone, used on the façades of splendid monuments of Salamanca (a World Heritage City); Bath Stone, used in the graceful Georgian Buildings of Bath (also listed by UNESCO) and the iconic Portland Stone used in St Paul's Cathedral in London; the black Podpeč Limestone from Slovenia, used in internationally important Slovenian buildings: Parliament, City Hall, National Library and University Library; and Virolahti Pyterlite from Finland, used extensively for the construction of the city of St Petersburg in Russia. From the Americas, a stone of great local importance is the sandstone Piedra Mar Del Plata from Argentina, which produced a unique architectural style symbolic of the middle class; and Tennessee "Marble", a limestone from North America that has been quarried continuously since colonial times and has great importance in the United States and Canada. Canada itself showcases Tyndall Stone, a dolomitic limestone from Manitoba, used in numerous important buildings in Canada, the USA and even Germany; while Tezoantla White Tuff of Mexico was the stone of choice for notable Baroque and Neoclassical monuments in the historic centre of Mexico City. Brazil showcases Facoidal Gneiss as the most representative natural stone of the city of Rio de Janeiro; India boasts Jaisalmer Limestone, used to build the Jaisalmer Fort (a UNESCO World Heritage Site) and one of Rajasthan's most magnificent forts, and also employed for intricate carvings and monuments; Makrana Marble is the stone of the Taj Mahal. Australia celebrates Malmsbury Bluestone, a basalt which was used widely throughout Oceania.

Other stones presented here have had a wider reach and influence. Carrara Marble from Italy was used by Renaissance artists to carve sculptures which still grace the cities of Rome and Florence and has been exported all over the world. Afyon Marble from Türkiye has also spread since Roman times to shores as distant as South Spain and South England. Solnhofen Limestone from Germany is not only known as a building stone but also the world's most famous lithographic stone. Welsh Slate has been used since Roman times and has been exported all around the world. We illustrate also other slates: Valentia Slate (Ireland), German Roofing Slate and Himachal Slate (India). From Norway, Larvikite is one of the world's most popular ornamental stones, a symbol of fashion and wealth used on prestigious façades in London and Paris.

Many other stones appear in this informative compendium of IUGS Heritage Stones. From Europe we present Belgian Black Marble and Petit Granit (Belgian Bluestone), French Échaillon Stone, German Rochlitz Porphyry Tuff and Jura Limestone, Italian Pietra Serena, Rosa Beta Granite and Sardinian Basalt, Norwegian Iddefjord Granite, Portuguese Lioz and Ançã Limestones, Portland Stone (UK), Radkow Sandstone (Poland), Brecha da Arrábida, Estremoz Marble and Porto Granite (Portugal), Spanish Alpedrete Granite, Bernardos Phyllite, Lugo Green Phyllite, Red Ereño Limestone and White Macael Marble, Swedish Hallandia Gneiss and Kolmården Serpentine Marble. From a country straddling both Europe and Asia, we have Denizil Travertine (Türkiye). From Mexico we present Tezontle Scoria, Asia is graced with Indian Alwar Quartzite, Deccan Basalt, Charnockite and Western Ghats Laterite, as well as Tsukuba Massif Granite from Japan. Africa makes an appearance with the Lalibela Basaltic Scoria (Ethiopia) and the United States presents us with Jacobsville Sandstone.

Having admired this carousel of beautiful and meaningful Heritage Stones, we will arrive at the end of our journey. We have greatly enjoyed preparing this richly illustrated overview of a representative sample of our Heritage Stones, spanning four continents and many millennia, highlighting their sources, composition and properties, iconic buildings, statuary and decorations, created locally and elsewhere. It is hoped that this book will give the reader equal pleasure.

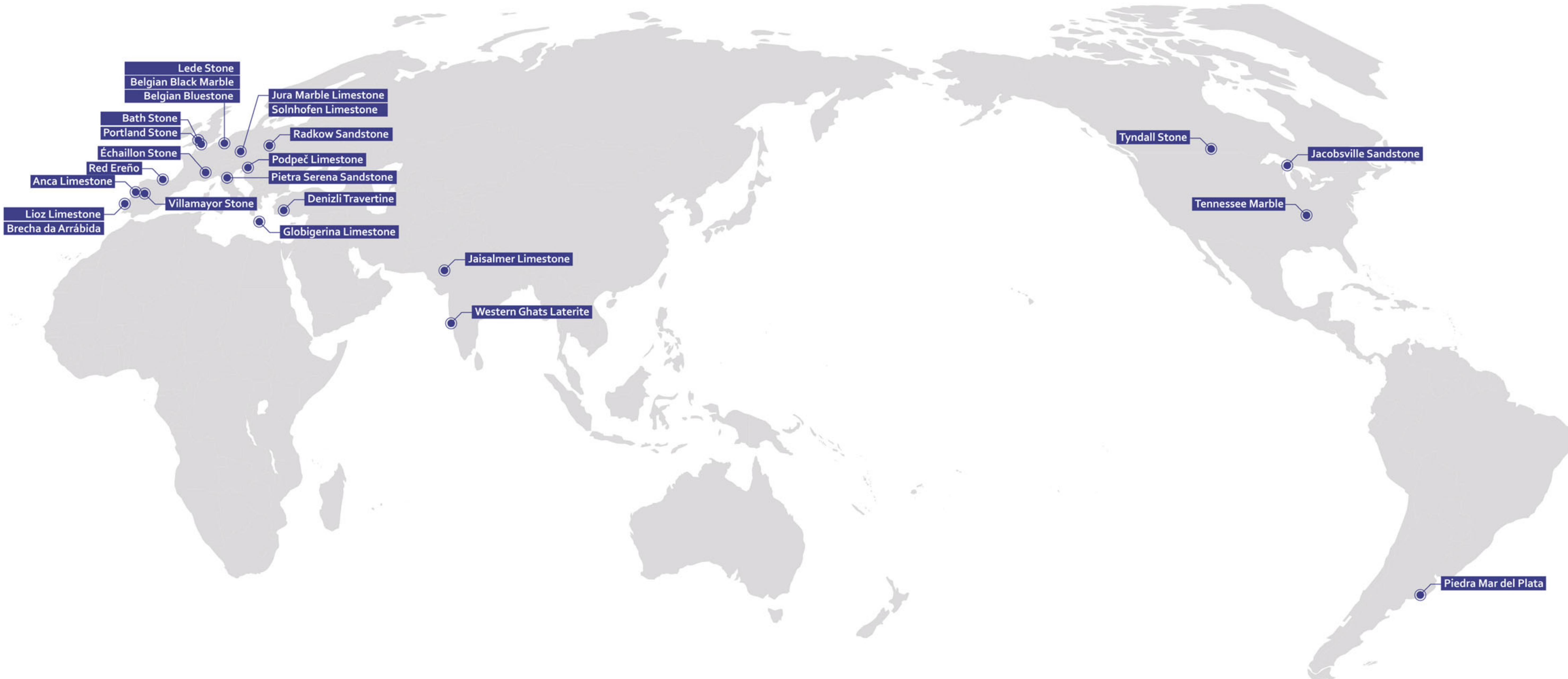
We all look forward to the next Heritage Stones to be nominated and designated.

The Rock Cycle and the three rock types

The **Rock Cycle** refers to a dynamic scheme whereby the three major types of rocks, igneous, sedimentary and metamorphic, are all linked. Taking a cross section through the Earth's crust, the igneous rocks are formed at depth or are extruded at the surface from volcanoes. All the surface rocks are subjected to mechanical and chemical breakdown, and their products are transported by water or wind and deposited, often in layers, and later lithified into sedimentary rocks. As burial depth of these rocks increases, so too do pressure and temperature and they may can be converted into metamorphic rocks at depth. Increased heating can ultimately result in the melting of rocks and the formation of magmas that become igneous rocks, and the rock cycle continues.

Sedimentary rocks are those formed from fragments of eroded rocks, precipitates of minerals, or of shelly and skeletal materials. They are deposited in a wide range of environments, the most common being marine, and generally form horizontal beds or layers. The clastic sedimentary rocks include conglomerates, sandstones and siltstones and are classified according to the diameter of the grains. These are cemented together with a variety of minerals including quartz, calcite or iron oxides. Chemical sediments include limestone produced by the precipitation of calcium carbonate while biogenic limestones are largely formed of the remains of fossil shells.

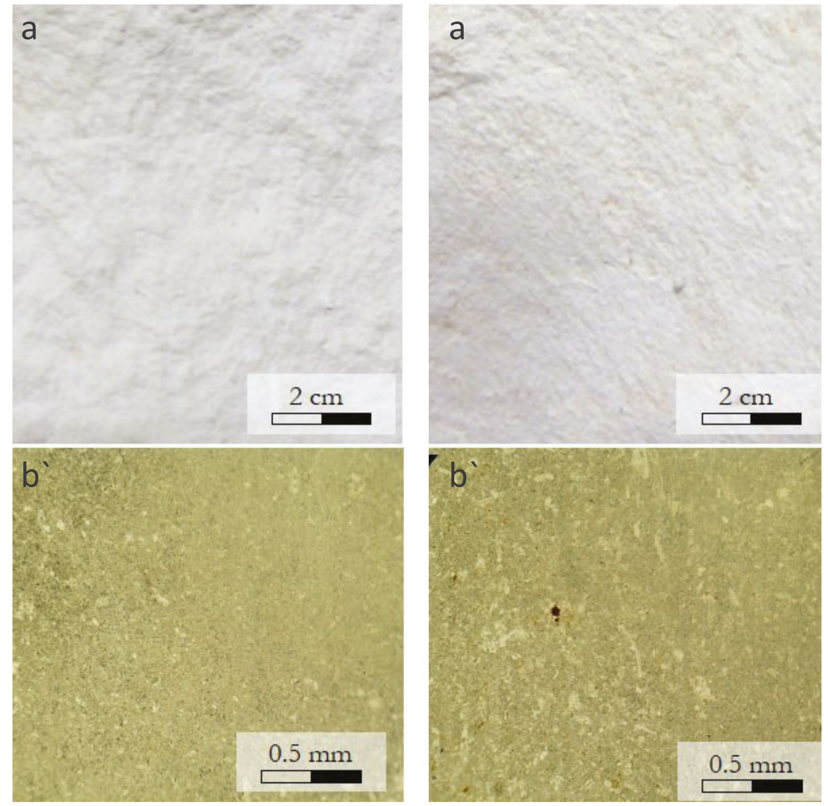
Sedimentary rocks



ANÇÃ LIMESTONE

Portugal

Entrance sign to Ançã village



Macroscopic appearance above, photomicrograph below.
a: Pedra de Ançã from d'El Rei historical quarry.
b: Limestone from the Ançã Formation currently exploited.

Petrography
Micritic Limestone

Geological setting
Mesozoic – Middle Jurassic – Bajocian and Bathonian; Lusitanian Basin

Occurrence
Cantanhede municipality, Coimbra, Portugal

The stone that carved Portugal

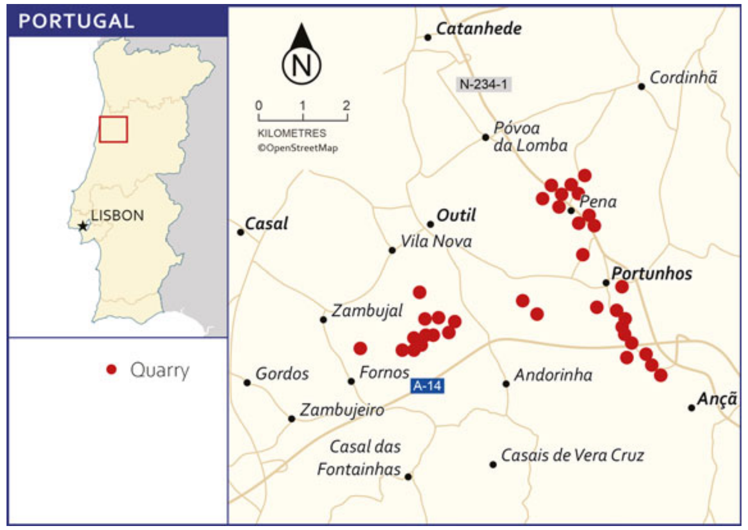
D.M. Freire-Lista
F. Figueiredo
M. H. Henriques

Ançã limestone is one of the most used building stones in Portuguese heritage. It has traditionally been used to make mill wheels, oil presses, and chests to preserve food. In addition, it was used in monuments like monasteries, churches, palaces, altarpieces, tombs, and sculptures, especially from the 13th century onwards. This building stone has expanded to Portuguese colonies such as Angola, Mozambique, S. Tomé and Príncipe, Guinea-Bissau, Cape Verde, and East Timor.
Pedra de Ançã is the local name given to a level of the Ançã Formation, traditionally used in sculptures. It was distinguished as a Portuguese brand and an icon of national reference in 2021. Several Geotourism routes show historical quarries and ethnographic material related to traditional stone extraction in Cantanhede municipality, where this Heritage Stone outcrops.

Petrography

Ançã limestone is notably white, homogeneous, and fine-grained. Pedra de Ançã from d'El Rei historical quarry is described in the literature as a micritic limestone of very low hardness and highly porous. It has an extremely low content of clay and dolomite and a few quartz grains.
Microscopically, the matrix fraction is made up of micritic calcite in a quantity much higher than the sparitic one, the detrital fraction presents with around 1% (made up of detrital quartz and grains of pyrite and iron oxides) with organic matter, and the allochemical components are composed of oolites and fossil fragments partially recrystallized with mosaics of spathic calcite.

Location and geology



The middle Jurassic Ançã Formation was deposited at the Lusitanian Basin (Central west of Portugal) between the Bajocian (170.9-168.2 M.y.) and the Bathonian (168.2-165.3 M.y.).
This formation is approximately 250 m thick and comprises fine-grained limestone beds with different properties, either in terms of fossil content, clay amount, colour, or petrophysical properties.

Quarries

The historical quarries of Ançã limestone can be grouped into five zones:

- Ançã and Portunhos (alongside EN.234-1 road).
- Portunhos, Pena and Cordinhã (alongside EN.234-1 road).
- Portunhos and Andorinha (close to EN.584 road, at W of Portunhos).
- Andorinha and Vila Nova (North side of EN.584 road).
- Fornos and Zambujeiro.

The current quarries of Ançã limestone are in Portunhos.

Architectural and cultural impact

Ançã limestone was exported from Cantanhede region by land and sea. It was transported in oxcarts to Quinta do Rol, close to the town of Gândara, then loaded onto barges that went down the Ançã ditch to the Mondego River, followed to Figueira da Foz, to be loaded on boats to different locations and countries. The easiness of Ançã limestone carving allowed the production of masterpieces that played a determinant role in the Manueline, Renaissance, Baroque, and Neoclassical styles. Consequently, Ançã limestone can be found in many emblematic monuments and buildings in Portugal, including constructions classified as UNESCO World Heritage.
Coimbra has a lot of monuments built in Ançã limestone such as the Monastery of Santa Clara, pantheons of the Conchada Cemetery, churches, palaces, and the two Coimbra cathedrals. The University of Coimbra (UNESCO World Heritage Site since 2013) was built with this stone. One of the most beautiful palaces in Europe, which stands out for the very fine workmanship of its sculptural details, is the Bussaco Palace, built with Ançã limestone between 1888 and 1907. Batalha Monastery is an example of Portuguese late Gothic architecture, or Manueline style, with its profusion of enormous pediments, spieres, pinnacles, and buttresses of Ançã limestone. It was declared a World Heritage Site by UNESCO in 1983.
King Pedro III converted the Palace of Queluz (Lisbon) into an authentic royal palace during the 18th century using Ançã limestone. In addition to these monuments, numerous sacred art sculptures were worked on and consequently distributed throughout the country, and today there is a vast heritage that can be seen in urban and rural churches. The Museu da Pedra in Cantanhede comprises permanent exhibition rooms devoted to Ançã limestone, Machado de Castro Museum, in Coimbra, has a rich collection of sculptures made with this stone, as well as the National Museum of Ancient Art, in Lisbon, among many others.
Additionally, as mentioned above, Ançã limestone has been used to decorate churches outside mainland Portugal. It has been used in the Azores Islands and Brazil. Also, sanctuaries in Santiago de Compostela, Rome, and Jerusalem have sculptures carved with Ançã limestone.

Bussaco Palace, Luso, Portugal.

Machado de Castro Museum, Coimbra, Portugal.

Main references

Catarino, L. et al., 2019. The use of dolostone in historical buildings of Coimbra (Central Portugal), Sustainability 11.

Freire-Lista, D.M., Catarino, L., Figueiredo, F.; Henriques M.H.P. 2023. The limestone of Pedra de Ançã: a heritage stone from Portugal. EGU23-3284, https://doi.org/10.5194/egusphere-egu23-3284.

Henriques, M.H., Pena dos Reis, R., Pêgo, M.C. 2004. Public understanding of a facies: the "Ançã limestone" (Bajocian, Lusitanian Basin) (abs): 23rd IAS Meeting of Sedimentology, Coimbra, 2004, Abstract Book, p. 141.

BATH STONE

UNITED KINGDOM

Royal Crescent, Bath, built 1767-74 in classic Georgian style from Bath Oolite

English oolitic limestone used continuously since Roman times

Andy King

Oolitic limestones from the Chalfield Oolite Formation of southwest England have been worked as building stones for almost 2000 years for vernacular dwellings and agricultural buildings, palaces, churches, cathedrals, industrial buildings, bridges and aqueducts. Many of these buildings and structures have been conferred conservation designations.

The extensive use of Bath Stone in Bath has given the city an aesthetic and architectural integrity that enabled its designation as a World Heritage Site in 1987. In 2021 Bath received further UNESCO World Heritage recognition, becoming one of 11 spa towns identified as the 'Great Spas of Europe'. It is a major tourist destination.

Bath Stone (10cm width)

Petrography

Limestone; current-bedded and shelly oosparites

Geological setting

Mesozoic- Middle Jurassic (Upper Bathonian); Chalfield Oolite Formation

Occurrence

South-west England, United Kingdom

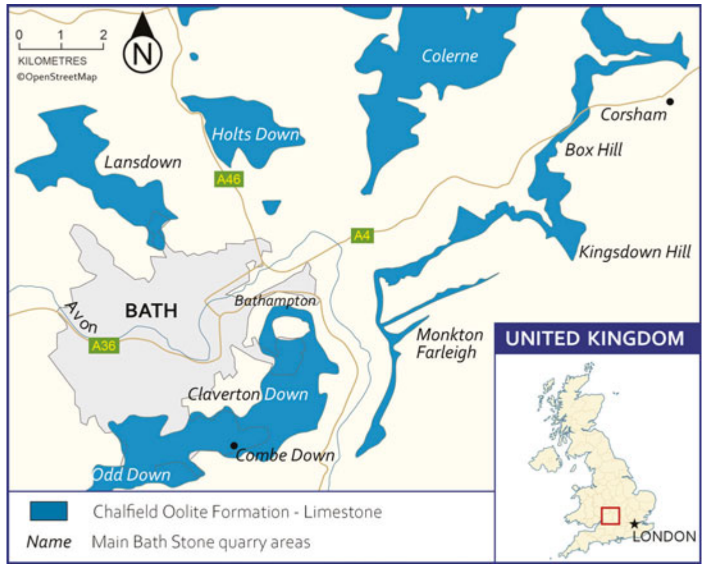
Petrography

Bath Stone comprises pale grey to buff or cream coloured, current-bedded ooidal grainstones with sparite cement and varied bioclastic content. There are three facies: Combe Down Oolite Member; Twinhoe Member; and Bath Oolite Member. The main freestone beds used for building are in the Combe Down and Bath Oolite members.

Combe Down Stone is the most resistant variety, it often contains fine calcite-cemented stringers; Twinhoe Stone is more yellow-buff coloured, sometimes becoming ferruginous and pisoidal.

Bath Oolite is a very pure, uniform, cream-coloured oosparite which lacks scattered shelly bioclasts and calcitic stringers. It is softer than other Bath Stone types and when newly dug it is easily cut and is ideal for carving or moulding. It rapidly hardens on exposure to air.

Location and geology



Bath Stone occurs within the Chalfield Oolite Formation of the Great Oolite Group. It accumulated in a shallow marine, high energy environment which was subjected to tidal currents; erosion surfaces and current-bedded units are common within the oolitic limestone sequences.

It is one of the main Bathonian aged (165-158 Ma) oolitic bioclastic limestone formations that occur in the Middle Jurassic 'stone belt' which extends from southwest to central England; this belt has yielded several high quality and extensively used building stones along its length.

The Chalfield Oolite Formation mainly occurs in an area between the City of Bath and town of Corsham. The formation is typically 25-30 metres thick and has an irregular surface outcrop pattern which rarely exceeds a few kilometres in width.

Quarries

Bath Stone has been worked since Roman times and during the Medieval period it was mostly won from surface quarries.

Rising demand in the C18 led to the development of extensive underground stone mines; by 1900 in the Corsham area, there was a 95 km long network of tunnels and tramways.

The Kennet & Avon canal (1794-1810) and Great Western Railway (1836-1841) facilitated transport of the stone and by 1864 Tunnel Quarry (Box) was producing 100K tonnes of Bath Stone annually. However, subsurface mining was constrained by the need for a sound roof bed above the mined freestone horizons, levels of overburden, potential subsidence, fault zones, landslide and camber areas and aquifer groundwater ingress.

Historically nearly 50 quarries worked Bath Stone, but today around five are active.

Hartham Park Bath Stone Quarry (part of Lovell Stone Group), Corsham

Architectural and cultural impact

The Chalfield Oolite Formation includes some of the most important building stones in England. Within the formation the Bath Stones and Combe Down ooidal freestones are world famous and have been employed for many important buildings and structures nationally and internationally.

These freestones have been employed extensively in Bath and its surroundings where they were first used by the Romans for the construction of the Aquae Sulis hot baths. They have been used from medieval times to the present day.

Redevelopment of Bath in the early C18 coincided with growing interest in Roman and Greek culture and antiquities and attracted important British architects.

The attractive appearance of the World Heritage City of Bath owes much to the consistent use of Bath Stone, especially during the C18-C19 when many of the magnificent, classic Palladian and Georgian-style terraces and crescents were built.

The stone is often employed as ashlar but is soft enough to be intricately carved. Many C19 church and chapel restorations in England and Wales employed Bath Stone, especially as window and door dressings or for decorative purposes.

Notable examples of its use worldwide include Canada: Toronto School of Theology (C20); Ireland: Medieval Museum, Waterford (2013); South Africa: Town Hall, Cape Town (1905); UK: All Saints House, Bristol (1903), Apsley House, London (1828), Avoncliff Aqueduct (1797-1801), Bath Abbey, Bath (C12, C16), Buckingham Palace, London (C19, C20), Dundas Aquaduct (1795), Gatcombe Park (1771-1774), Guildhall, Bristol (1843), Lacock Abbey (C13), Longleat House (1568-1580), Monkton Farleigh Priory (C12, C13), Naval College, Dartmouth (1905), Old Vic Theatre, Bristol (1766), Pultney Bridge, Bath (1770), Queen Square, Bath (C18), Roman Thermal Baths, Bath (C1-4), Royal Crescent, Bath (1767-1774), Royal Pavilion, Brighton (1820), Temple Meads Railway Station, Bristol (1839-1841); USA: Union Station, Washington DC (1903-1907).

Bath Abbey, built in Perpendicular style mainly in the C16 from Combe Down Oolite

Main references

Marker, B.R. 2014. Bath Stone and Purbeck Stone: A comparison in terms of criteria for Global Heritage Stone Resource Designation. Episodes 38(2), 118-123.;

Hunt, B.J. 2015. Bath Stone – a construction stone to challenge the rules. Natural Stone Specialist 50(1), 30-33.

BELGIAN BLACK MARBLES

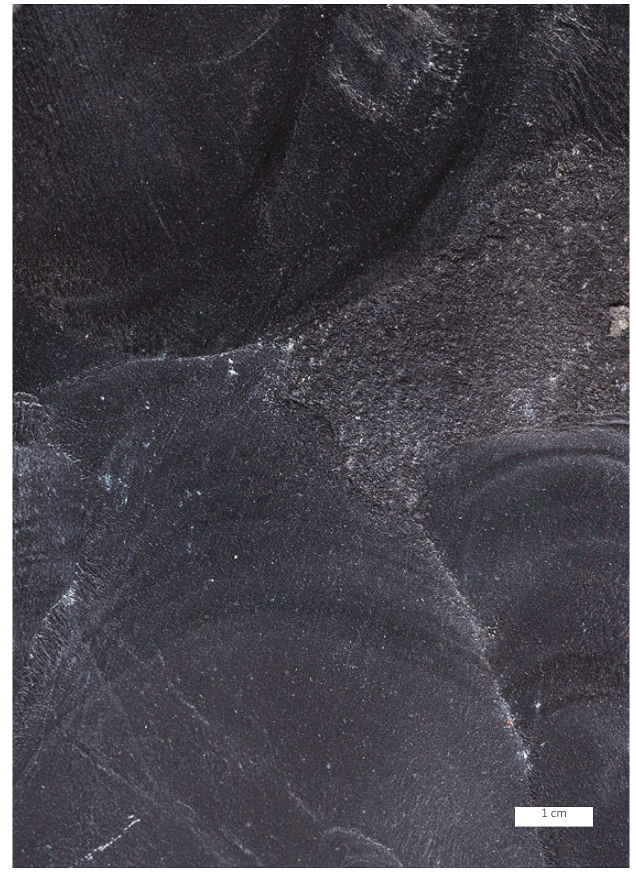
Belgium

Cologne, Dom, black marble tomb

The darkest of all dark limestones

Francis Tourneur

The Belgian black marbles are very compact and fine grained limestones, taking a rare intense and uniform black colour when honed and polished. Appreciated for ever as very dark materials, the Belgian black marbles were widely exported since the Middle Age, first throughout Europe, then worldwide starting from the end of the 19th century.
They were used for funeral purposes (tombs, mausolea, etc.), in architecture and decoration (columns, floors, staircases…), alone or in contrast with pale materials.
They are also apt for sculpture, jewelry or trinkets (clocks…) and have been used as a dark background ('Paragone') of colourful Pietre Dure marquetries like those of Florence since the end of 16th century.



Petrography
Dark micritic limestones with very poor fossil content

Geological setting
Paleozoic - Upper Devonian (Frasnian) and Lower Carboniferous (Viséan) ; Brabant Parautochton and in the Ardenne Allochton

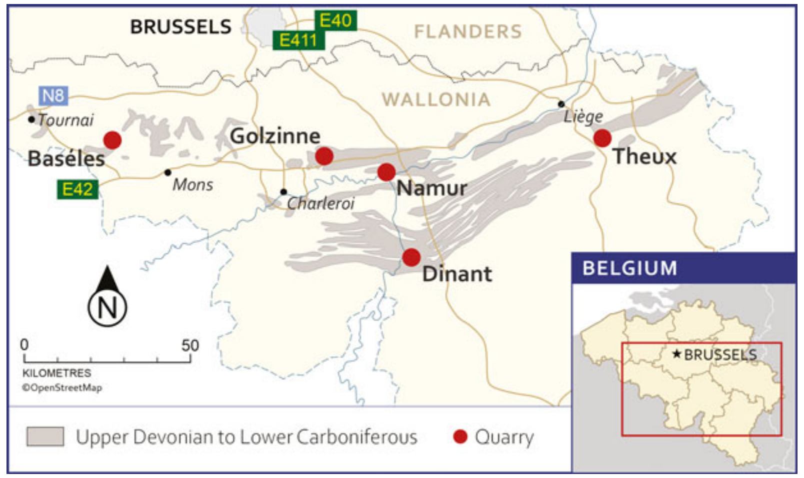
Occurrence
Wallonia / South Belgium

Petrography

The Belgian black marbles are dark micritic limestones, very poor in macrofossils, with peloids, small bioclasts like echinoids and ostracods.
They are dark grey in honed surfaces and pure black in polished ones, but they take a light grey patina when exposed to the atmosphere.
Their composition is almost pure calcium carbonate (calcite, with small traces of dolomite), with some minimal presence of silica and metallic minerals (pyrite).

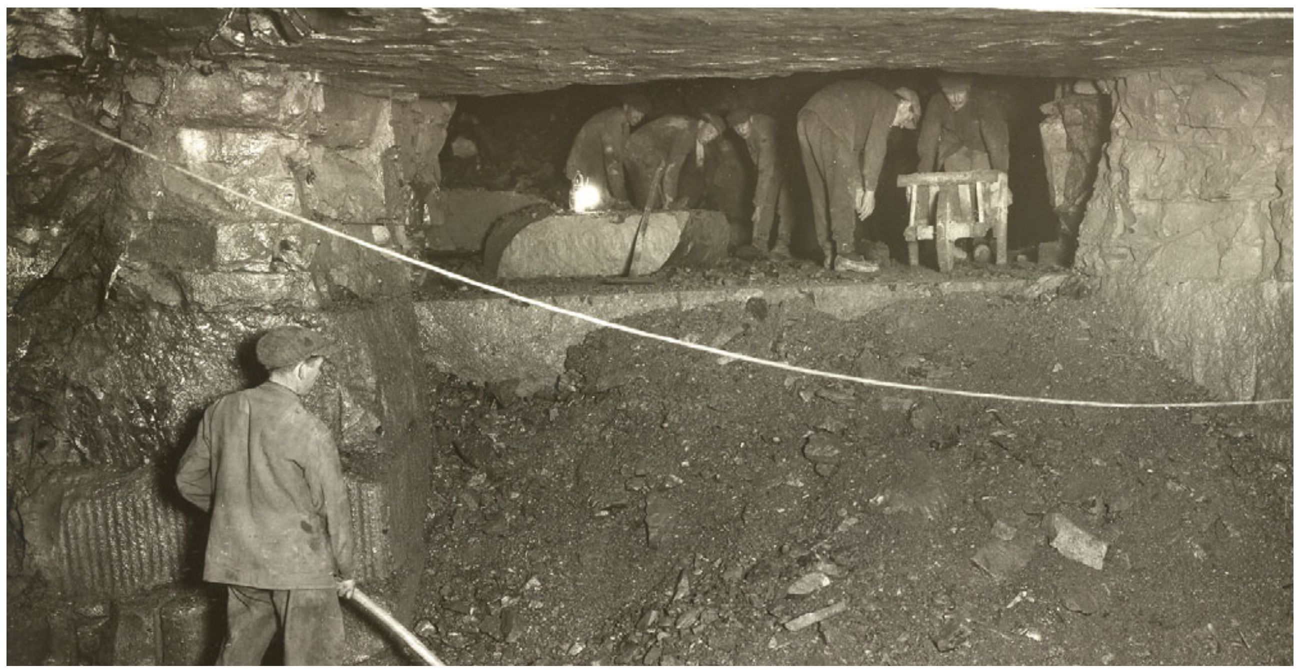
Location and geology

These fine-grained limestones are present at several levels of Upper Devonian (Frasnian) and Lower Carboniferous (Viséan) strata in South Belgium (Wallonia), in the Brabant Parautochton and in the Ardenne Allochton, both structural units of the Variscan Front, in diverse tectonic contexts. They were exploited mostly in the regions of Namur, Dinant, Theux (Liège), Basècles (Hainaut) and Golzinne (Mazy and Orneau valley). They are usually disposed in rather thin beds, with slight variations between pure black and dark grey, according to the grain, sometimes with rare narrow calcite veins and small fossils as white spots, but generally with a uniform black aspect.



Quarries

The Belgian black marbles stones were and are still exploited in South Belgium (Wallonia), since Antiquity. They were produced in several localities.
They were extracted in many open air and underground quarries, in different tectonic context, with floors being gently to steeply sloped. In many places, only the marble beds were exploited in low ceiling galleries. Today, only one underground quarry is still exploited, at a depth of some 70 m., in Golzinne (Gembloux entity). Some 5 or 6 beds of Middle Frasnian age are extracted with modern equipment in a sustainable industrial strategy (including protection of biodiversity).
The production is used for modern architecture and decoration or sculpture and design, as for restoration of the most prestigious heritage buildings in Belgium and throughout the world.



Golzinne, underground black marble quarry in 1929 (Merbes-Sprimont archives)

Architectural and cultural impact

The Belgian black marbles had already been used since Antiquity as marble sheets for inscriptions and dark tessera for mosaics. Later, the epitaph of Pope Adrian 1st, offered by Charlemagne around 800 AC and preserved in St Peter's Basilica in Rome, was produced in the Meuse region. During the Middle Ages, the famous tombs of the dukes of Burgundy (now in the Dijon museum) created a fashion for this kind of mausolea, replicated in many churches of Western Europe. Quarries around Namur and Dinant were very close to the Meuse river, one of the major European trade routes. Upstream, black marbles were transported to France, downstream, materials were able to reach the sea through Holland and to travel further to the North (following the Hanseatic network to Denmark, Poland and the Baltic States), to England or to the South, sometimes over large distances. The black marbles were also transported on the Rhine, upstream from the Meuse confluence in Dordrecht (for example to the Cologne Dom). In the early 17th c., many elements were transported through the ports of Amsterdam and Leghorn to Florence, for the Medici workshops of Pietre Dure marquetries.
The black marbles were often used for Baroque decoration, in churches following the Trento Council, or in secular buildings, in contrast with lighter or brighter colours. Since the 19th c., Belgian black marbles were exported all over the world, from North and South America to India, and are still today appreciated everywhere by architects, designers and artists. Anecdotally, black marbles were also used to create music instruments, similar to Chinese classical instruments, and lithographic stones, as their fine grain allows detailed carving and engraving but the dark background was not in sufficient contrast with the drawings.

Florence, Opificio delle Pietre Dure, on background of black marble

Main reference

Francis Tourneur, 2018/2020 – Global Heritage Stone: Belgian black 'marbles', in J.T. Hannibal, S. Kramar & B.J. Cooper (eds.), Global Heritage Stone: Worldwide examples of heritage stones. – Geological Society, London, Special Publication, 486, p. 129-147.

BELGIAN BLUESTONE
- PETIT GRANIT -

Belgium

Brussels, Cinquantenaire palaces (1880) and triumphal arch (1905)

A classic stone in fine arts

Francis Tourneur

The Belgian bluestone is a very compact limestone, rich in crinoids, taking different shades of bluish grey to dark grey according to finishing. The traditional name of 'Petit Granit' is linked with the irregular shining broken surfaces of the coarse grain rock, somewhat similar to those of true granites.
This stone has been exploited since the Middle Ages at least, in South Belgium (Wallonia), and is still considered today as the most important building stone of the country. It has been extensively used in many different kinds of applications, for exterior and interior uses, as a marble stone.
It is also appreciated by many artists for sculpture. It has been widely exported throughout Europe since the 19th c. and sometimes overseas, throughout the entire world (for the banks of the original Suez Canal, for example).

Petit Granit

Petrography
Bioclastic limestone; packstone or biomicrite, with debris of crinoids and other fossils

Geological setting
Paleozoic - Lower Carboniferous - Middle to late Tournaisian

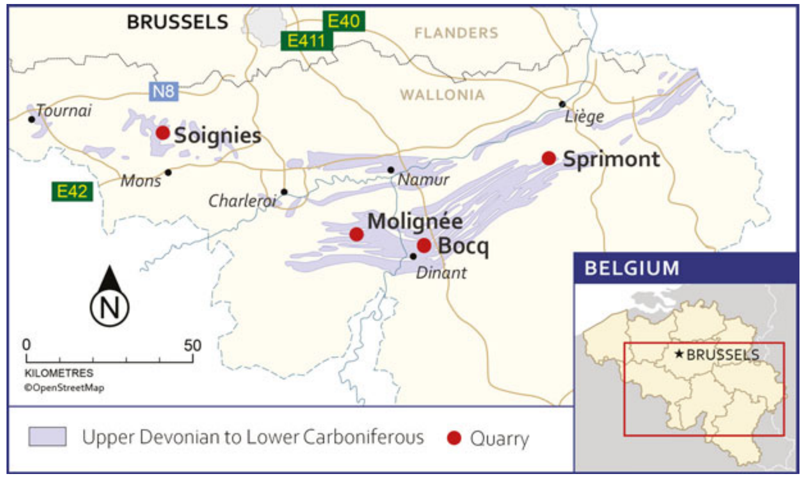
Occurrence
Wallonia, province of Hainaut and in the Condroz region, Belgium

Petrography

The Belgian bluestone is a bioclastic packstone or a biomicrite, with debris of crinoids and other echinoderms, brachiopods, rugose and tabulate corals (Michelinia and Syringopora) and bryozoans (fenestellids).
The composition is of 96 to 99 % carbonate (mostly calcite), small quantities of quarz and metallic minerals (pyrite), with organic carbon as finely dispersed pigment, giving the dark colour in fresh surfaces.

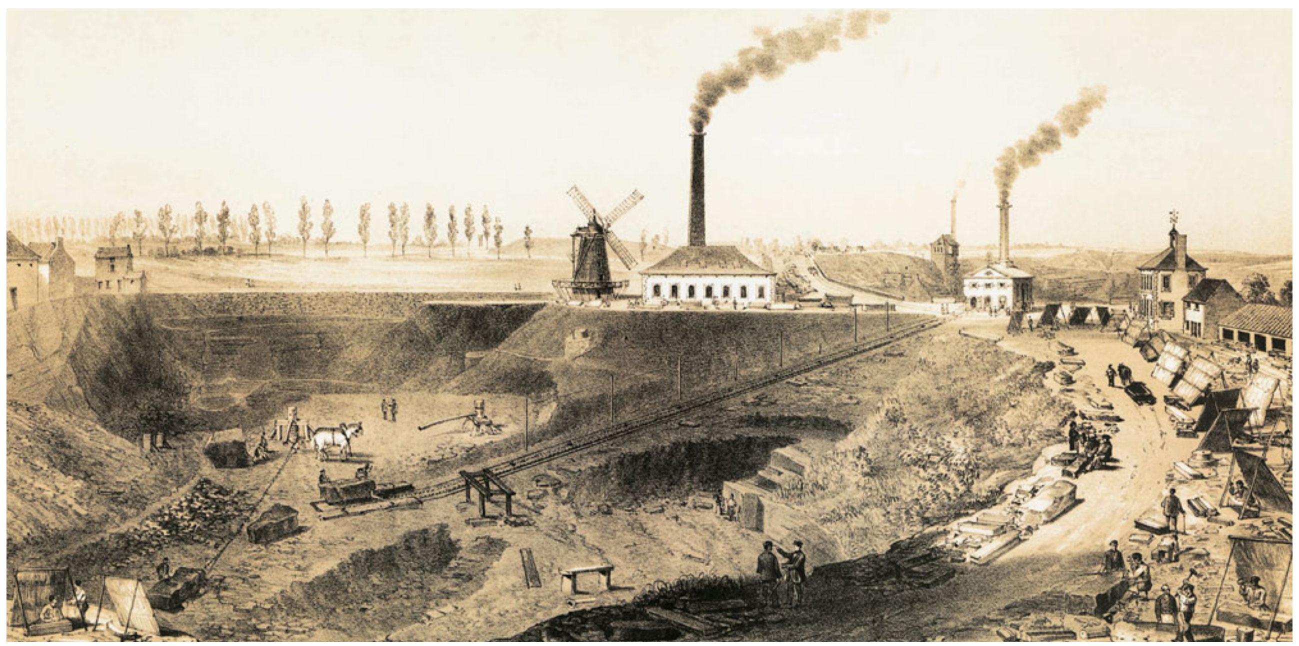
Location and geology

These crinoidal limestones are known in the Late Tournaisian strata (Early Carboniferous, Mississippian) of different areas in South Belgium, within diverse tectonic contexts (Brabant Parautochton and Ardenne Allochton).
They were exploited mainly in Hainaut province, around Soignies and Écaussinnes in very large quarries, and also throughout the multiple folds of the Condroz area, especially in the eastern part of this tectonic structure, to the South of Liège (around Sprimont and the Ourthe valley).
A slightly different variety, with darker and finer grained background and some particular fossils (huge solitary rugose corals forming large white crescents), is called 'Petit Granit du Bocq' because it is still exploited today in the valley of the small river Bocq, a tributary of the Meuse river.



Quarries

The Belgian bluestone is exploited in thick beds, reaching occasionally more than 1 m in thickness, possibly in huge blocks, often plurimetric.
They can be used for massive built buildings or cut in thick to very thin slabs to make a lot of different products. The stone is able to take many distinctive surface finishings, rough or smooth, grinded, honed or polished, chiseled, bush hammered or with different decorative patterns (like frost flowers), also flame treatment.
The colours and the outdoor patinas change from light to dark grey, slightly bluish to deep blackish with small white spots of crinoids or other fossils, shells or corals.



Soignies, Wincqz quarry around 1850

Architectural and cultural impact

The 'Petit Granit' has been extracted in several regions of South Belgium since the Middle Ages and used in many architectural and sculptural creations since at least the 12th c. As a resistant limestone, it was especially appreciated for gothic architecture, at is was available in elements of large dimensions, able to be deeply carved and sculpted, and to be put in or against the layer.
For example, collegiate church of Sainte-Waudru in Mons (15th to 16th c.) is built in dimensional bluestone interlaid with Tertiary sandstones. Later, from 16th to 18th c., the production followed the evolution from Renaissance, Baroque to neoclassical forms.
The castle of Seneffe is a spectacular example of this latter style, with two columned galleries composed of high monolithic columns.
The wonderful floors of the Panthéon, in Paris, were realized in a strong geometric pattern by of Belgian bluestone and French beige limestones (early 19th c.). During the 19th c., Belgian bluestone became the most frequently used stone material of the country, in all the historical styles, for sacred and civil buildings, like the 'Galeries royales Saint-Hubert' in Brussels (around 1845), or the huge monumental complexe of palaces for the 'Cinquantenaire' (fiftieth anniversary of Belgium, in 1880), with the famous triumphal arch (1905).
All the Art Nouveau buildings of the architect Victor Horta (with 5 urban houses as UNESCO heritage) contain bluestone elements, mixed with light French limestones. From the same architect in Brussels, the Beaux-Arts Palace is a marvel of Modernism, with typical grey geometric facades.
Today, the material remains appreciated for monumental works like the new Guillemins railway station in Liège, designed by Santiago Calatrava.

Paris, Panthéon, floors in marble, French limestone and dark grey `Petit Granit'

Main reference

Dolores Pereira, Francis Tourneur, Lorenzo Bernáldez & Ana Garcia Blásquez, 2015 – Petit Granit: A Belgian limestone used in heritage, construction and sculpture. – Episodes, 38 (2), p. 85-90.

BRECHA DA ARRÁBIDA

Portugal

Jesus Monastery, Setúbal

The stone of the Manuelino style

José Carlos Kullberg
António Prego

Brecha da Arrábida is a particular type of chromatic conglomerate breccia, outcropping in the Arrábida Natural Park, near Lisbon, with its extraction being halted nowadays. It marks a wide unconformity in the basin in Upper Jurassic, with infilling of paleokarst surfaces during the first episodes of the North Atlantic opening.
It was exploited as a structural stone from the Roman period to the 15th century, when it started to be used as an ornamental stone in the exterior of the monuments and, from the 17th century on, just for interiors.
The best-known applications are located in Portugal, but there are examples in other countries (Spain, France, United Kingdom, Austria, Mozambique and Brazil), largely in historic buildings and some integrated within UNESCO classified sites.

Arrábida Breccia polished slab

Petrography
Breccia; granular support of different colours

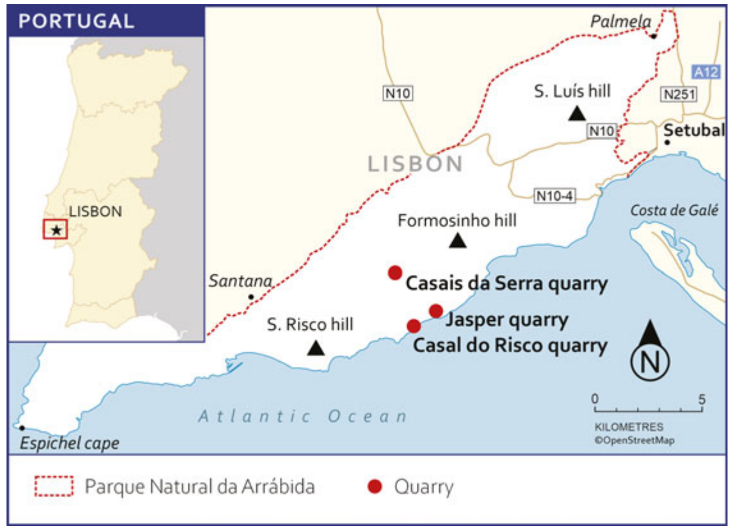
Geological setting
Upper Jurassic- Middle to Upper Oxfordium; anticlines of the Arrábida tectonic chain

Occurrence
Arrábida Natural Park, Portugal

Petrography

Brecha da Arrábida, macroscopically, consists of an intra-formational conglomerate breccia of granular support with carbonate karst of different colours in a carbonate-clayferruginous cement, whose genesis is associated with an immersed karst.
Microscopically, it features two main components - a reddish clayey matrix and crystalline cement - with the first presenting a variable fabric but often consisting of spherical peloid aggregates, with an average diameter between 100/200 µm.
The crystalline component is observed in fractures filled with newly formed calcite or distributed in the clayey matrix nodules of micritic calcite.
The vivid tones of Brecha da Arrábida, its textural uniformity and the absence of quartz distinguish it from other polygenic conglomeratic units.

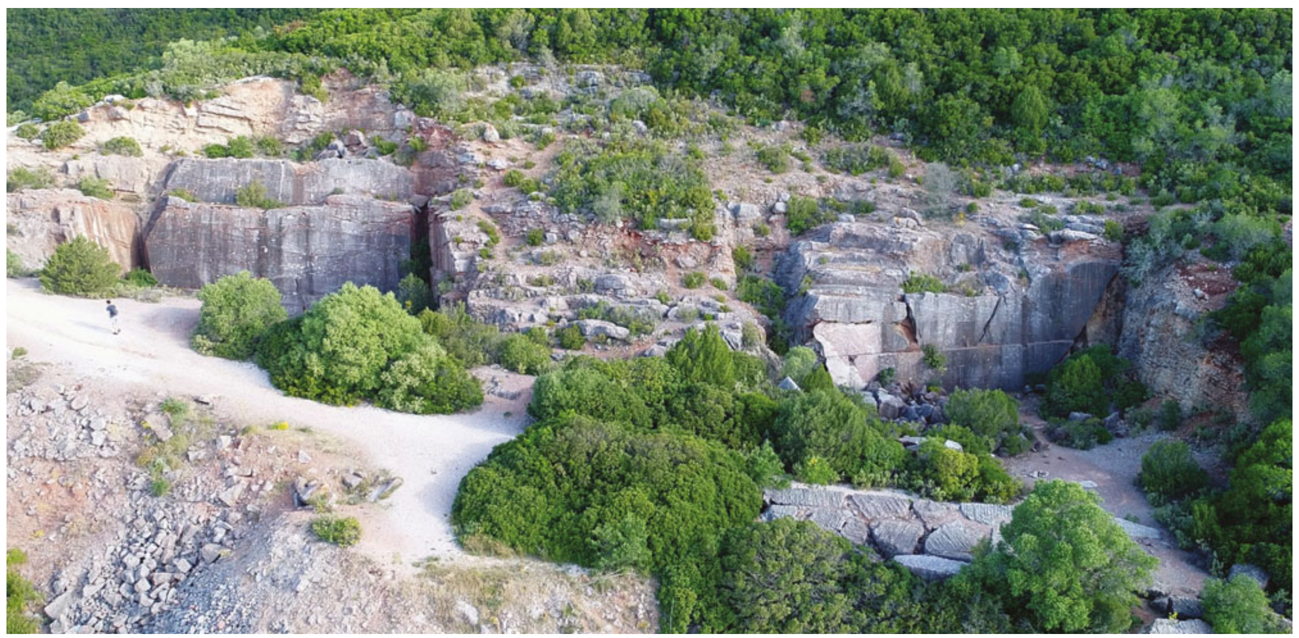
Location and geology



Brecha da Arrábida emerges in a discontinuous fashion around the anticlines of the Arrábida tectonic chain, occupying the territory of the municipalities of Palmela, Sesimbra and Setúbal. In stratigraphic terms, it consists of an informal unit of the Upper Jurassic (Middle to Upper Oxford) located at the base of the"Marls, clays, limestone with black pebbles and conglomerates of Arrábida" unit.
It is found in the fillings of paleokarst surfaces that materialise the Middle/Upper Jurassic unconformity, correlating with the Cabaços Formation located in the central sector of the Lusitanian Basin, which constitutes an important geodynamic marker whose genesis is associated to regional emersion processes during pre-oceanization rifting episodes of the North Atlantic opening.

Quarries

The unique occurrence of Brecha da Arrábida in the geographical area of the currently Arrábida Natural Park led to the closure, in the 70s, of the last remaining quarry still operating, making this geo-resource extinct.
The set of Brecha da Arrábida quarries is formed by a small number of disused quarries that can now be visited (Casal do Risco, Casais da Serra and Jaspe). The Jaspe Quarry is the largest and, currently, the one with the best accessibility.
It has two disassembling units prepared by mechanical sawing.
In the past, there were other mining places, and countless small quarries consisting of cavities from which rudimentary blocks of outcropping breccia were extracted, but their vestiges became covered by vegetation or were absorbed by large industrial rock quarries.



Jasper quarry aerial view.

Architectural and cultural impact

The extraction of Brecha da Arrábida as a construction/decorative stone component is entangled with Portuguese history, revealing this stone as an element of particular prestige in the adornment of several national monuments. Its widespread use as an ornament can be identified in diverse applications: pavements and coverings; masonry for civil, military and religious monuments.
The oldest evidence as a constructive element dates back to the Roman presence in the Setúbal region in the 1st century BC at the archaeological site of Troia and on the stone paved way of Viso. Later, it was also used in the construction of the medieval defensive wall of the old village. Its ornamental use apogee took place during the Manueline period (a later Portuguese variant of Gothic) between the end of the 15th and early 16th centuries, with the Monastery of Jesus being the most splendid example of it.
In the 18th and 19th centuries, the aesthetic particularities of Brecha da Arrábida gained a prominent role in decorative interior arts with its internationalization phase through exporting orders to other European countries. In fact, of the occurrences listed in Portugal, 65 exist in classified Monuments, 24 of which are National Monuments, some with UNESCO classifications.
Several other uses can be identified in monuments from Austria, Brazil, France, Mozambique, Spain and United Kingdom. As a scientific object, Brecha da Arrábida is profusely referenced in bibliography, the oldest one dating back to the 17th century.
The facies and petrographic description, as well as its cartographic representation, aroused the interest of some scientists who marked the beginning of Portuguese geology in the first half of the 19th century.
For didactic purposes, the set of Brecha da Arrábida quarries provides several possibilities for earth sciences research and historical itineraries for field trips targeting elementary, secondary and university education levels.

Baptismal font, Italian Church, Lisbon

Main reference

Kullberg, J.C., Prego, A. (2019). "The Historical Importance and Architectonic Relevance of the "Extinct" Brecha da Arrábida." Geoheritage 11: 87-111. https://doi.org/10.1007/s12371-017-0272-x.

DENİZLİ TRAVERTINE

Türkiye

Arched structure, ancient city Tripolis, Denizli

Banded travertine block, Yenice, Denizli

Petrography
Limestone, travertine

Geological setting
Cenozoic – Neogene; hydrothermal waters upwelling to the surface

Occurrence
Çürüksu Basin, province of western Türkiye

The treasure of Lycus valley known since ancient times

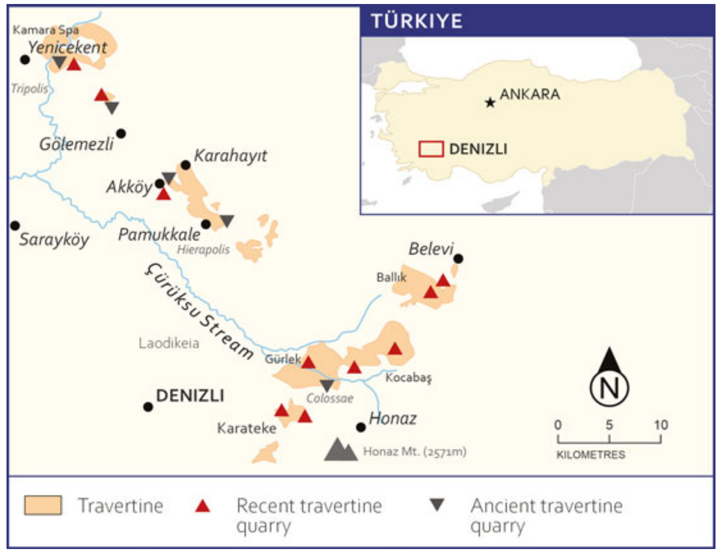
Mehmet Özkul
Arzu Gül, Tamer Koralay
Hülya Özen, Barış Semiz
Bahadır Duman

In the past, the Denizli Travertine has been used widely as a construction material in the ancient cities of Hierapolis, Laodikeia, Colossae and Tripolis in the Denizli Basin, western Türkiye. In these cities, from the 2st century BC, travertine was the leading building stone in the construction of necropolises, fortifications, theatres, agoras, latrine, stadiums, bridges, fountains and monumental tombs. In addition, some tools are made of travertine such as gang saw reliefs, mortars, olive oil processing stones.
Apart from the Roman and Byzantine periods, the Seljuks also used travertine in their castles, caravanserais and monumental tombs.
Contemporarily, the stone is widely used as flooring, cladding, stair steps, countertops, tables, coffee tables and sculptures and is traded worldwide.
The travertine terraces of Pamukkale and the ancient Greek city of Hierapolis are both on the UNESCO World Heritage List.

Petrography

The Denizli Travertine, precipitated from hydrothermal springs, is relatively hard, crystalline, with low porosity. It is composed of various lithotypes that are easily observed in hand specimen, on the block surface, in tiles and on the quarry wall. It is also described as crystalline crust, shrub, pisoid, paper-thin raft, coated bubble, reed and lithoclast travertine.
Calcite is the main mineral of the travertine, however, some types include aragonite and rare dolomite. Although micrite is most common, the banded travertine, crystalline crust travertine and secon-dary pore fills are formed
mostly of spar and microspar calcite. Other than carbonate minerals, detrital minerals are also present in very small quantities.
Under the microscope, various names have been attributed to the travertine depending on the major components present such as peloid, micrite, dendrite, shrub, cyanobacteria, bryophyte, reed, phyto, gastro-pod etc., phytoclast and coated grains.

Location and geology



Denizli Travertine of Quaternary age located in the Çürüksu Basin, one of the grabens in the extensional province of western Türkiye. The basin was bounded by normal faults along its north and south margins.

The faults and fissures are natural pathways for the hydrothermal waters upwelling to the surface. There are many travertine bodies, including world famous Pamukkale Travertine, in the basin.

The travertine underlain unconformably by the Neogene sequence, composed of alluvial, lacustrine and fluvio-lacustrine deposits. Basement rocks of Paleozoic to Mesozoic age, exposed on the graben shoulders and horst areas, are composed mostly of schist and marble.

Second group of the basement rocks is the allochthonous Mesozoic carbonate and gypsum of the Lycian Nappes, tectonically overlie the Menderes Massive.

Quarries

Ancient quarries of the Denizli Travertine located mostly in Pamukkale, Karahayıt and Yenicekent. At Pamukkale, more than 20 travertine quarries have been identified 3 km away from the urban area. Some of them take place in the fissure ridges where particularly the banded travertine or alabaster were extracted as in the central part along the ridge axis as in the Çukurbağ, Pamukkale. In some cases, chisel marks can be observed on the quarry walls even today. Second group of the ancient quarries are those excavated in the marbles of the Menderes Massive on the uplifted areas north and south margins of the graben. Recent travertine quarries are distributed in different parts of the Denizli Basin. However, the quarries located mostly in the Ballık area, the number of which is around fifty there. Apart from Ballık, other travertine quarries located at Aşağıdağdere, Kocabaş, Gürlek, Karateke, Akköy, Gölemezli and Yenicekent.

Recent travertine quarry, Ballık area, Denizli

Architectural and cultural impact

Denizli Travertine has an important place in the architecture and culture of the societies that lived in the Çürüksu Valley in western Anatolia, Türkiye in the past. The travertine was used widely for ornamental and building stone in ancient cities of the Çürüksu Basin at least since the 2nd century. In these ancient cities (e.g. Hierapolis, Laodikeia, Tripolis and Colossae) the stone was the most leading construction material of the public buildings (i.e. temple, castle, theatre, agora, gymnasium, monumental tomb-fountain, public toilet, street, bridge, ...).

Use of the travertine continued during the Seljuk period (starting from the 13th century). Apart from the buildings, it is observed that in the past, some objects such as olive processing stone and mortar stone were carved from travertine blocks. The banded travertine, a crystalline variety of travertine, so-called also 'alabaster' were commonly utilised for luxury or decorative objects. Small goods (i.e. bibelot, mosaic tables, vases of various form, bowls and dishes, drug jars) and greater objects (e.g. colossal statues, column, sarcophagi, ornamental tombs and street paving) made up from the banded travertines, have been documented in many archaeological studies. Even this variety with name of 'Coloured Hierapolis Marble' was brought to Rome (Italy) during the Augustian period, the 18th century.

Contemporarily, use of the Denizli Travertine still continues, for example, in flooring, cladding, sculpture, etc. In 2011, it was officially registered for geographical indication on behalf of the Denizli Chamber of Commerce in Türkiye. The stone, which can be easily processed, is preferred due to its color variety, texture, soft-aesthetic appearance and price compared to the many other stones.

There are many examples where the Denizli travertine was used in the qualified buildings and monuments both at home and abroad. The Denizli Travertine is exported as blocks, tiles and slabs to many countries (e.g. Middle East countries, European Union, the U.K., the USA, Canada, Australia and New Zealand.

Syrian street, ancient city Laodikeia, Denizli

Main references

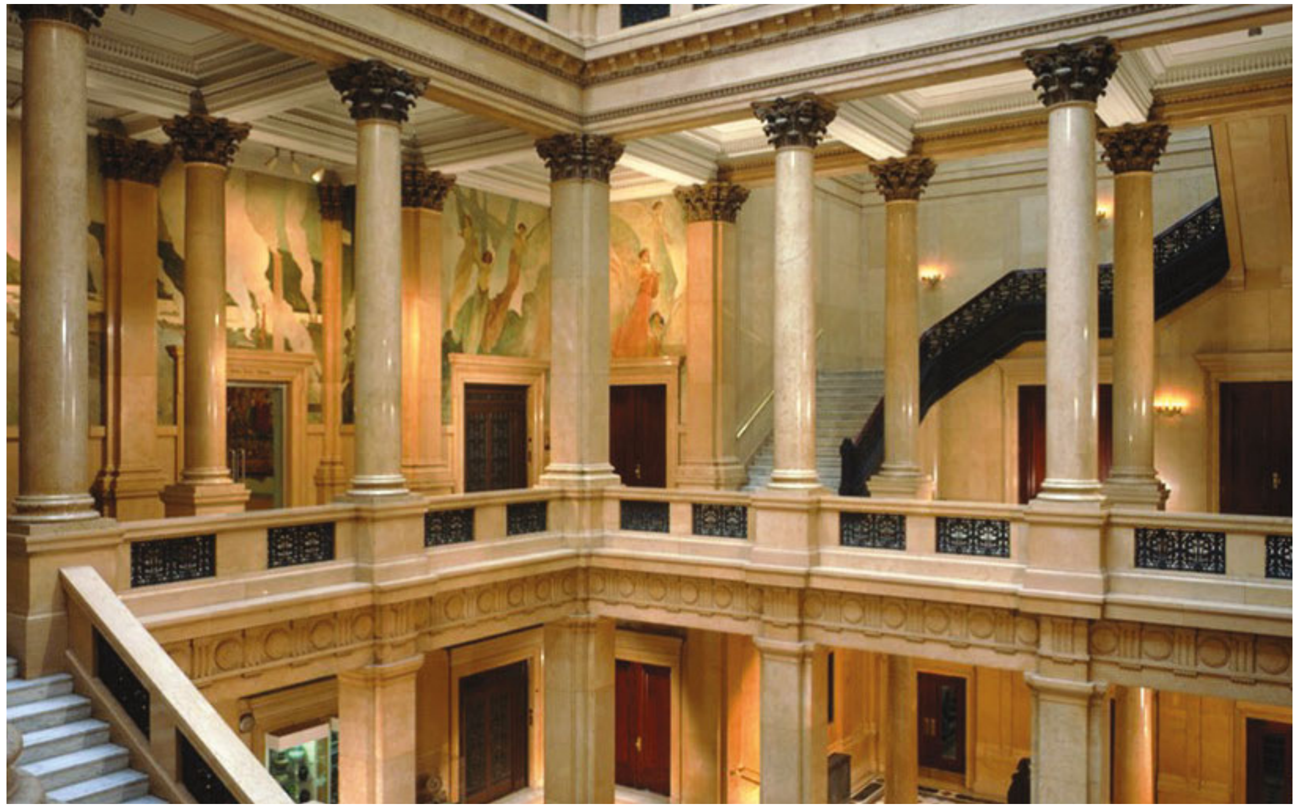
Koralay T, Kılınçarslan S (2015) Minero-petrographic and isotopic characterization of two antique marble quarries in the Denizli region (western Anatolia, Turkey). Periodico di Mineralogia, 84 (2): 263–288.;

Özkul, M., Varol, B., Alçiçek, M.C., 2002. Depositional environments and petrography of the Denizli travertines. Bulletin of the Mineral Research and Exploration 125, 13–29.;

Özkul M, Kele S, Gökgöz A, Shen C-C, Jones B, Baykara MO, Fórizs I, Nemeth T, Chang, Y-W, Alçiçek MC (2013) Comparison of the Quaternary travertine sites in the Denizli Extensional Basin based on their depositional and geochemical data. Sedimentary Geology (294): 179–204.

ÉCHAILLON STONE

France

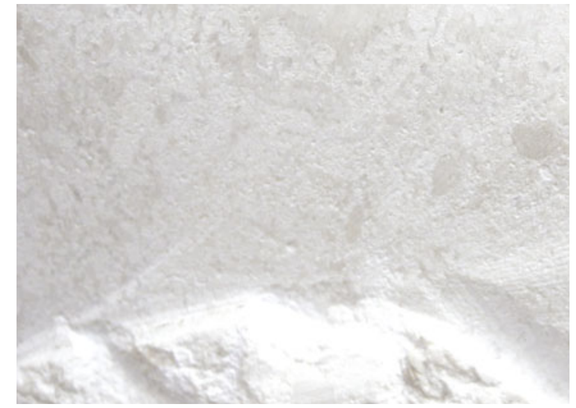


Carnegie Institute extension, Pittsburgh, Pennsylvania, USA. Grand Staircase Hall, circa 1907. Columns and pillars are made of Yellow Échaillon stone.

French limestone used since the Roman period

Thierry Dumont
François Ferrer-Laloë

A prized building and ornamental stone used in many significant historical buildings in Europe, North Africa and the USA. Although the first use of Échaillon stone in buildings dates from the Gallo-Roman period, the industrial use ranges from the mid-nineteenth century, during the heyday of the Beaux-Arts architecture period in France, to the mid-twentieth century.
The reputation of Échaillon stone was bolstered by world-renowned architects, sculptors and artists who used it for outstanding building ornament and sculptures. By the turn of the twentieth century, production started to decline and ceased by the middle of that century.



Échaillon varieties

Petrography
Limestone; bioclastic grainstone to packstone

Geological setting
Mesozoic - Late Jurassic to Early Cretaceous,
Platform margins from the Vercors Massif

Occurrence
Dep. Isère; downstream of Grenoble,
on the left bank of the Isère River, France

Petrography

Échaillon stone is a Mesozoic reefal limestone quarried in southeastern France. The three varieties of Échaillon stone: white, pink and yellow, are carbonate bioclastic grainstone to packstone (Dunham 1962).
These stones are carbonates, with a small amount of magnesium carbonate (dolomite), varying from traces to 3%, and all grains are of bioclastic origin. White Échaillon is of the Late Jurassic varieties (Portlandian facies, Tithonian in age), Pink Échaillon, also of the Late Jurassic variety, is a hard, very fine-grained, partly crystalline limestone with a pinkish colour due to diffuse hematite content. Yellow Échaillon is a dense, fine-grained platform limestone of Early Cretaceous (Barremian to Early Aptian) age.

Location and geology

The Échaillon quarries are located in the western Alps of SE France, at the North-western margin of the Vercors Massif, on the left bank of the Isère River between 15 and 30 km downstream from the city of Grenoble, at Saint-Quentin-sur-Isère, La Rivière and Rovon.

The geodynamic forces that formed the western Alps occurred with the closure of the Tethys Seaway that developed in the middle Jurassic (Lemoine et al. 1986). By Miocene time, the westward fold-and-thrusting occurred (Philippe et al. 1998), with the uplift of the Vercors Massif, bringing the Mesozoic strata near to the surface.

During the Quaternary Period, climatic events formed the Alpine glaciers and the Isère River Valley. Eventually glacial and fluvial erosion of the valley exposed the Mesozoic rocks that are now recognized as the Échaillon, Lignet and Rovon quarries.

Quarries

The Échaillon main quarries, from which are derived the 'White Échaillon' and 'Pink Échaillon' varieties, are located near Saint-Quentin-sur-Isère, on a rocky headland named 'l'Échaillon'. Original quarries were located at the bottom of the valley at river level but due to the folding of the quarried strata, mid-nineteenth century operations had to move some hundred metres above. To extract the stone, first open-pit and later, huge underground cavities were created and steep funicular railways were built to lower stone monoliths to the workshops close to river level. There are two ancillary quarries, where the 'Yellow Échaillon' variety comes from, the Le Lignet quarry, located 14 km SW on the left bank of the Isère River near a village named 'La Rivière', and the Rovon quarry. At these two quarries, stone extraction was only open-pit. The Rovon quarry was also equipped with a steep funicular railway.

White Échaillon underground quarries past and present.

Architectural and cultural impact

"La Danse": Copy of the sculpted group by Jean-Baptiste Carpeaux, representing Dance at the front of the Paris Grand Opera House. The original in White Échaillon stone is now exposed at the Orsay Museum, Paris.

The Échaillon Stone unique characteristics and aesthetic values made it a prized building and ornamental material used in many significant historic buildings such as the Paris Grand Opera House created by architect Charles Garnier and inaugurated in 1875.

Many interior and exterior architecture features of the building are made of White, Pink, and Yellow Échaillon; the four sculpted groups representing dance, music, drama, and poetry of the façade, are made of White Échaillon.

In Pittsburgh (USA, PA), at the Carnegie Institute extension, the characteristic rudist fossils that distinguish the Yellow Échaillon are found in the 18 pillars and the 22 columns (82 metric tons) that rise 3.8 meters or 12.5 feet about the Beaux-Arts Style Grand Staircase, and in the walls (64 metric tons) of the Music Hall Foyer. The buildings were commissioned to the architects Longfellow, Alden and Harlow at the apex of America's Gilded-Age building boom, circa 1907. (Kollar et al. 2018). During construction of the Suez Canal in Egypt, two managers of the company and friends of Ferdinand de Lesseps died in 1867; monuments in White Échaillon were built in their memory at Suez and Ismailia.

Back in France, many pedestals for statues were built in White Échaillon; for example at Bordeaux and Roybon to support scaled down copies of the Statue of Liberty by Bartholdi.

A pedestal at Cayenne, French Guyana, supports a statue of Victor Schoelcher, recognised for having abolished slavery in France.

Échaillon stone has been recorded in more than two hundred historic buildings and sculptures all over Europe, France and its former colonies, as well as the Americas and Africa. It was the preferred ornamental stone of famous sculptors such as Bartholdi, Carpeaux, Injalbert, Ding and even Rodin who showed interest for it.

As well, Garnier, Quesnel or Gaston Cousin, famous French architects, strongly recommended its use.

Main references

Dumont, T. (2020). "Échaillon stone from France: a Global Heritage Stone Resource proposal." in: Hannibal, J.T., Kramar, S. and Cooper, B.J. (eds) 2020. Global Heritage Stone: Worldwide Examples of Heritage Stones. Geographical Society, London, Special Publications, 486, p. 115 – 128. https://doi.org/10.1144/SP486. ISBN 978-1-78620-408-0.

SPIA (2019). „La Pierre de l'Échaillon, Une histoire locale, une renommée internationale", SPIA Saint-Quentin-sur-Isère, France. ISBN 978-2-9559334-2-8.

GLOBIGERINA LIMESTONE

Malta

An elaborately carved portal in Globigerina Limestone

More than 6000 years of history

JoAnn Cassar

The Globigerina Limestone of the Maltese Islands has been used continuously for 6000 years in a local setting and was also exported in the past to other Mediterranean countries such as Italy, Greece and Libya. Used extensively for building and sculpture, the earliest known use is in the construction of the UNESCO recognised Megalithic Prehistoric Temples of Malta (built between the fourth and third millennia B.C.).
The most significant and prestigious existing buildings are of the Baroque period (16th - 18th centuries) and style and are located in the walled cities of Valletta (also UNESCO recognised), Mdina and Cottonera, and the Citadel in the sister island of Gozo.
Numerous villages spread all over the Maltese Archipelago are built of this porous and easily carved material, such that vernacular architecture in this honey-coloured stone characterises the Maltese landscape. The stone continues to be used today, albeit less, and especially for restoration purposes.

Different shades of Globigerina Limestone

Petrography

Biomicritic Limestone; also biomicrosparites, wackestones and packstones dominated by globigerinid tests

Geological setting

Cenozoic - Neogene - Miocene - Aquitanian - Globigerina Limestone Formation

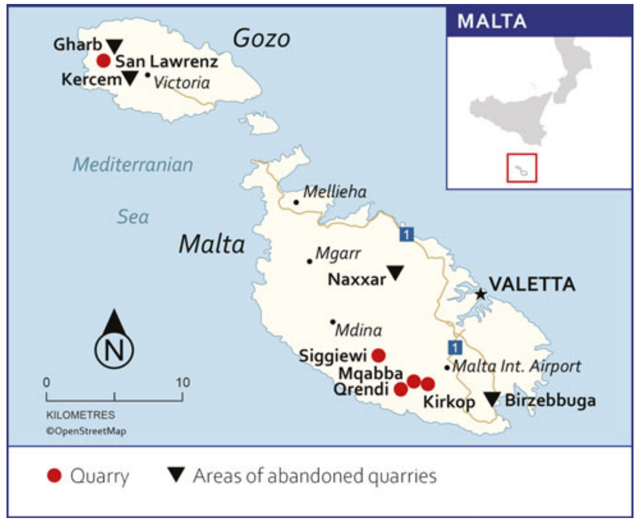
Occurrence

Central and Southern part of Malta and Northwest of the island of Gozo, Malta

Petrography

Globigerina Limestone is a yellowish-white, fine-grained and soft biomicritic stone, and is comprised of calcite (over 92%) as well as small amounts of quartz, feldspar, apatite, glauconite and clay minerals.
This rapidly absorbing stone has a high porosity, ranging from 24 to 41%. It includes planktonic foraminiferal biomicrites, biomicro-sparites, wackestones and packstones dominated by globigerinid tests. The stone is usually pale yellow to cream in colour, is massively bedded and medium to fine grained and often bioturbated.

Location and geology



The Globigerina Limestone Formation forms part of the Oligo Miocene 'soft limestones' found widely in the Mediterranean Basin, including Türkiye, Israel, Tunisia, Spain and Italy. It is the most widely distributed Formation on the Maltese Islands. It was deposited in outer shelf environments between the Late Chattian and Langhian, and is up to 200 m thick.
The Formation is made up of three members: Lower Globigerina Limestone, Middle Globigerina Limestone and Upper Globigerina Limestone, separated from each other by two phosphatic hardgrounds (named C1 and C2). It is the Lower Globigerina Limestone, the oldest member of the Globigerina Limestone Formation, which has been used as the main local building material for millennia.
The thickness of this member varies from over 100 m in the Valletta Basin in the east of the island of Malta, to less than 5 m along western Malta.

Quarries

Globigerina Limestone, mainly quarried as building stone, is today primarily used for restoration purposes with its use in new buildings decreasing in recent years. Historically, the location of quarries has been closely associated with the extensive outcrops in the central and southern part of the island of Malta and more limited exposed areas in the northwest of the island of Gozo.

A typical quarry in Malta

Architectural and cultural impact

Neo-Gothic Church- Addolorata cemetery

Prehistoric carvings (Tarxien Temples, 3600 to 2500 BC)

Limestone characterises the landscape of the Maltese Islands, both rural and urban. This easily cut and carved stone has always been readily available and easy to obtain; thus, for more than six thousand years, every generation of inhabitants in the Maltese Islands has gone through more or less intensive periods of building.
The UNESCO listed prehistoric megalithic monuments, considered to be amongst the oldest freestanding buildings in the world, as well as the UNESCO inscribed capital city of Valletta (with its magnificent buildings and fortifications), all built of the yellowish soft stone, typify the architectural heritage of the Islands. But Malta's rich architectural legacy extends beyond, and bears witness to the many cultures which controlled the Islands over the centuries.
Thus, a rich Renaissance and Baroque architecture is to be found in Valetts in the walled city of Mdina, the old capital of Malta as well as in the fortified Three Cities (Senglea, Cospicua and Vittoriosa) in the Grand Harbour area. Malta has over 60 kilometres of fortifications surrounding these walled towns, which also house palaces, churches and historic houses all built in this soft limestone.
Numerous villages spread all over the Maltese archipelago, also built in Globigerina Limestone, are characterized by large, magnificent and elaborate Baroque churches dominating over small, flat-roofed vernacular buildings. Architectural styles and building techniques changed from 1800, under British Colonial Rule, but the main construction material, the local limestone, remained the same. At the beginning of the twentieth century, new aesthetic ideas were introduced, with the Romanesque, the Neo-Gothic, and the Art Nouveau movements being the main ones, using the limestone in new and untested ways.
In the last two decades, more innovative, hybrid styles were introduced, influenced by an increased appreciation of the Islands' architectural heritage and current trends in Europe – all continuing to make extensive use of the local limestone.
The stone has also been extensively used for sculpture, being very easy to carve and shape, ranging from very simple forms to elaborate representations, even from prehistoric times, up to and including the elaborate façades of Malta's prestigious palaces, churches and cathedrals, with the pinnacle of stone carving being exemplified by the elaborately carved, and gilded, interior of St John's Co-Cathedral in Valletta. It is therefore not an exaggeration to state that the Maltese Islands are often said to be synonymous with the honey-coloured Globigerina Limestone which is ubiquitous in the cities, towns, villages and countryside.

Main references

Cassar, J., Torpiano, A., et al. (2017). "Proposal for the nomination of Lower Globigerina Limestone of the Maltese Islands as a "Global Heritage Stone Resource"." Episodes 40(3): 221-231.

Pedley HM, House MR, Waugh B (1976) The geology of Malta and Gozo. Proc Geol As 87(3):325–341

JACOBSVILLE SANDSTONE

USA

One of many cliff exposures of the Neoproterozoic Jacobsville Sandstone, here about 1 km N of the town of Jacobsville. Cliff exposures are found in dozens of locations within Keweenaw Bay. Photo: Steve Brimm.

Fashionable sandstone from Michigan

William Rose

Jacobsville Sandstone is a well-known red bed sandstone of Neoproterozoic age from Upper Michigan, USA. Cliff exposures show crossbedding and channels and are interpreted as fluvial deposits, part of a sequence called the Keweenaw Supergroup, which follows flood basalts and fills a rift of Rodinia.
The Jacobsville was used extensively in Eastern North America from 1880 to 1920 in hundreds of prominent buildings, including the famous Astoria Hotel in New York City. It was mined from several quarry sites near Jacobsville, Michigan.
The location is part of a significant geoheritage location where native copper has also been mined for thousands of years.
Development of copper mining along with sandstone quarrying drove extensive immigration of Europeans to Upper Michigan.

Cliff exposure of Jacobsville from near Rabbit Bay, Keweenaw Peninsula. (1.2 m horizontal dimension)

Petrography
Subarkose to quartz sub-lithic arenite

Geological setting
Neoproterozoic; fluvial and channel infills

Occurrence
Southern shore of Lake Superior, Michigan, USA

Petrography

Subarkose to quartz sub-lithic arenite, with some beds of arkose and quartzite and minor siltstone, shale and conglomerate. Grain size mainly between 30 and 100 mesh (0.15–0.6 mm diameter).
Chemical composition of quartz-rich rock is 98.76% Silica; 0.72% Alumina, 0.33% Potash, but most samples contain 25% potash feldspar and silicic volcanic clasts. Colour is mainly red, but also some brown and white. The main recognized colour varieties were the redstone (uniformly red) and the variegated (red streaked and mottled with white).
One variety known as "Marquette stone" had a brown and purplish colour and was regarded as the handsomest stone quarried, but supplies were limited.

Location and geology

Jacobsville Sandstone is a fluvial deposit marked by conspicuous river channels and variegated red/white colours. These rocks sit on top of mid-continent rift igneous rocks and its post-rift sediments. The rift formed ~1100 Ma and is a ~3000 km long feature in North America, centered on the Lake Superior area. The Jacobsville are the youngest of the area's Precambrian rocks, and its age is during the ending of the Rigolet Phase of the Grenvillian Orogeny (1090-980 Ma).
The formation occurs along the southern shore of Lake Superior. It likely correlates with similar red bed units nearby, the Bayfield Group in northern Wisconsin and Hinkley Sandstone and Fond du Lac Formations in Northern Minnesota.

Quarries

There are 10 quarries within 3 km of Jacobsville, Most quarrying occurred from 1885–1910, operations mostly ceased by 1923.There are no active quarries at the date of this writing (2024) although there is some industrial interest in renewed supplies. Three Quarries near Jacobsville are best known:
(1). Portage Entry Quarry (46.9806N; 88.4107W): Operated by the Wolf and Jacobs Company beginning in 1883.
Largest and most extensive quarry in the area, and by 1891 had acquired all the other quarries and changed its name to Portage Entry Quarries Company. (2). Craig Quarry (46.9968N; 88.4193W): Earliest Quarry started by George Craig, north of Jacobsville. (3). Stone Quarry Lake (47.0034; 88.3950W):
The Kerber-Jacobs Quarry, also the Excelsior Redstone Company, northeast of Jacobsville near Red Rock 1891–96.

Cutting sandstone at the Jacobsville Quarries, 1880s

Architectural and cultural impact

Jacobsville Sandstone was a fashionable building stone of much of Eastern North America, 1885–1920. With of the development of North America's first great metal mining district, centered at Calumet, (30 km north of Jacobsville) beginning in the 1840s, predating the California Gold Rush and continuing for many decades, Michigan's Copper Country became a major industrial and immigration focus. Many new buildings were needed.
Quarries were developed and Great Lake Shipping lanes were used for stone transport. The sandstone was fashionable for public buildings for a few decades (1885–1915), perhaps especially reflecting hazards of wood constructions following the famous Chicago fire of 1871. It was used mainly for building blocks.
Jacobsville adorns many hundreds of churches, public buildings, breweries, and residences in the Lake Superior area (Upper Michigan, Wisconsin and Minnesota) and 115 buildings listed in Eastern US, most built 1885–1900.
It was shipped as far west as Kansas City, south to St Louis and New Orleans and east to Cleveland, New York and Philadelphia. Duluth, Chicago and Buffalo were the lake ports utilized for inland distribution.
The Jacobsville Redstone, more widely used, was available as dimension stone in sizes up to 75 cm thick.
Many buildings are with 100% Jacobsville walls. Some have Jacobsville bases and decorative Jacobsville trimming.
In addition to its use as ordinary building stone, surfaces of the blocks could be carved readily into intricate relief designs.
Since quarrying has ceased, Jacobsville's quarries have been overgrown and are often overlooked. Highlighting the significance of these places and increasing access offers an opportunity to teach locals and visitors about a unique period in Earth's history. It also further connects people to an important element of Keweenaw geoheritage often eclipsed by the history of copper mining.

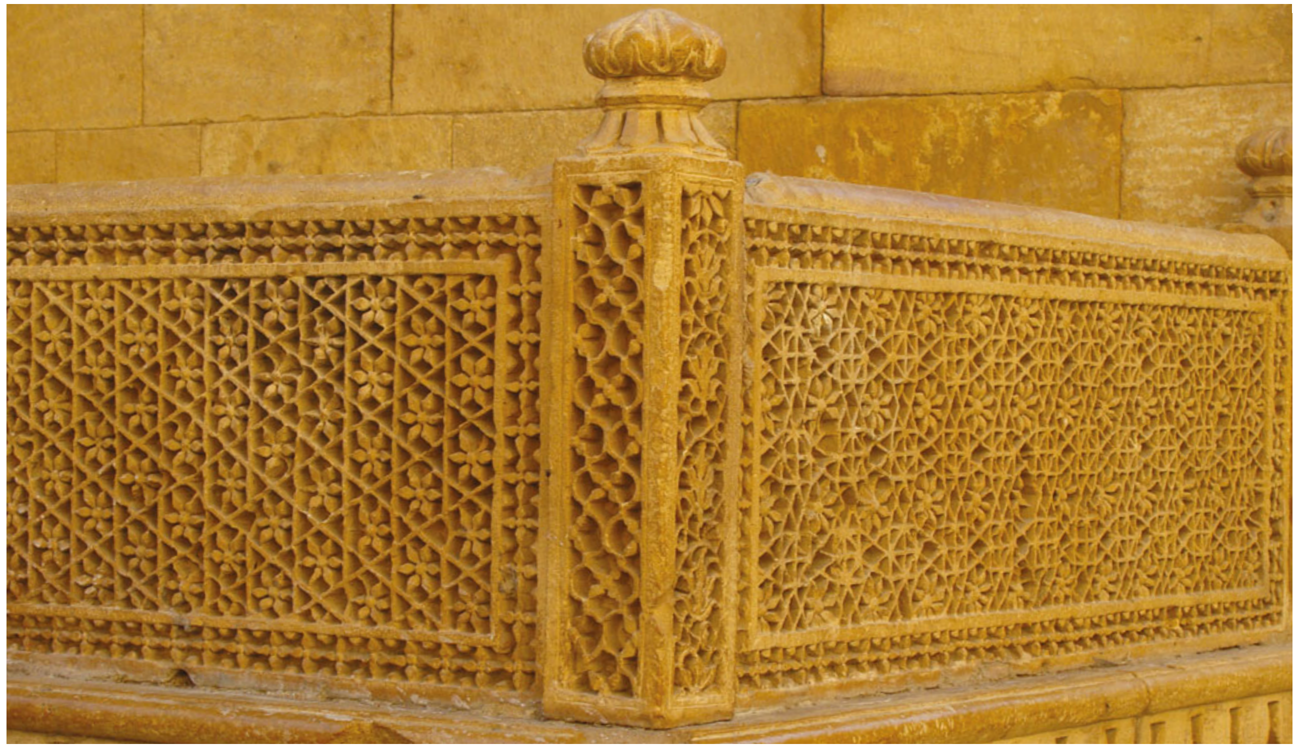
Blocks of Jacobsville Sandstone from Firehouse Building, Houghton Michigan. (45 cm horizontal dimension)

Main reference

Rose, W.I., Vye, E.C., Stein, C.A., Malone, D.H., Craddock, J.P. and Stein, S. 2017. Jacobsville Sandstone: A candidate for nomination for "Global Heritage Stone Resource" from Michigan, USA. Episodes 40(3), 213-219.

JAISALMER LIMESTONE

India



Close up of yellow limestone used in cladding and fine lattice work.
Photo: Anuvinder Kaur

A Heritage Stone from the desert of Western India

Gurmeet Kaur

The yellow limestone of Jaisalmer indeed holds a significant place in the architectural heritage of western India, particularly in the city of Jaisalmer itself. Its golden hue lends a unique charm to the structures built from it, earning Jaisalmer the moniker of `The Golden City'.
The renowned Jaisalmer Fort and its UNESCO World Heritage status further underscores its importance. Not only does the limestone contribute to the visual appeal of the city's landmarks, but it also boasts remarkable properties such as hardness, compactness, and a smooth surface.
These characteristics, along with its pleasing color and texture, make it highly sought after for architectural and ornamental purposes.

Jaisalmer Limestone (15x15cm)

Petrography
Limestone

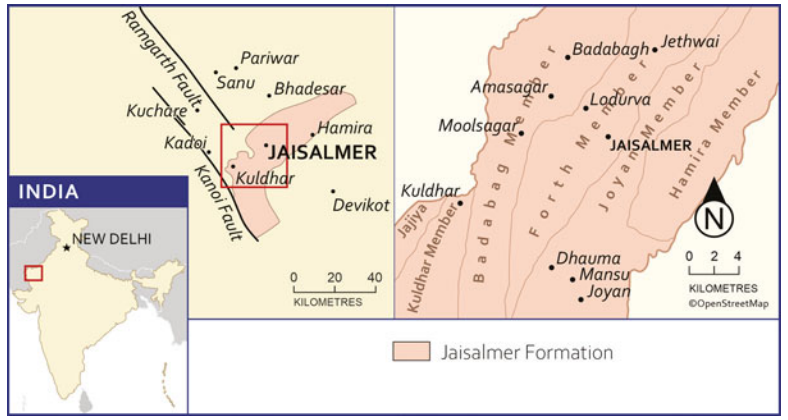
Geological setting
Mesozoic – Jurassic- Callovian to Oxfordian; Jaisalmer Formation

Occurrence
In and around Jaisalmer city, Rajasthan, India

Petrography

The Jaisalmer Limestone primarily is a golden yellow-brown colored, hard, and compact fossiliferous limestone. This limestone exhibits carbonate microfacies including oolitic, peloidal to bioclastic grainstone, and packstone to wackestone.
Common fossils found within this formation include molluscs, corals, foraminifera, ostracods, and echinoids. Non-skeletal allochems such as pellets and oolites are prevalent, while quartz grains are typically fine to medium grained and sub-angular to sub-rounded in shape.
Micrite and sparite serve as pore-fillings, with micrite enveloping most allochems.

Location and geology



The Mesozoic – Tertiary Jaisalmer rift-basin developed to the west of Aravalli-Delhi Fold belt, in response to the Gondwana supercontinent break-up during the Jurassic – Cretaceous period.

Sedimentation in the Jaisalmer Basin began with Liassic–Bathonian continental fluvio-deltaic deposits of the Lathi Formation, followed by the marine Jaisalmer Formation (Callovian – Oxfordian).

The Jaisalmer Formation comprises six members: Hamira, Joyan, Fort, Bada Bag, Kuldhar, and Jajiya. The yellow Jaisalmer limestone forms part of the Jaisalmer Formation.

The deposition in Jaisalmer basin ceased during the Late Cretaceous.

Quarries

Yellow limestone deposits primarily originate from the Jaisalmer Formation, extensively quarried in areas surrounding Jaisalmer city. Major quarries are situated in Amarsagar, Lodurva, Bada Bagh, and their vicinity.

Quarry site. Photo: Anuvinder Kaur

Architectural and cultural impact

Finely carved Jaisalmer Limestone and latticework

The yellow limestone of Jaisalmer has been extensively used in many iconic monuments such as the 12th century Jaisalmer Fort (UNESCO World Heri-tage Site). There are plenty more magnificent monuments within the walls of the Jaisalmer citadel. These include palaces with excellent engravings, a collection of Jain temples, and homes constructed for the servants of the nobility.

The well-known havelis (mansions) of Jaisalmer, namely, Patwon ki Haveli, Salim Ji ki Haveli, Deewan Nathmal's Haveli, are well renowned for their screened jali windows and carved balconies in yellow limestone. These havelis belonged to the bankers and merchants in the past.

The yellow limestone Jain cenotaphs further enrich Jaisalmer's architectural landscape.

The Lodurva temple, built in yellow Jaisalmer limestone, showcases eight-cornered architecture, while the Amarsagar Jain Temple, boasts intricate floral carvings, latticed screens, and detailed sculptures in yellow limestone. Most of the local abodes are also made in yellow Jaisalmer Limestone.

In addition to heritage buildings in and around Jaisalmer, the Jaisalmer yellow Limestone found its way into renowned monuments like the Agra Fort, Taj Mahal, and Red Fort, all UNESCO World Heritage Sites, dating back to the 16th and 17th centuries. The intricate pietra dura work in the Itimad-ud-Daulah, also known as `Baby Taj' or `Mini Taj' in Agra, showcases the extensive use of Jaisalmer Limestone in geometrical floor designs and wall inlays, including the tombs of Itimad-ud-Daula and his wife.

Main reference

Kaur, G., Kaur, P., Ahuja, A., Singh, A., Saini, J., Agarwal, P., Bhargava, O.N., Pandit, M., Goswami, R.G., Acharya, K. and Garg, S., 2020. Jaisalmer golden limestone: a heritage stone resource from the desert of Western India. Geoheritage, 12, pp.1-16.

JURA MARBLE LIMESTONE
- JURA MARMOR -

Germany

Maritim Hotel Ingolstadt, Germany
Photo: Anette Ritter-Höll

The most popular stone in public buildings in Germany

Anette Ritter-Höll
Angela Ehling

After many centuries of regional use, Jura Marble had its first heyday in the 19th century and its second in the 1930s - both in connection with the expression of national identity. It was used for important German national monuments like the Walhalla (1842) near Regensburg and the Liberation Hall (1863) in Kelheim. The actual spread and significance began about 60 years ago.
Today, the Jura Marble is the most used and most popular natural stone in Germany, especially in interior architecture! It is used in almost every second public and many private buildings throughout Germany for many decades for flooring, staircases, as windowsills and sometimes as façade cladding.
It is also used for façades of skyscrapers in China, USA and United Emirates as well as in Berlin, London and Munich.

`Jura Gelb´ (8 x 25cm) `Jura Goldgelb´ (8 x 25cm) `Jura Grau´ (8 x 25cm)

Petrography
Limestone; biopelmicrite and biopelsparite; Wackestone to Packstone

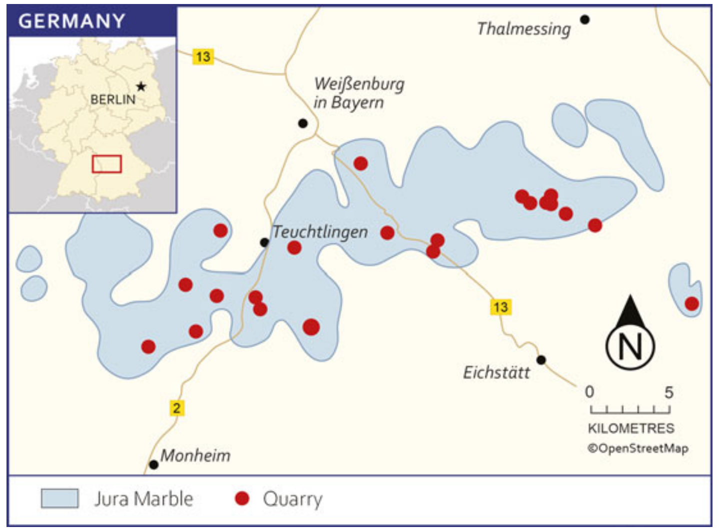
Geological setting
Mesozoic – Upper Jurassic (Germany: Malm) – Kimmeridgian – Treuchtlingen Formation

Occurrence
Bavaria, Southern Fränkische Alb, Germany

Petrography

The Jura Marble occurs in a certain range of varieties: yellow, light brownish to greyish-blue, micritic, bioclastic with intraclasts, micro- and macrofossils (ammonites) - Biopelmikrit and Biopelsparit; Wackestone to Packstone. Jura Marble commonly reveals an alternation of more micritic, fine layers and coarser layers.
Coarse layers are composed of peloids, lithoclasts and so-called `white flames´, which are the microorganism *Tubiphytes*.
The grey Jura Marble is denser and commonly contains fragments of sponges floating in micrite, containing thin fragments of shells (`Filaments´).
The limestone beds of high density reveal varying amounts of different microfossils. About one third of the 36 beds can be used for inside floors and one third for monuments under atmospheric conditions. The last third can be used for gravel (street work).

Location and geology



The Jura Marble was deposited in a huge shallow marine carbonate platform environment at the northern margin of the Late Jurassic Tethys Ocean. The sedimentation was characterized by the coexistence of bank limestones and massive limestones.

This includes sponge reefs as well as dolomites and dedolomites, which are also mostly diagenetically transformed former `sponge reefs´ in the sense of the common interpretation so far. In a standard profile of the area, it consists of up to 36 beds.

The limestones and marls have always been of special interest for stratigraphic classification, because in them almost exclusively the corresponding ammonite diversity is found.

Quarries

The Jura Marble was and is predominantly quarried along the steep slopes of the Altmühl Valley and associated smaller valleys in southern Fränkische Alb since Roman times. It is assumed that the first large-scale quarrying of Jurassic marble took place during the construction of Willibaldsburg Castle (1351-1365). Quarrying of Jura Marble cannot take place throughout the year because of moisture freezing within the limestone. In the winter half-year the quarries close down and no quarrying takes place. Machine processing with saws began around 1900.

Today the Limestone is quarried in about 20 quarries, which are not continuously active.

Active quarry of Jura Marble near Treuchtlingen

Architectural and cultural impact

Jura Marble has been used since Roman times in Bavaria: for the Limes and the Roman thermal baths near Weißenburg. Later on the limestones were used for all kind of simple building purposes especially since the 12th century for the masonry of the so-called Jurahouses with roofs made of limestone plates. The form and material of the houses are unique worldwide and they blend harmoniously into the landscape.

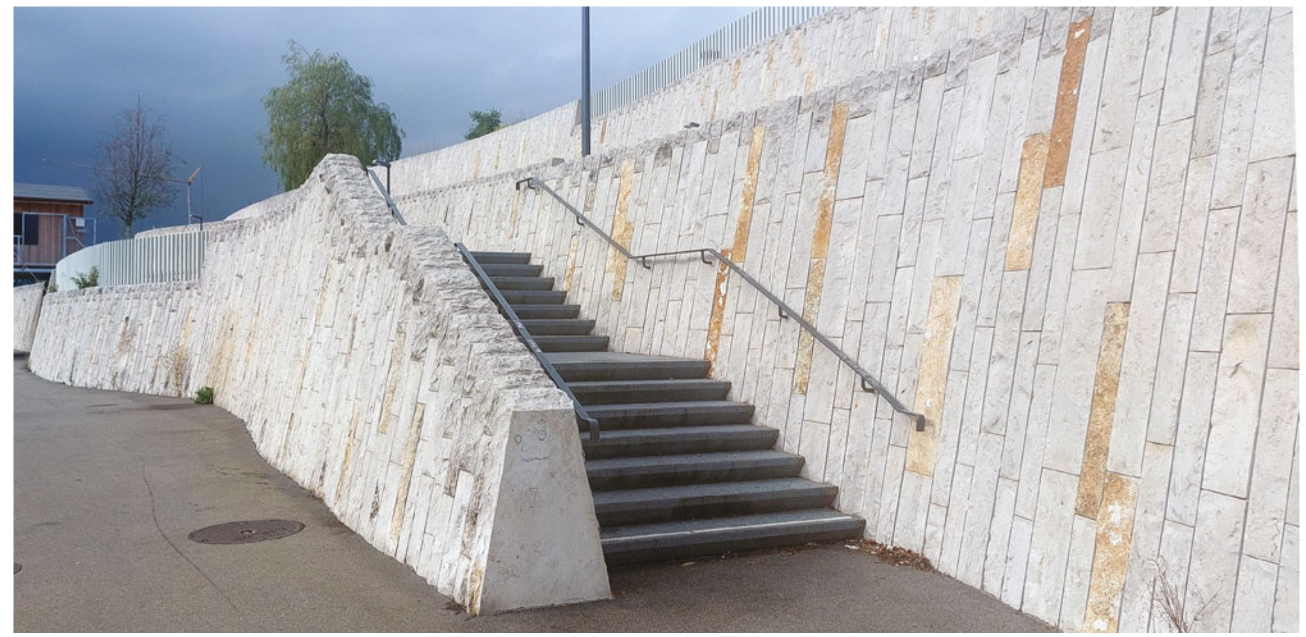
The Pappenheim altar in Eichstätt Cathedral in 1495 depicting the crucifixion scene is one of the most famous, artistic works made of Jura Marble (layer 7).

Jura Marble was transported on the rivers Altmühl and Danube and thus they are found in many representative buildings along the rivers and also in Munich.

The use of the stones was seen as a symbol of the German nation when it was still emerging in the middle of the 19th century and also in the 1930s. Examples of this include the important German national monuments Walhalla (1842) near Regensburg and the Liberation Hall in Kelheim (1863) as well as the big architectural complex of the National-socialists, the Zeppelin Field in Nuremberg.

The Jura Marble is the most used and most popular natural stone in Germany during the last 60 years, especially in the interior architecture. It is used in almost every second public and many private buildings throughout Germany.

Two of the most prominent modern examples are the flooring of the Berlin International Airport in 2012 and the Humboldt Forum in Berlin in 2020. It is also used for façades of skyscrapers in China, USA and United Emirates as well as in Berlin, London and Munich. The highest existing building with natural stone, the Al-Hambra-Tower (Kuwait City) is 413 m high and is clad with Jura Marble.



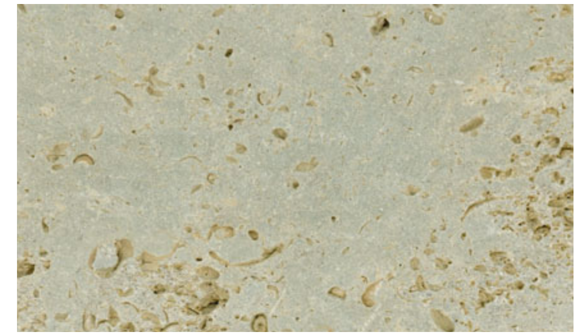
riverside promenade, Basel, Swiss. Photo: Anette Ritter-Höll

Main reference

Koch, R. & Ritter-Höll, A. (2021): Jurassic limestones: Solnhofen Limestone (Solhofener Plattenjkalk) and Treuchtlingen Limestone (treuchtlinger Kalkstein).- In: Ehling A, Häfner F, Siedel H (eds.) UNESCO Sites in Germany. Natural Stone and World Heritage Series, vol. 3. CRC Press (Taylor & Francis Group), Boca Raton, London, New York. https://doi.org/10.1201/9780367823061

LEDE STONE

Belgium



Blocks in Lede stone after a conservation cleaning treatment, forming a former arch at the Maiden's House in Antwerp, Belgium.

Lede stone, stone types

Petrography
Sandy, fossil-bearing limestone

Geological setting
Cenozoic – Eocene – Lutetian; Lede Formation

Occurrence
Landscape between Brussels and Ghent, Belgium

Erecting the Belgian heritage

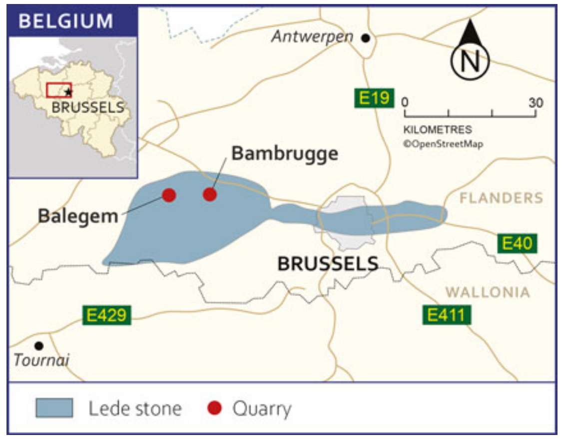
Tim De Kock

Lede stone is one of the few local stone resources in a stone-poor landscape of the Low Countries, Flanders (Belgium) and The Netherlands. It is abundantly used in monumental, local and vernacular architecture across this region, including in cities as Bruges and Ghent which were upon the largest cities of northwestern Europe in the medieval times, and Antwerp and Brussels which emerged in the early modern age and the latter informally becoming the capital of Europe. The stone can be found in multiple World Heritage Sites, like the Flemish Béguinages, Belfries, the Museum Plantin-Moretus, the historical city center of Bruges and Grand-Place in Brussels. However, as a traditional material it is increasingly replaced during renovation works, because of it's decreasing availability.

Petrography

The stone can be described as a sandy limestone, with up to 50 % glauconitic quartz sand, often angular and fine but contaminated with coarse, rounded quartz. It contains numerous micro- and macrofossils, among which the foraminiferal is dominant. These include both planktonic and benthic forams, incl. diverse miliolid species and the characteristic Nummulites variolarius, indicating a shallow marine deposit. Furthermore, bivalve fragments and moldic shell pores can be present, as well as echinoderm fragments and the characteristic Ditrupa strangulata. The grains are bound by a micritic to microsparitic calcium carbonate cement, which is typically enriched in iron.

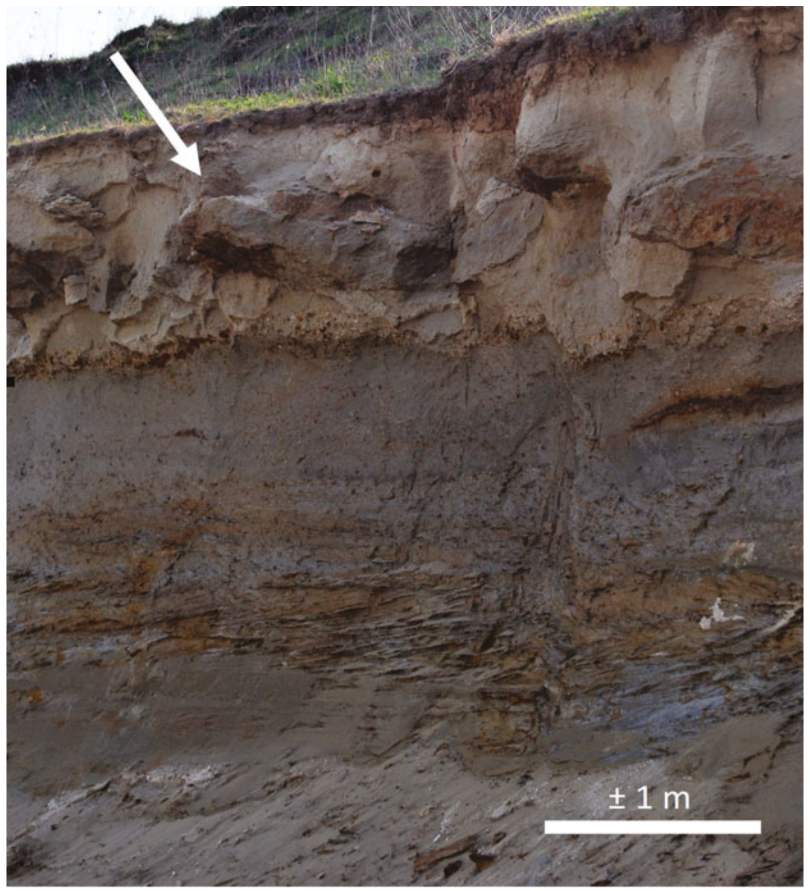
Location and geology



Northern Belgium is dominated by a sequence of clastic Cenozoic sediments. Lede stone occurs as lithified horizons in the sand deposits of the Lede Formation (middle Eocene, Cenozoic). The prevailing glauconite and both benthic and planktonic microfossils are indicative of its shallow marine nature. Unpublished stable isotope analysis further indicates the carbonates in the range of common marine limestones. However, diagenetic carbonate cementation is believed to have occurred from reprecipitation of marine carbonates under fluctuating continental ground water levels. The Lede Formation outcrops in an almost east-west strike between Brussels and Ghent.

Quarries

In its eastern outcrops, around Brussels, Lede stone is mainly quarried in small underground quarries, while towards center and the west it is more dominantly quarried in open air pits. As the number of stone banks is often limited to less than three, and the thickness to a few decimeters, the horizontal extension of stone sourcing must have been significant. Indeed, many landscape relicts can be found over a large area between Brussels and Ghent, of which some can historically be directly attributed to Lede stone extraction. The contemporary last quarry ceased to exist by the end of the 19th century. Subsequently, initiatives were undertaken to explore new resources for restoration purposes,. This led to the re-opening of new quarries in Balegem and Bambrugge. However, by the mid 1920's also these quarries ceased. In the 1960's, a new quarry opened in Balegem. This quarry exists to date but it's production is limited, giving the stone an exclusive character. It is mainly used for restoration works.



Quarry Balegro in Balegem, showing discrete stone banks in the sandy deposits of Lede Formation, overlying the cross-beddet sands of Vlierzele Mbr.

Architectural and cultural impact

The first documented use dates back to Roman times, which is evidenced by archaeological findings of water wells. The main historic buildings in Lede stone, however, were constructed in late medieval and early modern times. This coincides mainly with the emergence of gothic architecture, renaissance and to a lesser extent with baroque, which are strongly represented in the historical built environment of the Low Countries. It is also used in more traditional and vernacular buildings, which not necessarily show the majestic features typical to the main styles. In the 19th and 20th century, the number of new buildings drastically increased. These were mainly built in neo- and revival styles, and new stiles as art nouveau, art deco and modernism. This coincides with increased international trade, and the establishment of railways, which marginalizes the use of Lede stone in these more recent buildings and instead favored the use of foreign limestones which were available in larger quantities.

Late Gothic guild house of the Free Boatsmen in Ghent, Belgium, with front façade entirely constructed and decorated with Lede stone.

Main references

De Kock, T., Turmel, A., Fronteau, G., Cnudde, V., 2017. Rock fabric heterogeneity and its influence on the petrophysical properties of a building limestone: Lede stone (Belgium) as an example. Engineering Geology, 2016, 31-41. DOI10.1016/j.enggeo.2016.11.007;

De Kock, T., Boone, M., Dewanckele, J., De Ceukelaire, M., Cnudde, V., 2015. Lede Stone: A potential "Global Heritage Stone Resource" from Belgium. Episodes, 38(2), 91-96.;

De Kock, T., 2020. Perceptions of stone: some examples from the historical use of Lede stone, Belgium. In: Siegesmund, S. & Middendorf, B. (eds.), Monument Future: Decay and Conservation of Stone: proceedings of the 14th International Congress on the Deterioration and Conservation of Stone. Halle: Mitteldeutscher Verlag, 1047-1052.

LIOZ LIMESTONE

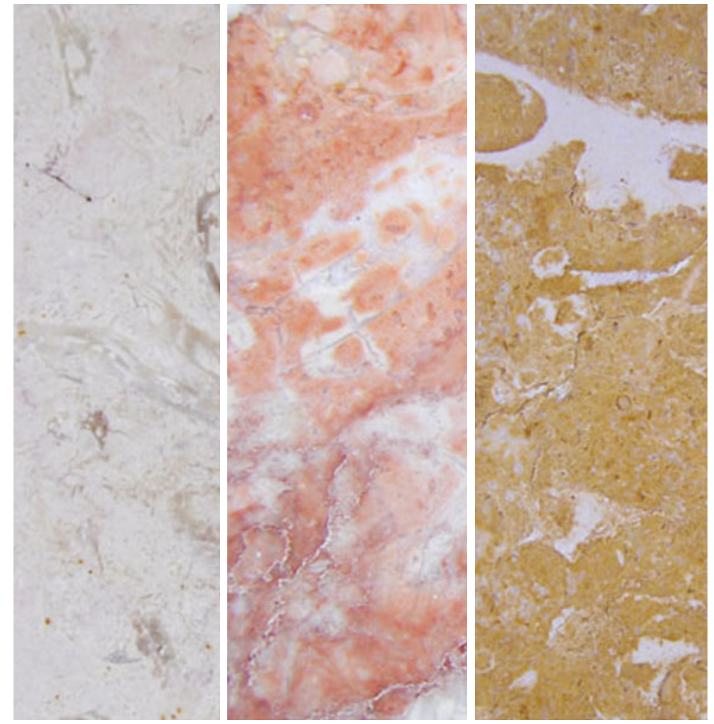
PORTUGAL

The Belém Tower in Lisbon

From the old to the new world

Zenaide C. G. Silva

Lioz is a Cretaceous, microcrystalline limestone which occurs in Portugal and outcrops in Lisbon and neighboring counties. Its color is usually ivory and, less commonly, pink. Rudist fossils imprint a unique pattern on the rock, contributing to its decorative application.
The rock has been used in Portugal in constructions from the sixteenth century to the present, mainly in Lisbon, on monuments, official buildings and churches of different ages. Due to its wide use during the eighteenth century, Lioz got recognition as the Royal Stone.
The rock was carried to Brazil as vessel ballasts during the time of intense commercial activity between Europe and the New World.
The path followed by its use in Portugal and in old Portuguese Colonies (Silva, 2017, 2019) led it to the status of a Heritage Stone in 2019.



Lioz Encarnadão Amarelo Negrais

Varieties of the Lioz limestone

Petrography

Microcrystalline bioclastic limestone

Geological setting

Mesozoic – Cretaceous – Mid Turonian

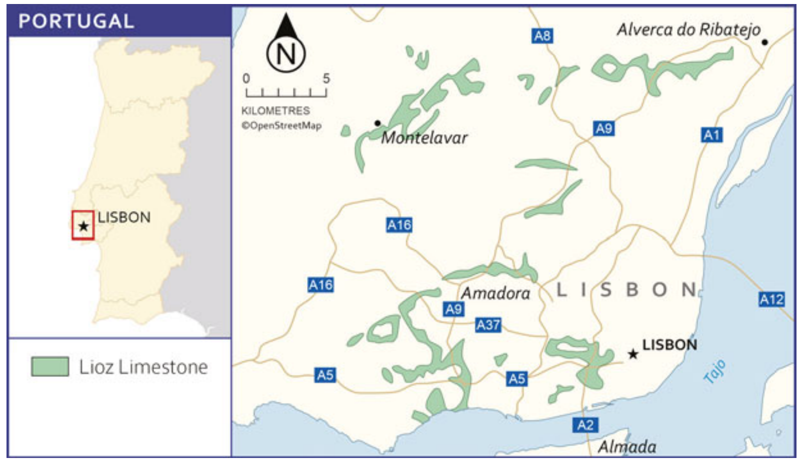
Occurrence

Lisbon, Sintra, Negrais, Pero Pinheiro, Oeiras and Paço d'Arcos, Portugal

Petrography

Lioz is a calcite microcrystalline, bioclast limestone containing Rudists fossils, bivalves of Cretaceous age. Ivory or light pink coloured varieties are common, but those as Encarnadão, the dark pink or red Lioz, and Amarelo Negrais, a dark yellow type, are also known, corresponding to facies variations.
The light gray variety is found in small amounts in old buildings or churches as a decorative material.
Two different cuttings of Lioz, parallel or across the bedding surfaces of the Rudists shells, give different appearances to the rock. Under the microscope, they are all biosparite and microsparite.

Location and geology



Lioz Limestone occurs in a Cretaceous (Mid Turonian) Unit described initially by Choffat (1900) as a crystalline limestone with Rudists, whose stratigraphy was summarized by Zbyszewski (1963) and identified as corresponding to shallow clear and warm water, typical of reef environ-ment by Callapez (2008).
The area of occurrence is mainly the disc-tricts of Lisbon, in Alcântara, Campolide and Belém, where the limestone sequence was exposed in quarries. The rock occurs also in areas surrounding Lisbon, such as Sintra and neighboring counties: Pêro Pinheiro, Morelena and Negrais.

Quarries

Lioz limestone quarry at Pêro Pinheiro

Outcrops of Lioz Limestone are identi-fied in a few localities in Lisbon and between Lisbon and Sintra, such as Oeiras and Paço d'Arcos, where the rock was used in constructions.
Most old quarries in Lisbon are un-known at present; nowadays, the locality which best witnesses the past and present exploitation of Lioz Limestone is Pêro Pinheiro, where old and current quarries can be visited.

From Pêro Pinheiro, a great volume of rock was extracted in the eighteenth century to build the Mafra Complex.

Architectural and cultural impact

Throughout centuries architects have used Lioz in construc-tions and as a decorative element. Mineral compo-sition, texture, colour variation and textural patterns related to the cutting orientation are all strong features to justify that use. In Lisbon, near Alcantara quarry, the old Acqueduct (Águas Livres) was built between 1713 and 1748, and in Belém historic monuments such as the Belém Tower, Jerónimos Monastery, and the Cultural Center of Belém (from the 15th to the late 20th century), built in Lioz, feature different architectonic styles to celebrate episodes of Portuguese history.
The baroque Mafra Complex, a large architectonical ensemble of three buildings – Basilica, Library and Convent – built during the reign of D. João V, exhibits all varieties of Lioz, displayed as decorative elements in inlays in pavements, altars and chapels.
The meaning of each piece of rock at Mafra is beautifully described by Gandra (1995, 1998). During the sixteenth and seventeenth centuries, the Jesuits had a great influence on the architecture of churches in Portugal and abroad. In Brazil, at that time a Portuguese colony, and in Bahia, the first capital of Brazil, the Jesuit model was followed all over. Several religious orders built their churches as copy of Portuguese ones, and Lioz was always present.
At the Jesuit Cathedral Square and vicinity, the neighbor São Francisco Church is one of the most representative pieces of Baroque art in Brazil. Its cloister is built in Lioz and the main altar pavement shows a notable work of inlays in Lioz, also found in other contemporary churches, transferring fashion and styles from Europe, recognized as a vehicle of culture and art between Portugal and Brazil, as summarized by Silva (2007): "In this way, the Portuguese Lioz had its life cycle defined, carrying an enormous cultural burden from Europe to Brazil.
From Cretaceous Portuguese seas, around 120 million years ago, it left the quarries from Pêro Pinheiro area, crossed the Atlantic Ocean as vessels ballasts and in Salvador it became art in Convents and Churches of Bahia".

Lioz lavabo at Misericordia Church. Salvador, Bahia, Brazil

Main references

Callapez, P.M. (2008). "Paleobiogeographic evolution and marine faunas of the Mid-Cretaceous Western Portuguese Platform." Thalassas, 24(1), p. 29 – 52.

Silva, Z.C.G. (2017). "The Portuguese lioz, a monumental limestone." In: 2017 EGU General Assembly. 19, EGU 2017-9019.

Silva, Z.C.G. (2019). "Lioz – a Royal Stone in Portugal and a Monumental Stone in Colonial Brazil." Geoheritage, 11, p. 165 – 175. https://doi.org/10.1007/s12371-017-0267-7.

PIEDRA MAR DEL PLATA

ARGENTINA

Sea Lion. Photo: Lia Trucco

The stone that defined an architectural style

Eliane Aparecida Del Lama
after F. Cravero et al.

Piedra Mar del Plata is a well-known stone from the city of Mar del Plata (a famous beach resort on Argentina's Atlantic coast) used to create an architectural style that represented the rise of the middle class in between 1930-1950 and has become an Argentine heritage. Until then, the city's style had been of mansions built by wealthy families using imported stone.
Piedra Mar del Plata was used in houses, statues and monuments not only in the city of Mar del Plata, but also in the province and city of Buenos Aires. It is a solid stone of high hardness, resistant to chemical and physical weathering, with no problems of salt crystallization.

Piedra Mar del Plata

Petrography
Sandstone

Geological setting
Paleozoic- Cambro-Ordovician;
Balcarce Formation

Occurrence
Between the cities Mar del Plata and Balcarce, in the Batán area; Argentina

Petrography

Piedra Mar del Plata is a quartz sandstone with 98% of the clasts made up of subangular quartz around 0.1 mm in size.
The matrix is made up of clay minerals and sericite with siliceous cement. Its colour varies from yellowish white to light gray, and it can appear reddish due to iron oxide staining.

Location and geology

The major outcrops of this stone are found between the cities of Mar del Plata and Balcarce, in the southernmost region of the Rio de la Plata Craton, in the Tandilia System. Three sedimentary units were deposited at the base of this system, and Piedra Mar del Plata comes from the upper unit, the Balcarce Formation, of cambrian-ordovician age, formed in coastal and platform environments influenced by tides and storms.

Quarries

The most important quarries are located in the Batán region, about 10 km from Mar del Plata. Quarrying began in the late 19th and early 20th centuries, with production peaking in 1965 when there were 21 active quarries. In 2011, however, there were only 11 active quarries.

Yaravi quarry

Architectural and cultural impact

Argentina is a big country, but it has few stones suitable for construction. Against this backdrop, during in between 1930–1950, Piedra Mar del Plata stood out and gave rise to an architectural style in the city: Mar del Plata style, also known as marplatense.

The new style adapted the main features of the grand mansions of the Belle Époque to a domestic scale. The Mar Del Plata-style chalet captured the main characteristics of eclecticism for the domestic space: sandstone façades, chimneys, front porches, French tiles, gable roofs, dormers and projecting eaves.

At that time, social mobility in Mar del Plata was much more dynamic than in Buenos Aires, allowing the rise of the middle class through tourist services and the growth of the construction and commercial sectors.

The 2 sea lion sculptures located on the esplanade in front of Plaza Colón – made with this stone by the artist José Fioravanti in 1941 – are an unmistakable symbol of the city. This stone has been used for over a century, and its use reflects the social and architectural changes of an important period in Argentina.

Mar del Plata-style chalet, Isla family (Marazzato, 1941). Mar del Plata architectural heritage

Main reference

Cravero, F., Ponce, M.B., Gozalves, M.R., Marfil, S.A. (2015). "'Piedra Mar del Plata': An Argentine orthoquartzite worthy of being considered as a 'Global Heritage Stone Resource'". Geological Society, London, Special Publications 407: SP407.21. Pereira, D., Marker, B.R., Kramar, S., Cooper, B.J. and Schouenborg, B.E. (eds) 2015. Global Heritage Stone: Towards International Recognition of Building and Ornamental Stones. Geological Society, London, Special Publications, 407, p. 263 – 268. https://dx.doi.org/10.1144/SP407.9.

PIETRA SERENA SANDSTONE

Italy

Columns in Pietra Serena sandstone in Loggiato dei Serviti (Florence)

The stone of Renaissanse

Fabio Fratini
Elena Pecchioni

The most used material in the Florentine Renaissance architecture is Pietra Serena, a sandstone that in the following centuries has been used in architectural decoration throughout Tuscany.
In Florentine architecture, the cerulean colour of this sandstone, used in colonnades, pilasters and string-course cornices, contrasts with the white renderings providing a unique the Renaissance style.
There is also a variety of Pietra Serena called Pietra Bigia, yellow-brown in colour, whose use has been in fashion from the 16h century. Pietra Serena is a workable material.
Indeed, the absence of sedimentary structures like convoluted laminations and calcite veins provides a high degree of homogeneity although durability is not high due to the presence of a clay matrix.

Image of a florentine palace with a stone manufact in Pietra Serena sandstone.

Petrography

Petrographical studies reveal a sandstone rich in clay matrix with a low amount of carbonate cement (calcite). A high presence of calcite as sparitic cement can be observed only in some layers of this sandstone, for example, in Gonfolina quarry.
The clastic grains consist of quartz, feldspars, fragments of metamorphic and magmatic rocks, muscovite and biotite, often transformed into chlorite. This sandstone can be classified as lithic arkose.

Petrography
Sandstone; clay matrix with a low amount of carbonate cement

Geological setting
Upper Oligocene to Lower Miocene, submarine landslides of Tuscan Sequence of the Northern Apennines

Occurrence
North Appennines and Chianti Mountains, Italy

Location and geology

Pietra Serena is the name given by masons and architects to the sandstones of the Macigno and Monte Modino Formations (Upper Oligocene/Lower Miocene) cropping out in the Northern Apennines.
These sandstones were formed in turbidity currents, better known as submarine landslides, capable of moving and transporting large quantities of material from the coastal zone to great sea depths.

These formations are part of the Tuscan Sequence of the Northern Apennines in the stratigraphic succession with the Scaglia Toscana Formation (formerly Scisti Policromi). The maximum thickness (reaching about 3000 m) occurs along the Monte Orsaro-Monti del Chianti line.

Quarries

Fiesole, on the hills to the north of Florence, gives evidence of the use of Pietra Serena in antiquity. After the Etruscans and Romans, the Lombards capitalized on the stone.
There is little evidence of use of Pietra Serena during the early Middle Ages; however, from the 13th century, the Florentines employed this stone extensively, acquiring the stone from the quarries located very close to the city.
At first, the quarries of Fiesole met the demand, but in the 15th century the opening of new quarries in the same place in the hills to the north of the city (Mugnone valley, Settignano) and to the west along the Arno River (Gonfolina) became necessary.
Other quarries were opened in more recent times to the south of the city (Tavarnuzze-Montebuoni and Greve).

Quarry of Pietra Serena sandstone in the hills of Florence

Architectural and cultural impact

The use of Pietra Serena for architectural decoration and domestic, religious, and civil objects is known from the archaic period, as documented by the Etruscan stelae found in Fiesole, a small city on the hill north of Florence. Then, it was used by the Romans and the Lombards, as shown by tombs covered by Pietra Serena slabs and one/two reused capitals present in the crypt of the Fiesole Cathedral. There is no evidence of continuity in the use of Pietra Serena in the early Middle Ages but, starting in the 13th century, the Florentines began to use the stone with the development of the free commune of Florence.
The urban expansion of Florence and the new style proclaimed by illustrious artists (above all, Brunelleschi), whose most salient artistic characteristic was the use of monolithic blocks and the grey-white contrast of Pietra Serena with renderings or marble (the renaissance style), brought Pietra Serena to its greatest use in the 15th century. Among the most important monuments of this period are Spedale degli Innocenti, the churches of San Lorenzo and Santo Spirito with their imposing monolithic columns (by Brunelleschi), the Laurentian Library and Sagrestia Nuova of San Lorenzo (by Michelangelo Buonarroti), the Uffizi building (by Vasari) and Loggia del Mercato Nuovo.
By the second half of the 16th century, Pietra Serena had assumed such prestige that the extraction from the quarries sited around Florence was strictly linked to the embellishment of the city, capital of the Grand Duchy of Tuscany, to exalt the power of the ruling house.
However, the Renaissance style had come into fashion and spread to the whole of Tuscany, so it became necessary to supply Pietra Serena from quarries scattered throughout the region.

Staircase in Pietra Serena sandstone of the Laurentian Library realized by Michelangelo Buonarroti (Florence)

Main references

Carmignani, L., Lazzarotto, L. & Coordinators 2004. Carta Geologica della Toscana 1:250.000, Direzione delle politiche territoriali e ambientali – Servizio Geologico Italiano, Regione Toscana;

Fratini, F., Pecchioni, E., Cantisani, E., Rescic, S., Vettori, S. (2015). “Pietra Serena: the stone of the Renaissance.” in: Pereira, D., Marker, B.R., Kramar, S., Cooper, B.J. and Schouenborg, B.E. (eds) 2015. Global Heritage Stone: Towards International Recognition of Building and Ornamental Stones. Geological Society, London, Special Publications, 407, p. 173 – 186. https://dx.doi.org/10.1144/SP407.11.

PODPEČ LIMESTONE

Slovenia

Bench made of Podpeč limestone, interior of National University Library - UNESCO World heritage list. Photo: Barry Cooper

A black and lustrous limestone with white litioid shells from Slovenia

Sabina Dolenec, Boštjan Rožič, Ana Mladenović, Mojca Bedjanič, Maja Gutman Levstik, Nina Žbona, Nina Zupančič

Podpeč Limestone is distinguished by its dark grey to nearly black colour adorned with white fossil shells of the mollusc *Lithiotis*. This Lower Jurassic formation occurs in southern and south-western Slovenia.
The main quarry is located near the village of Podpeč near Ljubljana, and has been recognised as a geological site of national importance and it is officially protected as a natural monument.
The utilisation of Podpeč Limestone was first documented during the Roman period in Slovenia.
The internationally renowned Slovenian architect Jože Plečnik (1872-1957) used Podpeč Limestone in various Slovenian buildings, some of national importance and included in the UNESCO World's heritage list.

Façade cladding, Triglav insurance company palace – monument of national importance

Petrography

Limestone with organic matter, and white in colour due to the pure low Mg calcite (sparite) in fossil bivalves.

Geological setting

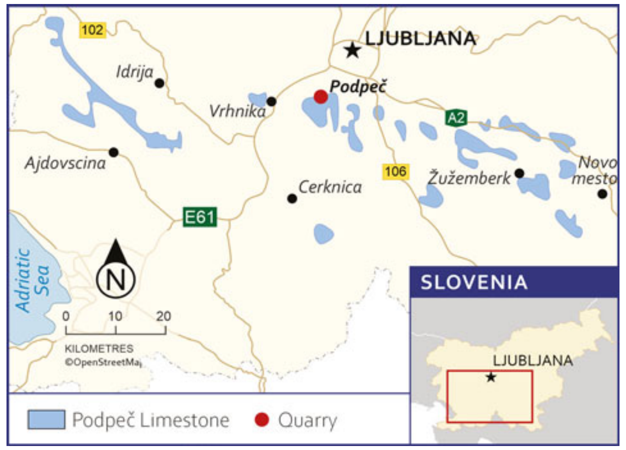
Mesozoic – Early Jurassic – Pliensbachian – Lithiotis Horizon; Dinaric Carbonate Platform

Occurrence

Podpeč, SW of Ljubljana, Slovenia

Petrography

Podpeč Limestone is dark grey or black in colour with white fossil shells. Styliolites are present with associated limonitization and chromatic variation occurring as a consequence of the dark grey limestone weathering to light grey hues.
Its composition includes calcite, with the limestone being black due to the presence of organic matter, and white due to the pure low-Mg-calcite (sparite) fossil bivalves. Some shells are dolomitized, and quartz also occurs as terrigenous grains.



Location and geology

Paleogeographically the Lithiotis Horizon (including the Podpeč Limestone) is situated within the shallow water lagoonal facies of the Dinaric Carbonate Platform.
It is interstratified within ooidal limestones. Other types of lagoonal limestones are present, and are mainly non-fossiliferous or contain large benthic foraminifers, gastropods and bivalves.
Today the Lithiotis Horizon is interpreted to extend across the entire External Dinarides of southern and south-western Slovenia. Some localities are reported also from the Julian Carbonate Platform, which is located today in the Julian Alps. The Lithiotis Horizon beds have been dated as Early Jurassic, or more precisely the Domerian substage of the Pliensbachian Stage.

Quarries

The main quarry of Podpeč Limestone is located close to the village of Podpeč, approximately 10 km southwest of the Slovenian capital of Ljubljana, hence its name. At present, there is no active quarrying of Podpeč Limestone.
The current protection regime accords the principal quarry status as a geological site of national importance.
This does not allow re-opening of the quarry with natural stone extraction for economic gain.
However, under certain conditions it is possible to extract small quantities of stone for the renovation of cultural monuments of great importance. In addition to the main source quarry, Podpeč Limestone has been sourced from a few smaller quarries along the outcrop continuation from the Podpeč Village towards Mt. Krim, all of which have now been abandoned.

The main quarry of Podpeč Limestone – Podpeč quarry – geological site of national importance. Photo: Valentin Benedik

Architectural and cultural impact

Podpeč Limestone holds a rich historical significance in Slovenia, with documented use dating back to the Roman period. The quarry at Podpeč provided limestone for various constructions such as funerary stelae, votive altars, and boundary stones. During the Roman Empire, the material was transported along the Ljubljanica river to Emona (present-day Ljubljana) where it was extensively utilized in prominent buildings.
After the collapse of the Roman Empire, stone-cutting ceased at Podpeč for centuries until the material regained recognition towards the end of the 19th century. Before the first half of the 20th century, there were few significant stonecutting workshops in Podpeč.
However, after this period, there was a resurgence in its use, with Podpeč Limestone becoming widely utilized in Ljubljana and central Slovenia for various architectural elements.
Renowned Slovenian architect Jože Plečnik played a pivotal role in popularizing Podpeč Limestone.
Throughout his career, he incorporated the stone into numerous iconic buil-dings, including the Central Stadium in Ljubljana, the National University Library (UNESCO World's Heritage list), and various churches and monuments across Slovenia. Some other important buildings with Podpeč Limestone are Slovenian Parliament, High rise building, etc.
The utilization of Podpeč Limestone extended beyond Slovenia's borders. Notably, parts of the Antonius Church in Belgrade, Serbia, feature Podpeč Limestone. Plečnik's innovative use of local materials, including Podpeč Limestone, contributed to the unique character of Slovenian architecture, leaving a lasting legacy that continues to inspire architects and admirers alike.
In summary, Podpeč Limestone holds a significant place in Slovenia's architectural heritage, from its Roman origins to its resurgence in the modern era, driven in part by the visionary work of Jože Plečnik. Its utilization in iconic buildings both domestically and internationally underscores its enduring appeal and contribution to the cultural landscape of Slovenia.

Interior of National University Library with Podpeč limestone.
Photo: Valentin Benedik

Main reference

Kramar, S. et al. (2015). 'Podpeč limestone: a heritage stone from Slovenia'. In: Pereira, D., Marker, B.R., Kramar, S., Cooper, B.J. and Schouenborg, B.E. (eds) 2015. Global Heritage Stone: Towards International Recognition of Building and Ornamental Stones. Geological Society, London, Special Publications, 407, p. 173 – 186. https://dx.doi.org/10.1144/SP407.11.

PORTLAND STONE

United Kingdom

Jordans Basebed in a store in London

English oolithic limestone used extensively for two millenia

Terry Hughes
Graham Lott †
Michael Poultney
Barry Cooper †

Portland Stone is a cream-coloured oolitic limestone of late Jurassic age. It outcrops in southern England particularly in the Isle of Portland. Three stones are worked: Whit Bed, Roach and Base Bed. Respected as a construction material throughout the British Isles it has been used for 2000 years, but its wider use began in the 17th century.
Available in block sizes up to several cubic metres it is of high quality as a carvable freestone and its pale colour, and the ready access to shipping, increased its use especially in London in the redevelopment after the 1666 Great Fire.
It is England's premier modern building stone. Internationally it has been used in the United Nations building New York and for memorials of British Commonwealth dead from two World Wars and up to the present day.

Portland Stone (width: 12cm)

Portland Stone (width: 12cm)

Petrography
Ooidal and bioclastic Limestone

Geological setting
Mesozoic- Upper Jurassic (Upper Tithonian);
Portland Limestone Formation

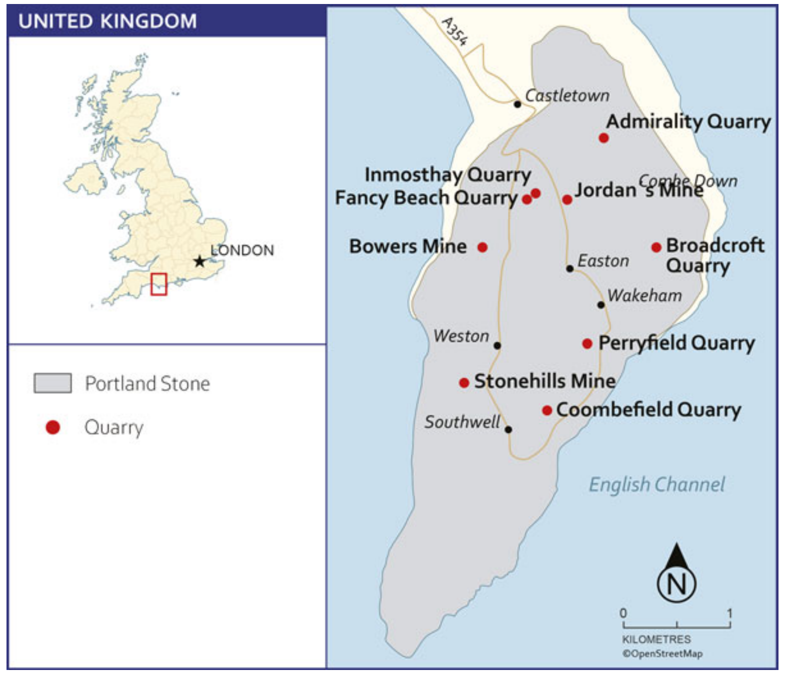
Occurrence
Isle of Portland, Dorset, United Kingdom

Petrography

Portland Stone shows a grain-dominant, cement-poor texture, with individual ooliths around 0.3-0.4 mm in diameter. It contains very little permeability-reducing lime mud between the grains and the pore space is well-interconnected allowing ready drying of the stone, so that it is not susceptible to weathering damage from water-based processes.
Its pale colour indicates that it contains few sulphide minerals and that therefore less carbonate-dissolving acidity is produced when the stone becomes wetted.The stone has a variable fossil content.
One variety of Roach displays prominent cavities (up to c. 50 mm long) representing the moulds of dissolved aragonitic gastropods (Aptyxiella portlandica being the most common) and bivalve shells. In contrast the Base Bed is almost free of shelly fossils, and the Whit Bed has a variable content, which ranges from scattered oyster shell debris to cross bedded shell-rich horizons, and meter-scale patch reefs of oysters, bryozoans, and coralline algae (Arkell, 1947).
The durability of the stone is partly attributed to the low porosity and the mechanical strength of the individual ooliths, which have been made stronger and more rigid by calcite cement infilling of microcavities produced by boring microbes, and also to compression of the ooliths, forming a compact grain supported texture, augmented by a thin cement at grain junctions.

Location and geology

Portland Stone is today quarried only on the Isle of Portland. Geologically, it lies on the southwest margin of the Permian-Mesozoic succession of the Wessex Basin.
The exploited beds all come from the Portland Freestone Member, of the Portland Stone Formation, Tithonian age Portland Group.
The sequence is 10-15 m thick and was deposited in a shallow tropical marine environment, accumulating in oolitic sand shoals.
The pale colour of the stone is attributed to a drop in sea level soon after deposition, preventing formation of iron sulphides during burial in the marine sulphate reduction zone.
The uplifted sediment was rapidly lithified by meteoric water derived from the overlying freshwater deposits (Purbeck Beds), and which accelerated the dissolution of the aragonitic shelly component.



Quarries

Historically, Portland Stone was quarried from cliff-fall material. The expansion of stone working from quarries on the island top took place in the 19th century, with stone transported by rail or ship. In its early days the stone was lowered by ropes onto small boats or barges.
By the mid 20th century, many of the earlier quarries had become amalgamated and much of the increasingly rare stone was lying beneath increasingly thick overburdens.

Today underground mining by Albion Stone uses the room and pillar method.
Slots are cut into the top, bottom, sides and middle of the stone mass and blocks are broken off at the back with an inflated steel pillow without stressing the stone, giving a higher yield, and saving valuable reserves for future generations.

Jordan´s Mine, Isle of Portland, England

Architectural and cultural impact

Early construction: Rufus Castle (1080); Palace of Westminster (1347); First stone London Bridge (1350); Exeter Cathedral and Christchurch Priory (14th century); Portland Castle (c.1540); Hurst Castle (1540); Banqueting Hall London (1619).
Wren churches London: St Paul's Cathedral (1667-1713); St Martin's in the field; St Mary-Le-Bow; St Brides Church, Fleet Street; Christ Church, Spitalfields (Hawksmoor); St Annes Limehouse (Hawksmoor); St George in the East (Hawksmoor); St George, Camden (Hawksmoor); St Leonard, Hackney; St Pancras new church; St George, Hanover Square, Mayfair.
Regional administrative buildings and City of London: Reform Club (Charles Barry); Royal Naval College, Greenwich; Maritime Museum, Greenwich; Bank of England (1826); General Post Office (1829); Somerset House (1776-92); Grosvenor Place, Belgravia; Oxford Street, Regent St, Bond St, Mayfair, Knightsbridge and Belgravia; County Hall, London (1911); Town Halls: Deptford, Cardiff, Nottingham; British Museum (1753); Buckingham Palace; Fitzwilliam Museum, Cambridge; Parliament House, Stormont, Northern Ireland (1932).

Recent buildings: 27-33 Finsbury Square, London; New London Stock Exchange; New Bar Library, Belfast; BBC Broadcasting House, London; Lisburn Civic Centre, Northern Ireland; Imperial War Museum; Shell Centre, London (1950 skyscraper); Arundel Great Court, London; St James' Market, London; Cabot Circus, Bristol.
Other countries: United Nations Headquarters building, NewYork City, USA; National Gallery of Ireland, Dublin Ireland; Custom House, Dublin, Ireland; Trinity College, Dublin, Ireland; Parliament Building (now Bank of Ireland), Dublin, Ireland; Casino Kursaal, Ostend, Belgium; Chubu Electric Building, Japan; Auckland War Memorial and Museum, Auckland, New Zealand; Flanders Memorial Garden, Canberra, Australia.
Sculptures: Cenotaph Whitehall London; Monument (to Great Fire of London); Tibetan peace garden Imperial War Museum; Armed Forces Memorial; Bomber Command Memorial, London; British Memorial Garden, New York; Headstones for British and British Commonwealth personnel killed in war during and since World War 1.

St. Pauls Cathedral, London, England: Portland Whitbed and Basebed

Main reference

Hughes, T., Lott, G.K., Poultney, M.J. and Cooper, B.J. 2013. Portland Stone: A nomination for "Global Heritage Stone Resource" from the United Kingdom. Episodes 36(3), 221-226.

RADKOW SANDSTONE

Poland

Chrobry Embankment (Wały Chrobrego), Szczecin.

Inconspicuous rock in the beautiful architecture of Poland, Germany and beyond.

Katarzyna D. Zagożdżon

The Radkow sandstone is outstanding because of the petrographical variance in grain size and color, its characteristic weathering color, its use for building stones as well as for sculpture even it is not fine grained. The sandstone has an interesting quarrying history and an interesting history of use.

The first utilisation is associated with the processing of large loose blocks on the mountainside. The first quarries belonged to Germany and now to Poland. From the end of the 19th to the middle of the 20th century many valuable architectural structures were built in Germany, especially in Berlin, and in several neighbouring countries for example in Latvia and in Denmark.

Among them were UNESCO World Heritage sites, such as the Colonnades in Potsdam-Sanssouci, and the Bode Museum on Museum Island in Berlin. After 1945, large quantities of sandstone were used for the Old Town of Warsaw, which is also an UNESCO World Heritage site.

Radkow sandstone color varieties

Petrography
Sandstone, Subarenite

Geological setting
Mesozoic – Cretaceous – Middle Turonian; Mid-Sudetic synclinorium

Occurrence
Stołowe Mountains, Lower Silesia, Poland

Petrography

The Radkow sandstone is a feldspar-quartz subarenite. It contains 60-84 % quartz, 6-21 % feldspar, 3-24 % rock fragments and 3-6 % clay. Muscovite, tourmaline and zircon grains are present in subordinate amounts. Inclusions of small hematite crystals in the feldspars give their surfaces, and the rock, a reddish color, while limonite colors the rock yellow. This Fe-content causes the typical red-brown patination of the surface after some time exposed.

The structural parameters vary with the large variance in grain size: the fine-medium-grained varieties are better sorted and are comparatively better rounded than the coarse-grained varieties. The bond is siliceous-clayey via grain contacts, thin siliceous growth seams and clayey grain seams.

This siliceous-clayey bond, together with the significant feldspar content, is the reason for the good workability of the sandstones with high strength at the same time.

Location and geology

The Stołowe Mountains are located in the western part of the Kłodzko region in SW Poland.
The height of the range varies between 400 and 919 m. It is a unique area in Poland with outstanding landscape and scientific values. They are the only example of mountains with plate relief, characterized by unique morphology and a great variety of sandstone erosion forms.
There are three main lithosomes of Cretaceous sandstones: the Upper Cenomanian, Middle and Upper Turonian.
Their sedimentation occurred in the epicontinental zone of the Tethys Sea from 98 to 86 Ma. The Middle Turonian Radkow Sandstone delivered the most significant quantities of building stones.
The outcrops are located in particular on the northern slope of the Stołowe Mountains.

Quarries

Before systematic extraction began in the quarries, the loose blocks, some of which were very large (up to 20 cubic metres), were recovered on the slopes and at the foot of the Stołowe Mountains.
The origin of the Radków quarry is linked to Carl Schilling, a master stonemason from Berlin. In 1882, he established a stonemason's workshop, and in 1895 he leased a site at the foot of the Szczeliniec massif.
The increase in demand for stonemasonry products at the beginning of the 20th century led Schilling to build a modern factory, which employed 600 people in 1905.
In the 1980s, mining was carried out on five levels. Currently, the quarry area is an enclave within the National Park of the Stołowe Mountains and occupies an area of 9.76 ha. There had been several other quarries in operation between 1880 and 1950, which were run by local tenants.

Radków quarry

Architectural and cultural impact

No precise date is known for the start of sandstone quarrying in the Stołowe Mountains. At first the sandstone was used locally for mill, grinding and quern stones, for road construction as well as for secular and sacred buildings.
The town hall, parish church and many sculptures in Radków were made of this sandstone, but quickly it was found useful throughout Silesia. In Kłodzko it was utilized as a structural element of the medieval St. John's Bridge, in the parish church, for the construction of the town hall and Renaissance townhouses.
In the basilica in Wambierzyce, sandstone was used for, among other things, a baptismal font and altar mensa dating back to the 12th / 13th century.
In Wrocław the sandstone was used at the city hall and at several churches. Its use outside the region began after the conquest of Silesia by Prussia in the 1760s. From then on, Radkow sandstone began to gain increasing recognition in the building industry, especially in Berlin and Brandenburg. Transportation of raw material over such distances was very difficult at the time - for example, to build the colonnade of the New Palace (Sanssouci) in Potsdam, it was necessary to transport 6,000 tons of sandstone over a distance of about 450 kilometers. It is likely that the semi-finished products for the colonnade were transported on horse-drawn carts with specially constructed wheels. Railroad construction in the 19th century led to an intensification of exploitation as it allowed the sandstone to be easily transported over long distances.
From the end of the 19th to the middle of the 20th century the quarries provided large quantities of building material, thanks to which valuable architectural structures were built in many European cities for example in Riga, Copenhagen and Den Haag.
In 1909, the sandstone for a monument plinth was even taken to Dar es Salaam in Tanzania. Among them were UNESCO World Heritage sites, such as the Colonnades in Potsdam-Sanssouci, the Bode Museum on Museum Island in Berlin and the Old Town in Warsaw.

Colonnades (1769) in Park Sanssouci, Potsdam. Photo: Ulf Schönitz

Main references

Ehling, A. (2012): Bausandsteine in Schlesien.- Ehling, A. & Siedel, H. (Eds.): Bausandsteine in Deutschland, Vol. 2 Sachsen-Anhalt, Sachsen und Schlesien (Polen); Schweizerbart.
Jerzykiewicz, T., Wojewoda, J., (1986). The Radków and Szczeliniec sandstones: an example of giant foresets on a tectonically controlled shelf of the Bohemian Cretaceous Basin (Central Europe).- In: Knight, R.J. and McLean, J.R. (Eds.): Shelf sands and sandstones. Canadian Society.of Petroleum Geology, Memoir II, 1-15; Calgary.
Migon, P. (2024): Diversity of added cultural values to geomorphosites – Evidence from sandstone landscapes of Central Europe.- Geomorphology, volume 451. www.sciencedirect.com/journal/geomorphology

RED EREÑO

Spain

Fountain built in 1894 located in Iturribide Street, Bilbao (Spain).

Cretaceous rudist platforms - from natural construction to cultural heritage

Laura Damas Mollá

Red Ereño is a limestone with a red micritic matrix and abundant white and grey coloured fossil shells of rudists. This colour contrast confers its character as an ornamental stone.
This limestone unit is part of an Urgonian succession (Aptian-Albian, Lower Cretaceous) that outcrops in the North of the Iberian Peninsula, in the Basque Country (Spain). It has been used as an ornamental stone from the 1st century AD until the end of the 20th century. In the Basque Country, it has been used extensively and its use largely defines the urban landscape of the Old Town and the Ensanche in cities such as Bilbao (Bizkaia, Spain).
This stone has been exported throughout Spain and internationally, and elements built with Red Ereño can be found in Italy and America.

Detail of the floor slab of the main entrance of St. Peter's Basilica in the Vatican made in polished Red Ereño with Polyconitid rudists in cross section.

Petrography
Biomicritic limestone with abundant fossil content, mainly rudist shells

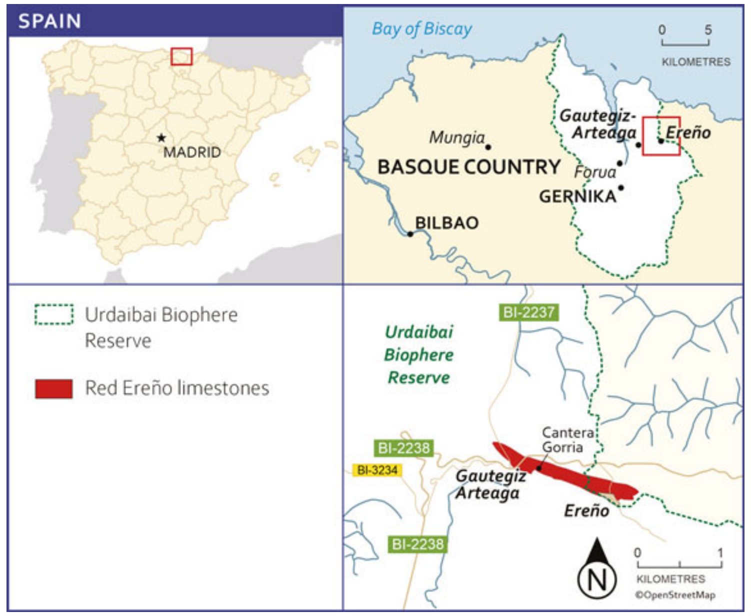
Geological setting
Mesozoic – Cretaceous – Aptian-Albian; Santimamiñe Limestone Unit

Occurrence
Ereño and Gautegiz-Arteaga villages (Bizkaia), Spain

Petrography

Red Ereño is a biomictic limestone with abundant fossil content (Boundstone). Mainly bivalves are preserved, especially rudists (polyconitids, requenids and monopleurids) and Chondrodonta sp. Remains of echinoderms, corals, bryozoans, gastropods and benthic foraminifera are also recognised as allochemicals components.
The main mineral is calcite, with some traces of quartz and clay minerals. The impregnation of the matrix with ultrafine-grained pigmentary haematite during diagenesis gives it its characteristic red colour.Early diagenetic processes modified the rudist shells: The aragonite of the inner layer is transformed into calcite (white) and the prismatic calcite of the outer layer (grey) is protected from fluid intrusion. Therefore, iron staining did not affect the preserved light-coloured shells.

Location and geology



The red Ereño limestones are a differentiated and singular, lenticular, lithosome at the base of a carbonate succession with a grey micritic matrix. They have an east-west direction and subvertical dip. This lithosome outcrops in the area around the Ereño and Gautegiz-Arteaga villages (Bizkaia), located in the Basque-Cantabrian Basin.
These limestones were deposited in a subtropical shallow marine shelf. The palaeoecology was formed by extensive bioconstructions (thickets) of polyconitid rudists developed in areas of moderate energy conditions and requienid rudists and Chondrodonta sp.in more restricted platform environments.
These levels alternate with bioclastic facies (rudstone) formed by large storms. These facies are repeated in several metric sequences. Facies with polyconitid rudist sections in a living position are the most valued as ornamental stones.

Quarries

Red Ereño has been exploited in several quarries located in the north of Bizkaia (Spain). In the Ereño village (from which it takes its name) there are several small quarries that correspond to private quarries. The largest quarry is Cantera Gorria (Red Quarry), located in the Gautegiz-Arteaga village and is a place of both cultural and geological reference. The quarry faces allow us to observe both the sedimentary sequences and the biotic associations (bio-constructed) in different sections. The quarry has been declared historical heritage of Bizkaia (Andrabide Quarry) and forms part of the regional and national inventory of Places of Geological Interest. Its activity ceased in the 1980s and it was abandoned until 2022, when Gautegiz-Arteaga Town Council assumed responsibility for its conservation.

General view of the main front of Cantera Gorria (Andrabide Quarry) located in Gautegiz Artega (Bizkaia, Spain).

Architectural and cultural impact

Red Ereño was first used as an ornamental stone by the Romans in the 1st century AD. In the Arkeologi museum (archaeological museum of Bilbao) there is a votive altar and a funerary pedestal from the archaeological site of Forua (Bizkaia, Spain).
The Romans were also the first to export this stone; ashlars and other elements have been found in the Roman city of Iruña Veleia (province of Alava), more than 100 kilometres from its natural outcrop area.
The quarries during most of its exploitation were small, private and manual methods of extraction were used, of which little remains today.
Until the 19th century, its ornamental use was restricted to notable elements, above all in religious buildings, such as the numerous holy water fonts made using this stone. At the end of the 19th century, technological development allowed its industrial exploitation with helicoidal wire and automated drills.
Red Ereño was used in many of the emblematic architectural elements of the large cities in the surrounding area, such as the Victor Chavarri Palace (Bilbao, 1888) or the Sociedad Bilbaína (1913).
But it was also used in civil urban architecture, covering numerous entrances to dwellings with slabs of this stone. The exportation was intensive during most of the 20th century and examples of it are found all over Spain, from Murcia to Oviedo, Madrid, Seville or Barcelona, among others.
The popularity of Red Ereño has crossed frontiers and it is found in such emblematic places as St. Peter's Basilica in the Vatican (Italy) or the Teatro Colón in Buenos Aires (Argentine).
Furthermore, in the Basque Country, the stone itself has a very important intangible cultural value and there are numerous traditional sport activities focused on it, such as *harrizulatzaileak* (Stone borers in basque language), *idi probak* (Ox tests in basque language) or *harrijasotzaileak* (Stone lifters in basque language).
Red Ereño and Cantera Gorria bring together geological and cultural heritage.

Column of the main hall of the Bilbao City Hall made with polished Red Ereño with polyconitid rudists in cross section.

Main references

Damas Mollá, L., Uriarte J. A., Zabaleta, A., Aranburu A., García Garmilla, F., Sagarna, M., Bodego, A., Clemente, J.A., Morales, T.& Antiguedad, I. Red Ereño: an Ornamental and Construction Limestone of International Significance from the Basque Country (northern Spain). Geoheritage 13:2 (2021) https://doi.org/10.1007/s12371-020-00529-5;

Damas Mollá, L., Aranburu, A., García-Garmilla, F., Uriarte, J.A., Zabaleta, A., Bodego, A., Sagarna, M. & Antiguedad, I. Cantera Gorria and Red Ereño: Natural and Cultural Geoheritage (Basque Country, Spain). Geoheritage 14, 76 (2022). https://doi.org/10.1007/s12371-022-00709-5,

Damas Mollá, L., Aranburu, A., Villalain, J.J., García-Garmilla, F., Uriarte, J.A., Zabaleta, A., Bodego, A., Ladron de Guevara, M., Monge-Ganuzas, M. & Antiguedad, I. Why Did Red Ereño Limestone Go Red? Linking Scientific Knowledge and Geoheritage Story-Telling (Basque Country, Spain). Geoheritage 15, 89 (2023). https://doi.org/10.1007/s12371-023-00856-3

SOLNHOFEN LIMESTONE

Germany

Solnhofen lithographic plate, collections BGR, Berlin. Photo: BGR, Berlin

The fine and noble one and the lithographer's stone

Anette Ritter-Höll
Angela Ehling

The Solnhofen Limestone has been used already by the Romans nearly 2000 years ago. The fine homogeneity of the stone and its good cleavability allow a variety of uses: as brick stones, as roofing slabs as well as sculpture stones.
It became known beyond the region for its use as floor tiles from the 16th century onwards. They were used inside as floors in various patterns in hundreds of churches, castles and representative as well as private buildings in Germany and along the Danube river also in Austria, Hungary and since the end of the 19th century beyond. Internationally the stone became exceedingly well-known mainly through the invention of lithography as the most used lithography stone in the world. Besides, the Solnhofen Limestone is also famous for its spectacular fossil finds (e.g. Archeopterycx).

The judgement of the Paris, Solnhofen Limestone, around 1529;
Staatliche Museen zu Berlin, Photo: CC BY-SA 4.0

Petrography
Limestone; micrite and lime mudstone

Geological setting
Mesozoic – Upper Jurassic – Tithonian; Altmühltal Formation; 145-152 million years

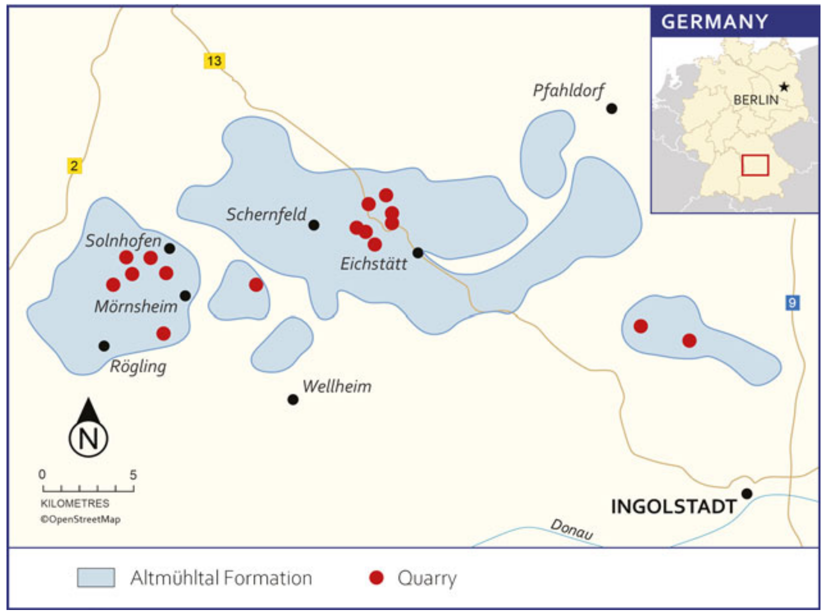
Occurrence
Southern Fränkische Alb, Bavaria, Germany

Petrography

The Solnhofen Limestone consists of alternations of thin-bedded, laminated, fine-grained, very pure limestones, called Flinze (Solnhofen Limestone stricto sensu), together with softer interlayers with slightly lower carbonate content that are also laminated and show a foliaceous weathering appearance (Fäule).
In the quarry Flinze alternate with Fäule-layers, which have to be discarded in spoil heaps or may instead be used for making concrete. The Flinze are microsparites or lime mudstones with tightly interlocked crystals, showing a pitted structure.
Mineralogically the limestones consist of 95-98 % calcite (particles and cement). Bluish to reddish variants are characterized by up to 5% by Mg, Fe components, SiO_2 and other substances. Colour is characterized by a large variance of yellow shades up to brownish.
It is mostly not frost resistant.

Location and geology

The Solnhofen Limestone occurs in a very limited area of 30 x 20 km in the southern Fränkische Alb between Langenaltheim / Mörnsheim / Solnhofen in the West and Eichstätt in the East.
Due to the flooding of the Vindelician land, which was located approximately in the area of today's Alps, a shallow epicontinental sea was formed at the northern margin of the Tethys.
Solnhofen Limestone originated as fine calcareous ooze, which settled in the subtropical Jurassic sea at the bottom of shallow, and sometimes deeper, basins within the huge carbonate platform.
Due to elevated salt and depleted oxygen content, only specialized microbial mats were able to colonize the seafloor.
These mats separate individual limestone layers from one another and point to a possibly seasonal rhythm between high carbonate production and periods when there were breaks in sedimentation.



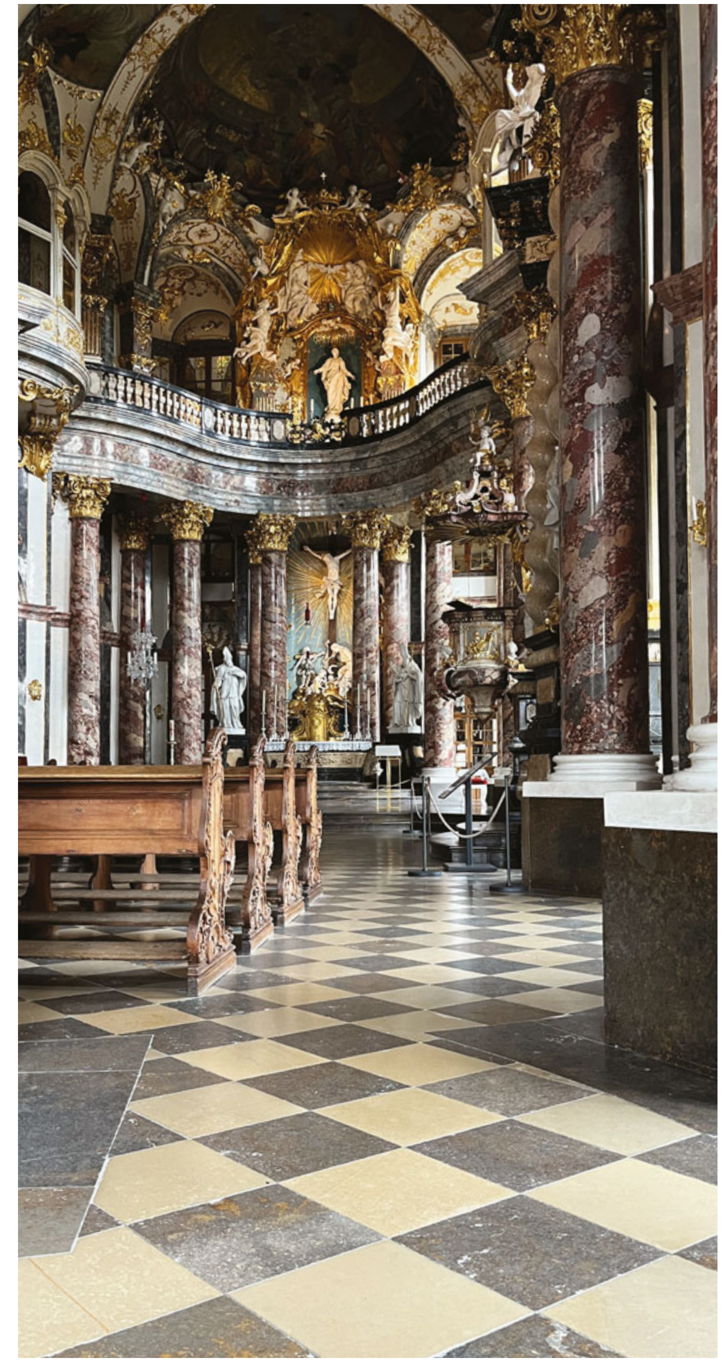
Quarries

Actual Solnhofen limestone quarry. Photo: Anette-Ritter Höll

Although their use has been documented since the 2nd century, the first record of a quarry does not exist until 1423. There has been continuous evidence of quarrying activity since the 15th century.
The thickness of the benches varies between 1 mm and 32 cm. Thick benches were loosened in the using pit hews in cycles with up to 6 people. Thin layers are loosened with a hammer and a flat iron.
Today the Solnhofen Limestone is still quarried. Only in Mörnsheim the Solnhofen high quality beds show the greatest thickness with 32 cm - also with blue color and especially for Lithostones. In other locations (e.g. Eichstätt and Zandt), only very thin beds occur.

Architectural and cultural impact

For the first 1400 years it was mainly used regionally, but not only as a normal building stone but also as roof slabs, so that many houses were built entirely of this stone („Jurahaus"). There are also known many historical gravestones made of it.
The most common use of the Solnhofen Limestone is as floor tiles. First in Bavaria and along the rivers Altmühl and Danube and later throughout Germany they decorate the floors of countless castles and churches but also in private houses from the 16th century onwards.
This includes several UNESCO Sites in Germany as there are the museums of the Museum Island in Berlin as well as the Roman and medevial buildings in the old towns of Regensburg and Bamberg. Other examples are the residence in Munich, the Berlin Cathedral and several buildings in the famous Burgstraße and the Karl Church in Vienna.
Because of the softness of the stone as well as the homogeneity it was also often used for relief art.
In the 19th century, the Dachau house plaques were widespread in the Dachau region as house decoration and protection symbol at the same time. The panels made of Solnhofen limestone show religious motifs that were chiselled into the stone slabs in low Bas-relief and painted. Impressive and precious relief arts, especially from the 16th century, can be admired today in museums (e.g. Berlin) and cathedrals (e.g. Bamberg).
The uniqueness of the Solnhofen Limestone lies in its suitability as a lithography stone, for which it has been known worldwide since 1796.
The quarrying of Solnhofen Limestones was closely linked to the development of the civic community and the development of transport routes. The first Solnhofen quarry regulations date from 1596.
The ownership, the system of levies, the safeguarding of mines and the settlement of disputes were regulated.
The „Jurassic Solnhofen Archaeopteryx Serial Site" has been designated as one of the first 100 Geosites worldwide in 2022.



Würzburg Residence, church, floor with slabs of, Solnhofen and Muschelkalk limestones. Photo: A. Ehling

Main reference

Kölbl-Ebert M, Cooper BJ (2020) Solnhofener Plattenkalk: a heritage stone of international significance from Germany. In: Hannibal JT, Kramar S, Cooper BJ (eds) Global Heritage Stone: Worldwide Examples of Heritage Stones. Geological Society, London, Special Publication 486: 103-113. https://doi.org/10.1144/SP486-2017-324

TENNESSEE “MARBLE”

USA

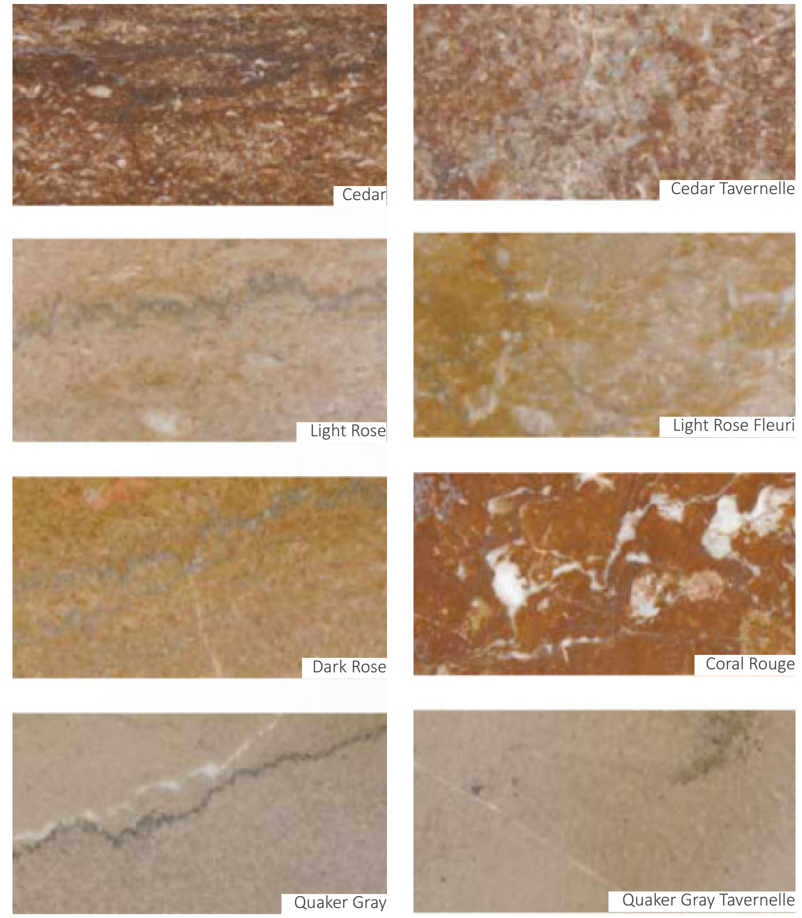
Ramsey House, 1797, Knox County (Tennessee USA), Photo: Susan Knowles, 2016

A heritage stone from the New World

Susan W. Knowles

The Holston Formation aka Tennessee “marble,” though not steeped in antiquity as many European or Asian stones, has been quarried continuously in Tennessee for dimension stone, sculpture, and lime for over 200 years.

Federal, state and county government buildings, as well as banks, hotels, office buildings, libraries, museums, and railroad terminals (many of which are listed in the National Register of Historic Places, National Park Service, United States Department of the Interior) in the United States of America and Canada are constructed from Tennessee “marble.”



Petrography
Limestone; coarsely crystalline boundstone or calcarenite

Geological setting
Paleozoic- Middle Ordovician;
Chickamauga Group, Holston Formation

Occurrence
Eastern Tennessee, USA

Petrography

The Holston Formation is a coarsely crystalline limestone consisting of two basic lithologies: a white-pink-red bryozoan boundstone (Dunham, 1962) composed of abundant bryozoans that bind micrite and fossil debris into mound-like structures to form a reef core and a white-pink, cross-bedded, pelmatozoan calcarenite that fills spaces between and forms the reef flanks.

According to Folk (1959) the reef cores could be classified as biolithite and the reef flanks as biosparite. Calcite is the dominant mineral comprising the fossil Bryozoa and Pelmatazoa. Hematite and rhodocrosite add the pink tint; hematite and limonite the darker cedar or chocolate-like tints. Other mineral content includes Collophanite, Dolomite, Feldspar, Pyrite, Quartz and Siderite.

Location and geology

The white to red, massive, coarse-grained limestone occurs as a conspicuous stratigraphic unit within the Middle Ordovician Chickamauga Group in the Valley and Ridge province of East Tennessee.

Tennessee “marble” has been extracted from quarries located where the Holston Formation is exposed along a 100 km NE-SW trending strike belt in eastern Tennessee. Due to folding and faulting the formation does not crop out continuously along the trend.

Though not marble in the geological sense, it is crystalline, takes a high polish, and possesses physical properties that typically surpass those of metamorphic marble.

Quarries

Historically, the primary quarry districts were in Blount, Hawkins, Knox, and Union counties. As many as 70 quarries were recorded between 1850 and 1950.

The known occurrence of the Holston is limited geographically to East Tennessee where it is quarried from surface exposures. Currently not all surface exposures have been exploited.

The Holston Formation is now being mined underground in the Luttrell (Union County) area for aggregate and lime.

The Tennessee Marble Company, Friendsville (Blount County), now the sole source for dimensional marble, operates large quarries in Knoxville and Friendsville, extracting the gray and light pink varieties. In the 1930s, some historical quarry sites in Hawkins, Knox, and Blount counties were inundated by Tennessee Valley Authority dam projects.

Tennessee Marble Company, Brown Quarry, Blount County (Tennessee, USA)

Architectural and cultural impact

Tennessee “marble” has been quarried for lime and dimension stone since colonial times in North America.

Undoubtedly valued by indigenous groups for use in agriculture, toolmaking, and ceremonial/sculptural objects, the first published notice of “marble” in Tennessee was by natural scientists and itinerant ministers. Such accounts appeared in the American Journal of Science (Cornelius, 1818; Kain, 1819).

The first architectural use was Francis Alexander Ramsey’s home, Swan Pond (1797), by British architect Thomas Hope, built of hewn pink “marble” quarried nearby. In 1814, U.S. Congressman John Sevier, first governor of Tennessee, extended the potential market by taking a sample to Giovanni Andrei, one of two Italian sculptors at the U.S. Capitol.

After considerable national debate over suitable construction material for federal buildings, Tennessee “marble” appeared in three significant architectural interiors in the 1850s: two memorial stones inside the Washington National Monument; three of four grand staircases and the Senate Retiring Room, U.S. Capitol; and the main staircase and balustrade, Tennessee State Capitol. While the dark cedar color was fashionable for interior use during the Victorian era, by the early 20th century, light pink Tennessee “marble,” seen in certain light as off-white, was being employed for exterior construction.

The Morgan Library (1902-1906) in New York City, designed by architect Charles McKim, was built entirely of Tennessee “marble.” The appearance and physico-chemical properties of the Holston Formation have made it an excellent stone for interior and exterior construction as well as for sculpture. Its chemical purity and crystalline texture provide high compressive strength, low absorption, and high durability, making Tennessee “marble” a popular choice among architects and sculptors past and present.

Along with Vermont and Georgia (both white marble) Tennessee has always ranked among the top three marble producers in the U.S.

Bloomberg Center, Johns Hopkins University, Washington, DC, 555 Pennsylvania Ave—facing US Capitol, 2023 (Tennessee Marble Company/Tennessee, USA)

Main references

Byerly, D.W. and Knowles, S.W. 2017. Tennessee “Marble”: a potential “Global Heritage Stone Resource”. Episodes 40(4), 325–331.

Dale, T.N. 1924. Marble Deposits of East Tennessee: Pt. 2, Construction and adaptation of the Holston Marble of East Tennessee. Tennessee Division of Geology Bulletin 28, 87–160.

Gordon, C.H. 1924. History, Occurrence and Distribution of the Marbles of East Tennessee, Marble Deposits of East Tennessee. Tennessee Division of Geology Bulletin 28.

TYNDALL STONE

Canada

Student residence, University of Saskatchewan, Saskatoon. The first floor has rustic finish from slabs split along bedding plane-parallel stylolites. Second to fourth floors are split-face blocks. Decorative courses are sawn parallel to bedding.

The stone from Manitoba

Brian R. Pratt
Graham A. Young

Tyndall Stone is a unique, slightly porous, fossiliferous limestone with distinct dolomitic mottling (sometimes called "tapestry"), which has been widely used in Canada, especially western Canada, since the early part of the 20th century. It ranges from light grey with darker grey mottles to cream-coloured with brownish mottles.

It has been used as cladding and for decorative elements for numerous iconic buildings, such as the legislative buildings of Saskatchewan and Manitoba.

It is durable and performs well in a northern climate, although it can be damaged by salt spread on adjacent sidewalks. While the specific properties of the stone are present only in a single area northeast of Winnipeg, Manitoba, there is no prospect of reserves being exhausted in the foreseeable future.

Surface sawn parallel to bedding showing bioclastic packstone (light) with dolomite mottles (dark) related to burrows.

Petrography
Dolomitic limestone; bioclastic wackestone to packstone (biomicrite)

Geological setting
Paleozoic – Late Ordovician- Red River Formation- Selkirk Member;
Williston Basin of Laurentia

Occurrence
NE of Winnipeg, Manitoba, Canada

Petrography

Tyndall Stone is a fossiliferous bioclastic packstone and locally wackestone (in the Dunham limestone classification scheme). The biomicrite matrix appears churned and is rich in crinoid ossicles, along with calcareous green algae, bryozoans, gastropods, ostracods, and other fossils.

Macrofossils are abundant and diverse. Common fossils include receptaculitids, tabulate and rugose corals, stromatoporoid sponges, nautiloids, and planispiral and conical gastropods, and there is a range of rarer fossils such as brachiopods and trilobites.

Many of the fossils reach unusually large sizes in comparison with their correlative counterparts elsewhere. The matrix is riddled with burrows: large horizontal forms and multiple generations of smaller ones. Dolomite replaces the burrow infills and the adjacent matrix, producing the distinctive, interconnecting mottles.

Location and geology

Tyndall Stone is extracted from a quarry complex belonging to Gillis Quarries Ltd. in the village of Garson, 37 km northeast of Winnipeg, Manitoba. It comprises a 6–8 m interval in the lower part of the massive-bedded, 43 m thick Selkirk Member of the Red River Formation.

This horizontally-bedded unit is Late Ordovician (Katian) in age (approximately 450 million years old) and was deposited in the Williston Basin of central North America, or Laurentia, part of the shallow epicontinental sea that covered most of the craton.

Quarries

Blocks of Tyndall Stone weighing 6–8 tonnes are extracted after being cut vertically with either a circular saw or a belt saw mounted on tracks.

After aging the stone is taken to the nearby finishing plant and cut to the sizes and with the finishes specified for each individual construction project.

These can include large slabs sawn parallel to bedding, typically with a rubbed or sawn finish for exterior and interior cladding; blocks with a split face perpendicular to bedding mainly for exterior walls; varicoloured rustic finish from splitting parallel to bedding for exterior walls; floor tiles with a honed finish; and various machine-shaped decorative elements.

Blocks of Tyndall Stone are occasionally selected by stone carvers and sculptors.

Gillis Quarries Ltd. in operation, showing front-end loaders, sawn grid, and circular and belt saws.

Manitoba Legislative Building, Winnipeg, photograph taken ca. 1925. Image credit: PC013424, Prairie Postcards Collection, courtesy of Peel's Prairie Provinces, a digital archive of University of Alberta Libraries.

Architectural and cultural impact

Besides the legislative buildings of Saskatchewan and Manitoba and part of the interior of the Centre Block, House of Commons in Ottawa, Tyndall Stone has also been used for many government buildings such as post offices, court houses, train stations, museums, concert halls, art galleries, schools, universities, hospitals and city halls, and many commercial buildings such as banks, department stores, office buildings, hotels and residential buildings.

Early in the 20th century, common architectural styles were Beaux Arts and Neo-classical, sometimes with Romanesque touches. Some were constructed in the Art Deco style in the 1930s, although the Depression saw a reduction in commercial building in Canada. Modernist style was popular in the 1950s and 1960s.

There were occasional forays into Brutalist and Contemporary classical styles in the latter part of the 20th century, and Châteauesque, Collegiate Gothic, and Expressionist styles in the 21st century. Use as cladding is still common, although in recent years different sizes and finishes have been mixed in ashlar for exterior walls, lending attractive texture.

The indoor use of Tyndall Stone tile is expanding. During most of the 20th century, cladding that had large visible fossils tended to be avoided because they interrupt the visual homogeneity.

Nowadays, however, the striking fossil content is accepted and even celebrated, such as with feature walls where spectacular fossils are displayed.

Commercial and government buildings made with Tyndall Stone in the first decades of the 20th century comprised a major and distinctive part of the centres of prairie cities during their early growth phase.

These buildings are still in good condition, and while some have been repurposed, many are quite monumental and lend a sense of permanence. Most of the older buildings have been designated as heritage properties.

Main reference

Pratt, B.R., and Young, G.A., 2023, Heritage Stone 9. Tyndall Stone, Canada's first global heritage stone resource: geology, paleontology, ichnology and architecture: Geoscience Canada, v. 50, p. 17–51.

VILLAMAYOR STONE

Spain

Archivo Histórico Provincial of Salamanca 1992-95
Photo: xiquinhosilva from Cacau, CC BY 2.0

A singularly beautiful arkose sandstone

Jacinta Garcia-Talegón
Adolfo C. Iñigo
Patrick N. Wyse Jackson

Villamayor Stone is quarried in a small district in north west Spain. Also known as Golden Stone (Piedra Dorada in Spanish), or locally and historically as Fr Ançã Stone or Honest Stone (Piedra Fr Ançã).
It is particularly important in Salamanca as it has imparted a distinctive character to the city and outlining villages where it has been used in many public, ecclesiastical, educational and domestic buildings and monuments. The city of Salamanca was designated a UNESCO World Heritage City in 1988. Villamayor Stone is just one of a number of important stone materials quarried in this part of Spain that together contribute significantly to the cultural, artesanal and architectural heritage of the region which has been referred to as a Global Heritage Stone Province.

Façade of the University of Salamanca

Petrography
Arkosic sandstone

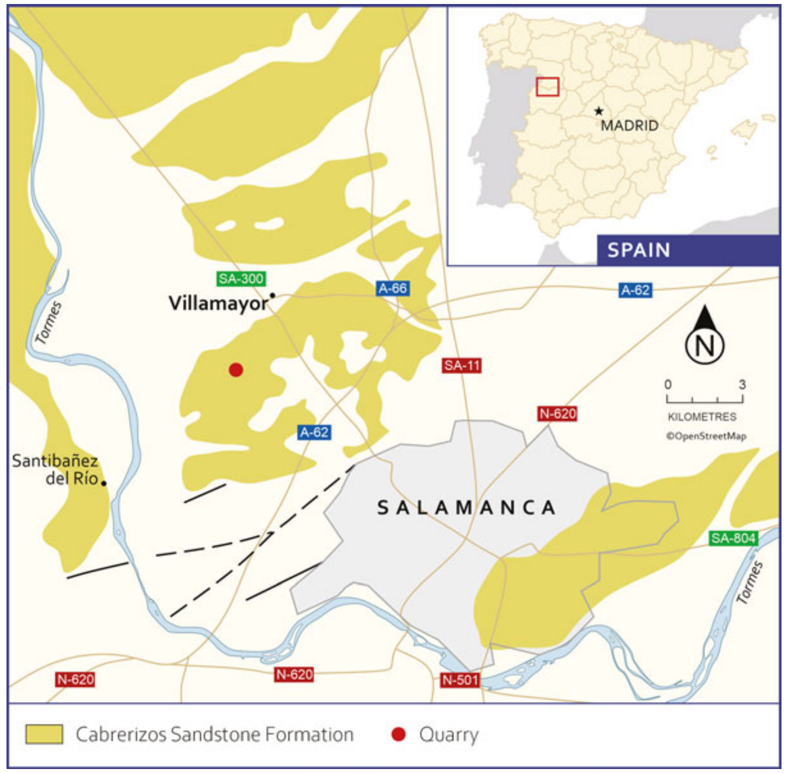
Geological setting
Cenozoic – Paleogene – Middle Eocene ;
Cabrerizos Sandstone Formation

Occurrence
Villamayor de Armuña, Salamanca, North-West Spain

Petrography

The Villamayor Stone is a arkose sandstone, fine to medium-grained in texture, quartz and feldspar rich in composition with lower volumes of phyllosilicates, Fe-oxihydroxides and locally dolomite.
When fresh it has a surface colour that it is white to ocher and red but over time on exposure to the atmosphere develops an ochreous to golden patina as iron and manganese oxides leach out of the stone onto the surface of quarried and worked blocks.
The Villamayor Stone has a medium clay content (smectites, palygorskites and kaolinites) and as a result are good aquifers given their high porosity of greater than 30% and permeability.

Location and geology



Villamayor Stone is an arkosic stone of Middle Eocene age and belongs to the Cabrerizos Sandstone Formation that comprises braided fluvial systems and palaeosoils at the top of each stratigraphic sequence.
In the Cenozoic Duero Basin, the palaeodynamic and palaeogeographic context comprised a river system that drained a granitoid and metamorphic source area located to the SW which flowed towards the NE.
The sediment load, moved by saltation and traction, formed large sand deposits, with overlapping megaripples, which sometimes constituted authentic sandy plains.
The active and dynamic channels in this fluvial system deposited cross-stratified medium to coarse sand which are those currently exploited as Villamayor Sandstone.

Quarries

Quarried at the village of Villamayor de Armuña located 5 km to the northwest of Salamanca. Traditionally it is quarried by a small number of family businesses, using traditional methods, producing stone for cladding facades of new buildings, and for restoration and conservation of historic buildings in the city centre of Salamanca. Unfortunately, during the economic crisis in 2008 extraction levels fell and this led to migration out of the area.
Villamayor Stone is still the main stone used in the city of Salamanca for the restoration of monuments, although it is used in relatively small volume in comparison with that before 2008.
Recent heritage initiatives have included the rehabilitation of a historical quarry as an interpretation center for knowledge of quarrying prior to industrial development.

Villamayor Sandstone stonework marks made with the pick, without industrial technology.

Architectural and cultural impact

New Cathedral, Salamanca, Photo: Jesusccastillo, CC BY-SA 4.0

The particular charm of a city is a product of the geological environment in which it is located. In the case of Salamanca, Spain, the singular beauty of the city is provided by the Villamayor or Golden Stone which is extensively used throughout the city center and resulted it being called the 'Golden City'.
Villamayor Stone was quarried and used in the construction of Romanesque monuments such as the Old Cathedral (prior to 1120) and San Julian Church, Gothic monuments in the Spanish plateresque style, including the New Cathedral (construction commenced 1513 and completed 1733), the Church of San Estebán (1524) and the façade of the University of Salamanca, one of the oldest such institutions in Europe established in 1250. It was utilised in various Baroque buildings in the city, notably the Plaza Mayor (Main Square) (1729).
More recently the building housing the Archivo Histórico Provincal de Salamanca erected between 1992 and 1995 is faced with the stone cut into fine ashlar. The stone being rather porous allowed stone cutters and sculptors to carve it with ease when wet and this is why it became known as 'Honest Stone'.
Once dried out the stone was durable especially on surfaces with good surface runoff on which the strong patina developed, but it decays badly in areas of buildings where water can be retained.
A number of buildings in Salamanca such as the Clerecia were constructed of Villamayor Stone for upper stories and Piedra Pajarilla Granite, another locally quarried IUGS Heritage Stone, for the base courses and Sandstone and Conglomerates silicified with CT opal from Salamanca Sandstone Formation (upper Cretaceous).
Where there has been subsequent replacement during restoration of the former with the latter, this has not generally been successful. In other buildings an artificial wash was applied to the sandstone to replicate the naturally occuring golden patina.

Main reference

Garcia-Talegón, J., Iñigo, A.C., Alonso-Gavilán, G. and Vicente-Tavera, S. (2015). Villamayor Stone (Golden Stone) as a Global Heritage Stone Resource from Salamanca (NW of Spain). Geological Society of London Special Publications 407, 109–120.

WESTERN GHATS LATERITE

India

Ruins of church of St. Augustine, Goa

Echoes of Heritage in India´s Western Ghats

Gurmeet Kaur
Raymond A. Duraiswami

Laterite, from the Western Ghats of India, has been extensively used in the construction of countless structures, including iconic monuments and local dwellings all along the Western Ghats. Its unique properties, such as hardening upon exposure to air despite its initial soft nature, have made it a preferred material for various prestigious monuments like forts, temples, cave monuments, convents, and cathedrals.
The Churches and Convents of Goa, built with laterite as the core material, are UNESCO World Heritage Sites. The churches and convents feature impressive architecture, intricate craftsmanship, and historical significance, making them important cultural landmarks not only for Goa but also for the broader world heritage community. The extensive use of laterite in the Western Ghats region reflects the ingenuity of ancient builders and the diverse cultural influences that shaped the region.

Western Ghats Laterite

Petrography
Laterite

Geological setting
Weathered material on Deccan basalts, greywackes and granulites

Occurrence
Konkan-Kanara belt from Maharashtra to Kerala, India

Petrography

Laterites of the Western Ghats are reddish brown to dark red in colour with yellow to white lining around the cavities. Laterites of the Western Ghats constitute ferruginous minerals like magnetite, hematite (oxides), goethite (hydroxide) and clay minerals such as gibbsite and kaolinite with minor quartz in the matrix.
The main rock types of the Westren Ghats viz. basalts, greywackes, granulites contain minerals like feldspars, pyroxenes, and micas. The conversion of primary minerals (pyroxenes, micas and feldspars) to phyllosilicates and clay minerals (smectite, chlorite, illite, vermiculite and halloysite) occurs which upon leaching by the weathering agents are further converted to goethite, hematite, kaolinite and gibbsite in the residual rock. The laterite found along the Western Ghats has high iron and aluminium contents.

Location and geology

Laterites in western Peninsular India occur on flat tablelands, forming the Konkan-Kanara belt from Maharashtra to Kerala. They are of two types: autochthonous (formed in situ) and allochthonous (formed from transported material).

Classified by altitude, they are ´low level` along coastal regions and ´high level` on mesa tops along the Ghats ridge. Low-level laterites are widespread from Maharashtra to Kerala, formed on Deccan basalts and various rock types. High-level laterites cap mesa tops of Deccan lavas in the north and southern Archean and Proterozoic rocks.

These formations result from weathering in sub-tropical climates with heavy seasonal rainfall, particularly influenced by the Indian Summer Monsoon, aided by the topography and tectonic stability of the Western Ghats.

Quarries

Laterite profiles typically consist of unaltered bedrock at the base, followed by partially altered saprolite, a Fe-rich mottled zone, and finally indurated laterite duricrust and soil. Laterite occurs predominantly on Deccan basalts in Maharashtra, with exposures in high plateau and Konkan regions. The quarries dot various regions of southern Maharashtra, particularly in Ratnagiri, Sindhudurg, and Kolhapur districts. In Goa, laterites form over metabasalts, metagreywacke, and argillites, with notable occurrences on tablelands and seafront cliffs. Laterite quarries are distributed across Goa, with notable examples in North Goa. The quarrying of laterite is now banned in many places in Goa for several resaons. Laterite deposits are prominently observed across various districts in Karnataka, including Mangalore, Coorg, Hassan, Chikmagalur, Shimoga, Dharwar, Belgaum, and North Kanara. The laterite stone quarries are primarily situated in the Shimoga and Dakshina Kannada districts of Karnataka State. Laterite-capped mesas are distributed across the Malappuram, Nilambur valley, Kannur, and Kasaragod districts of Kerala. Additionally, laterite exposures can be found in parts of Thrissur, Palghat, and Thiruvananthapuram districts. The laterite is extracted for construction purposes in Vellarikundu, Manjeswaram, and Hosdurg in Kasaragod District; Angadipuram in Malappuram District; and Varkala, Chemmaruthy, and Ayroor in the Thiruvananthapuram District of Kerala State.

Laterite Quarry site in vicinity of Goa

Architectural and cultural impact

Chapel of saint Catherine, old Goa. Photo: Parminder Kaur

The Western Ghats is dotted with numerous forts along Maharashtra, Goa, Karnataka, and Kerala. Maharashtra boasts a variety of forts, including inland, headland, and island forts, with Vijaydurg Fort being a prominent example. Coastal forts in Ratnagiri and Sindhudurg predominantly utilize lateritic rocks. Similarly, Goa's rich heritage is evident in its churches, convents, and forts, with the oldest petroglyphs found in Usgalimal village.

The Arvalem caves and Rivona caves showcase ancient rock-cut structures in laterite.

The churches and convents of Old Goa, built between the sixteenth and eighteenth centuries, owe much of their construction to laterite blocks. These historic structures, collectively designated as a UNESCO World Heritage Site, reflect the architectural fusion of Manueline, Gothic, and Baroque architectural styles, born from 450 years of Portuguese influence in Goa. The forts in Goa, such as Reis Magos Fort and Chapora Fort, exhibit Portuguese military architecture using laterite bricks. Kerala's megalithic monuments, including umbrella stones and topikkal, utilize laterite extensively, with landmarks like Angadipuram Laterite recognized as a National Geological Monument. Laterite blocks are also prevalent in the fortifications of St. Thomas Fort, Bekal Fort, and others in Kerala, as well as in structures like Taj Baudi and Veerbhadra Temple in Karnataka.

Main reference

Kaur, P., Saini, J., Sharma, U., Duraiswami, R., Mathew, B.P., Sreejith, C. and Kaur, G., 2023. Western Ghats Laterite: an Architecturally and Culturally Iconic Stone from India with Special Reference to Goa. Geoheritage, 15(1), p.38.

Metamorphic rocks are produced when a rock is subjected to heat and or pressure and undergoes transformation. The nature and type of the resultant metamorphic rock depends on the composition of the original rock, or protolith, and the degree of heat and pressure applied.

This alteration can be generated at a large regional scale through tectonic collision or locally where a hot igneous rock comes into contact with an adjacent older country rock.

The greater the change, the higher the metamorphic grade. Limestone gets transformed into marble, mudrocks into slates or schists, and granites, at a high grade, into gneiss.

Metamorphic rocks

AFYON MARBLE

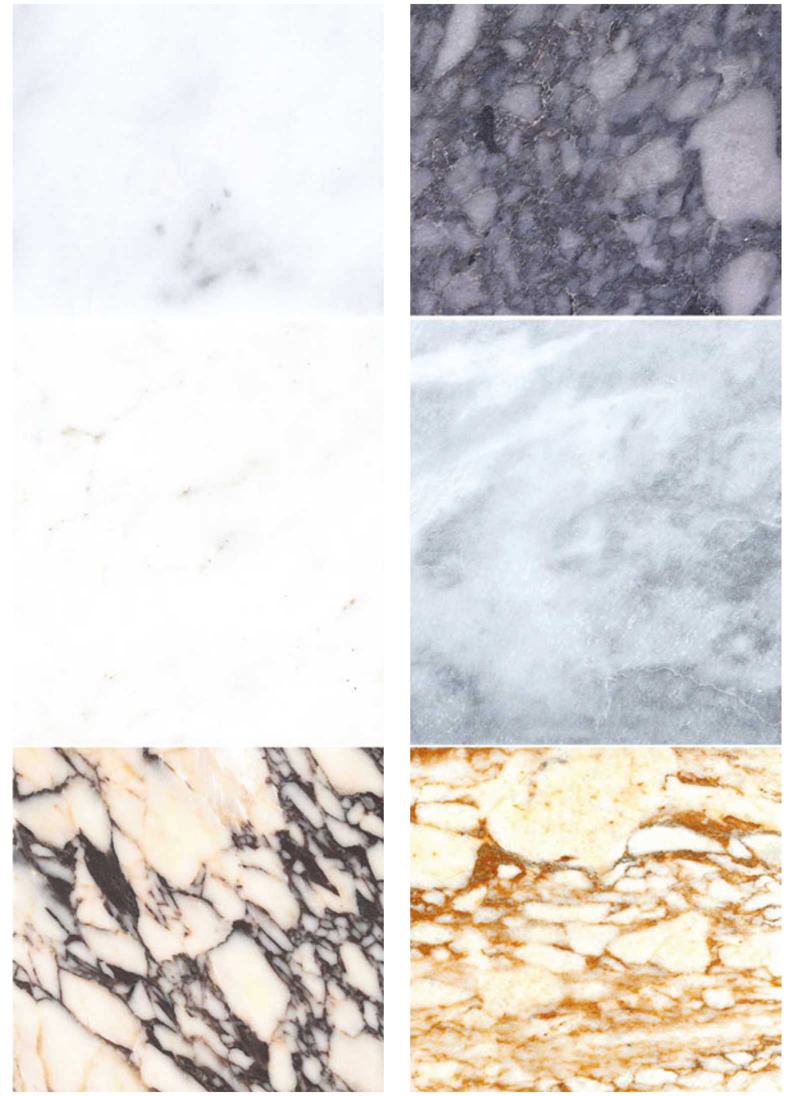
Türkiye

Stone table (Afyon violet/Pavonazzetto)

A precious marble - from antiquity to the present day

Tamer Koralay
Metin Bağcı
Can Başaran
Mehmet Özkul

İscehisar (ancient name Dokimeion) town (Afyon region), where modern Türkiye's important marble deposits are located, was founded in the Hellenistic period by Dokimos, one of Alexander the Great's Generals, to produce white and violet marble. Significant quantities of marble have been extracted from Iscehisar town, the most famous marble production center of Anatolia together with Proconnesus, dating back to 300 BC.
Afyon marble is exported to more than 120 countries (China, USA, Australia, Germany, etc.) presently, in ancient periods, it was exported to Europe (Italy, Spain, England), North Africa (Tunisia, Libya) and the Middle East (Syria, Israel).
Afyon marble has been widely used in the construction of flooring, cladding, sarcophagi, columns, statues, bathtubs, sinks, and small artifacts in ancient times.



Color varieties of Afyon marble.

Petrography
Calcite marble with siliciclasts and brecciated varieties

Geological setting
Paleozoic, Afyon Zone

Occurrence
Northeast of İscehisar town, Türkiye

Petrography

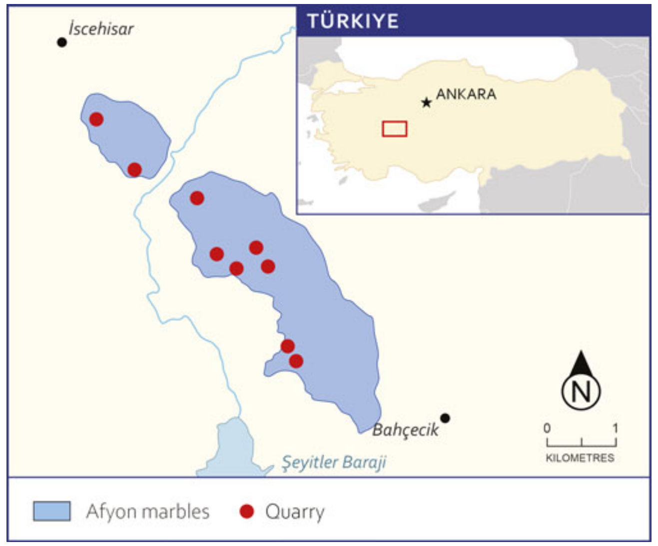
Afyon marble is marketed under different names in the natural stone industry in terms of color and appearance: Afyon white, Afyon cream, Afyon sugar, Afyon grey, Tigerskin, and Afyon violet (Pavonazzetto).
Afyon white, cream, and sugar marbles may partially contain light greyish, and light yellowish veins/spots. They consist of fine to medium-grained calcite crystals and have homoblastic polygonal texture. Afyon grey has light and dark grey bands. It contains fine-grained calcite crystals with a homoblastic polygonal texture. Tigerskin and Afyon violet marbles show brecciated structure. White inclusions on a dark grey background are observed in tigerskin marble, whereas light and/or dark purple colored inclusions are observed on a generally light background in Afyon violet. Tigerskin is composed of fine to medium-grained polygonal calcite crystals showing pressure twinning with a homoblastic polygonal texture, while Afyon violet is composed of fine-grained calcite ± muscovite ± quartz and opaque minerals with a lepidogranoblastic texture.

Location and geology

Afyon marble deposit is located in the Afyon Zone, one of the tectonic units of Türkiye. Paleozoic-aged Afyon metamorphics, represented by schist and meta-granitic rocks, have undergone metamorphism in greenschist facies.

Marble, graphite-schist, quartzite, and a lesser amount of garnet-biotite-muscovite and quartz-albite-muscovite schists are chiefly rock lithologies in Afyon metamorphics. Mica schists and graphite-chlorite schists are also observed as thin layers in marble.

Afyon marbles are composed of three stratigraphic levels. The lower level contains grey marbles (Afyon grey) and Tigerskin, the middle level includes fine-grained white marbles (Afyon white, cream, sugar), and the upper level contains Afyon violet (Pavonazzetto) marbles. Mesozoic-aged micritic limestone consisting of sparry calcite and fossil-bearing unconformably overlies the Afyon marbles.



Quarries

Afyon marbles occur as two lens-shaped bodies at the upper levels of the Afyon metamorphics and are located 1.5 km northeast of the modern İscehisar town.

Fine-grained white (Afyon white, cream, sugar) and polychrome brecciated marbles (Tigerskin, Afyon violet) have been extracted from quarries since 300 BC. Although there are still partially preserved cutting marks left by pickaxes and pointed chisels on the working surfaces of some quarries, modern marble mining, which started in the early 1980s has caused most of the traces from the ancient quarries to disappear. On the other hand, unfinished columns, sarcophagi, bathtubs, and statues, from the ancient period can be seen in the open-air museum in Iscehisar town. In addition, detailed information on ancient quarries was given in the book „Marmi Dell' Asia Minore" by Monna and Pensabene (1977).

Modern quarry with cutting surfaces with uniform geometric shapes.

Architectural and cultural impact

Afyon marbles were often mentioned in ancient manuscripts, legal and trade documents. Strabo, the famous geographer of antiquity, stated the quarrying activity at Docimium in the early first century (Geographica 12.8.14).

Emperors such as Augustus, Trajan, and Hadrian used Afyon marble (especially Pavonazzetto) in many civilization projects. In addition, the price per ft3 of Afyon marble had been set at 200 denarii in the Edict on Maximum Prices (Edictum de Pretiis Rerum Venalium was issued in 301 AD by Emperador Diocletian).

Due to its high strength, fine-grained structure, and color varieties, Afyon marble has been widely used throughout the Mediterranean in architectural elements (such as columns, flooring, and cladding), sarcophagi, statues, bathtubs, and small artifacts from the past to the present. Its variety of colors (especially violet was a royal color in Roman and Byzantine) and its harmony with other stones bring the structures to a privileged position.

It is possible to see the use of Afyon marble with different stones in the Pantheon, Hagia Sophia Mosque, Topkapi Palace, Leptis Magna, and the Vatican Museum.

Afyon violet (Pavonazzetto) marble were used in column shaft of the Celcus Library in Ephesus (İzmir-Türkiye)

Main references

Bağcı M., (2020). Mineralogical, Petrographic, and Geochemical Characterization of Coloured İscehisar Marbles (Afyonkarahisar, W-Turkey). Turkish Journal of Earth Sciences, 29: 946-975.

Çelik M.Y. and Sabah E., (2008). Geological and Technical Characterisation of Iscehisar (Afyon-Turkey) Marble Deposits and the Impact of Marble Waste on Environmental Pollution. Journal of Environmental Management, 87: 106-116.

Herrmann Jr, J.J. and Tykot, R.H., (2009). Some Products from the Dokimeion Quarries. Craters, Tables, Capitals, and Statues. ASMOSIA VII, 59-75.

ALWAR QUARTZITE

India

Ruins of the Bhangarh Fort, Rajasthan

Quartzite exposure

Petrography
Quartzite

Geological setting
Proterozoic – North Delhi Fold Belt, Alwar Group

Occurrence
Alwar-Jaipur-Delhi, India

The Stone as a symbol of power

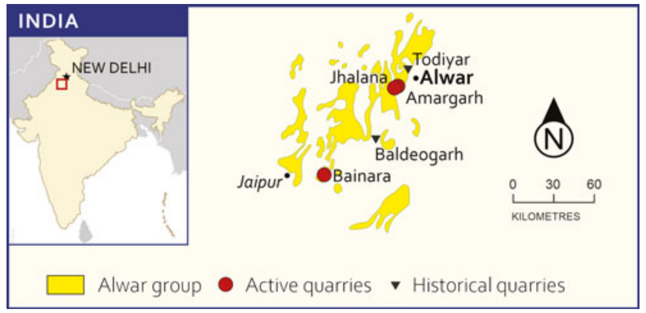
Gurmeet Kaur

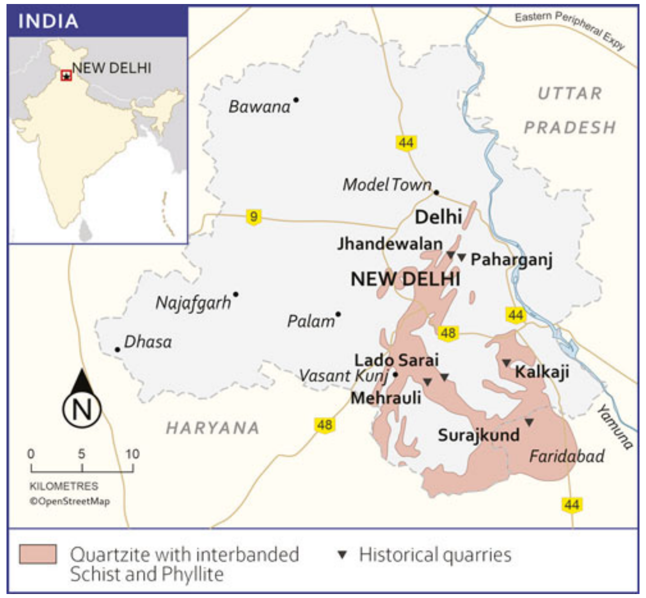
Alwar Quartzite, nearly monomineralic, a compact rock primarily composed of quartz that has been recrystallized is known for its remarkable shear and compressive strength, and resistance to physico-chemical weathering.
This stone has been extensively used in some of the prominent monuments in north and northwestern India by several cultural groups during different time periods, such as Lal Kot Citadel, Purana Quila, the Qutb Complex (UNESCO World Heritage Site), Humayun´s Tomb Compex (UNESCO World Heritage Site), Amber Fort, and Bhangarh Fort, to name a few.

Petrography

Alwar Quartzite is mainly composed of recrystallized quartz and commonly demonstrate a granoblastic texture. The triple junction contact is produced at an angle of 120° intersection by the majority of quartz grain boundaries. The quartz grains exhibit both non-undulose and undulose extinctions. The recrystallization of silica cement has sutured the grain boundaries of quartz. Other minerals which constitute Alwar Quartzite are trace amounts of mica, amphibole, tourmaline, zircon, and opaques.

Location and geology





The Aravalli mountain shapes the geological and geomorphic features of northwestern India.
Its oldest rock formations, the Banded Gneissic Complex, serve as the foundation for the metavolcanic-sedimentary sequences of the Aravalli and Delhi Supergroups, as well as the relatively undeformed sedimentary sequences of the Vindhyan Supergroup.
Within the Delhi Supergroup, two distinct belts exist: the older North Delhi Fold Belt and the younger South Delhi Fold Belt. The Alwar Group belongs to the North Delhi Fold Belt and is predominantly an arenaceous facies. The Alwar Group quartzite exposures occur along the North Delhi Fold Belt and form the prime source of the Alwar quartzite for scores of monuments in this region. The Alwar Group quartzite shows a profound development in the Alwar-Jaipur sub-basin of North Delhi Fold Belt and has been variously described as the Mortalab Quartzite, the Mohioni Conglomerate, the Kanawar Quartzite and the Lakhanpur Sandstone. In the Delhi region, Alwar Quartzite occurs as low-level outcrops, rising above the Quaternary sediments.

Quarries


Alwar Quartzite quarry near Jaipur

In Delhi, the Alwar Quartzite outcrops are present at Tughlaqabad, Noor Nagar, Jasola, Abul Fazal Enclave, Jaunapur, Okhla, Bhatti mines area, Asola, Mandi, Greater Kailash, Aya Nagar, Vasant Vihar, Mahipal Pur, Ghitorni, Jawaharlal Nehru University, Vasant Kunj, Naraina, Pusa, Dhaula Kuan and Nicolson Lines. New Delhi holds exposure at the Buddha Jayanti Park, the Raisina Hills, the Birla Mandir, the Mahavir Banasthali and the American Embassy School. In the early twentieth century, quartzite was quarried on a large-scale at Lal Kuan, Jhandewala, Paharganj, Rathia Lado Sarai, Kalkaji and Mehrauli, but quarrying was banned by the Supreme Court of India on account of being a major threat to the environment and natural habitat of scores of plants, birds and animals. In the Alwar-Jaipur sub-basin, quartzite quarries are located in the steeply dipping quartzite ridges and hills. The Alwar Quartzite ridges surround the city of Jaipur and were quarried in the past. The quartzite outcrops occur in the region from Ramgarh (Alwar) to Jaipur. The Alwar Quartzite was once quarried from the hills of Nahargarh, Adarshnagar, Amar Singh Fort, Jhalana, Amer and Maheshwas regions in Jaipur district, Rajasthan. The quartzite is now quarried in the form of blocks and slabs near Ramgarh and Bari village, respectively.

Architectural and cultural impact

Alwar Quartzite, renowned for its durability and distinct aesthetic appeal, has been a foundation in the construction of numerous noteworthy monuments across north and northwest India. This unique geological formation, with its characteristic texture and resilience, has lent itself to the creation of architectural marvels that stand as enduring symbols of the region's rich heritage and cultural legacy.
Alwar Quartzite's widespread use as a preferred building material is demonstrated by the monuments all throughout Delhi that date back to the pre-Sultanate and British Raj periods. The adaptability of Alwar Quartzite is visible throughout the city's architectural history, from the sturdy fortifications of well-known forts like Purana Qila and Tughlaqabad Fort to the careful ashlar masonry seen in British Barracks. Within the grounds of famous locations like the Qutb Complex and Humayun's Tomb Complex, both of which are included as UNESCO World Heritage sites, Alwar Quartzite was frequently used in the construction of tombs, mosques, and victory towers. Further evidence of the extensive use of Alwar Quartzite at this time is provided by a few monuments dotted about the old city of Delhi.
Alwar Quartzite was extensively used for fortifications, as can be seen in forts in the northeastern region of the state of Rajasthan, including Amer, Jaigarh, Nahargarh, Bhangarh, and Moti Dungri.
This extensive use highlights the stone's durability, accessibility, and versatility to different architectural styles and goals.


Tomb of Isa Khan in Humayun's Tomb Complex, Delhi

Main reference

Kaur, G., Agarwal, P., Garg, S., Kaur, P., Saini, J., Singh, A., Pandit, M., Acharya, K., Rooprai, V.S., Bhargava, O.N. and Kumar, M., 2021. The Alwar quartzite built architectural heritage of North India: A case for global heritage stone resource designation. Geoheritage, 13, pp.1-17.

BERNARDOS PHYLLITE

Spain

Monastery of El Escorial

Phyllite roofs from the Spanish Baroque

A legacy quarrying since the late 16th century

Victor Cardenes

The extraction of Bernardos Phyllite dates back to the late 16th century, initiated by the directive of King Philip II. His mandate aimed at locating slate deposits in the vicinity of Madrid to supply the necessary material for the development and construction of new imperial structures.
For centuries, the Bernardos Phyllite was synonymous with nobility and excellence, with an important representation on the Spanish Stone and Architectural Heritage.
Today, these quarries continue to yield phyllite, serving the needs of both contemporary architectural projects and restoration endeavors. Notably, Bernardos Phyllite faces no significant heritage concerns, with its only challenge being the competition posed by foreign rocks of lesser quality.

Bernardos Phyllite (20 x 30 cm)

Petrography
Phyllite

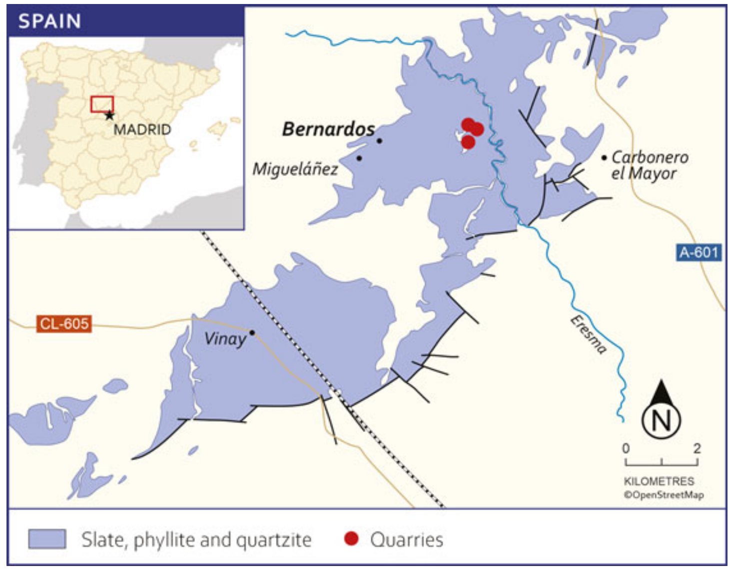
Geological setting
Precambrian- Lower Cambrian;
Massif of Santa María La Real, (Iberian Massif)

Occurrence
Bernados, Province of Segovia, Spain

Petrography

Bernardos Phyllite displays the characteristic texture for a fine-grained phyllite. There is a strong structural control due to the intense and penetrative slaty cleavage.
Texture is porphyro-lepidoblastic, with grains of quartz and chlorite deformed by the slaty cleavage, developing cinematic structures such as pressure shadows.
The matrix is composed mainly by mica. Accessory minerals are biotite, rutile and some iron sulphides and carbonates. Texture and mineral composition is that typical for roofing slates.

Location and geology



The Massif of Santa María La Real, (Iberian Massif) is an outcrop of Precambrian - Lower Cambrian materials, affected by the Hercynian Orogeny and surrounded by the Tertiary basin of eastern Spain. This structure is the result of the compression stresses that occurred during the Alpine Orogeny. From a petrological standpoint, there are two units: the Ollo de Sapo Gneiss and the Schist-Greywacke Complex.
The Schist-Greywacke Complex (SGC) is a series of pelitic and carbonate sediments of different grain sizes affected by metamorphism.
Productive outcrops are located in the upper part of this unit, where the phyllitic levels reach up to 30 metres thickness and the slaty cleavage (S1) is penetrative and homogeneous enough to allow the split of the rock in thin, regular and flat tiles.

Quarries

Nowadays, only a few quarries are still working in the area. The most important are the historical quarries of Engorduro and El Castillo, operated by the company Naturpiedra, employing between 40 to 50 workers out of the company's total of 150.
Engorduro is one of the oldest mining explotations in Segovia, with an estimated surface of 90 hectares, and proven reserves of roofing slates for, at least, 2 milion metric tons. In turn, El Castillo has a surface of 10 hectares, with proven reserves of 500.000 metric tons.
The factory has incorporated the lastest advances in natural stone processing, so in addition to roofing slates other materials are manufactured, such as ashlars, tiles, blocks and chips. In addition, there is a special line for producing historical formats, which are used in restorations.

Quarry, Bernardos

Architectural and cultural impact

Spain has been, since the 60s of the last century, the world's leading producer of slate for roofs. The starting point of this industry dates back to the opening of the Bernardos quarries.
At that time, expert craftsmen from France and Belgium moved to Segovia to work and teach the locals the art of artisanal slate production.
Some of them married and remained in Bernardos, founding lasting dynasties of slate makers. Today there are still descendants of these slate masters living in Bernardos. Therefore, Spanish slate architecture is influenced by the Franco-Belgian School, unlike the German School, which uses different formats and installation systems.
The first building in Castile that had a slate roof „in the Flemish way" was the Casa del Bosque de Valsaín, completed in 1562. Later, the Palacio del Pardo, current residence of foreign leaders when visiting Spain, the Alcázar of Toledo, and the Monastery of El Escorial.
From the architectural point of view, new construction techniques for roof frames, necessary for the stratification of slates, were incorporated into Spanish architecture. During the following centuries, the phyllite industry became one of the main economic drivers of the region, along with agriculture and livestock.
At the beginning of the 20th century, production experi-enced a decline, due to the Spanish Civil War and changing architectural trends.
However, towards the 60s of the last century this industry was revitalized by the new operation of abandoned quarries and a new interest in vernacular architecture.
Today, this activity once again leads the development of this region of Spain.

Historical photo, Bernardos

Main reference

Cárdenes, V., Rubio, aA. & Ruiz de Argandoña, V. G. (2019): Roofing slate from Bernardos, Spain: a potential candidate for global heritage stone.- Episodes Vol. 44, 1, 3-9.

CARRARA MARBLE

Italy

Instruments from Roman times

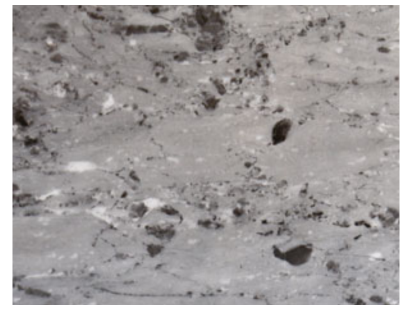
The essence of classic sculpture

Eliane Aparecida Del Lama
after P. Primavori

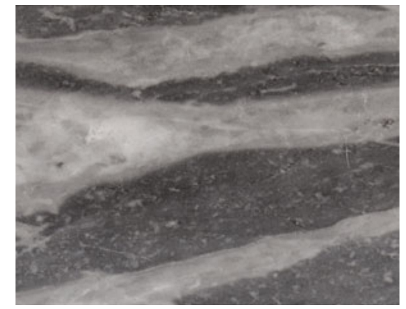
Carrara Marble is certainly one of the most famous ornamental stones in the world, having been mined since pre-Roman times in the region of the Italian city of Carrara.
The first record of marble exploration dates back to the 1st century BC. Carrara Marble was immortalized by Michelangelo's sculptures, as well as other works by famous artists and architects, such as Donatello, Jacopo Della Quercia, Canova, Bernini and many others. Many buildings built with this stone have been classified as UNESCO World Heritage Sites.
In addition to its constant presence in Roman and Italian heritage, it is also found in several countries. Its versatility has allowed its use for various fields of application in architecture, fine arts and funerary art. It is still being explored and is exported all over the world.

Bianco Venato, (5 x 6 cm)

Venato, (5 x 6 cm)



Bardiglio, (5 x 6 cm)



Nuvolato, (5 x 6 cm)

Arabescato, (5 x 6 cm)

Calacatta Vagli, (5 x 6 cm)

Petrography
Marble; pure and impure calcitic marbles, dolomitic marbles and metabreccias

Geological setting
Triassic to Miocene, Apuan Alps

Occurrence
Carrara district, NW of Tuscany, Italy

Petrography

Although Carrara Marble is recognized as a white marble, the term encompasses a variety of types with different chromatic and structural features. The main commercial types are: Bianco Carrara (white), Venato (veined), Bardiglio, Nuvolato (cloud-like), Arabescato, Statuario and Calacata. Compositionally, they are made up of pure and impure calcitic marbles, dolomitic marbles and metabreccias.
The mineralogy is mainly calcite, and the accessory minerals are pyrite, muscovite, quartz, dolomite, hematite, magnetite, sericite, epidote and titanite. The granulation varies from fine to medium and the stone has a saccharoid structure, presenting more homogeneous or more venulated varieties. The color varies from white, ivory white, pearly white to light/dark gray. Darker varieties have more pyrite.

Location and geology

The Carrara district is part of the Apuan Alps, northwest of Tuscany, Italy, where there are five important extraction areas for marble production: Lunigiana, Garfagnana, Versilia, Massa and Carrara, totaling 75 km².

The Apuan Alps is a mountainous and highly eroded region, and the base is formed of the Apuan Metamorphic Complex, comprising the Massa Unit and the Apuan Unit.

The latter includes practically all ornamental stones that are generically called Carrara Marble.

The Apuan Unit, from Triassic to Miocene in age, was deposited over a portion of the palaeo-African margin and during the Neogene was affected by the Alpine orogeny through two main tectonic events which deformed the complex synmetamorphically.

Quarries

Carrara Marble has been mined for over 2000 years and is still being explored, producing 1,500,000 tons per year.

Currently, there are around 80 quarries in operation, making the Carrara district the area with the largest number of underground quarries in the world.

The quarries are located throughout the Apuan Alps region, distributed in the municipalities of Carrara, Massa, Fivizzano, Vagli, Minucciano, Vila Collemandina, Stazzema and Seravezza.

There is no assessment of marble reserves in the region, but estimates allow us to state that exploration will continue for centuries.

Quarry in the Carrara disctrict

Architectural and cultural impact

First used in public buildings of the Roman Empire, there are numerous applications in private buildings, columns, sidewalks, streets, walls, stairs, balconies, skirting boards, internal and external cladding, sculptures, decoration, funerary art and furniture in general.

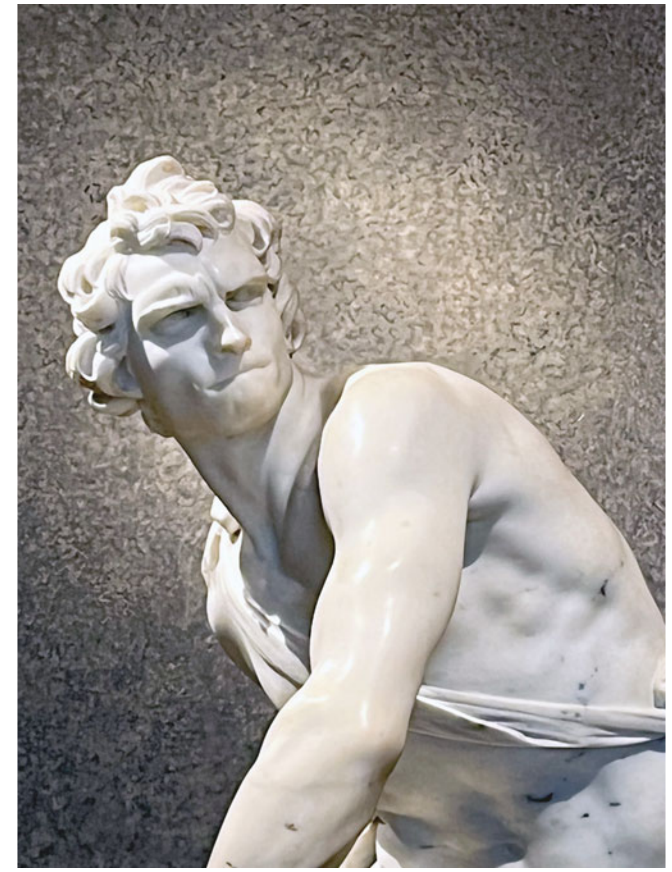
After the Romans, there is no news of marble exploration until the end of the 13th century. Until then, the exploration was done manually, and it began to be extracted with the use of explosives in the 18th century.

At the end of the 19th century, helical wire was used in its extraction, which allowed large cuts to be made directly into the face of the mountain, until it was replaced by diamond wire in 1978-1979, resulting in better productivity rates, security and versatility.

The use of Carrara Marble is so vast that it is difficult to make a list or select examples. In terms of sculptures, the following stand out: David, Pietà and the tomb of Pope Julius II, all by Michelangelo, and Ecstasy of Saint Teresa. In terms of buildings, the following stand out: Ara Pacis Augustae (Rome), Cathedral and Leaning Tower (Pisa) and Santa Maria del Fiore Cathedral (Florence), all in Italy. Examples in other countries include: Marble Arch (London, UK), Palace of Congress (Paris, France), St. Petersburg Museum (Russia), Royal Palace (Warsaw, Poland), Oslo Opera House (Norway), Central Post (Stuttgart, Germany), Robba Fountain (Ljubljana, Slovenia), Tripoli Auditorium (Lybia), National Library (Canberra, Australia), Bogotá University (Colombia) and Buddhist Temple (Singapore).

The main conservation problems of this stone, which occur in only a few varieties, are: granular disaggregation, bowing and discolouration. Extraction in Carrara has always been, and still is, an international reference for equipment and exploration techniques.

Due to its very pure calcitic composition, the waste material is used in the production of calcium carbonate by several industries, such as paper, painting and pharmaceutical products.



Galleria Borghese, „David“ by Gian Lorenzo Bernini. Photo: Angela Ehling

Main reference

Primavori, P. (2015). “Carrara Marble: a nomination for ‘Global Heritage Stone Resource’ from Italy.” Geological Society, London, Special Publications 407: SP407.21. Pereira, D., Marker, B.R., Kramar, S., Cooper, B.J. and Schouenborg, B.E. (eds) 2015. Global Heritage Stone: Towards International Recognition of Building and Ornamental Stones. Geological Society, London, Special Publications, 407, p. 137 – 154. https://dx.doi.org/10.1144/SP407.21.

CONNEMARA MARBLE

Ireland

Connemara Marble columns on either side of a Dunlewy White Marble column in the Oxford University Museum of Natural History (1855-60). Photo: Louise Caulfield

An iconic Irish decorative stone

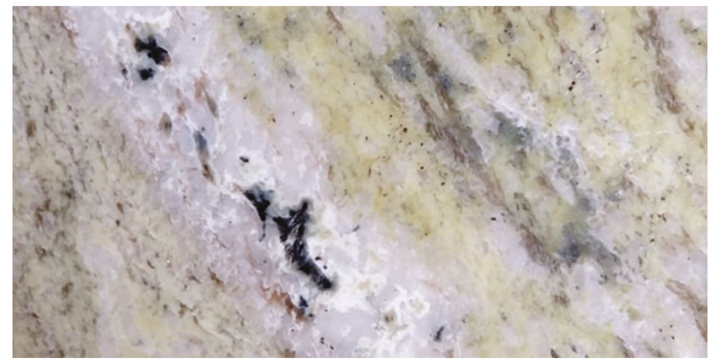
Louise Caulfield
Patrick N. Wyse Jackson

Connemara Marble is a well-known distinctive decorative stone from the west of Ireland. It is an ophicarbonate, displaying intricate corrugated layers that range in colour from white through sepias to various shades of green. Nationalistic affinity of this stone is prompted and reinforced by its prevalent green colouration.

It has been used since Neolithic times but only commercially quarried in Connemara since the early nineteenth century. It was widely applied for architectural decoration, cladding and structural columns in Ireland, Britain and the United States. Its many uses as an ornamental stone in building interiors and in Irish jewellery commands worldwide acclaim.

The active Streamstown quarry and disused Cregg quarry are designated Geological Heritage Sites by the Geological Survey of Ireland on account of their excellent exposure of the range of variation in Connemara Marble.

Connemara Marble dark variety (Width of view 10cm)
Photo: Patrick Wyse Jackson



Pale variety below (Width of view 10cm) Photo: Patrick Wyse Jackson

Petrography

Sillimanite-grade ophicarbonate dominated by dolomite and calcite with varying proportions of serpentine, diopside, forsterite, tremolite, clinochlore and phlogopite

Geological setting

Lower Dalradian, Grampian Metamorphic Complex

Occurrence

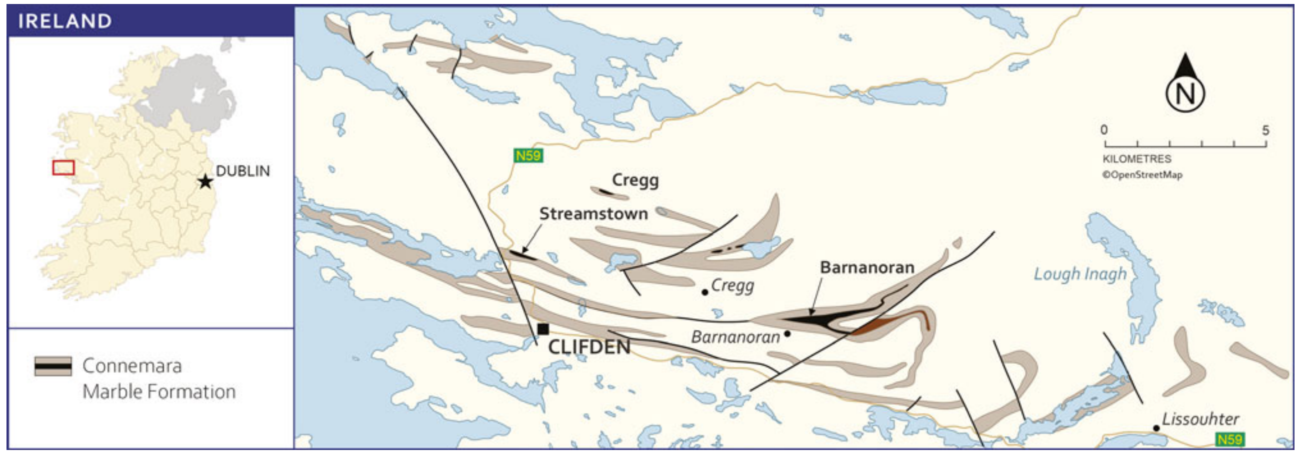
Connemara, Co. Galway, Ireland

Petrography

Connemara Marble is a sillimanite-grade ophicarbonate.

The varying shades are determined by the extent and diversity of coloured minerals present, changing from white to green with increasing serpentine content. Typically, cream dolomite and white calcite form the groundmass in which varying distributions of metamorphic minerals, including serpentine, diopside, forsterite, tremolite, clinochlore and phlogopite, create decorative interwoven bands of pale to dark green, sepia and occasionally grey and black. Maximum hydration of magnesium silicates creates the deepest coloured ophicarbonates. Mineralogically defined microlayers are visible in thin section and at outcrop scale. Only a small part of the Connemara marbles contains sufficient proportions of carbonate minerals to be classed a true marble. However, this impure chemistry, imparting the distinctive colour, enhances the economic value of the marble.

Location and geology



Connemara Marble occurs in isolated outcrops in an east-west-aligned trend from Clifden to Lissoughter, Co. Galway, Ireland. It belongs to the Lower Dalradian (= Appin Group) of the Grampian Connemara Metamorphic Complex.
All of the commercially significant marbles are concentrated in one stratigraphic horizon, the Connemara Marble Formation. Connemara Marble protoliths comprised both calcareous and clastic lithologies; it is a metamorphosed ophicarbonate, interbedded with Dalradian schists and quartzites, which were deposited on a shelf environment at the end of the Precambrian period.
Metamorphism occurred during the Grampian Orogeny. Later pervasive hydrothermal metamorphism, possibly linked to the generation of hydrothermal fluids during the emplacement of the Galway Granites and/or a regional temperature decrease after the metamorphic peak, led to serpentinization and the greening of the marble.

Quarries

The principal quarries yielding the celebrated green marble are Streamstown, Ballinahinch and Lissoughter, while white and sepia marbles were raised at Cregg. Connemara Marble has been intermittently quarried since the 1820s.
Thomas Weaver, Engineer to the Hibernian Mining Company, first ascertained the economic viability of the marble in his 1825 report. It was subsequently extracted in significant volume by John D'Arcy of Clifden Castle and Richard Martin of Ballinahinch Castle on their respective estates.
Late-Victorian management of the Connemara quarries by prominent marble workers, Messrs Sibthorpe and Son and Richard Colles of the Kilkenny Marble Works, was a crucial stage in the development of the industry in that it provided a secure and affordable supply of indigenous green marble for fabrication.
Ongoing investment into machinery and proximity to waterways were also essential for the success of the quarries.

Streamstown Quarry. Photo: Louise Caulfield

Architectural and cultural impact

Connemara Marble column in the Church of Saints Peter and Paul, Athlone (1930-1936). Photo: Patrick Wyse Jackson

Connemara Marble tazza by William Manderson in the Natural History Museum, London. Photo: Louise Caulfield

Drawing parallels with the esteemed Thessalian Verde Antico, Connemara Marble emits timeless beauty, elegance and endurance. Its inclusion in native historical architecture and monuments anchors the structures in the vibrant surrounding geological landscape. Chronicles of materials, quarry ownership and stone fabrication invites new ways for people to identify with their rich built and geological heritage. The gap between geology and architecture is bridged by stone.
The use of Connemara Marble, amongst other Irish marbles, for robust columns in the neo-Gothic Museum Building of Trinity College Dublin (1853-7) represents the first thoroughgoing instance of structural polychromy derived from native stone in Ireland and Britain. Thereafter, Connemara Marble embellished nearly every Victorian Church across Ireland, together with other elite buildings.
An outstanding example is the Church of Saints Peter and Paul, Athlone (1930-6), for which 120 tons of Streamstown Marble was extracted.
Fabricated at the Merlin Park Marble Works by Messrs Whitehead and Sons of Kensington Oval, 3 to 6 drum columns of this marble dominate the interior of the church. Another noteworthy building is the Cathedral of Our Lady and St Nicholas, Galway (1957), in which the floor consists mainly of marble tiles from Streamstown and Ballinahinch.
First exported to London in the mid-1820s, Connemara Marble now adorns and upholds prestigious buildings across the globe. It stands beside other Irish and English polished stone in the Oxford University Museum of Natural History and envelops interior surfaces of Westminster Cathedral. An ornate tazza, now displayed in the Natural History Museum, London, was shaped from Ballinahinch Marble by William Manderson of the Killaloe Marble Works, Co. Clare, originally for the Museum of Practical Geology.
From the towering 30-foot columns that elevate the Gould Memorial Library in the Bronx, New York to the delicate ornamentation of the staircase in Chicago Cultural Centre, the prized green marble is well represented in the United States. It even reached as far as St Mary's Cathedral, Capetown, featured in an altar, crafted by Richard Kirwan of Bolton Street, Dublin.
The application of Connemara Marble in prominent international buildings stands as a testament to the magnificence of Irish decorative stone.

Main reference

Wyse Jackson, P.N. et al. (2019) 'Connemara Marble, Co. Galway, Ireland: a Global Heritage Stone Resource proposal', in Hannibal, J.T., Kramar, S. and Cooper, B.J. (eds) Global Heritage Stone: Worldwide Examples of Heritage Stones. Geological Society, London, Special Publications, 486, pp. 251-268.

ESTREMOZ MARBLE

Portugal

Perelman Performing Arts Center in New York, designed by REX.
Photo: Iwan Baan

A Portuguese known brand in the world since ancient times

Luís Lopes
Ruben Martins

The systematic quarrying of marbles in the Estremoz anticline began in the 1st century AD, during the Roman Period. Marbles were widely used as structural and decorative features of buildings that today are important architectural monuments, e.g. the Roman Temple in Évora and the Roman Theatre in Mérida (Spain). In the Middle Ages, marbles were used for the construction of palaces, castles and buildings.
From the 15th century marbles began to have a more prominent use, both nationally and internationally, having been transported by Portuguese explorers worldwide.
They appear in many monuments integrated into UNESCO classifications, such as Jerónimos Monastery (Portugal), Escorial Monastery (Spain), Louvre, Notre Dame and Versailles (France), sometimes inlaid with polychromatic materials.

Estremoz marble varieties.

Petrography

Calcitic marble; varieties of colours: pink, white, cream, grey and blue dark

Geological setting

Upper Precambrian- Lower Cambrian to Ordovician (?), anticline of the Iberian Variscan Belt

Occurrence

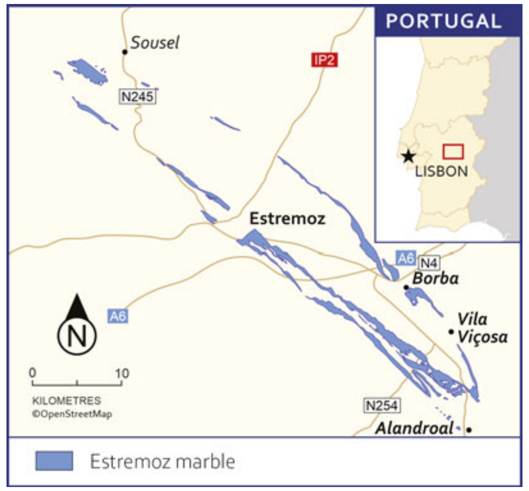
Marble Triangle: Estremoz, Borba and Vila Viçosa, Portugal

Petrography

Estremoz Marbles correspond to a calcitic marble with granoblastic texture, even though the preferred lattice orientation of the crystal is almost always present, and medium to fine grains (rarely coarse). A milonitic texture is often present and occasionally nematoblastic texture can be found in more heterogeneous varieties.
Their mineralogical composition includes calcite (98 – 100%) and accessory minerals (quartz, dolomite, sericite, muscovite, biotite, chlorite, zircon, apatite, pyrite, magnetite, graphite). Regarding the colours, there is a close relationship between the occurrence of mafic metavolcanic green layers and the pink colour in the marble due to the enclosure of Mn in the crystal lattice of calcite. At the top of the stratigraphic sequence, a dark blue carbon marble is found (Ruivina).

Miscellaneous of geological structures including fold interference patterns in Estremoz marble.

Location and geology



The Estremoz Anticline extends NW – SE for 42 km between Sousel and Alandroal. It is a major structure in the Ossa-Morena Zone (Iberian Variscan Belt, Portugal).

An Upper Precambrian siliciclastic sequence is found in the core and, in discordance, a Lower Cambrian to Ordovician (?) Volcano–Sedimentary–Carbonate sequence has formed.

At the bottom, the carbonates are essentially dolomitic and intensely fractured.

At the top of this Dolomitic Formation there is a siliceous horizon, formed during the aerial exposure of carbonates and consequent karstification.

The dating of the Estremoz stratigraphic sequences reinforce that this anticline is itself a major Variscan structure of the Ossa-Morena Zone (Portugal), being part of the North-Gondwana margin during the late Ediacaran to early Cambrian times.

Quarries

The quarries are located in the „Marble Triangle": Estremoz (23 quarries) – Borba (55 quarries) – Vila Viçosa (119 quarries). Currently most of these quarries are inactive.

In Vila Viçosa around forty remain in operation. There is one in Borba and two in Estremoz. Annual production is below 700 k tons. Conservative accounts indicate reserves for more than 500 years of exploitation maintaining the current average annual production rate and not going beyond 100 meters deep, when it is known that in some places the surveys found marble beyond 400 meters deep. Despite the intensive historic exploitation, there still is a quarry from Roman times where it is possible to observe the exploitation methods and the marks left by the different tools. It is a unique space that needs to be preserved.

Quarry panorama

Architectural and cultural impact

Being a symbol of economic strength, good taste and distinction, it can be said that there is no city in Portugal where Estremoz Marble has not, somehow, been used in both small works of art or utilitarian objects, such as public monuments and private homes. For sure, thousands of buildings have used Estremoz Marble.

Historically documented, exploitation dates back to the Roman times and it was used in many places in the Roman Empire.

Its processing and application extends to our days, owing to the global commercial trade. Estremoz Marble can be found all over the world.

On "Information System for Architectural Heritage" (http://www.monumentos.pt), at least 179 national monuments where Estremoz Marble has been used are referenced. By itself, this fact constitutes an indicator of the marble's importance in the history of Portugal and certifies its value as a Heritage Stone to be preserved.

This long-term intense use is a sign of its high quality- the only way to justify the demand that has continued for more than 25 centuries, otherwise demand would have ceased.

In the 20th century, with the introduction of new exploitation and manufacturing technologies, especially in the 70's with the opening up of the Portuguese economy, the marble industry took a step forward and, since then, marble has been exported worldwide. But only in the late decades of the 20th century did the marble dimension stone industry of Portugal achieve international importance.

Nowadays, business associations and Portuguese dimension stone companies have been making a huge effort towards the promotion and international marketing, whose recognition is expressed in the choice of Estremoz Marbles to cover the Perelman Performing Arts Center, in New York (https://pacnyc.org), opened on September 19, 2023.

Estremoz Marbles, in addition to the historical legacy they have already passed on to us, continue to be part of the choices of the most prestigious architects who today design heritage for the future.

Marble scupture (detail) "Son of the sun" by Cesar Valerio

Estremoz Marble coat of arms, in a private house in Évora.

Main reference

Lopes, L., Martins, R. (2015). "Global Heritage Stone: Estremoz Marbles, Portugal." Geological Society, London, Special Publications 407: SP407.10. Pereira, D., Marker, B.R., Kramar, S., Cooper, B.J. and Schouenborg, B.E. (eds) 2015. Global Heritage Stone: Towards International Recognition of Building and Ornamental Stones. Geological Society, London, Special Publications, 407, p. 57 – 74. https://dx.doi.org/10.1144/SP407.10.

FACOIDAL GNEISS

Brazil

Salt Stone outcrop.

The most ‘carioca’ of rocks

Nuria Fernández Castro
Kátia Leite Mansur
Maria Heloisa Barros de Oliveira Frascá
Eliane Aparecida Del Lama

Facoidal Gneiss is the most representative lithology of Rio de Janeiro’s natural and built heritage. Due to its abundance on the rocky outcrops around Guanabara Bay, it was continuously used to build Rio’s World Heritage site from the Portuguese occupation (16th century) to the mid-20th century, evolving from rough to monumental works. In the 18th century, Master Valentim, the most representative Brazilian artist of Rio from the colonial period, produced several artistic works with this rock.
Among the many examples of its use in Rio, the world’s heritage sites Valongo Wharf and Burle Marx’s House can be cited, as well as other examples in some Brazilian cities. Its geological history and features shaped the famous landscape of Guanabara Bay, including the IUGS Geosite Sugar Loaf.

Macroscopic view of Facoidal Gneiss.

Detail of Widow’s Hill Quarry.

Petrography
Orthoderived gneiss with K-feldspar megacrystal in a biotite rich quartz-plagioclase matrix

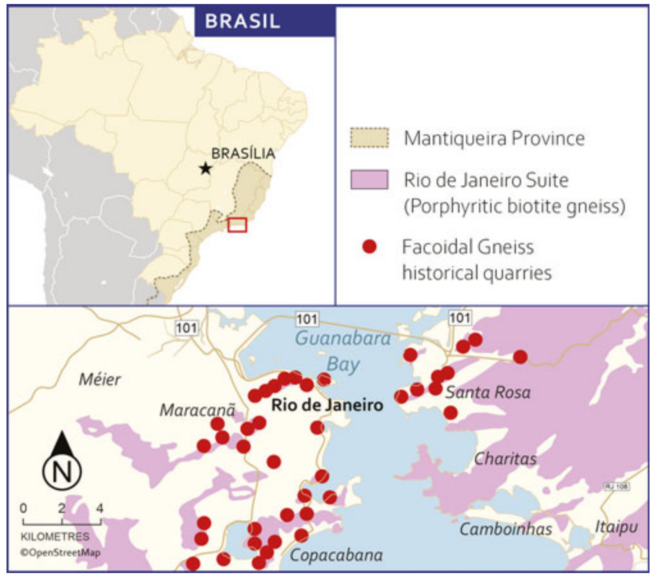
Geological setting
Cambrian-Proterozoic, Ribeira Belt orogenic system

Occurrence
Rio de Janeiro and Niterói Counties; Brazil

Petrography

Facoidal Gneiss is orthoderived (syeno- to monzogranitic), light coloured (from pinkish grey to yellowish red), and coarse-grained, displaying K-feldspar and minor plagioclase as megacrysts (2 to 15 cm) that usually constitute oriented pinkish or whitish augens in a biotite rich quartz-plagioclase matrix.
Due to the metamorphic deformation in the cross-cut sections to the gneissic banding, the K-feldspars resemble an almond shape; on the parallel faces, they are rounded. Idiomorphic feldspar crystals can be observed, too.
The main composition is K-feldspar (microcline) (35%), quartz (30%), plagioclase (20%), and biotite (10%). It may contain garnet, muscovite, and other accessory minerals. Microcline can constitute more than 50% in samples with larger crystals.

Location and geology



Facoidal Gneiss crops out in Rio de Janeiro and Niterói Counties (State of Rio de Janeiro, Brazil).
Its geological history began in the Cambrian-Proterozoic Gondwana amalgamation within the 1,400 km long Ribeira Belt orogenic system. Facoidal Gneiss was formed around 560 Ma ago, at the peak of the deformation phase of that orogen, from a granitic pluton.
It is cut by aplite and pegmatite veins related to the collapse of the orogen (Cambrian to Ordovician) and by tholeiitic dykes of the South Atlantic Ocean opening (c. 130 Ma).
A reactivation of faults (c. 60 Ma) formed the Guanabara Graben, uplifting the mountains and peaks that shape the landscape around Guanabara Bay.
The most prominent of these in Rio are supported by Facoidal Gneiss, which resisted better to weathering than other rocks.

Quarries

Many quarries produced this stone. They closed in the 20th century due to dense urbanization and environmental protection regulations.
First, coastal outcrops and rocky islands provided material for fortresses and some ecclesiastic buildings.
Downtown quarries (e.g. Conceição and São Diogo) supplied most of the Facoidal Gneiss in the colonial period (1565-1822), and as the city expanded west and south, quarries spread on the Tijuca Massif skirts. The southern isolated hills (e.g. Widow's Hill) became key, yielding high-quality material for 19th-20th-century monumental constructions and massive urban reforms. Historic paintings and chronicles show that quarrying and stoneworking were tasks for enslaved people, replaced mainly by Portuguese and Spanish immigrants after the abolition of slavery in 1888.

Widow`s Hill Quarry. Photo: Felipe A. Monteiro

Architectural and cultural impact

Since Facoidal Gneiss was very important to Rio de Janeiro, it has been acknowledged as the most carioca of rocks (Porto granite outcrop surrounded by city buildings).
There are countless examples in Rio: cut-stone for public works (e.g. Old Port, Imperial Dock on Snakes Island, old pavements); urban decorative elements (e.g. Master Valentim's Public Promenade, Grandjean de Montigny Fountain); rubble masonry walls, stairs, quoins, lintels and jambs in residential and ecclesiastical buildings (e.g. Candelária Church, Travessa do Comércio residences); and masonry blocks, stairs, balustrades, arches, ashlars, pediments, columns and ornaments in monumental buildings (e.g. National Archive, National Historical and Artistic Heritage Agency building, Earth Sciences Museum, Capanema Palace).
It can be considered a token of the birth of Brazilian architecture (19th-20th century), and it was recycled in important landscape works by Burle Marx (e.g. Burle Marx's House, World Heritage Site).
There are examples of this stone's use in many cities around Rio, especially Niterói (e.g. Santa Cruz da Barra Fortress), where it was also quarried, and in other places in Brazil (e.g. Tiradentes Monument in Ouro Preto, Minas Gerais). This gneiss makes up some of the city's most important natural tourist and recreational places (e.g. Corcovado Mountain and Sugar Loaf, the latter an IUGS Geoheritage site).
Facoidal Gneiss was the main building material of the Valongo Wharf (World Heritage Site), standing as a re-membering of the enslaved Africans' suffering.
It is also a material witness of the driving source of Afro-Brazilian culture at the National Heritage Site of the Salt Stone, a Facoidal Gneiss outcrop in a downtown's continuously inhabited black neighbourhood regarded as the birthplace of samba and Carnival.

Building of the Bank of Brazil Cultural Center, Rio de Janeiro.

Main reference

Castro, N.F., Mansur, K.L., Frascá, M.H.B.O. and Silva, R.E.C. (2021). "A heritage stone of Rio de Janeiro (Brazil): the Facoidal Gneiss." Episodes, v. 44, p. 59-74. https://doi.org/10.18814/epiiugs/2020/0200s13.

GERMAN ROOFING SLATE

Germany

Old German roofing, Bamberg.
Photo: Theis-Böger

Traditional craft shaping cultural landscapes

H. Wolfgang Wagner

The name German Roofing Slate refers to the occurrences of slate in Central Europe, especially Germany, as well as to the traditional laying techniques that prevail there, which are called `Deutsche Deckarten´ (English: German types of roofing and cladding).
These are scale-shaped slates that are laid in a particularly artistic way that does not exist anywhere else in the world, where usually only rectangular coverings are common.

Slate wall cladding with the previously existing 3 slate colours (from outside to inside: black, green, purple) (figure diameter approx. 2.5 m) (over 100 years old).

Petrography
Black-grey slate

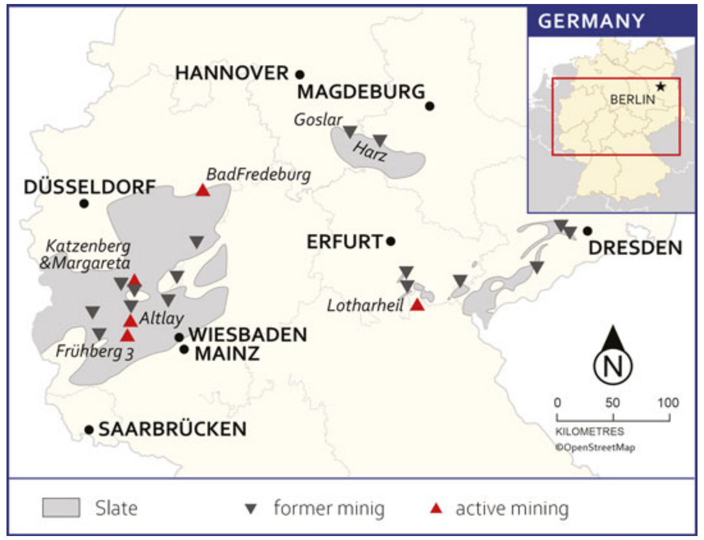
Geological setting
Paleozoic- Ordovician to Lower Carboniferous / Mississippian;
Rhenohercynian and Saxo-Thuringian Zone of the Variscan Orogen

Occurrence
Rhenish Slate Mountains to the Harz Mountains, S Thuringia/Saxony, NE Bavaria, Germany

Petrography

The mineral inventory of the rocks described here corresponds to that for black roofing slate typical composition: mica 32-42 %, chlorite 14-20 %, illite (hydro-micas) 6-8 %, quartz 27-31 %, carbonates 1-10 %, and accessory minerals.
The primary colour and aesthetics of the stone is dark blue, grey to black, and also rarely green and red. The slate slabs also have a glossy splitting surface. The Lithotype after Cardenes et al. 2020 is black-gray slate B1.
The natural variability of the German Roofing Slate includes 2 types: Black slates with > 5 % Carbonate. This slate is not color stable after covering (semiweathering) and partly forms a silvery, colored patination. Black slate with < 2 % Carbonate. This low-carbonate slate retains its dark color.

Location and geology



The majority of the active and former German roofing slate deposits are located in a SW-NE striking zone running from Luxembourg/Ardennes over the Rhenish Slate Mountains to the Harz Mountains".
Another important centre of slate mining was in S Thuringia / NE Bavaria and some smaller deposits had been quarried in Saxony. Most of the roofing slate deposits originate from the Lower and Middle Devonian (412 - 392 m years ago) and the Mississippian/Lower Carboniferous (approx. 345 m years ago), some occurrences are of Ordovician and Silurian age.
They were deposited as fine-grained sediments in a back arc basin along the southern passive margin of the paleocontinent Laurussia. The roofing slate and the slaty cleavage were formed during the Hercynian orogeny (about 350 to 280 m ago).

Quarries

Exactly in the center of the UNESCO World Heritage „Upper Middle Rhine Valley" is one of the formerly most important German slate areas around Kaub. Until 1967, Middle Devonian slate was mined in the lower Lahn valley in the colors black but also exceptionally green.
The slate deposits in the Harz near Goslar are in the geological-tectonic continuation of the slate deposits in Westphalia. The most important mines here are the Ratsschiefergrube (1359 with interruptions until 1896) and most recently Glockenberg (1887-1969).
Since the late Middle Ages, there have been numerous slate mines in Thuringia. Until 2008, the black-blue slate was most recently mined in mines near Lehesten and Unterloquitz.
To this day, a Lotharheil slate mine still mines slate for architecture in NE Bavaria.
Active Roofing Slate mines are Altlay mine, Frühberg 3 quarry in Bundenbach, Katzenberg mine in Mayen (until 2019) and Magog mine in Bad Fredeburg.
In addition to these quarries, there were other larger slate mines after World War II active (from southwest to northeast): Since the 17th century, there has been the roofing slate mine Kesselstatt near Thomm and smaller mines in Fell, both near Trier. On both sides of the Moselle are several slate mines near Lütz (approx. 1860 to 1952).
A heritage zone and a nature reserve now include the former mines Colonia, Maria Schacht and the Müllenbacher Dachschieferwerk.

Most roofing slate quarries operate underground

Architectural and cultural impact

With a water absorption of < 0.6 in mass % and a modulus of rupture > 40 MPa in both directions, the technical properties of the G-slate are sufficient for outdoor use as roof covering or façade cladding.
The other values also prove its suitability as a stone for architecture. Both, roofing slate mining and its use, including the traditional German and Old German slate formats, date back to Roman times and the Middle Ages. This is shown by many examples with slate roofs in UNESCO World Heritage Sites:
The Roman Upper German-Rhaetian Limes with watchtowers and associated forts (from 9 AD), Roman Monuments in Trier, Aachen Cathedral, Hanseatic City of Lübeck, Bamberg Old Town, Würzburg Residence, Castles at Brühl, Palaces and Parks of Potsdam (e.g. Fortuna portal 1701, blown up in 1960, rebuilt in 2001), Margravial Opera House Bayreuth, 18th century, Speicherstadt in Hamburg and some more.
The German slate region is also the focal point of the roofing and slate crafts. In the tradition of the medieval slate roofing guilds, today's roofer schools and training are run by the craft and not by the state. The neighboring slate companies actively supported the roofing schools in Lehesten, Mayen, Eslohe and Aue-Bad Schlema.
In the traditional roofing slate areas, there is an impact on tourism. In Germany, there are 3 slate holiday routes, which connect a total of 10 slate museums and slate show mines.

Slate façade from 1828 with later renewed decorations with tin foil (`Stanniol`), typical of northeastern Bavaria.
Photo: S. Scheidig

Main references

Wagner, HW (2021) Roof slates. In Ehling A, Häfner F, Siedel H (eds.) UNESCO Sites in Germany. Natural Stone and World Heritage Series, vol. 3. CRC Press (Taylor & Francis Group), Boca Raton, London, New York. https://doi.org/10.1201/9780367823061,

Wagner, HW (2021b) Rohstoffgeologie des Dachschiefers. Habilitation Thesis, University of Trier. https://www.academia.edu/77261623/Rohstoffgeologie

Wichert, J. (2020): Slate as Dimension Stone - Origin, Standards, Properties, Mining and Deposits.- Springer Mineralogy, 1-492, https://doi.org/10.1007/978-3-030-35667-5_7

HALLANDIA GNEISS

Sweden

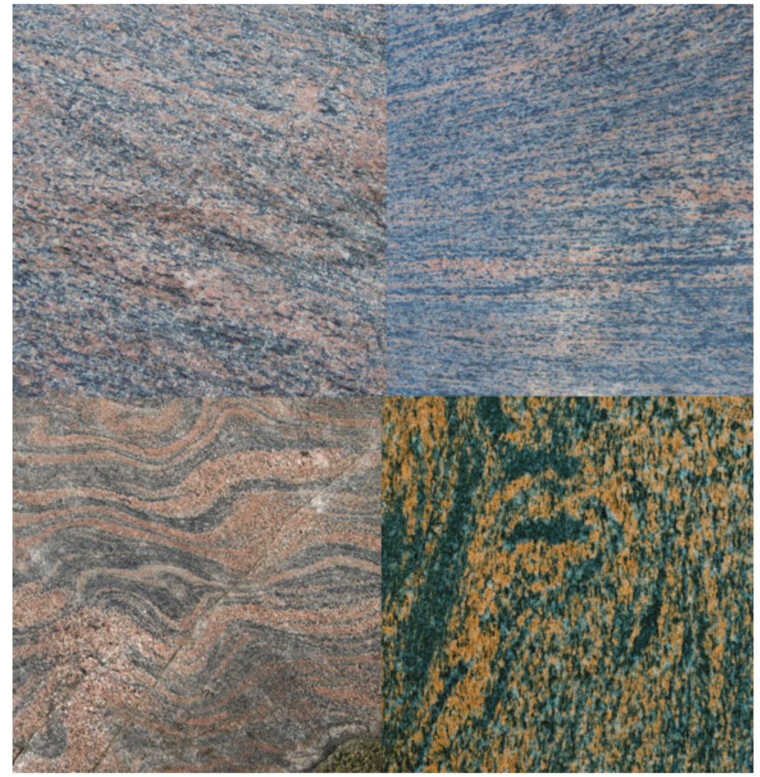
Stone and glass art by Pål Svensson and Arne Isacsson. The sculpture is located in Karlskrona (Blekinge county), southeasternmost corner of Sweden.
The artwork is called Bleke (dead calm water).

A muilti-coloured hard rock from Sweden

Björn Schouenborg

The Swedish Hallandia gneiss has been industrially quarried and exported over more than 150 years (Möller, 2010). In older times it was mostly used for paving and as structural elements (masonry units). Information about smaller quarrying goes back at least 1000 years and the number of places (stone pits) where local villages and people have quarried for their own needs can be counted to about 500 hundred.
Internationally, the Hallandia gneiss was especially frequently used in neighbouring Denmark, Germany and Poland. Trading has been frequent with these countries for many centuries. Many of the northern German, so called Hanseatic cities are paved with Swedish granites and the Hallandia gneiss, e.g. in Lübeck, Wismar and Stralsund, all UNESCO sites. Several Swedish churches abroad include applications of the Hallandia gneiss, e.g. the first "Swedish church" abroad, in Paris.

IUGS International Commission on Geoheritage



Images showing the typical, aesthetical variation in the Hallandia gneiss

Petrography
Migmatitic Orthogneiss

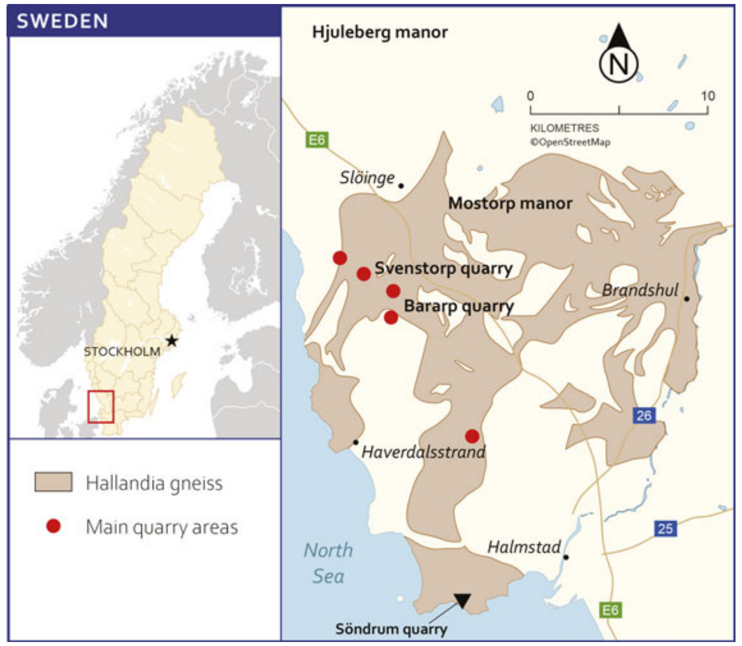
Geological setting
Paleoproterozoic; poly-phase metamorphism; Fennoscandian Shield

Occurrence
Coastal areas of the Halland County, Sweden

Petrography

The geological denomination of the Hallandia gneiss is a granitic to granodioritic migmatitic orthogneiss. The main minerals are potassium feldspar, plagioclase, quartz, biotite and amphibole.
The Hallandia gneiss varies in colour from dark reddish grey to light greyish red.
The dark varieties have a dark grey groundmass and light red leucocratic segregates and veins.
The groundmass is either even grained, fine- to medium grained to in places showing relict augen gneiss texture. The light greyish red to near red varieties have greyish-red groundmass and abundant leucocratic material. Relict groundmass textures are less prominent.

Location and geology



The Hallandia gneiss is an aesthetically distinct gneiss unit characterised by multiple phases of deformation and veining at high-grade metamorphic conditions, exclusively found in the coastal areas of the Halland County, southwestern Sweden.

The formation occurs in the south-westernmost parts of the Fennoscandian Shield that exposes poly-metamorphic orthogneisses reworked at high-grade conditions during both the 1.14-0.90 Ga Sveconorwegian, and the 1.47-1.38 Ga Hallandian orogenies (Möller et al., 2007). Protolith rocks to the Hallandia gneiss are 1.74-1.66 Ga old granitic to granodioritic intrusions.

In summary, the Hallandia gneiss is a product of a complex poly-phase tectonic and metamorphic evolution that included repeated recrystallization and deformation at high-temperature conditions, well exceeding conditions for wet partial melting of granite.

Quarries

There are presently only two significant stone producers quarrying the Hallandia gneiss; Scandinavian Stone and Hallinden Granite. Both of them qualify as SME (small and medium sized enterprises). All in all, the present production volume is small compared to the market demands and future demand for restoration and replacement units.

The Svenstorp quarry. One of very few quarries presently in operation

Architectural and cultural impact

Quarrying of the Hallandia gneiss was documented by the Geological Survey of Sweden in the late 19th century (Lundbohm, 1887). Around 1850 the Hallandia gneiss was already exported in large quantities. It has also been discovered in churches from the 12th and 13th centuries and has thus been used for building purposes for several hundred years.

Remnants of hundreds of small quarries can be seen in the landscape. In total, 502 quarry sites have been detected (Caldenius et al., 1966). This includes very small quarries, operating for a few years. Between late 1800 and 1910 almost one hundred quarries were in operation. Most of them were closed in the period between 1910 and 1950. At 1950, only 25 remained active.

At the beginning of industrial quarrying in 1844 (Friberg and Sundnér, 1995) and onwards, most of the products were paving stones. Many of them were used in the nearby cities or exported to Denmark, Germany and Poland.

A rapid increase in the use and the diversity of building stone products is also associated with this period, not least shown by the occurrences in many Swedish buildings and city pavings.

Today, the stone is much sought after for building, construction and sculptural purposes. One, particularly well-known, sculptural artist using the Hallandia gneiss in large quantities is Pål Svensson who was given the medal of Merit by the Swedish Stone Industry Federation in 2011. The Hallandia gneiss was chosen as Stone of the year in Sweden in 2023 and desribed in an online paper: STEN-2301_Arets-sten_Svenstorp-H.pdf.

The cover photo shows one of his more well know sculptures, a combination of glass art and stone. The sculpture is placed in Karlskrona harbour, SE Sweden.

Almost every larger city in Sweden and the old Hanseatic towns around the Baltic Sea have paving, steps, walls or foundations made of the Hallandia gneiss.

Norrbro ("North bridge") in Stockholm (capital of Sweden). Paving stones of Hallandia gneiss and other Swedish granites.
The Royal castle can be seen in the background.

Main references

Caldenius C., Larsson, W., Mohrén, E., Linnman, G., and Tullström, H., 1966. Beskrivning till kartbladet Halmstad. Geological Survey of Sweden, SGU Series Aa No 198, pp: 12-42; Friberg, A. and Sundnér, B., 1995. Natursten i byggnader. Göteborgs och Bohus län samt Hallands län. Riksantikvarieämbetet och Statens historiska museer. pp: 1-82;

Friberg, A. & Sundne´r, B. 1995. Natursten i byggnader. Göteborgs och Bohus län samt Hallands län. Riksantikvarieämbetet och Statens historiska museer.

Lundbohm, H., 1887. Beskrifning till kartbladet Halmstad. Geological survey of Sweden. Publication SGU Ab12, pp: 1-77.; Möller, C., Andersson J., Lundquist, I. and Hellström, F., 2007. Linking deformation migmatite formation and U-Pb geochronology in polymetamorphic orthogneisses, Sveconorwegian province, Sweden. Journal of Metamorphic Geology 25, 727-750;

Möller, C., 2010. Sten och människor – Den Halländska gnejsen. Makadam förlag. Pp: 1-200.

HIMACHAL SLATE

India

Laxmi Narayan Temple with slate roof in Himachal Pradesh.
Photo: Amritpaul Singh

The sustainable stone of the hills

Gurmeet Kaur

The Proterozoic Himachal Slates have played a significant role in shaping the architectural heritage of the northern mountainous states of India and in particular Himachal Pradesh and the adjoining areas.
Used for various purposes such as roofing, paving, fencing, sculpturing and flooring, these slates have left their mark on numerous historic buildings across the region.
Notable examples include the Shimla Town Hall Building, the Gaiety Theatre, and the Bandstand in Shimla, as well as the Sarahan Palace and Bhimakali Temple. Additionally, structures in the Pragpur heritage village and the temples of Champavati and Laxmi Narayan in Chamba showcase the enduring beauty and versatility of these slates.

Himachal Slate

Petrography
Slate, greenschist facies

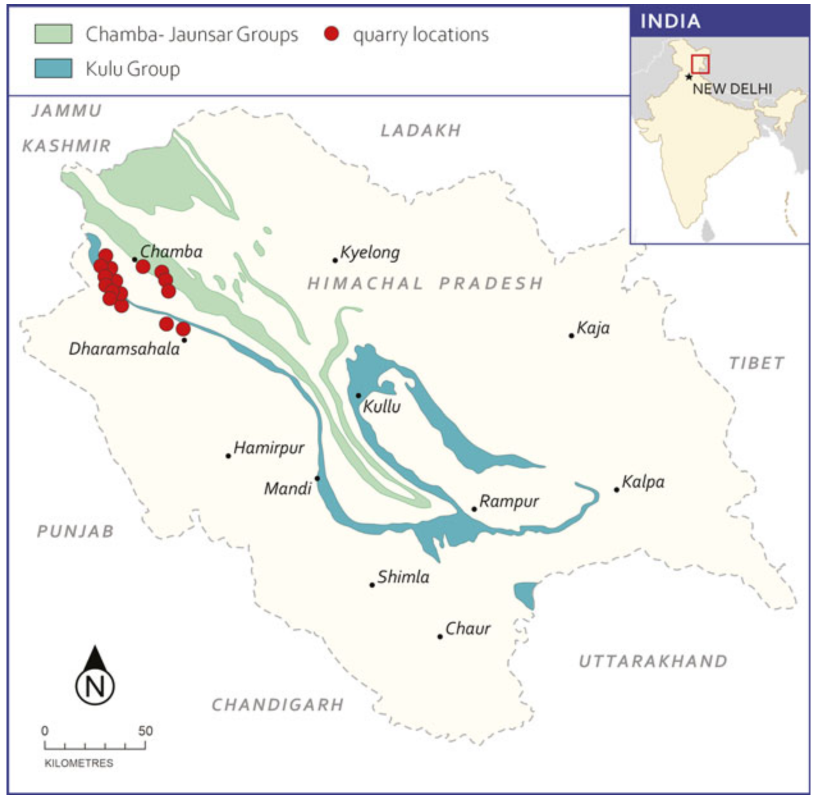
Geological setting
Proterozoic

Occurrence
Lesser Himalaya, Himachal Pradesh, India

Petrography

These rocks are fine grained, with a well-developed slaty cleavage, belonging to the sub-greenschist facies. Relict sedimentary bedding (S0) is parallel to (S1).
The phyllosilicates (mica and chlorite) are recrystallized, with their long axis aligned parallel to S1. The slates are lustrous, hard, and free of irregularities.
The main minerals include quartz, feldspars, mica, and chlorites—with carbonates, iron sulfides and epidote as secondary minerals, along with accessory minerals such as tourmaline, rutile and zircon.

Location and geology



Himachal Pradesh, located in the western Himalaya, can be divided into four geomorphological zones viz. the Sub-Himalaya, Lesser, Higher and Tethyan Himalaya.

The main slate horizons in Himachal Pradesh are found in Proterozoic terrains of the Lesser Himalaya in the districts of Kangra, Chamba, Mandi, and Kulu. A few outcrops are also present in the districts of Shimla, Kinnaur, Solan, and Sirmaur.

The Khokhan Formation of the Kulu Group and the Chamba-Katarigali Formations are well exposed in the northwestern part of the state and form the principal source of slates in this entire region.

Quarries

Formal quarrying commenced in the nineteenth century and continues into the present.

The Khokhan Formation of the Kulu Group hosts good-quality deposits of gray to black colored slates and phyllites. Important slate-yielding locations in the district of Chamba are Dulara, Dhanara, and Panthal. Dark-gray slate and phyllite, which have been mined since historic times, belong mostly to the Chamba Formation, although some belong to the overlying Katarigali Formation.

The Katarigali Formation contributes commercial varieties of slate and phyllite in the district of Kinnaur, especially in the NE of the Kalpa region. In Chamba, slate deposits belonging to the Khokhan Formation extend from Talai to the NW of the Makotsu region, with important occurrences located at Rupaina, Chaunda Devi, Bhora, Renda, Chauri, etc.

The best quality roofing slates are quarried from Khaniyara (Chamba Formation) of the Kangra district.

Himachal Slate quarry. Photo: Som Nath Thakur

Architectural and cultural impact

Sculpture of Nandi in one of the temples in Himachal Pradesh.
Photo: Amritpaul Singh

Himachal Slate has been used in buildings for centuries, demonstrating their continued importance in the history of architecture. Himachal Slate has been used extensively for roofing and flooring in buildings of different periods, from the tenth-century Laxmi Narayan Temple in Chamba to the twentieth-century Sankat Mochan Temple in Shimla.

Notable architectures include the Chandrashekhar Mahadev and Champavati Temples in Chamba, the thirteenth- and fourteenth-century Prashar Temple in Mandi, and the Hatu Temple in Narkanda.

These slates have demonstrated their adaptability in artistic expression by serving not only as useful materials for roofing and wall structures but also by being used in sculptures. Furthermore, from the ninth century, they have been used in fountain slabs and engraved with religious inscriptions and images, which are on display at the Bhuri Singh Museum in Chamba City.

Slate roofs were a common feature of structures even in the British era, as evidenced by the Gaiety Theatre and the Town Hall Building in Shimla, which boldly showcased their timeless charm and functionality.

Main reference

Kaur, G., Bhargava, O.N., Ruiz de Argandoña, V.G., Thakur, S.N., Singh, A., Saini, J., Kaur, P., Sharma, U., Garg, S., Singh, J.J. and Cárdenes, V., 2020. Proterozoic slates from Chamba and Kangra: A heritage stone resource from Himachal Pradesh, India. Geoheritage, 12, pp.1-20.

INDIAN CHARNOCKITE

India

The 133-foot tall sculpture of Tamil poet Thiruvalluvar and Vivekananda memorial made entirely of charnockite blocks on charnockite islands in the Indian Ocean.

The saga of a heritage stone of world-wide usage

C. Sreejith
Gurmeet Kaur

Charnockite forms one of the rare stones, which has been named after a monument, and is an excellent example of a heritage stone as a it was extensively used from time immemorial in the Indian subcontinent. Charnockite has also been largely used as heritage as well as a building stone in different parts of the globe.

Charnockite is entirely crystalline, composed chiefly of closely compacted crystals of quartz, feldspar and orthopyroxene, and acquires an excellent surface polish, which reinforce the recommendation of their use as dimensional and decorative stones. The charnockite exhibits high values for compressive and tensile strengths and bulk density with low porosity, low water content and isotropic distribution of minerals indicating their ability to withstand load and crack initiation. Thus, the physical and aesthetic characteristics of charnockites make it a sought-after construction material from time immemorial.

Mesoscopic view of massive-type charnockite

Petrography

Charnockite: Medium- to coarse-grained granulite-facies rock with quartz, feldspar and orthopyroxene mineral assemblages

Geological setting

Early- to Meso-Archaean and Neo-Proterozoic

Occurrence

Southern Granulite Terrain and along Eastern Ghats Mobile Belt, regionally termed as Precambrian granulite belts of Southern India

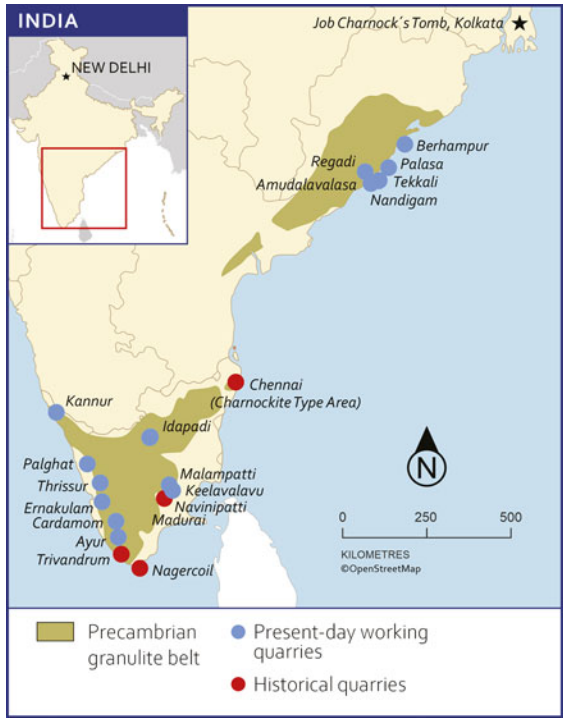
Petrography

Charnockite is a mesocratic rock characterized by medium- to coarse-grained texture and inequigranular, interlobate to polygonal granoblastic textures with mutual interlocking of grains.

Charnockite exhibits a massive to foliate structure, the latter being less frequent. The most common mineral assemblages in charnockite include K-feldspar + plagioclase + quartz + orthopyroxene (En_{40-60}) ± clinopyroxene ± hornblende ± biotite ± garnet.

It exhibits dark blue resembling smoky colours to a greasy green colour in fresh exposures and tends to have a grey, pink or light brown colour when altered. Depending upon/ on the presence of titanium rich minerals, the charnockite tends to exhibit a brownish-green colour as well.

Location and geology



In high-grade terrains of southern India, wide spread distribution of massive-type charnockite can be seen either as isolated large hillocks or as bands and lenses of several meters thickness within garnet-biotite and/or hornblende-biotite gneisses.

In southern India, charnockite is widely distributed within the Southern Granulite Terrain (SGT) and along the Eastern Ghats Mobile Belt (EGMB), regionally termed as Precambrian granulite belts.

The age groups of southern Indian charnockite comprise Early- to Meso-Archaean to the north of the Palghat–Cauvery shear zone and Neo-Proterozoic (related to Pan-African orogeny) to the south of the shear zone.

Other important global locations exposing charnockites include Ribeira Belt, Green Ubatuba and Venda Nova (Brazil); Mozambique and Limpopo Belts (Africa); Minto terrain (Canada); Bamble Sector (Norway); Bjørnesund (Greenland); Ivrea Zone (Italy); Swedish Granulite Region (Sweden); Adirondacks and Wyoming (USA); Musgrave Block (Australia); north China Craton; Antarctica.

Quarries

Fresh exposures of charnockites occur all across southern India, which have been quarried for many purposes from time immemorial.

A classic quarry location that is designated as the type-area of Charnockite at St. Thomas Mount, near Pallavaram in Chennai (then Madras), where from the charnockite slabs were transported to construct the Mausoleum of Job Charnock, has now been preserved as a National Geological Monument.

Further, active quarry locations of charnockite are spread across the states of Kerala and Tamil Nadu encompassing the vast granulite-facies formations of the Southern Granulite Terrain (SGT) of South India.

Large-scale quarrying of charnockites for building and construction purposes

Architectural and cultural impact

The charnockite terminology proposed by Sir Thomas Holland to the geological lexicon celebrated its Quasquicentennial Jubilee (125th year) in the year 2018. However, heritage made of charnockite is even far more ancient.

The term "charnockite" was coined to describe an acid variety of orthopyroxene-bearing rock found on the tombstone of Job Charnock (1630-1693) at St. John's Churchyard in Kolkata (then Calcutta) City, which was erected approximately 300 years before the present.

Based on the mineralogical composition, Holland concluded that Job Charnock's tombstone rock was transported from St. Thomas Mount, near Pallavaram in Chennai (then Madras), thus the stone has been transported at least 2000 km from the site of excavation to the monument location.

Some renowned historical sites made of charnockite are the group of monuments at Mahabalipuram dating back to the 7th century (AD 650-700), which has been designated as a world heritage site by UNESCO since 1984, Madura Meenakshi temple (17th century AD) and Sri Padmanabha temple (500 BCE to 300 CE), are Indian examples for ancient heritage made of charnockite. On the other hand, modern usage of charnockite in monument construction in southern India is depicted by Vivekananda and Thiruvalluvar memorials.

Similarly, a famous sculpture of Oscar Wilde in Ireland is one of the best examples of the usage of Indian charnockite in overseas monument construction in contemporary times.

The sculptures and memorials made of charnockite in India are so exquisite that they are exported to countries like Japan, Germany, Italy, Netherlands, UK, USA, Africa, Australia etc.

Charnockite monument at St. Thomas Mount, Chennai, wherefrom the tomb stone of Job Charnock had been excavated.

Main reference

Sreejith, C., Del Lama, E.A., Gurmeet Kaur, 2021. Charnockite: a candidate for 'Global Heritage Stone Resource' designation from India. Episodes, 44(1), 19–29. https://doi.org/10.18814/epiiugs/2020/0200s11

KOLMÅRDEN SERPENTINE MARBLE

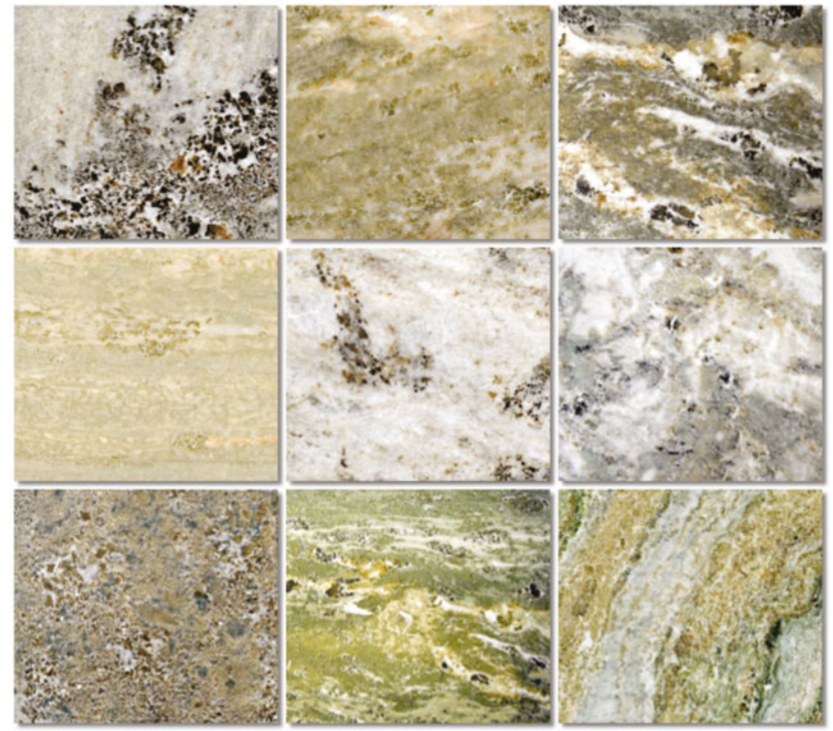
Sweden

Different size mortars made with the Kolmården marble.
Photo: Kerstin M. Lindgren

From castles to people`s homes

Anders Wikström †
Lola Pereira

Kolmården Marble is a green serpentine marble (one of the hardest marbles known in the world) that was used as early as the 13th century, as seen in a baptismal font in figure below.
The peak of popularity was reached during the 17th century. The stone has been used for major architectural buildings of Swedish national significance, especially in Stockholm, but also in other parts of Europe and North America during the 19th and 20th centuries.
Examples are the Rockefeller Center in New York, the University main building in Uppsala, the League of Nations building in Geneva and the University Library in Leeds, all of them built between late 19th century and middle 20th century.



Varieties of the Kolmården marble.
Photo: Kerstin M. Lindgren

Petrography
Serpentine Marble

Geological setting
Paleoproterozoic – Svecofennian orogeny

Occurrence
Kolmården, 100 km SW of Stockholm, Östergötland, Sweden

Petrography

Mineralogical composition is made up of calcite, dolomite, serpentine, phlogopite, pyroxene (diopside), olivine, some tremolite and quartz, in order of prevalence. Serpentine is mainly secondary after diopside.

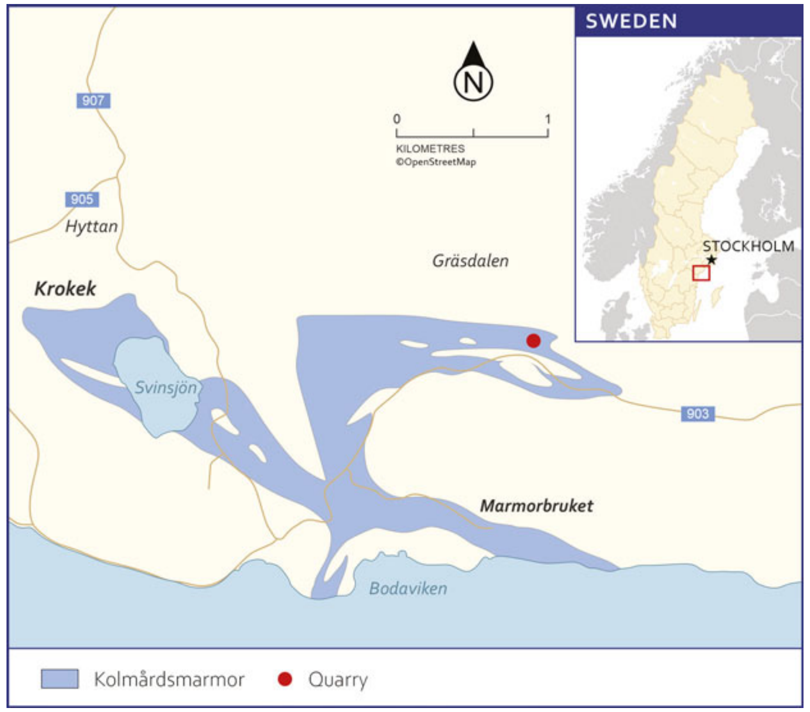
Location and geology

Kolmården is a large forest located around 100 km SW of Stockholm, in the northeastern part of the province of Östergötland in Sweden. The village of Marmorbruket (where the factory and major quarries are located) is close to and north of a major fault scarp defining the southern limit of the Kolmården area.

The green serpentine marble has also been quarried at other places in south-central Sweden (e.g., Gropptorp, Brännlyckan), although these deposits have never reached the status of the Kolmården serpentine marble.

The age of the rock is 1900 Ma (Svecofennian). Wikström (1979) placed this rock in eastward-dipping cross-folded, horseshoe-shaped synforms.

The serpentine marble is surrounded by migmatites and gneisses. Surrounding gneisses are mainly medium- to high-grade amphibolite facies migmatites. Minor, economically unimportant iron ores are also found in the vicinity.



Quarries


Kolmården quarry

Extensive quarrying operations have existed in Kolmården since the 17th century. The rock is currently quarried in a smaller open pit at the Oxåker farm, about 1 km north of the Marmorbruket village. Over the years, between 40 and 50 quarries have been operated with varying degrees of success. The number of workers varied from around 20 during the 18th century to 150 right before the industry closed. Each quarry is characterized by its own green colour. During the last years of activity, production was extensive, but it became too expensive and difficult to sell. Operations in the quarries finally ceased in the 1970s. However, in recent years a renewed interest in the stone has resulted in a small-scale operation in one of the quarries of the northern fold limb. In the Marmorbruket area there is no more quarrying, but a museum of the stone industry was opened there.

Architectural and cultural impact

The Kolmården serpentine marble was used as far back as the13th century, reaching a peak of popularity during the 17th century.

The stone was used for major architectural buildings, mainly in Sweden, but reknowed building around the world used this stone in their construction, like the Egyptian Hall in Piccadilly (London), built in 1812 to be an exhibition hall and demolished in 1905 to make room for blocks for offices and flats; the Copenhagen Town hall (1892–1905), the Paris Opera house (1875), the Manchester Consumption Hospital (1875), the Liverpool New Cathedral (1902), the Coliseum Theatre (1904) and the Strand Palace Hotel (1909), both in London, the Post Office of South Kensington Post Office (1909) the Royal Insurance Company Offices in Lincoln and other major buildings cited above.


Entrance hall of the Uppsala University main building, built at the end of the 19th century.
Photo: Anders Damberg

Main reference

Anders Wikström and Lola Pereira (2015) The Kolmården serpentine marble in Sweden: a stone found both in castles and people's homes. In: Pereira, D., Marker, B. R., Kramar, S., Cooper, B. J. & Schouenborg, B. E. (eds) Global Heritage Stone: Towards International Recognition of Building and Ornamental Stones. Geological Society, London, Special Publications,407, http://dx.doi.org/10.1144/SP407.22#2015

LUGO GREEN PHYLLITE

Spain

Shizouka Convention & Arts Center, Japan, cladded with Lugo Green Phyllite

Forged in the crucible of nature

Victor Cardenes

In the northwest of the Iberian Peninsula, between the regions of Terra Chá and A Mariña in Lugo, a unique and singular type of phyllite of Cambrian age, has been used since historical times as a building stone.
The quarries of this stone are located in the area of Bretoña, Lugo. The very evocation of these names awakens the echoes of centuries of history, places that were inhabited by ancient peoples who have already disappeared, such as the Castros culture, the Roman Empire, or the Bretons, among others. These civilizations took advantage of the exceptional constructive properties of this phyllite to erect their settlements, leaving a rich architectural heritage which can be traced centuries back. Today, this stone is still in use, exported to more than 50 countries, where it has shaped unique buildings such as the Shizuoka Convention Center, Japan.

Macro image of the slate outcrop at the quarry

Petrography
Phyllite

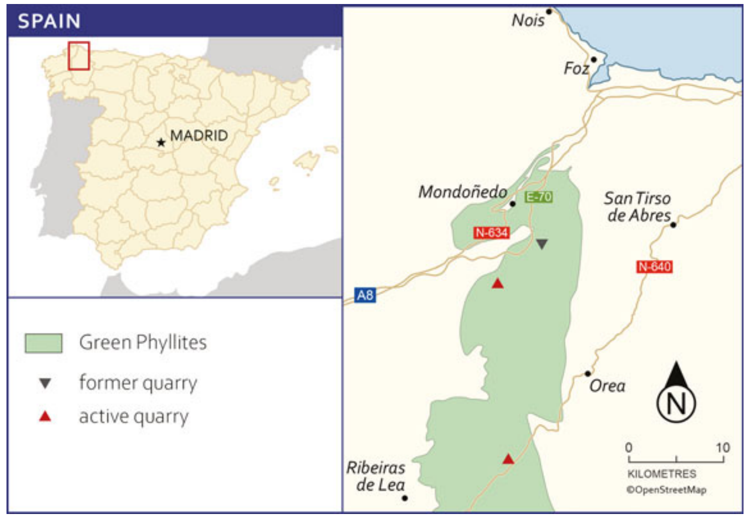
Geological setting
Paleozoic- Cambrian-Ordovician;
Iberian Massif, Lower Cándana Group
in the Asturian-Western Zone

Occurrence
near Bretoña, Galicia, Spain

Petrography

This rock is quarried in the Cándana Slates Member of the Lower Cambrian Cándana Group. Although the formal name of this member makes reference to slates, further research has shown that these rocks are in fact phyllites.
The petrographic examination highlights a porphyro-lepidoblastic texture, typical of this type of rocks, with a strong and noticeable slaty cleavage that defines the fisibility planes.
Main minerals are quartz, mica and chlorite. For the green variety, the dominant species of chlorite is clinochlore, which gives the characteristic green hue. All minerals are elongated along the cleavage planes. As accesory minerals, iron sulphides, carbonates and biotite can be found.
This last mineral marks the transition slate-phyllite.

Location and geology



As noted above, the Lugo Phylite is extracted in the Lower Cándana Group, in the Asturian-Western Zone (Cambrian-Ordovician), one of the main divisions of the Iberian Massif. This group is, in turn, made up of four members, of which the member Cándana Slates is the productive one.

This member is composed of greenish-gray phyllites, limestones and some levels of dolomite (locally known as Cándana Limestone), with occasional levels of sandstones, quartzites and elongate carbonates.

Pyrite cubes several square centimeters are common in the Pol outcrop. The average thickness of this member is estimated at 600 meters, of which the quarrying levels have an average thickness of around 100 meters.

Quarries

The quarries are located in two areas, near the town of Bretoña (43.36834150889189, -7.3519996955583692), and another near Pol (43.17139852690045, -7.34119391023974235), in the region of Galicia, extreme northwest of the Iberian Peninsula.

The Bretoña quarries are located in the Campo do Oso and the Beira do Río areas, and there are vestiges of quarrying work since at least the Middle Ages.

In Pol there is only one quarry, near the town of Lourixe. Bretoña produces the green and gray varieties, while in Pol only the green variety is extracted.

Due to regional tectonics and the surface of mining rights, production levels are falling in both areas, which forces quarrying work to deepen. Due to this, both areas consider continuing with underground quarrying work.

View of the Campo do Oso quarry

Architectural and cultural impact

At the beginning of the Iron Age (9th century BC), the northwest of the Iberian Peninsula was home to the Castros culture. The main characteristic of this culture was the construction of settlements protected by a fortified wall (oppida), which fulfilled both defensive and ornamental functions.

Phyllites and slates were highly valued building materials, since their fissility facilitated the carving of the blocks and slabs needed to erect these settlements. A good example of this type of construction can be found in the Viladonga Hillfort.

The Castros culture was assimilated by the Roman Empire, whcih continued to use phyllite not only in their own buildings, but also in roads that are still in use today. Eventually, the Roman Empire went into decline, and its influence faded, leaving only ruins and archaeological remains in the remains of Roman forts found in the area.

Between the 5th and 6th centuries, the Bretons were expelled from the British Isles by the Anglo-Saxon invasions coming from the continent after Rome withdrew its legions. A large part of the Breton people took refuge in what is now France, in the region of Armorica (Brittany), but there were groups that settled in the northwest of the Iberian Peninsula. The most important of them settled in a large plain that became known as Britonia (today Bretony). The Bretons, one of the six Celtic nations, brought their architecture with them, of which one of the characteristics was the use of stone.

During the following centuries, these outcrops were exploited by locals, who used them in walls and pavements as well as in roofs. The modern economic exploitation of these deposits dates back to 1909. From the following years until the Spanish Civil War, phyllite production increased slowly but steadily.

The 1960s saw the emergence of the slate industry in Spain. Following in the wake of the development of the industry, the phyllite quarries of Lugo were reactivated. The old outcrops were put back into production.

During this stage, some of the most significant works were carried out in phyllite, such as the Shizouka Convention Center in Japan, and the Lucus Augusti University Hospital in Lugo.

Roof with green phyllite in a traditional house

Main reference

Cardenes, V., Lopez-Piñeiro, S., & de Argandona, V. G. R. (2021). The Relevance of the Green Phyllites of Lugo (Spain) in the Architectonical Heritage: an Exceptional Roofing Slate Resource. Geoheritage, 13(1), 10. doi: 10.1007/s12371-021-00537-z

WHITE MACAEL MARBLE

Spain

The Lions Court in Nasrid Palaces of the Alhambra (Granada, Spain) (13th century)

The marble of the Alhambra

Rafael Navarro-Domínguez

The White Marble (WM) of Macael (Almería, Spain) boasts a history spanning over 5000 years. Initially utilized since the Neolithic (e.g. idols and jewelry), its prominence grew during the Roman Empire (e.g. sculptures and gravestones).
However, continuous exploitation started in the Muslim era, notably from the 10th c., marked by Abderramán III's use in Córdoba's palace (Medina Azahara) or the Alcazaba of Almería and later in the UNESCO WHS, in the Alhambra (Granada), which marks a significant historical milestone, revealing the importance of this material in Muslin's high society.
After the conquest of the Granada Kingdom (late 15th c.), its use expanded nationwide, gracing important royal and religious buildings. Nowadays, it is the most exported and valued Spanish marble.

Field aspect of WM

Polished WM banded

Petrography
Calcitic marble

Geological setting
Mesozoic- Triassic- Upper Unit of the Nevado-Filábride Complex- Bedar-Macael Unit

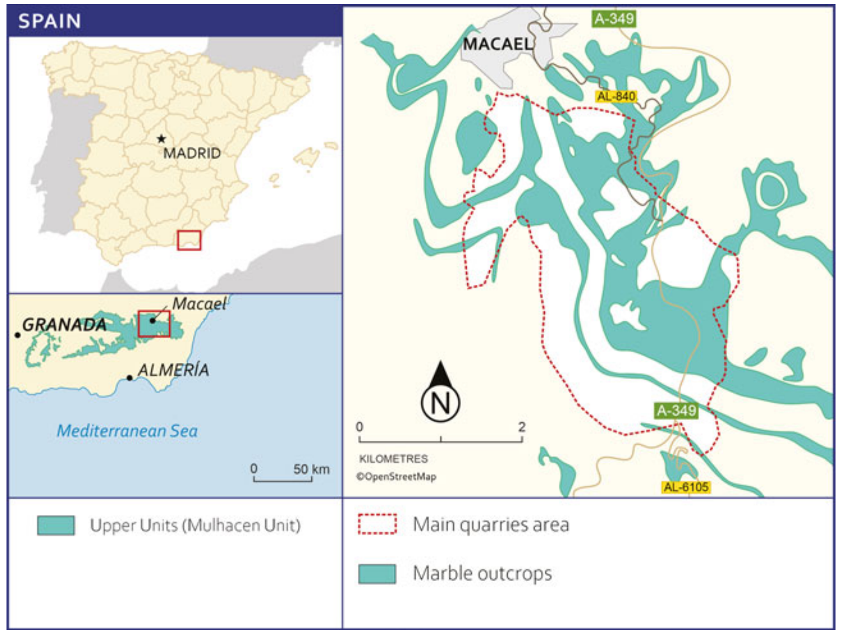
Occurrence
Macael and other places, Almeria, Andalusia, Spain

Petrography

The WM of Macael is a calcitic marble, composed of 99% calcite with quartz, micas, apatite, and opaques, which give it its characteristic soft grey banding. It has a granoblastic texture, straight intergranular contacts, and, generally, sub- to anhedral crystals, often twinned.
The grain size of calcite varies between approximately 1.20 and 2.20 mm. Geochemically, CaO is the main component, with a small amount of SiO_2 and Al_2O_3, indicating the presence of silicates such as quartz or micas, as confirmed by mineralogical observation.

Location and geology

The „Marble Region" is located in Almería (SE Spain), within the Sierra de los Filabres. It encompasses municipalities such as Macael, Olula del Río, Fines, Cantoria, Líjar, and Purchena, among others.
The marble deposits belong to the Upper unit (or Mulhacen Mantle) of the Nevado-Filábride Complex (Internal Zones, Betic Cordillera). In Sierra de los Filabres, this unit can be subdivided into two sub-units: Calar Alto (lower) and Bédar-Macael (upper).
The latter is further divided into various formations, with the „Las Casas" Formation being the most significant.
It comprises carbonated rocks (calcitic and dolomitic marbles) of white, grey and yellow colours (Triassic) with intercalations of serpentinites and quartzitic schists (Paleozoic).
The average thickness of the marble layers is 40 meters.



Quarries

In the „Marble Region," there are large quarries covering over 70 km^2, grouped in different areas. The most significant is Macael area, having the highest concentration of both quarries and factories. With WM marble are extracted other varieties as Grey, Yellow, and Anasol marble and Green Macael (serpentinite). Associated with this activity is the creation of a quarry landscape with extensive surface areas and significant vertical development, alternating the removal of waste coverings with commercially valuable levels (calcitic and dolomitic marbles).
Additionally, related to the marble industry, other subsidiary industries (micronized calcium carbonate and aggregates) have developed to recycle the generated waste, enhancing the sustainability of the extraction activity.

Quarries of "La Puntilla" area in Macael

Architectural and cultural impact

The White Macael marble (WM) is highlighted as part of several UNESCO World Heritage Sites. In the Alhambra of Granada (Spain), in the Nasrid Palaces (13th c.), notable places such as the Lions' Court or the Two Sisters Room stand out, where it is used for columns, sculptures or flooring. In this period, it was also extensively used in mosques, baths, and noble houses, serving both decorative purposes (e.g. floorings, claddings, sculptures, stairs, etc.) and structural functions (e.g. columns).
Its significance extends to iconic buildings such us the Monastery of El Escorial, in Madrid, or in the Palace of Carlos V, Cathedral and the Royal Chapel in Granada, cathedrals of Jaen and Almería, the Patio from the Castle of Vélez Blanco (Almería) (16th c.), The San Telmo Palace in Seville (17th c), the Royal Palace of Madrid and the Granja de San Ildefonso (Segovia) (18th c.), the Royal Palace of Aranjuez or the Congress of Deputies (Madrid) (19th c.), the Cathedral of the Almudena (Madrid) (19th-20th c.), among hundreds of others throughout the country.
As a milestone linked to WM, the first sawing and carving stone factory in Spain was established in Fines (1836).
In the late 19th c., the railroad facilitated the distribution of WM through Spain and Europe. Currently, WM is used in public and private buildings worldwide.
The old stonemasons enjoyed special recognition within the community. It also had strong social roots, with the craft being passed down from parents to children. Annually, in the month of May, they celebrate the historical reenactment „Stonecutters and Chiefs in the Struggle for Marble," which relives the quarries' disputes at the beginning of the 20th c. and recreates the techniques of extraction and crafting of marble objects from the early last century.
Additionally, the "Centre of Marble Interpretation" is the main museum of the city, showcasing the history and numerous objects related to the marble industry in the region.
The cultural impact of the WM in the „Marble Region," is very significant, to the extent that there is currently proposed the "Stonemasonry in Macael" as Intangible Cultural Heritage of Humanity by UNESCO.

Patio from the Castle of Vélez Blanco (16th century) (exposed at MET in New York, USA) (source: https://www.metmuseum.org/). OA Licence.

Main references

Navarro, R., Cruz, A.S., Arriaga, L. and Baltuille, J.M., 2017. Caracterización de los principales tipos de mármol extraídos en la comarca de Macael (Almería, sureste de España) y su importancia a lo largo de la historia. Boletín Geológico y Minero, 128(2): 345-361. https://doi.org/10.21701/bolgeomin.128.2.005;

Navarro, R., Pereira, D., Cruz, A.S. and Carrillo, G., 2019. The Significance of White Macael Marble Since Ancient Times: Characteristics of a Candidate as Global Heritage Stone Resource. Geoheritage, 11(1): 113–123. https://doi.org/10.1007/s12371-017-0264-x

MAKRANA MARBLE

India

Taj Mahal, Agra. Photo: Luis Lopes

The stone of the Taj Mahal

Gurmeet Kaur

Makrana Marble, prized for its aesthetic appeal and durability, is a calcitic marble utilised in significant architectural heritage in India and beyond. Its unique composition, predominantly white calcite grains with minimal impurities, lends it exceptional resilience against weathering.
Used in iconic structures like the Taj Mahal and the Victoria Memorial, its compact texture and granoblastic structure make it ideal for enduring monuments.
Beyond construction, it enriches public spaces through sculpture and handicrafts. With its global usage and cultural significance, Makrana Marble embodies centuries of craftsmanship and architectural excellence.

Makrana Marble

Petrography
Marble

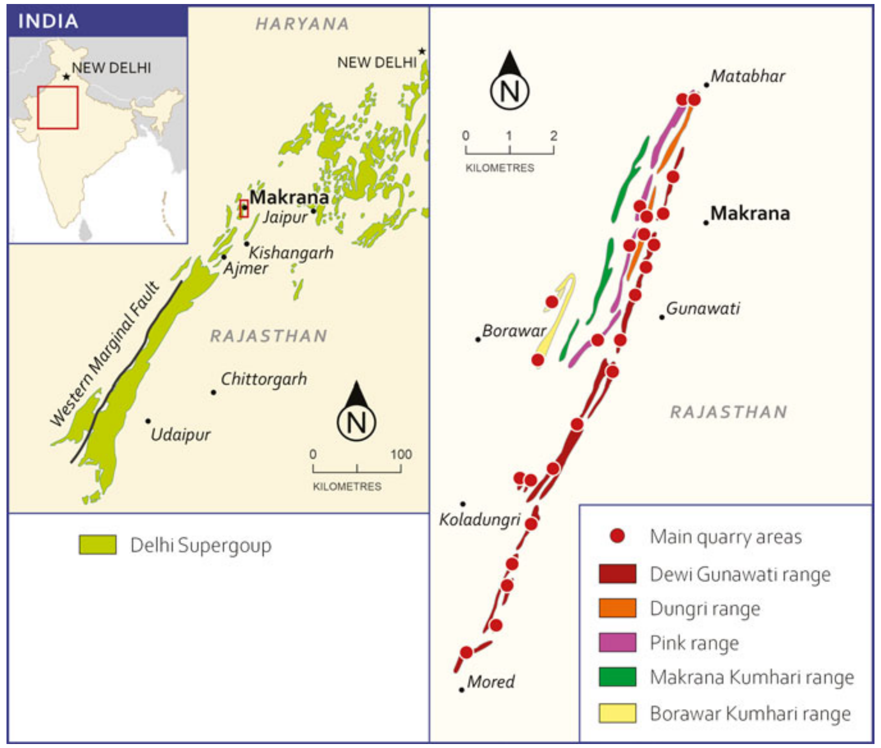
Geological setting
Proterozoic; Delhi Supergroup, South Delhi Fold Belt

Occurrence
Makrana, Rajasthan, India

Petrography

Makrana Marble exhibits a medium- to coarse-grained texture, characterized by closely interlocked calcite grains with well-defined polygonal boundaries, enhancing its strength. Its uniform texture and minimal impurities allow for a superior polish. In addition to the pure white variety, other Makrana Marble types feature hues of grey, pink, and brown, or distinct bands of various shades, creating a patterned appearance. Its mineral composition primarily comprises crystalline calcite, alongside minor quartz, biotite, diopside, tremolite, actinolite, olivine, and occasionally serpentine.

Location and geology



The Aravalli Orogen, stretching approximately 700 kilometers from Delhi in the north to Gujarat in the south, defines the geological and geomorphic landscape of northwestern India.

Its oldest rock formations, the Banded Gneissic Complex, serve as the foundation for the metavolcanic-sedimentary sequences of the Aravalli and Delhi Supergroups, as well as the relatively unaltered sedimentary sequences of the Vindhyan Supergroup. Within the Delhi Supergroup, two distinct regions exist: the older North Delhi Fold Belt and the younger South Delhi Fold Belt.

The Makrana Marble deposits are part of the Kumbalgarh Group of the South Delhi Fold Belt. The marble occurs as isoclinally folded bands intercalated with calc-silicate and quartzite rock. The Makrana Marble deposits are overlain by Quaternary aeolian deposits.

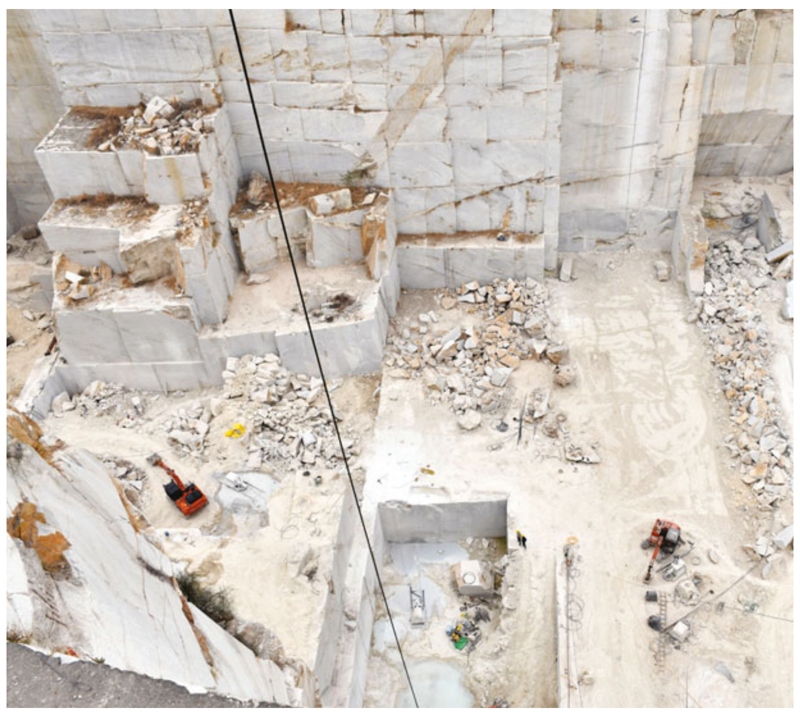
Quarries

Makrana, located about 100 km west northwest of Jaipur in the Nagaur district of Rajasthan, is renowned for its marble deposits. These deposits, exposed west of the town, consist of five prominent NNE–SSW trending marble bands known locally as the (1) Devi-Gunawati range, (2) Dungri range, (3) Pink range, (4) Makrana Kumhari range, and (5) Borawar Kumhari range.

Stretching approximately 13 km from Matabhar in the north to Billu-Mored in the south, with an average width of 1.6 km, these bands are isoclinally folded.

Quaternary aeolian deposits, including calcareous sand, pseudo-conglomerate, and grit, cover these bands/ridges. With a history spanning four millennia, the Makrana Marble mining area hosts around 800 quarries, ranging from manual to semimechanical operations.

The renowned white marble variety is predominantly quarried from the Devi-Gunawati range, with notable quarries including Chousira, Ulodi, and Pahad Kuan.



Makrana Marble quarry. Photo: Anuvinder Kaur

Architectural and cultural impact

The Taj Mahal, commissioned in 1632 on the banks of the River Yamuna in Agra, stands as an elaborate monument renowned for its elegant marble sourced from Makrana.

Adorned with intricate floral designs engraved in the same stone, its geometrically and symmetrically perfect structure has captivated generations with its aesthetics and charm. Similarly, the Victoria Memorial in Kolkata, an emblem of imperial architecture from the Victorian era, is constructed of Makrana Marble.

Beyond India, Makrana Marble has graced international landmarks such as the Sheikh Zayed Mosque in Abu Dhabi and the Moti Masjid in Lahore, Pakistan.

Moreover, Makrana stone has been integral to numerous forts, palaces, and archaeological sites across northwestern India, including structures within the Jaswant Thada in Jodhpur, Red Fort in Delhi and Agra, Humayun's Tomb, and Akbar's Tomb, among others.

Flower relief of the Red Fort, Agra

Main reference

Garg, S., Kaur, P., Pandit, M., Fareeduddin, Kaur, G., Kamboj, A. and Thakur, S.N., 2019. Makrana marble: a popular heritage stone resource from NW India. Geoheritage, 11, pp.909-925.

VALENTIA SLATE

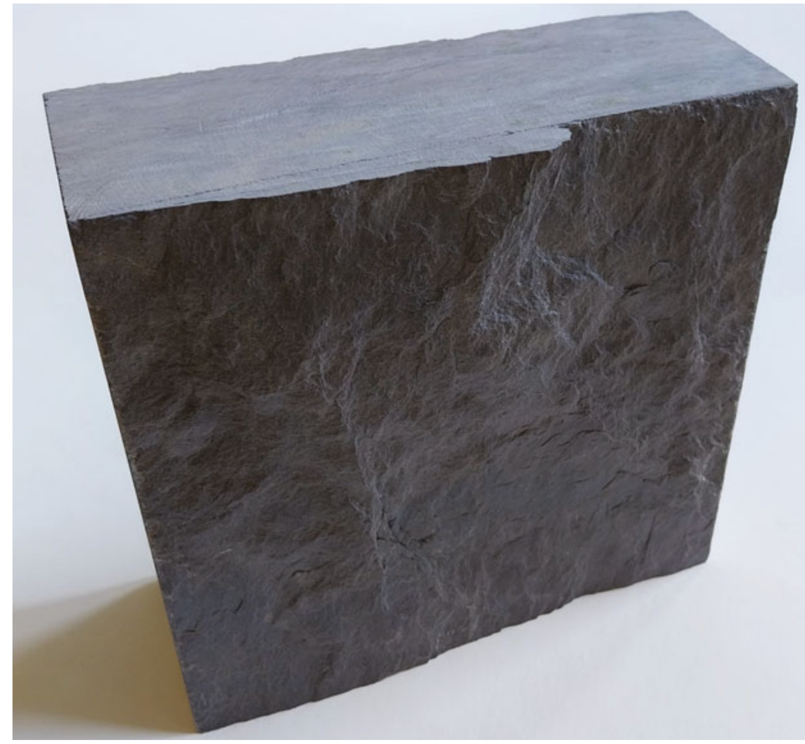
Ireland

Valentia Slate Paving and counter top in pub

Versatile paving and roofing slate

Patrick N. Wyse Jackson
Louise Caulfield

Slate from the Valentia Slate Formation is quarried in one location on a small island in Co. Kerry, southwest Ireland.
The extraction and fabrication of the stone became an important element in the island economy and led to the development of a Valentia School of stone carvers.
The quarrying and supply of this unique stone was of a number of initiatives that put Valentia Island on the map globally.
The other was its selection as the landfall site for the early Transatlantic cables.
The slate yard contains important buildings that are at the centre of modern conservation projects and heritage designation, while the quarry itself is contained by an Irish Government-designated National Heritage Area.



Valentia Slate split surface

Petrography
Penetratively cleaved siltstone

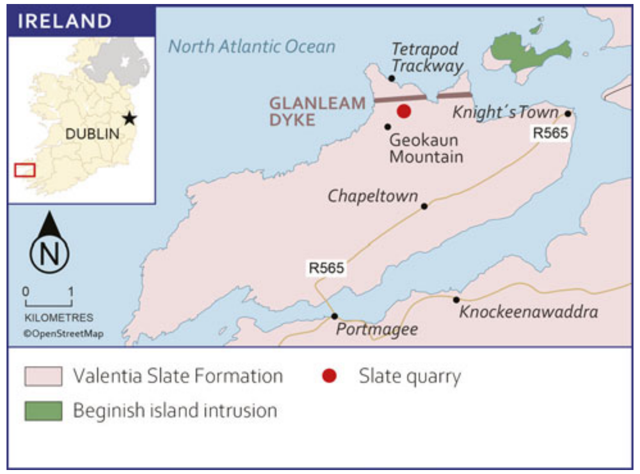
Geological setting
Valentia Slate Formation, Iveragh Group, Middle Devonian

Occurrence
Valentia Island, South-west Ireland

Petrography

Valentia Slate is a penetratively cleaved siltstone. The stone is well-compacted, mainly fine grained (10µm – 150µm) and dense, with a major mineralogical composition of quartz, mica (mainly muscovite) and chlorite which are evenly distributed along cleavage planes. It contains minor amounts of opaques (probably haematite) and calcite (<30µm, unevenly distributed on cleavage planes).
The slate is a very consistent purple colour. It is highly susceptible to a honed polish and develops an excellent patina in areas of heavy use, such as shop or bar counters, interior and exterior paving, and floors.
It exhibits very low porosity and surface salt crystallisation is minimal. Its durability is demonstrated in that memorials erected in graveyards in the 1840s maintain their crisp hand-cut lettering.

Location and geology



The Valentia Slate Formation (Iveragh Group; Givetian, Middle Devonian) extends throughout much of Valentia Island and in adjacent parts of the mainland. At an observed thickness of 1560 m, it is the oldest unit of the Old Red Sandstone in southwest Ireland. It comprises a number of lithologies, ranging from the most commonly occurring purple siltstone to fine-grained sandstones, which vary from purple to pale green in colour.

These sedimentary rocks represent an alluvial floodplain setting with the fine silts being deposited following sheet floods and the coarser sands being deposited in ephemeral shallow channels that migrated across the flood plain. Some horizons have yielded tetrapod trackways.

The quarried lithology is a cleaved homogenous siltstone, which shows strong deformation and low-grade metamorphism produced during the Variscan Orogeny.

Quarries

Valentia Slate has been exploited since the early 1800s, but larger-scale quarrying first commenced in 1816. The quarry at Dohilla was opened by the landlord Maurice Fitzgerald (the Knight of Kerry) and has been owner-operated or leased to a number of companies intermittently since that time. Initially, quarrying occurred at surface level, but from 1840 stone was extracted along strike from two underground chambers.

The deepest chamber, known as the 'Grotto Chamber', penetrates 150 m into the hillside and is 20 m high.

Stone was squared on site and then transported to a slate yard for further splitting into slabs, approximately 2 m long by 25 mm thick, prior to their export by sea. At the height of production these operations employed over 200 men. Between 1911 and 1998 the quarries were idle, but since then extraction is ongoing.

Valentia Quarry overview. Photo: Aidan Forde.

Architectural and cultural impact

Valentia Slate is a very workable and durable stone, which has been put to many uses. Its strength and capability of being raised as slabs led to its application beyond simply that of roofing. It has been utilised on a global scale for paving, roof slates, monuments and in domestic and industrial applications (see listing below).

Throughout the nineteenth century the premier market for Valentia slabs was in the United Kingdom where the stone was adopted in particular to floor and roof industrial units, bonded warehouses, schools and prisons. It was also fabricated into cisterns for holding water or spirits, and skilfully carved as garden furniture and billiard tables.

The stone was ideal for the latter on account of it being able to provide a very flat playing surface; some of these tables were decoratively enamelled in a process patented by George Magus, a one-time lessee of the quarry.

Notable examples of the use of Valentia Slate worldwide include: Ireland: Cladding on Skellig Lighthouse; First Message (cable station) building in the Slate Yard, Knightstown, Valentia Island (1830s); headstones, footstones and occasionally box tombs in Co. Kerry; flooring slabs, Muckross House, Killarney (1842); garden benches, Colles Sandes House, Tralee; paving, Tralee Courthouse; decorative chimneypieces, Shelbourne Hotel, Dublin (1867); roofing slates, Rubrics building, Trinity College Dublin (2022).

United Kingdom: Flooring, Pentonville Prison (1840s); enamelled billiard tables owned by Prince Albert at Osborne House, Isle of Wight (1847) and the Duke of Wellington at Stratfield Saye, Hampshire; roof slabs, interior flooring original building and whiskey vats, Palace of Westminster (Houses of Parliament), London (1850, 2015); shelving, Public Record Office, London (1850); malting floors, Bedfordshire and Herefordshire Breweries (1852); St Paul's Cathedral, London (c. 1860); British Museum, London; National Gallery, London; flooring at several London railway stations including St Pancras, Charing Cross and midland stations at Birmingham (1840s), Derby, Leicester, Nottingham and Rugby (1860s).

International: Railway sleepers, San Salvador city, El Salvador (1870); Paris Opera House, France (1870); sugar houses, Jamaica (c. 1840s); water tanks and reservoirs, Sydney, Australia (1830s).

Valentia Slate headstones Caherciveen Old Church, Co. Kerry.
Photo: Patrick Wyse Jackson.

Main reference

Wyse Jackson, P.N., Caulfield, L., Forde, A., Conlon, I. and Cox, P. 2022. Valentia Slate, Co. Kerry, Ireland: Heritage Stone. Irish Journal of Earth Sciences 40, 87-104.

WELSH SLATE

UNITED KINGDOM

Typical roofing with Welsh slate

The slate that roofed the world

Terry Hughes
Jana Horak
Graham Lott †
Dafydd Roberts

Metamorphic slate of the Llanberis Slate Formation of North Wales has been exploited for almost 2000 years. It is widely used throughout the British Isles, Europe and worldwide on buildings and structures ranging from vernacular cottages and agricultural buildings to palaces, cathedrals and industrial buildings. Thousands of these have been accorded conservation designation of all categories. The Welsh industry was responsible for technological developments from the 18th century to the present day and which were subsequently adopted worldwide. The industrial heritage together with the unique culture which developed in the quarrying communities lead to the Slate Landscape of North-West Wales being designated a UNESCO World Heritage Site of outstanding universal value in 2021.

Penrhyn Heather Blue, width = 50 mm

Petrography
Slate

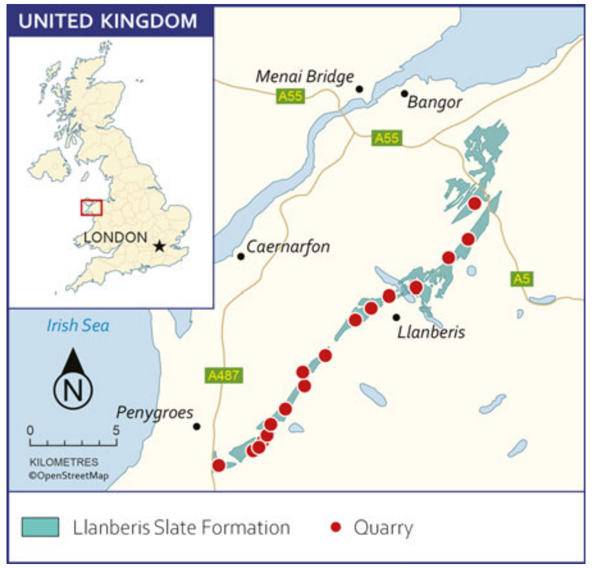
Geological setting
Paleozoic – Cambrian ; Llanberis Slate Formation

Occurrence
Gwynedd, North Wales, UK

Petrography

Macroscopically, the slate is homogenous and shows a very well-defined planar cleavage. It is typically dark purple in colour, but ranges from grey to blue grey and includes two shades of green and a red. A prominent feature in the purple and blue-grey slates are green reduction spots which have been used as strain markers; revealing up to 67% horizontal shortening and up to 157% vertical extension during cleavage development (Wood, 1971). The mineralogy is dominated by phyllosilicates (up to 5% by volume) and chlorite (25% by volume) with lesser amounts of hematite, pyrite and quartz. Disseminated grains of hematite along the cleavage fabric impart the distinct purple colour to the slate. Kubler Index illite crystallinity values of <0.25 Δ°2θ, indicate epizone metamorphism (Merriman & Peacor, 1999).

Location and geology



Cambrian Welsh Slate occurs within the Llanberis Slate Formation with an estimated thickness of 380m. It is part of a NE-SW trending belt of Cambrian strata, extending for 30km to the west of the Eryri (Snowdonia) massif in North-West Wales. The Formation accumulated as mud within a marine basin during extension of the Neoproterozoic Avalonian magmatic arc. The slate protolith age is constrained by a rare trilobite fauna, indicating it lies within Series 2, <520 Ma (Rushton and Molyneux, 2011). The Cambrian sequence was subjected to low-grade regional metamorphism, during the 'Acadian' deformation dated at around 400 Ma (e.g. Evans, 1996). This induced a well-developed slaty cleavage which lies subparallel to the regional (north-east to south-west) fold axes developed in this area.

Quarries

Extensive slate quarrying operations have existed in the region since the 17th century. By the 18th century the region reached a peak with 86 quarries and by 1840 Penrhyn quarry alone produced 734K tons per annum of roofing slates. The Llanberis Slate Formation is currently worked at Penrhyn quarry; in a small quarry, Twll Llwyd, and a number of quarries' tips are being reworked to produce aggregates. The industry was quick to adopt industrial innovations using waterpower and subsequently, steam and electricity. Innovative mining, quarrying and rock processing techniques were adopted or developed which were then adopted by stone industries in other countries including France and the USA. The locomotive-worked narrow-gauge railways evolved to carry slates to navigable water, and these were used extensively by engineers world-wide from 1870 onwards.

Penryn Quarry near Bangor, Wales

Architectural and cultural impact

Slate from the Cambrian succession is a well-known source of building products from the United Kingdom. During the C16th and C17th several small companies worked the slate but in the mid-C18th three large operations came to dominate the industry: Penrhyn, Dinorwic, and the Nantlle group.

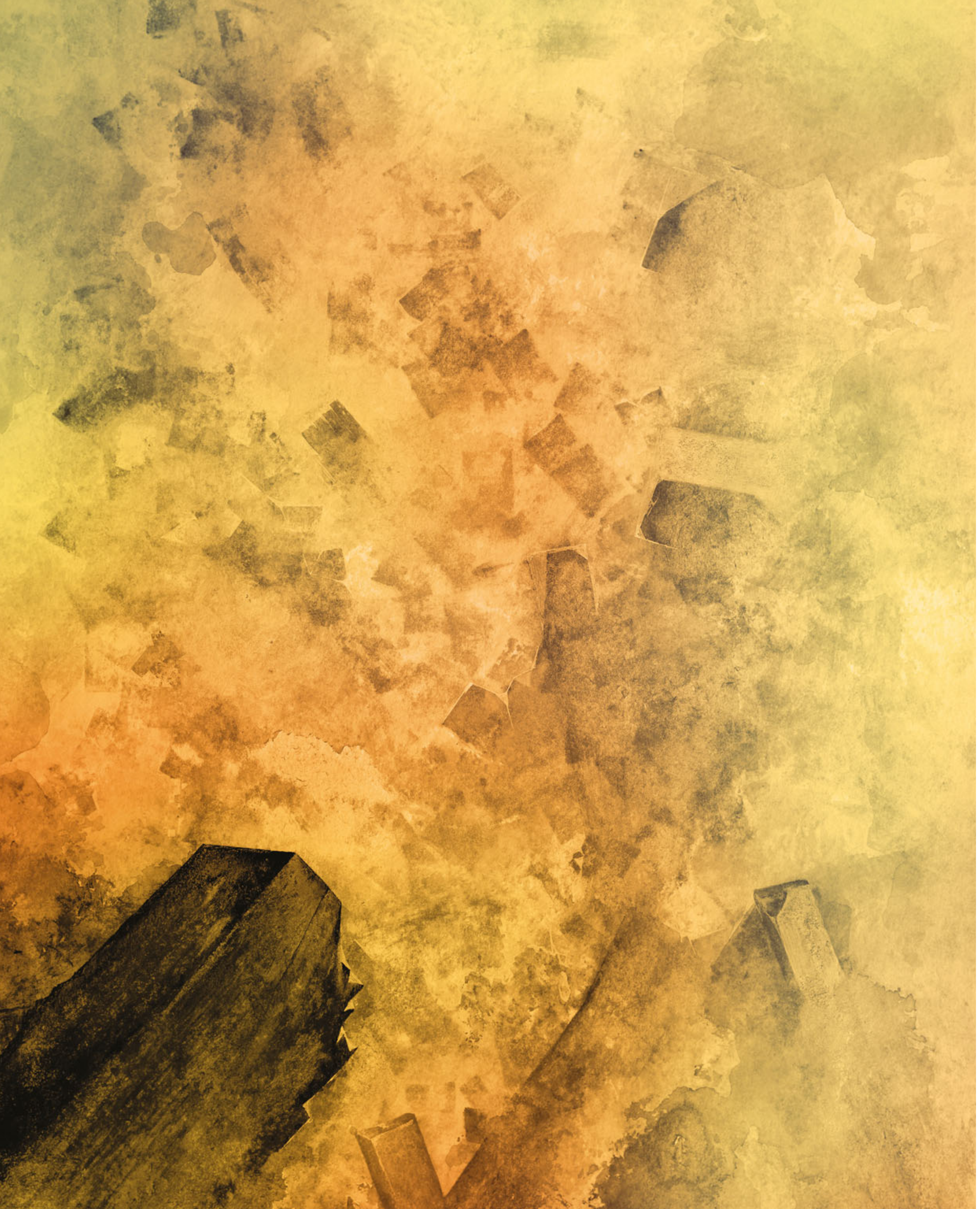
From the late C18th production expanded rapidly supplying markets worldwide especially to Europe and the British colonies. Slate has been used in all its forms but most notably as roofing slates in the construction of buildings at all levels of society and for buildings of the highest historical and architectural importance.

Austria	Kunsthistorisches Museum, Vienna 1891
Denmark	The Royal House Copenhagen 1750
France	Hotel de Ville Paris
Ireland	Trinity College Dublin
Sweden	English Church Gothenburg
UK	Buckingham Palace London C19 C20
	Bodelwyddan Castle 1840
	British Library 1992
	Welsh Assembly Building Cardiff C20
Australia	St. Pauls College Sydney 1856
	Glebe Town Hall Sydney 1880
	Old Farm Strawberry Hill Albany 1870
New Zealand	Arts Centre Christchurch 1882
USA	Shaker Museum Enfield
	New Hampshire
	Boston airport C20
West Indies	Red House Trinidad 1907
Hawaii	Royal Mausoleum

Ditherington Flax Mill, Shrobshire 1796: the first iron frame building in the world

Main reference

Hughes, T., Horak, J., Lott, G.K. and Roberts, D. 2016. Cambrian age Welsh Slate: A Global Heritage Stone Resource from the United Kingdom. Episodes 39(1), 45-51.



Igneous rocks are those that were originally molten and which formed in magma chambers deep within the Earth's crust. Divided into two major types, the intrusive variety -plutonitic rocks- includes granite and gabbro that cooled and crystallised in batholiths or other large accumulations several kilometres beneath the surface. Small intrusive bodies include dykes and sills that form thin intrusive bodies.
Extrusive igneous -volcanic rocks- are those erupted on the surface, either subaerially or beneath the oceans. These rocks typically include basalt and andesite as well as the ejected material deposited as tuff. Igneous rocks are classified according to their mineral content and texture, the longer a magma cools, the larger its crystals.

Igneous rocks

ALPEDRETE GRANITE

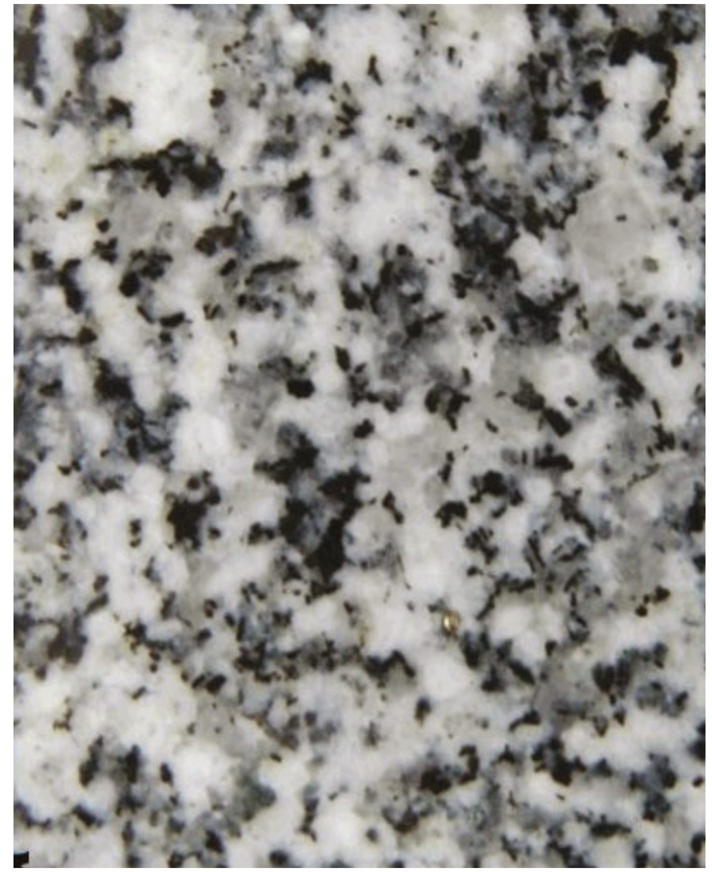
Spain

Prado Museum, Madrid

The backbone of Madrid Heritage

D.M. Freire-Lista
R. Fort
M. J. Varas-Muriel

Alpedrete granite was designated a Heritage Stone in 2019. It is the main traditional building granite of Madrid and it has relevance in the "Landscape of Light" UNESCO World Heritage Site declared in July 2021 in the category of Cultural Landscape. "Landscape of Light" is made up of Paseo del Prado, El Retiro Park, and the Jerónimos neighbourhood of Madrid. In addition, this heritage stone is used in rural architecture, including sheds, washing places, drinking troughs, irrigation canals, and boundary walls. Industrial heritage includes grinding stones for flour mills and cones to crush olives. The Alpedrete granite-related heritage has been turned to value in the form of divulgation mini-videos (https://www.youtube.com/watch?v=oLvmcevrDCY; https://www.youtube.com/watch?v=7A-IJjAGlKE&t=88s).



Alpedrete granite from a historical quarry, Macroscopic image

Petrography
Monzogranite

Geological setting
Paleozoic, Variscan orogeny

Occurrence
In and around Alpedrete village,
Sierra de Guadarrana province of Madrid, Spain

Petrography

Alpedrete granite is an equigranular, medium- to fine-grained monzogranite consisting of interlocking plagioclase aggregates (20-30 vol. %), quartz (2–5 mm and 30-40 vol. %), K feldspar (1–4 mm and 25-35 vol. %) and biotite (2 mm and 10-20 vol. %). Accessory minerals include ilmenite, apatite, cordierite, and zircon. Alpedrete granite is classified as a monzogranite and commercialised under that same name. Alpedrete granite has micro-granular mafic enclaves, usually with a tonalite composition showing fine-grained porphyritic textures, with phenocrysts commonly of millimetric size.

Location and geology

Alpedrete granite is quarried in the Sierra de Guadarrana (Spanish Central System) foothills in and around Alpedrete village, in the province of Madrid, Spain (Variscan orogeny). Alpedrete area granite has a highly homogeneous quartz, feldspar, and mica content and crystal size. Two varieties have been traditionally distinguished. Piedra Rubia (blonde stone), so called due to the yellowish tones induced by weathering, is quarried at shallower depths. The second variety Alpedrete granite, sensu stricto, is unaltered grey granite. The latter is the variety quarried at present.

Quarries

Around 400 historic, generally small, shallow quarries, where Alpedrete granite was extracted manually from the surface (to depths of approximately 1-1.5 m), have been located around Alpedrete and surrounding villages. The type of quarrying conducted varied depending on the period. Tors or whaleback boulders were extracted first, and once that resource was depleted, deeper quarrying was undertaken. The largest volumes of stone were extracted from the quarries at El Berrocal and Alpedrete. Beginning in the 1980s, because of their inability to adapt to new environmental regulations, many of the small traditional quarries have been closing. One quarry at Alpedrete village, whose operations can be traced back over 100 years, is still active. Its 6000-m^3 yearly outputs guarantee the supply of dimension stone.

Current Alpedrete granite quarry.

Architectural and cultural impact

Entretérminos dolmen was one of the first structures in which Alpedrete granite was used. Part of a Roman building is preserved at the El Beneficio-Miaccum archaeological site in Collado Mediano. However, widespread use of Alpedrete granite began after King Philip II moved the court to Madrid in 1561. It was not until the 18th century that Alpedrete granite became the stone most widely used in and around Madrid. This building stone was used in many monuments during the reign of Charles III (1759-1788). It was used to build Madrid's Royal Palace, Alcalá Gate, and Prado Museum among others. The mid-19th century construction of the Isabel II Canal that carries water to Madrid from the Sierra de Guadarrama spurred activity in the Alpedrete area quarries. Likewise, in the 19th century, Alpedrete granite was used in the new city quarters built to accommodate Madrid's expansion. An 11-km railway line operated exclusively to ship Alpedrete granite for 73 years (1883-1956) from El Berrocal (where granite from the nearby Moralzarzal, Becerril de la Sierra, Cerceda, and El Boalo quarries was loaded onto trains) to Collado Villalba. Alpedrete became the area's leading building stone producer with the founding of the Sociedad de Sacadores de Piedra de la Sierra (society of stone extractors) (1914) and the Sociedad Construcciones Hidráulicas y Civiles (Hydraulic and Civil Construction Society). These two societies disappeared in 1925, and output declined. Work in the quarries was suspended during the Spanish Civil War (1936-1939). In the 1940s and 1950s, Alpedrete granite was used to rebuild Madrid. The output of Alpedrete granite rose in the 1960s showing a boom, driven by Madrid's rapid population growth. Today this stone is used primarily in flooring, cobblestones, funeral art, building and monument restoration and rehabilitation across the region of Madrid.

Façade of Royal Palace, Madrid

Main references

Fort, R., Alvarez de Buergo, M., Pérez-Monserrat, E.M., Gómez-Heras, M., Varas-Muriel, M.J., Freire-Lista, D.M., 2013, Evolution in the use of natural building stone in Madrid, Spain. Quarterly Journal of Engineering Geology and Hydrogeology. 46. 421-429. https://doi.org/10.1144/QJEGH2012-041.

Freire-Lista, D.M., Fort, R., Varas-Muriel, M.J., 2015. Alpedrete granite (Spain). A nomination for the "Global Heritage Stone Resource" designation. Episodes. 38 (2): 106-113 https://doi.org/10.18814/epiiugs/2015/v38i2/006.

DECCAN BASALT

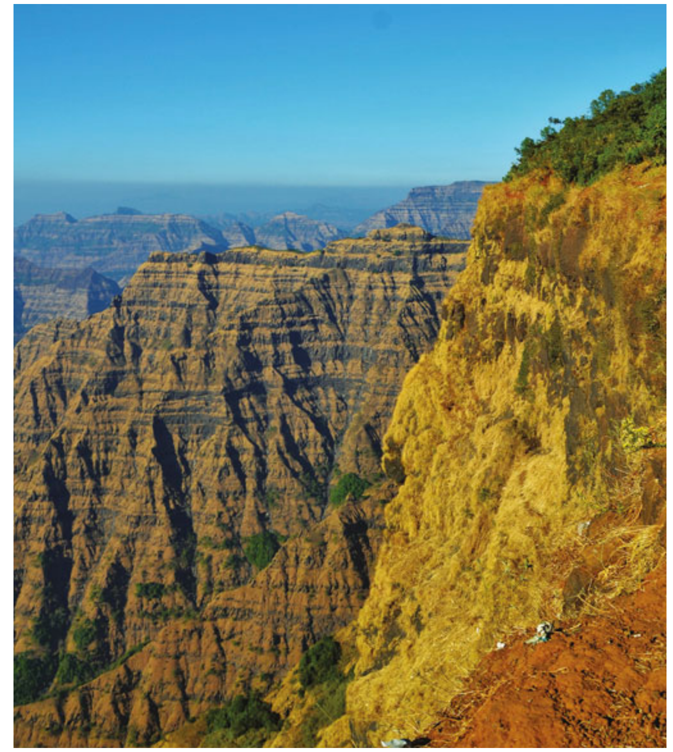
India

Deccan basalt St Xaviers College, Mumbai. Photo: Aaron Johns

Sculpting India's Cultural Diversity in Stone

Raymond A. Duraiswami
Gurmeet Kaur

The Deccan Basalts bear testimony to India's cultural and architectonic heritage, and have been used from antiquity to present times. The basalts occur over an area of more than 500,000 km^2 of Peninsular India and their abundance, ease of workability, and durability have made them the most preferred building material that has documented the cultural heritage and ethos of its inhabitants. Four of the UNESCO World Heritage Sites based in India viz. Ajanta, Ellora, the Elephanta cave temples and Chhatrapati Shivaji Maharaj Terminus, formerly Victoria Terminus are made of basalts. In all, about 1200 rock-cut caves along ancient trade routes occur in the Deccan basalt. Numerous, forts, temples, churches, mosques, hertiage buildings, colleges and market complexes have been built in basalts across the centuries and the rock continues to be in vogue even today.



Deccan basalt exposed near Arthur´s Seat Mahabaleshwar. Photo: Freddy Mathews

Petrography
Basalt

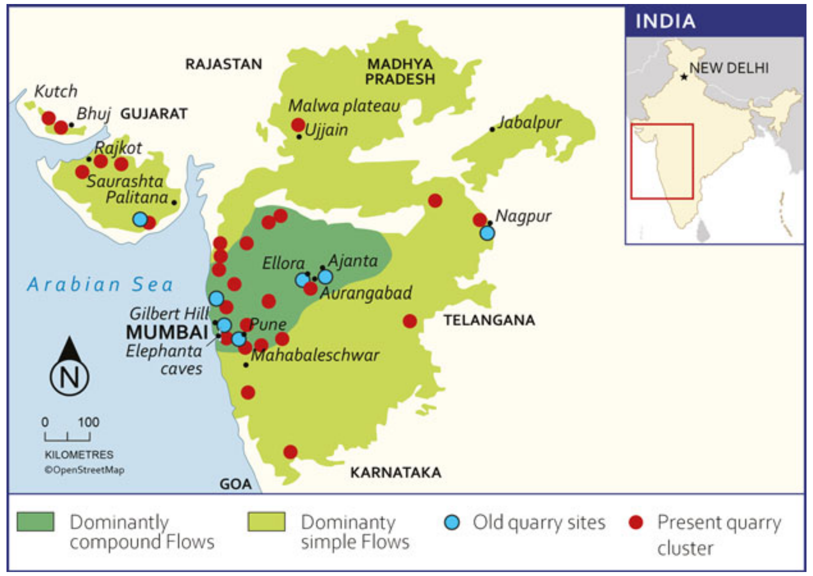
Geological setting
Cretaceous-Paleocene Deccan Trap lavas in a Continental Flood Basalt setting

Occurrence
Western India

Petrography

The basalt is commonly uniform grey, and referred to as 'Krushna shela' as it resembles the dark tone of the Hindu god of romance Shri Krishna. Variants include the reddish basalt when oxidised or greenish when spilitised. The rock is described as vesicular basalt or massive basalt depending on the presence or absence of gas vesicles. It's also called amygdaloidal basalt when the gas vesicles are filled by secondary minerals like zeolites, calcite, quartz, etc. Petrographically, the lavas are characterised by simple mineralogy consisting of plagioclase, augite, opaques and glass and are classified as tholeiite basalt. In thin sections, the basalt are fine to medium-grained, vesicular, with porphyritic or glomeroporphyritic texture wherein clusters of plagioclase laths define the dominant phenocryst phase. Other textures are intersertal, sub-ophitic and dyktitaxitic.

Location and geology



Deccan Traps is spread over half a million square kilometres in west-central India in the states of Maharashtra, Madhya Pradesh, Chattisgargh, Gujarat and Telangana.

Thick tholeiitic lava flows attain a cumulative thickness of ~2 km in the region along the Western Ghats escarpment and about ~1 km in the Satpura Range reducing to a few tens of meters towards the peripheral areas.

Quarries

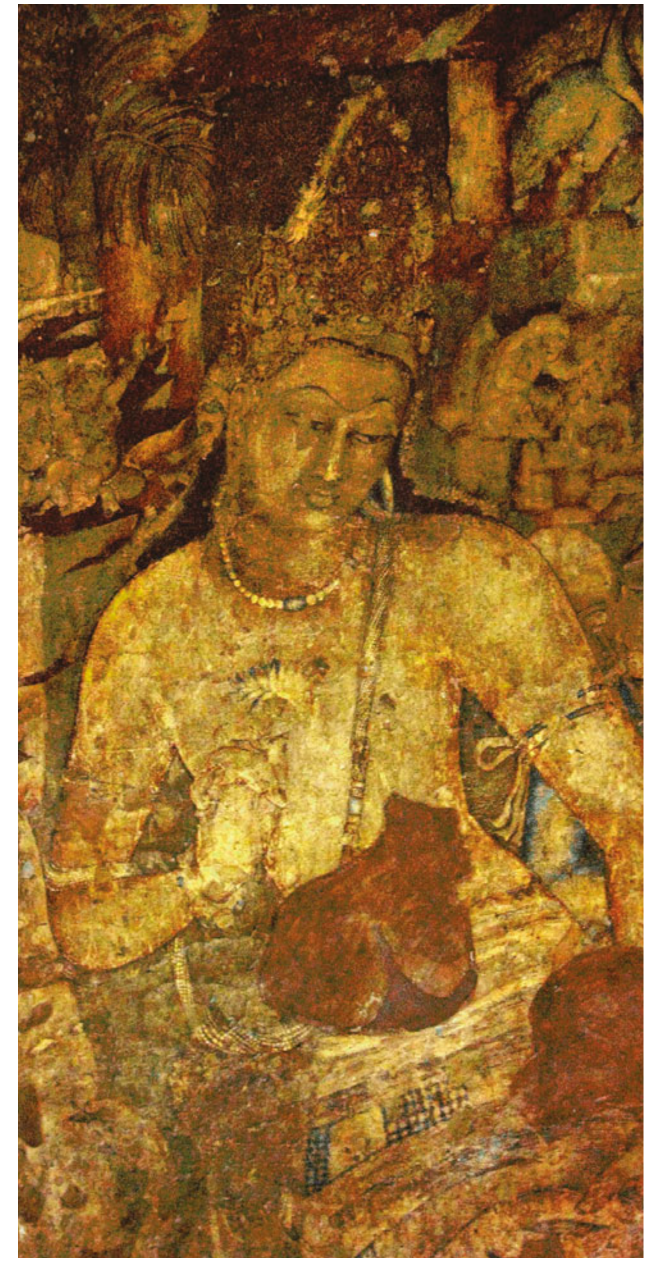
Quarrying for basalt is a major activity in the western Deccan Traps and is usually carried out in massive parts of thick pahoehoe or in columnar jointed lava flows. Such quarrying is generally around important cities like Pune, Navi Mumbai, Navsari, Daman, Jalgaon, Nashik, Aurangabad and other cities where demand for building stone and aggregate for civil engineering purposes is high.

Deccan Basalt quarry Wagholi, Pune. Photo: Satvinder Arora

Architectural and cultural impact

The use of Deccan basalt in architectonic heritages from west-central India is numerous and exhaustive. The world-famous UNESCO World Heritage Site at Ajanta is the second-century BC in-situ cut basalt Buddhist cave monument with paintings, beautiful sculptures and panels. The Ellora cave temple complex near Aurangabad depict various divinities of Hinduism, Buddhism, and Jainism that were excavated in basalt during second century BCE to about 480 CE. The Kailasa Temple of Ellora is the largest monolithic rock-cut temple in the world. Prayer halls with central stupas and large pillars are immaculately carved in basalt. The Elephanta caves are also carved in basalt on the isolated Gharapuri Island in the Arabian Sea, off the Mumbai coast and host the famed Trimurti Mahesh (Shiva). Rock-cut caves of lesser grandeur at Bhaja, Karla, Bedse near Pune and Mahad in Konkan contain beautifully carved stupas, pillars and chambers in basalt. Basalt was also extensively used in Heritage Buildings in Mumbai, Pune, Kolhapur, Ahmednagar, Aurangabad and many other cities. Several world-class buildings, conforming to the Gothic, Baroque and Saracenic architecture were constructed in stone in keeping with contemporary European architectural trends. Some of the prominent edifices of old Bombay constructed from basalt and associated trachyte include the Ballard Pier in the Bombay Docks, the High Court, Saint Xavier's College, Wilson College, Cathedral School, Old Customs House, the Prince of Wales Museum, The General Post Office, Taj Mahal Hotel, The Times of India Building, The Crawford Market Building, etc. Along with basalt, trachyte was used for the most important heritage buildings during British Raj, which are now the pride of old Bombay city, e.g. Gateway of India, a library of Saint Xavier's College, Rajabai Towers and the Convocation Hall of Mumbai University, the Chhatrapati Shivaji Maharaj Terminus, Mumbai Municipal Corporation Building and many more. In Pune, the icon of the city 'Shaniwar Wada' - home of the Peshwas, is made of basalt. The Indian Meteorological Department's Observatory, General Post Office, Central Building, etc. represent the architectonic essence of the city in basalt.

Thus, the intensive use of Deccan basalt over a span of 2200 years bear testimony to India's cultural and architectonic heritage making it a truly iconic Heritage Stone from India!



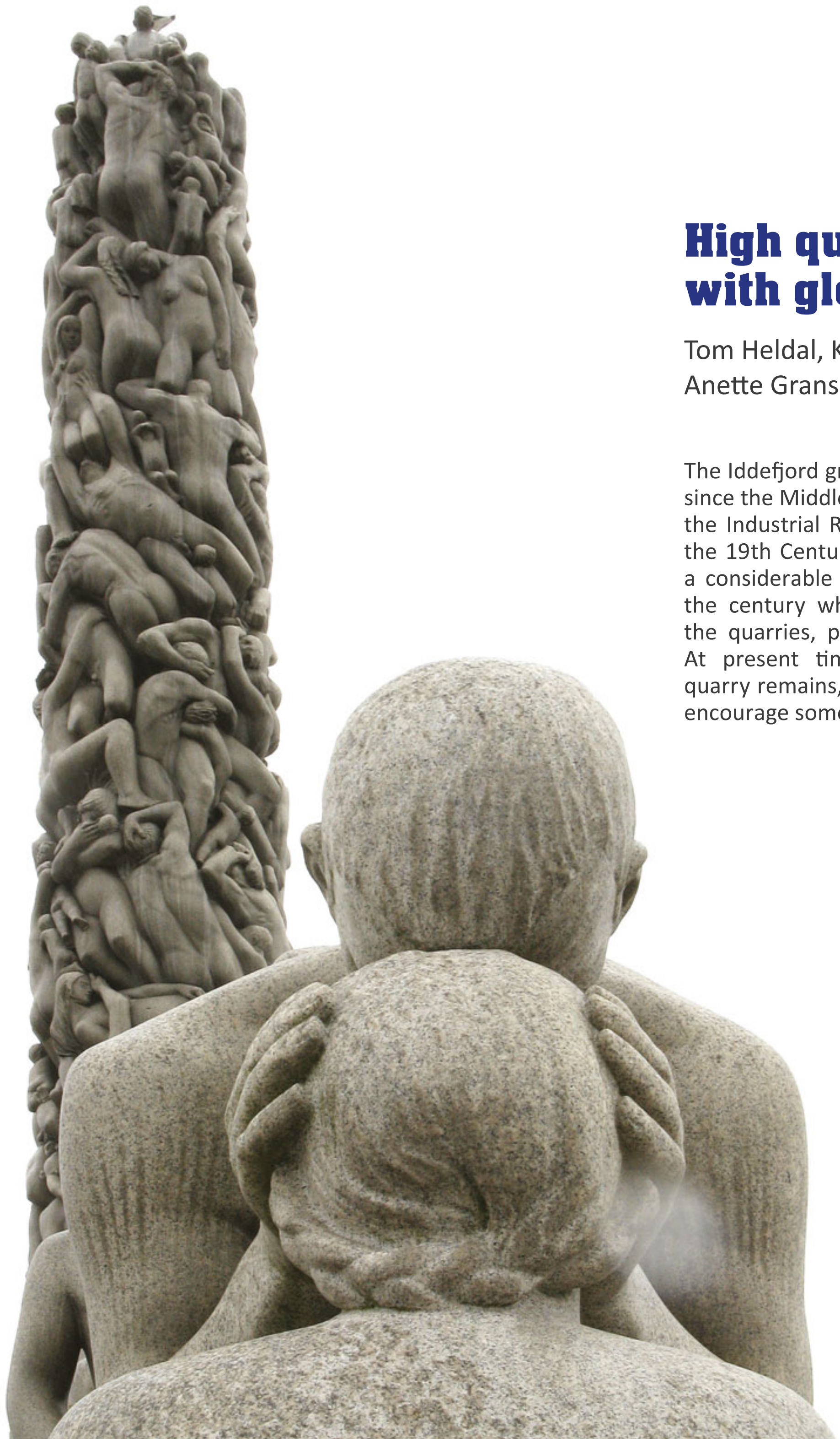
Deccan Basalt Ajanta Fresco. Photo: Poonam Ponde

Main reference

Kaur, G., Makki, M.F., Avasia, R.K., Bhaskar Bhusari, Duraiswami, RA, Pandit. M.K., Fareeduddin, Baskar, R., Shashi Kad (2019) The Late Cretaceous-Paleogene Deccan Traps: A Potential Global Heritage Stone Province from India. Geoheritage 11(3): 973-989 https://doi.org/10.1007/s12371-018-00342-1

IDDEFJORD GRANITE

Norway



High quality granite with global impact

Tom Heldal, Kari Aslaksen Aasly,
Anette Granseth

The Iddefjord granite, SE Norway, has been exploited since the Middle Ages, but the main phase came with the Industrial Revolution. During the second half of the 19th Century, the granite industry here grew to a considerable size, culminating around the turn of the century when thousands of people worked in the quarries, producing paving and building stone. At present time, only one active natural stone quarry remains, but the quality of the granite should encourage some further future developments.

From the Vigeland sculpture park, Oslo.
The Monolith in the background.
Photo: Tom Heldal

Iddefjord granite (18cm width)

Petrography
Granite

Geological setting
Proterozoic

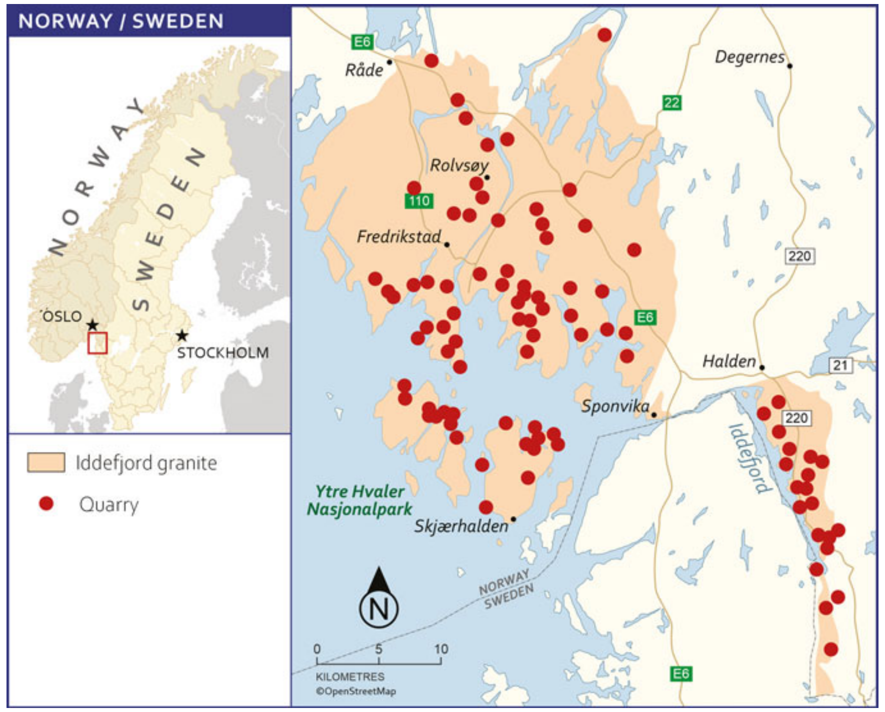
Occurrence
Municipalities of Fredrikstad, Råde, Sarpsborg, Hvaler and Halden, Østfold County, SE Norway

Petrography

Most of the plutons are composed of microcline-plagioclase-quartz-biotite in addition to minor and accessory minerals. They vary from fine- to coarse-grained, and from equigranular to porphyritic.
Typically, the Iddefjord granite diaplays greyish colours, often with a beige or pink tint.

Location and geology

The Iddefjord granite (sometimes referred to as the Østfold granite) forms a part of a huge batholith (Bohus batholith) divided by the Norwegian-Swedish border. On the Norwegian side, thirteen unique plutons have been identified, most of them of granitic composition. The intrusion age is established to ca. 918 million years, generally interpreted as the aftermath of the Sveconorwegian orogeny. The Norwegian part of the batholith outcrops in two distinct areas. A southern area defines a 2-5 km wide belt along the east side of the Iddefjord. The northern area covers an almost circular area, 30 km in diameter, with centre in the town of Fredrikstad. The plutons intruded in deep crustal conditions (small temperature difference with surrounding gneissic rocks).
This is supported by indications of a prolonged cooling history of the granites.



Quarries


Modern quarry in the Iddefjord granite, Photo: Tom Heldal

The first known quarrying of the granite was in the 12th century, for construction of stone churches in the area. A runic inscription in the Skjeberg Church, dating from the late 13th century, is the first written record of this early quarrying: "Stein þenna gerði Botolfr steinmeistari", which translates to English as: "Bottolf the stone mason made this stone". During the Swedish-Norwegian wars in the 17th and 18th centuries, several castles and fortifications were built from the granite. In the 19th century, commercial quarrying increased, initiated by stone for reconstruction in Hamburg after a great fire in 1842. By 1910, 5000 workers were quarrying and carving stone in several hundred quarries and the Iddefjord granite was sold all over the world. At present time, there is only one operating quarry, but huge resources for the future.

Architectural and cultural impact

The Iddefjord granite gained its success from excellent workability combined with extreme durability. This is partly due to the glacial erosion, exposing "fresh", unweathered granite right from the terrain surface. With some skills and tools, anyone could start quarrying and produce high quality products from day one. Thus, the Iddefjord Granite was applied for a large range of natural stone products: building- and ornamental stone, paving stone, drywall-stone, constructional stone (quays and bridges) and sculpture stone. Collectively, the Iddefjord granite was applied in large volumes in now listed buildings in Norway and abroad, the latter particularly in Northern Europe. From Medieval churches to Ritz Hotel in London, from the Fredrikssten Castle in Norway to Manchester stock exchange. The docks of Devonport, Gibraltar, Cape Town, Singapore, Vera Cruz, Bermuda and Mumbai all contain constructions of the Iddefjord Granite. The same applies for paving stones in Havana and Buenos Aires. However, the most prominent cultural heritage site made of the Iddefjord Granite is the Vigeland Sculpture Park in Oslo, Norway. The Norwegian sculpturer Gustav Vigeland made the Iddefjord granite his favorite choice, and all the stone sculptures in the Vigeland sculpture park in Oslo were made from this granite. The most famous piece known as the Monolith depicts 121 human figures and was carved from a 17 m tall and 270 tons heavy single block defining the centre of gravity of the sculpture park. In more than 200 sculptures in granite and bronze, the sculptures depict the cycle of human life from birth to death, and the park is so far the largest of its kind in the world displaying works of one single artist. In addition to the architectural heritage made from the Iddefjord granite, the quarrying and processing forms an integral and important narrative of the industrial revolution in this part of the world. The granite created communities and craft traditions. It created stories about immigrations and hardships, about the evolution of labour unions. he Iddefjord granite created a pool of skilled workers who spread their skills to other parts of the country, both for stone construction but also for building railways.
Thus, the Iddefjord granite had an impact on the Norwegian society and the industrial revolution herein, and the story about this production may serve as one among several important narratives of the industrial revolution in Northern Europe.


Art Nouveau style building, 1910 (university head office, Trondheim), Photo: Tom Heldal

Main reference

Heldal & Aasly (in press) Non-economic value assessment and complex stone quarry landscapes: the example of the iddefjord granite, Geological Survey of Norway Bulletin (draft uploaded)

LALIBELA BASALTIC SCORIA

Ethiopia

Outcrop of rock.

Quarried stone and outcrop.

Petrography
Basaltic scoria hydrothermally altered and laterized, porphyritic with a fine-grained texture

Geological setting
Vulcanism in Oligocene-Miocene, Northern Ethiopian Plateau

Occurrence
Region of Lalibela, Ethiopia

The Stone of Ethiopia

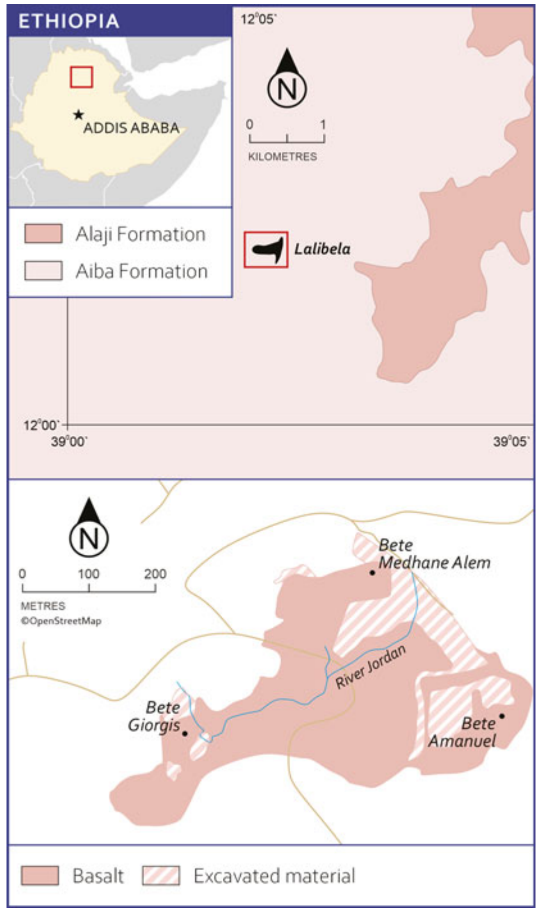
Blen Taye

The eleven rock-cut churches of Lalibela, carved from basaltic scoria, are among the most historically significant structures in Ethiopia and designated an UNESCO World Heritage Site. These churches were created approximately 800 years ago during the reign of King Lalibela and are considered sacred within the Ethiopian Orthodox Church. Unique in their construction, all eleven churches were excavated into the ground and are interconnected through trenches and underground pathways. The skilled artisans utilized naturally outcropping scoria to carve churches, ditches, trenches, canals, and monuments, making this a prime example of Ethiopian rock-cut architecture.

Petrography

The basaltic scoria has been characterised as a hydrothermally altered and laterized rock that is porphyritic with a fine-grained texture containing a hematite rich matrix that also contains clay minerals. It has abundant vesicles that are often partially void or fully filled with secondary minerals such as zeolites, smectites and calcite. The minerals that constitute the basaltic scoria are plagioclase, smectite, pyroxene, hematite, calcite and zeolites (heulandite, analcime and natrolite).

Location and geology



The basaltic scoria is found on the Northern Ethiopian Plateau and is the result of the Oligocene/Miocene volcanism which produced a thick sequence of tholeiitic to transitional continental flood basalts. Rhyolites and trachytes lavas and pyroclastic rocks are also present locally. The vicinity in which this rock crops out is made up of about 1800 m of basaltic and picritic lavas overlying a Mesozoic sedimentary basement. In the stratigraphic sequence, there are the Ashangi Basalts (Oligocene to Miocene, deep weathered basaltic flows and tuffs) at the bottom; the Amba Aibà Basalts (Oligocene to Miocene, thick flood basaltic flows with rare basic tuffs) in the middle; and the Amba Alaji Rhyolites (Miocene, rhyolite, trachyte, ignimbrites and tuffs) at the top. The geology of Lalibela, which is the area where this type of rock is found, is characterised by a basalt bedrock that is fresh at its base and weathered in its upper part. The basalt bedrock is overlain with a red moderately to highly weathered scoriaceous flow deposit that is basaltic in composition and has variously sized lithic fragments up to a diameter of 1 meter. The area in which this stone is found is a rugged topography that is made up of horizontal layers of aphyric basalts, basaltic scoria, rhyolites and ignimbrites. The basaltic scoria outcrops in the area where the rock-cut churches of Lalibela were excavated into the bedrock and other areas where the stone is quarried.

Quarries

The use of basaltic scoria in Lalibela's heritage construction is rooted in the natural geological formations of the region, minimizing the need for large-scale quarrying. Stone is taken out of locally occurring outcrops in order to be used in a variety of construction projects, including new home construction, structural repairs, and historic church restoration. There are no large scale quarry operations taking place at officially recognised quarry sites, the stone is quarried in places where the stone is easily available for construction. The extraction and management of this stone is carried out locally and informally, reflecting the small-scale, community-driven nature of these activities. Consequently, identifying and listing inactive quarries or specific extraction sites is challenging, as there is no systematic approach to their management or comprehensive record-keeping.

At quarry.

Architectural and cultural impact

The most prominent and significant use of basaltic scoria in heritage construction is evident in the rock-cut churches of Lalibela. These extraordinary structures are carved directly at the base of the Abune Yoseph Massif, which means their construction did not necessitate extensive quarrying operations. Instead, the natural outcrops of basaltic scoria in the massif provided the raw material for these remarkable religious edifices. The eleven rock-cut churches of Lalibela were carved in the early medieval times, around 800 years ago during the Empire of King Lalibela, and constitute a holy site in the Ethiopian Orthodox church. All eleven of these constructions are built using a very unusual construction technique: excavations. Expert carvers used the places where this stone naturally protruded as a creative tool to create churches, ditches, monuments, and canals. This UNESCO World Heritage complex is a singular example of rock-cut architecture in Ethiopia because of the distinctive way it was constructed. The churches have historical significance in addition to their religious and architectural value because they are among the rare surviving examples of Ethiopia's Zagwe period. A monarch of the Zagwe dynasty constructed the churches during the transitional period between the Axumite (1st–10th century) and Solomonic (13th–20th centuries) empires, which both lasted far longer and produced a greater body of archaeological material than the Zagwe period. The churches and other archaeological sites built from basaltic scoria in Lalibela provide us with greater insight into the history and evolution of architecture in this region.

Bete giyorgis.

Main references

Derat, M., Bosc-tiessé, C., Garric, A., Mensan, R., Fauvelle, F., Gleize, Y., Goujon, A. (2021). "The rock-cut churches of Lalibela and the cave church of Washa Mika ' el: Troglodytism and the Christianisation of the Ethiopian Highlands". Antiquity, 95(380), 467–486. https://doi.org/10.15184/aqy.2021.20

Renzulli, A., Antonelli, F., Margottini, C., Santi, P., Fratini, F. (2011). "What kind of volcanite the rock-hewn churches of the Lalibela UNESCO's world heritage site are made of?" Journal of Cultural Heritage, 12(2), 227–235. https://doi.org/10.1016/j.culher.2010.11.003

LARVIKITE

Norway

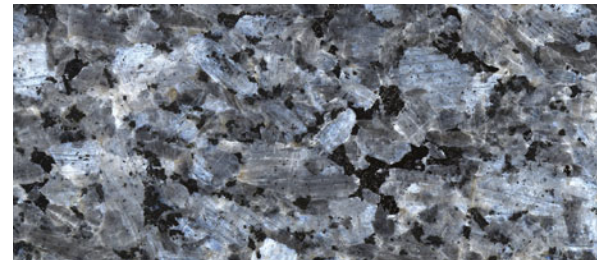
Oslo University Library (1999) is an example of modern, innovative use of larvikite
Photo: Hans Jørgen Kjøll

"All cliffs and rocks shine like they are from a strange world, such we are not used to see. This freshness and lustre in the feldspars, such large crystals, the extraordinary blue colour and the frequent labradoritic play of colours."

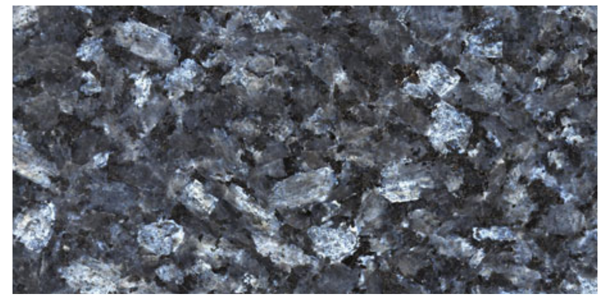
Rare ornamental stone with lustrous blue crystals

Tom Heldal
Anette Granseth

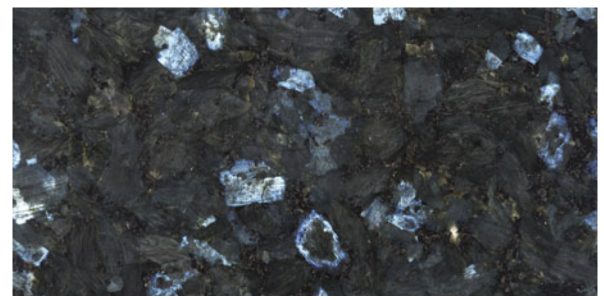
So wrote the German geologist and traveler Leopold von Buch in 1810. Although the larvikite rocks found their use in prestige buildings as far back as the 12th century, it was during the 19th and the industrial revolution that the great breakthrough in the world's stone markets occurred. The blue iridescence in the feldspar crystals made the rock particularly attractive as ornamental stone, and since the start of industrial scaled production in 1884, the use of larvikite has reached every corner of the global community. With resources for hundreds of years, the region will produce larvikite blocks far into the future.



larvikite Malerød (18cm width)



light larvikite (18cm width)



dark larvikite (18cm width)

Petrography

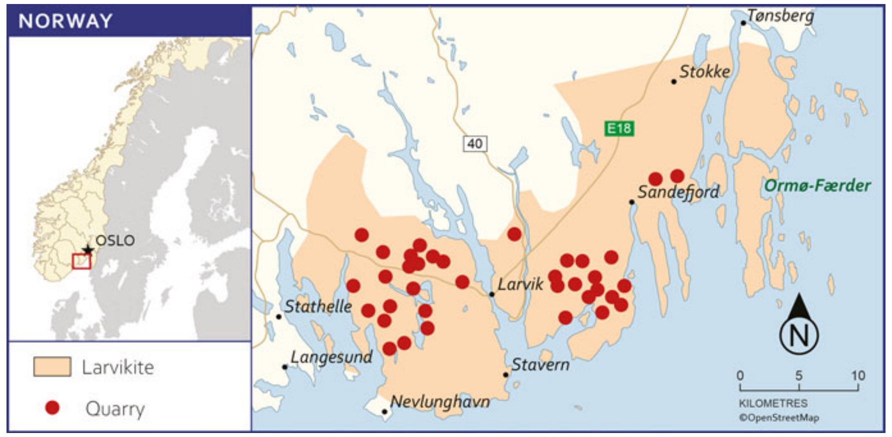
The term 'larvikite' is applied for a range of monzonitic rocks within the southern part of the Carboniferous–Permian Oslo Igneous Province, Norway. Larvikite is generally a coarse-grained, grey to bluish plutonic rock predominantly composed of tabular to prismatic feldspar crystals. The bulk composition of the feldspars is ternary. In the larvikite types used for dimension stone, microscopic lamellae of two phases of feldspars creates patchy, blue iridescence, created by interference between lamellae thickness and light wavelength. This play of colours is the main reason for the stone's reputation in the global stone market and its wide distribution.

Petrography
Monzonite

Geological setting
Paleozoic - Carboniferous-Permian;
rift related magmatism (Oslo Igneous Province)

Occurrence
Municipality of Larvik, SE Norway,
UNESCO Global Geopark Gea Norvegica, Norway

Location and geology



The larvikite complex is composed of eight ring-shaped intrusions, becoming younger from east to west (297±1.2 Ma to 293.2±1.3 Ma). There is a systematic change in the mineralogy from quartz-bearing larvikite in the east towards nepheline-bearing larvikite to the west in the plutonic complex. This represents an evolution from saturated to under-saturated magma fluxes, resulting from either multiple caldera collapses or a system of multiple ring intrusions from a deep-seated parental magma chamber. The different intrusions represent different commercial types of larvikite, such as light larvikite, dark larvikite, Malerød larvikite, Bergan larvikite and Stålaker/Krukåsen larvikite. In the northern part, there are brown, oxidized varieties, mostly used in the medieval period and 19th century architecture.

Quarries

With one exception (the oxidized, brown larvikite) all the classical varieties are still in production. Through the last 30 years, quarries have merged, creating large and efficient production units, applying diamond wire sawing as the principal method of extraction. It is important to quarry the stone in certain directions, so that sawing cuts are always parallel to or at low angle to the main directional orientation of the feldspar crystals, for obtaining maximum iridescence. Many efforts have been made recently for more sustainable quarrying, i.e. zero waste. Thus, several enterprises now live on quarry waste rock, for use as armour stone, drywall stone and crushed aggregate. Even dust from sawing, enriched in phosphorous and potassium, can be applied as an organic soil additive.

Large, operating larvikite quarry. Photo: Anette Granseth

Architectural and cultural impact

Larvikite was applied in several medieval churches (11th century) in the region, and later in the Norwegian Royal Castle from the 1820'ies. However, significant development of the production came as late as 1878. From then, larvikite gained an international reputation and the quarrying industry grew. Export of larvikite took many ways. Kessel & Röhl brought the larvikite blocks to Sweden for further processing for funerary monuments. These were re-exported to Germany under the name 'Labrador aus Schweden'. The company also introduced larvikite in many impressive buildings in Germany during the late 19th century. Before the turn of the century, larvikite was well introduced to the USA market. Through the stone workshops in Aberdeen, larvikite (often paired with red Swedish granite) found the way to fashionable buildings in London and other British cities, and due to the extensive use in London pubs, larvikite got a new nickname – 'Pubstone'. Larvikite rapidly gained a solid position in Norwegian architecture; from fashionable 'boutique' facades to massive, Art Nouveau buildings clad with ashlar masonry. In Norway and abroad, larvikite became a symbol of fashion and wealth. Many banks did use larvikite around their entrances, so did Harrods in London and Galleries Lafayette in Paris. Innovative architects used larvikite, as for example in some of the most well-known Art Deco buildings in London. In more recent times, larvikite has been applied in several landmark buildings throughout the world, such as Devon Tower, Calgary (1988), Bank of America tower, Jacksonville (1990), the Jame Asr Hassanil Bolkiah mosque in Brunei (1992) and the seven-star hotel Burj-Al-Arab in Dubai (1999). Since the beginning of the modern period production, a significant part of the larvikite has been applied for gravestones and funerary monuments. Already in the last quarter of the 19th century, gravestones were exported to Germany and the British Isles. At the present time, larvikite can be seen at funerary sites all over the world.

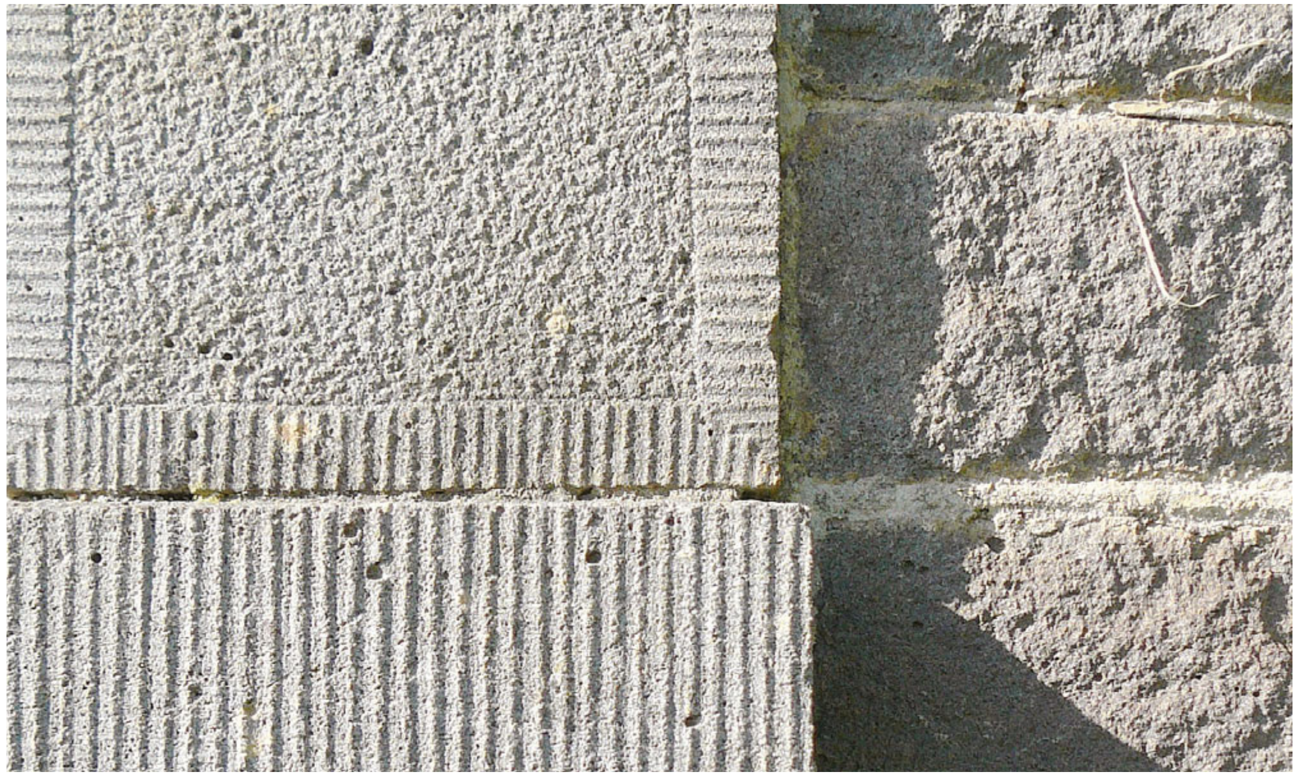
The old National Bank in Oslo (1906) was made from larvikite ashlars. Photo: Tom Heldal

Main reference

Heldal, T., Meyer, G.B. and Dahl, R., 2015. Global stone heritage: larvikite, Norway. Geological Society, London, Special Publications, 407(1), pp.21-34. https://doi.org/10.1144/SP407.14 p. 129-147.

MALMSBURY BLUESTONE

Australia



Malmsbury station window

Malmsbury war memorial close up

Petrography
Olivine tholeiite or transitional basalt

Geological setting
Pliocene- Newer Volcanic Group- Western District Province- Central Highlands Sub-province

Occurrence
Malmsbury, Victoria, Australia

Australia's Standard of Excellence

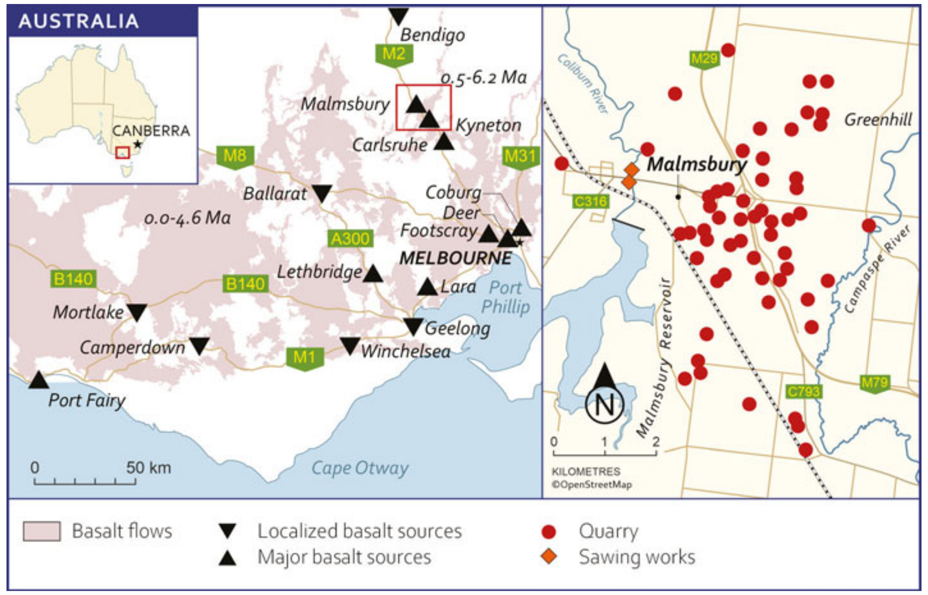
Susan Walter

Malmsbury bluestone, one of Victoria's basalt building stones, is renowned for its diversity and distribution in over 500 architectural, infrastructure and cultural uses. Between 1856 and 1930, this stone was used in basecourses of government, commercial and cultural buildings, with ornate doorways, interiors of churches and a stone viaduct as some of the more notable uses.
Large quantities were used in drains, pavements, kerbing, graves, steps, lintels, windowsills, monuments, and a reservoir. Some sites in Victoria, Tasmania, South Australia, and New Zealand feature in State or National heritage registers, however many structures have been demolished, the stone's presence is often not acknowledged in extant sites and the disused quarries have no protection or capacity for repair works.

Petrography

Malmsbury bluestone is a basalt primarily composed of plagioclase felspar lathes, pyroxene, olivine (often degraded into iddingsite), appatite and some magnetite.
The stone's lighter colour, compared to other bluestones, is explained by the presence of the plagioclase in the form of labradorite, and the relative lack of the titanaugite present in many of the darker forms of Victorian bluestone.
The stone's colour is uniform.

Location and geology



Malmsbury, Victoria, Australia, is 97 km north-west of Melbourne, and serviced by the Melbourne-Bendigo Railway line and the Calder Highway. The town is located on the edges of the Coliban River Valley adjoining the basalt plains which are part of the Central Highlands Sub-province of the Western District Province of the Newer Volcanic Group of the Pliocene epoch.

The stones in the vicinity of Malmsbury used as dimension stone are typically olivine tholeiite or transitional basalts. While many sources of bluestone typically have distinct patches or layers of large vesicles, the best quality Malmsbury bluestone had few of these patches and the stone typically had smaller vesicles distributed evenly throughout the stone.

Quarries

The Malmsbury quarries were primarily located on the east, south-east and north-east of the township on the basalt plains between the Coliban and Campaspe Rivers. Extraction of stone primarily took place between 1856 and the 1930s, with some sites re-opened in the 1970s to create the former Melbourne City Square. While the quarries appear to have had a columnar formation of basalt, these were quite wide which permitted the extraction of large pieces of stone.

Most of the commercial quarries were on private land, managed by co-operative groups of quarrymen, although there were a few government-managed sites on Crown land. Today the disused quarries are typically on private farming or rural-residential land.

Salvation Quarry

Architectural and cultural impact

The notable uses of Malmsbury bluestone are in architectural settings, typically base courses of commercial, private, government and cultural buildings. These include flour mills, multi-story office buildings, banks, and churches, many dating from Melbourne's gold-rush boom era of the late nineteenth century.

There was also a significant usage in government infrastructure such as railway and road bridges and culverts, reservoirs, drains, and kerbing and paving stones. In addition to this is usage in domestic and agricultural buildings such as rubble stone walls, steps, lintels, windowsills, flag and hearth stones. Further cultural use can be found in cemeteries, foundation stones and monuments.

The stone first came to the wider attention of the public after the construction of the Malmsbury Railway viaduct (1859-1861), with the initial spread of use occurring along the railway corridor north of Malmsbury. Use in Melbourne, and then into other states and countries, greatly increased following the introduction of bluestone sawing technology in Victoria (at Footscray) in 1867 and then in Malmsbury in 1874, and the sample displayed at the 1873 Sydney Exhibition. A sample sent to the 1908 Franco-British Exhibition in London won a gold medal.

The relatively limited distribution of the stone sources also heavily influenced the cultural, social and political structure of Malmsbury township in addition to the built heritage created. The quarries attracted stonemasons and quarrymen from diverse cultural backgrounds, some of which came from Portland, Dorset (UK), with multigenerational experience with working with the Portland Limestone (another GHSR). Some also came with experience in political fights over working conditions.

These stoneworkers often intermarried, worked co-operatively to run quarries and process the stone, and participated in local sporting, cultural, and political organisations, and local government. This contrasts with surrounding districts without quarrying industries. Local stone use diminished as the wider distribution increased.

Interior of St Paul's Cathedral, Melbourne (1880)

Main reference

Walter, Susan M. (2020). "Victorian Bluestone: a proposed Global Heritage Stone Province from Australia." Global Heritage Stone: Worldwide Examples of Heritage Stones. J. T. Hannibal, S. Kramar and B. J. Cooper. 486: 7-31 (https://www.lyellcollection.org/doi/abs/10.1144/SP486.1

PORTO GRANITE

Portugal

Porto granite defensive wall

A testimony of Porto history marked on the natural stone built heritage

Maria Ângela Almeida

Porto is an old town that hosts a monumental heritage with an architectonic profile drawn by the local granite buildings of different styles following history written in the city wall, the medieval and baroque monuments, the neoclassic houses and the charming humble habitations that broadly contributed to the designation of the historical Porto centre a World Heritage of the Humanity since 1996. The granite geomorphology landscape has been of extreme importance in the origin of the town, as a protection against invaders in distinct historical moments and in the urban planning. The widespread occurrence and applications of the Porto granite raised the need of carrying out a diversity of studies to a better understanding of its intrinsic properties that define the character of the city.

Porto granite drill core

Petrography
medium to coarse-grained Leucogranite

Geological setting
Paleozoic – Variscan orogeny; Central Iberian Zone, Porto granite massif

Occurrence
Porto region, Portugal

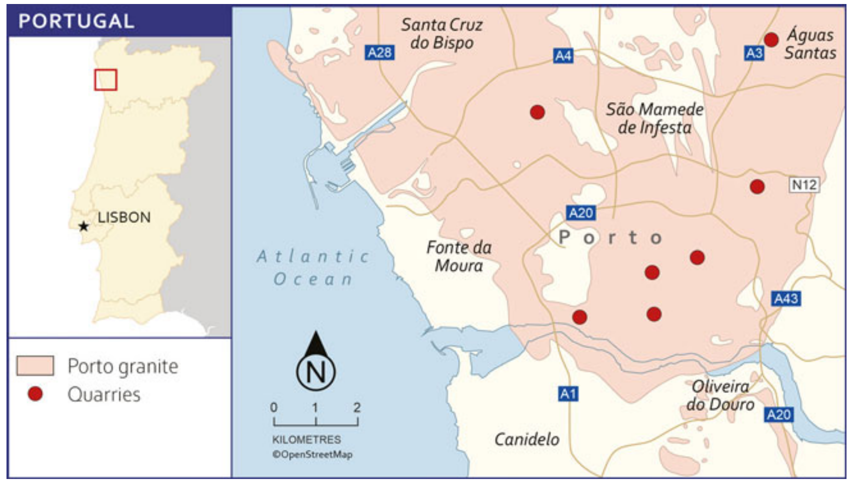
Petrography

The Porto granite may be classified as a medium to coarse-grained leucogranite, highly peraluminous, with petrographical, geochemical and tectonic features typically of S-type granites. The main mineral paragenesis is composed by quartz, orthoclase, microcline, albite, muscovite, mostly of primary origin, and biotite. Accessory minerals include zircon, apatite, monazite, rutile and ilmenite.
The Porto granite is affected to various extents by late- to post-magmatic alteration processes. Furthermore, the climate factors and the proximity of the Atlantic Ocean make this granite highly susceptible to hydrolysis reactions that transform the feldspars into a fine and almost pure clay, a kaolin of very high quality that produced the occurrence of a large kaolin deposit exploited until 1988.

Location and geology

Porto is situated in NW of Portugal, approximately 300 km north of the capital Lisbon facing the Atlantic Ocean. Porto has an elongated E-W shape and occupies an area of around 41km2. The Porto granite massif that supports the city is intruded in the Central Iberian Zone, one of the tectonostratigraphic and paleogeographic units within the Iberian Massif, close to the western limit with the Ossa Morena Zone.

The Porto granite emplacement was controlled by folding and shearing events that characterized the third tectonic phase of the Variscan orogeny, D3, being classified as syntectonic relatively to this tectonic phase. The combination of U-Pb, Rb-Sr and Sm-Nd geochronology suggests an age of 313 Ma.



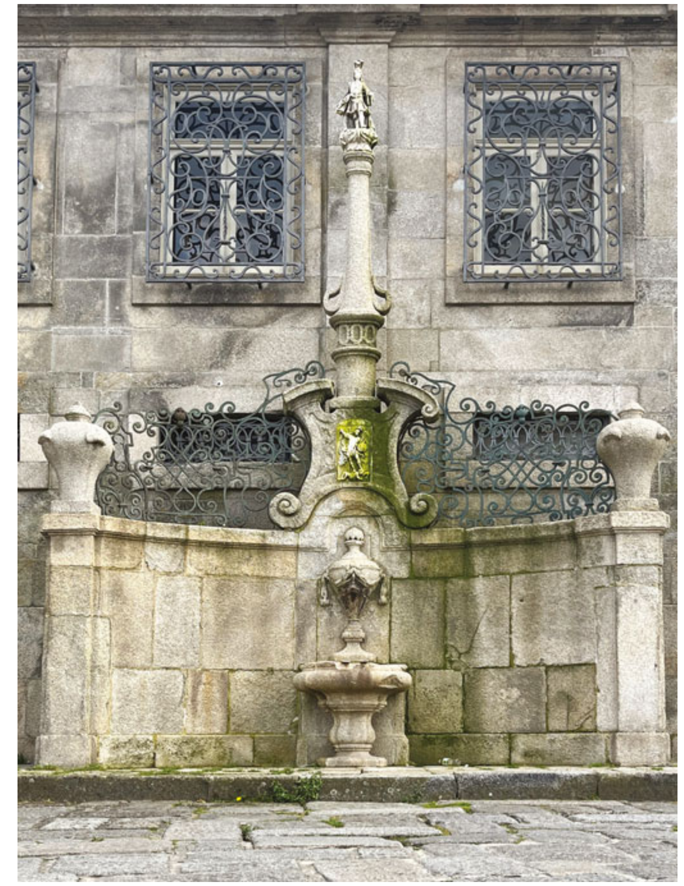
Quarries

Porto granite outcrop surrounded by city buildings

The Porto two-mica granite quarries exploitation was marked by intense activity since the origin of the city until the first half of the 20th century, for the construction of both historical and common buildings. Granite outcrops are still observed in some areas of the town, but the exploitation of the quarries, either within the city or in the surrounding municipalities, is no longer possible due to the urban development. However, few old quarries can still be observed particularly in the more rural areas in the outskirts of the main city. The most important quarries that contributed to the unique natural stone features of Porto city, ordered from the most central towards the environs, are the Monte Pedral, Lapa, Trindade, Arrábida, Areosa, Serra do Pilar, S. Gens and Águas Santas.

Architectural and cultural impact

The geological and geotechnical properties of Porto granite provide good workability and allows the sculpturing of architectural features of extreme elegance. A selection of some of the most significative applications that enhance the evolution of the use of Porto granite over time is proposed. The proto-historic castros of Roman age are considered the oldest structures. Then, the medieval defensive system marks two distinctive moments, namely the primitive wall of the 3rd century and the new wall of the 14th century whose remains end abruptly on the edge of the escarpments of Douro river. The Cathedral exhibits superposing architectural styles from the 12th to the 18th centuries. The Clerigos Tower is the landmark of Porto and the most challenging project of the Italian architect Nicollò Nasoni, being the tallest bare granite building in Portugal with a delicate and exuberant lace work of Baroque style. The St. Antonio Hospital, an imposing construction of the 19th century based on a project of John Carr, consists of an extraordinary example of neo-Palladian architecture and the first neoclassical building in the city. The Town Hall built in the 20th century is probably the last historical monument of Porto granite, inserted in a global project to expand the civil centre involving the Aliados Avenue, the Liberdade Square and the buildings that border both sides of the avenue. The Portuguese architect responsible for the first buildings in Aliados Avenue was Marques da Silva, a reference name that influenced greatly other important granite structures in Porto, being examples the St. Bento railway station built with stones from the total demolition of a previous convent, and the Monument to the Heroes of the Peninsular War. The impact of the Porto granite can also be appreciated in the built heritage in the outskirts of the city and in international destinations that include Brazil, France, Germany, United Kingdom, Canada, United States and Asian countries.



Porto granite fountain with Ançã limestone angel sculpture on the top

Main reference

Almeida, A & Begonha, A (2015). Contribution of Portuguese two-mica granites to stone built heritage: the historical value of Oporto Granite. In Pereira D, Marker BR, Kramer S, Cooper BJ and Schouenborg BE (eds) Global Heritage Stone: Towards International Recognition of Building and Ornamental Stones. Geological Society, London, Special Publications, 407, 75-91.

ROCHLITZ PORPHYRY TUFF

Germany

The old town hall (1557) seen from the entrance of the Underground Exhibition Hall (1924) in the city centre of Leipzig. The facades are decorated with Rochlitz Porphyry Tuff.

A unique stone from Saxony

Heiner Siedel

Among the pyroclastic rocks used as building stones there is hardly any that visually compares to the Rochlitz Porphyry Tuff with respect to colour and structure.
The warm red to pale red colour and the marbling by light veins are unique and attracted the interest of stonemasons and sculptors as early as in the Middle Ages. The material's tradition is strongly connected with the tradition of mason's lodges ("Bauhütten") in Germany and Europe in the Middle Ages.
Already in 1462 local stonemasons from Saxony gave themselves rules that regulated their rights and duties on construction sites. They are known as Rochlitz rules ("Rochlitzer Hüttenordnung"), since a copy survived in the possession of the later Rochlitz stonemasons' guild.

Facade of the Leipzig City History Museum

Petrography
Rhyolithic Ignimbrite

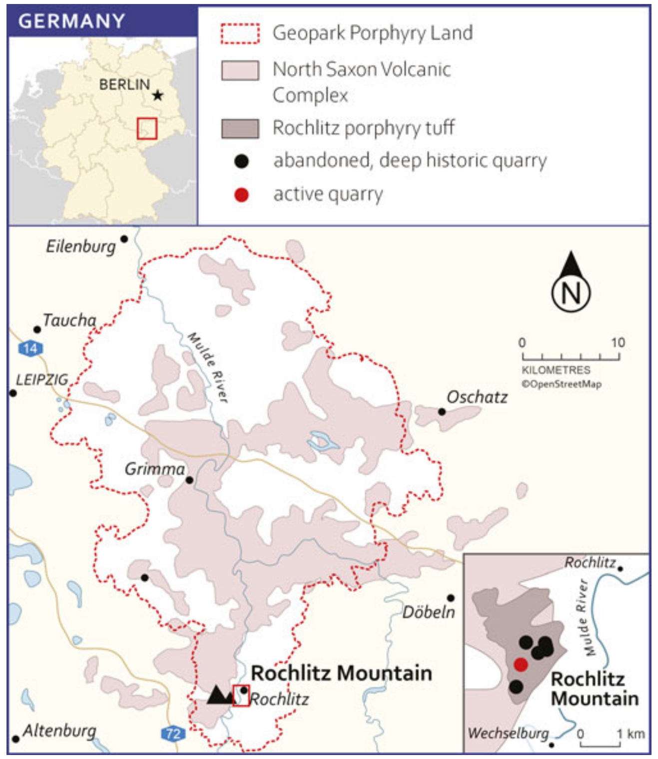
Geological setting
Paleozoic- Lower Permian,
Part of the North Saxon Volcanic Complex

Occurrence
Rochlitz Mountain, Saxony, Germany

Petrography

According to the classification scheme of pyroclastic rocks used in the IUGS classification, the Rochlitz Porphyry Tuff can be assigned to the group of lapilli tuffs with regard to the grain size of its components (ash with embedded lapilli).
Although the fabric with elongated and flattened lapilli indicates the ignimbritic origin from a pyroclastic flow, the traditional name "Rochlitz Porphyry Tuff" is maintained for the building stone.
Quartz, accessory biotite and shapes of corroded feldspar can be found as phenocrysts in the groundmass.
A high amount of kaolinite (from the matrix and from completely alterated feldspar phenocryts) and quartz, as well as traces of finely disseminated hematite, were confirmed by X-ray diffraction. Geochemical analyses reveal a rhyolitic composition.

Location and geology



The Rochlitz Porphyry Tuff belongs to the rocks of the North Saxon Volcanic Complex of Permian age that covers an area of about 2,000 square kilometres, situated in the Free State of Saxony in East Germany.

It is part of the late to post-Variscan magmatic activity in Central Europe. According to recent investigations, the rock can be assigned to a large series of ignimbrites with varying phenocryst content and composition and a radiometric age of about 295 Ma that nowadays is considered as the caldera filling of a supervolcano.

The occurrence of the weakly welded ignimbrite used as dimension stone is mainly limited to the geomorphological structure of the Rochlitz Mountain ("Rochlitzer Berg"), a small area of about 3 km^2 with maximum height of 353 m.

Quarries

Quarrying on the Rochlitz Mountain has been developed since the beginning of the 12th century when Rochlitz Porphyry Tuff first appeared as building stone on massive constructions.

More than 10 quarries were operating in the 19th century. Some of the abandoned quarries are up to 60 m deep and show tool marks of the old quarrying techniques on their walls.

Today, two quarries still produce the stone, which is preferably used for cladding façades, for sculpting and gravestones, for restoration purposes as well as for landscaping.

Builders in former times have utilized ashlars of Rochlitz Porphyry Tuff also for massive constructions such as bridges, walls, and buttresses. Furthermore, it was used for the production of millstones.

Abandoned historic Gleisberg Quarry on top of the Rochlitz Mountain

Portal of the collegiate church in Wechselburg, 12th century.

Architectural and cultural impact

Buildings and objects made of Rochlitz Porphyry Tuff are numerous. It has been used for sculpting and construction throughout all architectural periods from the Romanesque until today.

In the first centuries of use as a building and sculpting stone, the Rochlitz Porphyry Tuff was mainly spread in the region around the quarries, in most cases much less than 100 km (only a few daytrips by horse and car) away from Rochlitz.

This way, it became the very typical stone material for the rich cultural landscape of the north-western part of Saxony, i.e. the area between Chemnitz and Leipzig, throughout the first seven centuries of utilization. Since the middle of the 19th century, the rapid development of infrastructure with better roads and new railroads facilitated the wider distribution of Rochlitz Porphyry Tuff, at the end of the century also far beyond the borders of Saxony.

Buildings in many cities in Germany as well as in Austria, Denmark, Belgium, Poland and Russia bear witness to this development.

Examples for iconic monuments with Rochlitz Porphyry Tuff are the Renaissance town hall and the galleries in the church St Thomas in Leipzig, the Villa Esche in Chemnitz, designed by the Architect Henry van de Velde in Art Nouveau style, and the mausoleum of the philosopher Immanuel Kant in Königsberg (today Kaliningrad, Russia).

Distance column of the Saxon Post (1727) showing the travel time of carriages to various surrounding towns in Leisnig

Main reference

Siedel, H., Rust, M., Goth, K., Krüger, A. & Heidenfelder, W. (2019): Rochlitz porphyry tuff ("Rochlitzer Porphyrtuff"): A candidate for „Global Heritage Stone Resource" designation from Germany. – Episodes. Journal of International Geoscience 42 (2019)2: 81-91. https://doi.org/10.18814/epiiugs/2019/019007

ROSA BETA GRANITE

ITALY

Giants' grave 'Li Lolghi' in Arzachena, dated back to the Eneolithic age.
The Central stone is 4 m high. Photo: A. Mura

Building the Sardinian Countryside and Heritage since Prehistoric times

Nicola Careddu

Since ancient times, the life of the Sardinian people evolved in symbiosis with the stones in which the island is so rich.
Among them, along with basalt, is a pink-gray granitoid that is still in use: the Sardinian granite Rosa Beta (β).
The stone has been used since the late Neolithic (3300-2480 b.C.) for the building of megalithic monuments up to contemporary times, especially for the cladding of skyscrapers almost all over the world.

Rosa Beta granite (polished) (15cm x 15cm)

Petrography
Quartz-Monzonite

Geological setting
Paleozoic- Late Pennsylvanian-Early Permian; part of the Sardinia-Corsica-Batholith

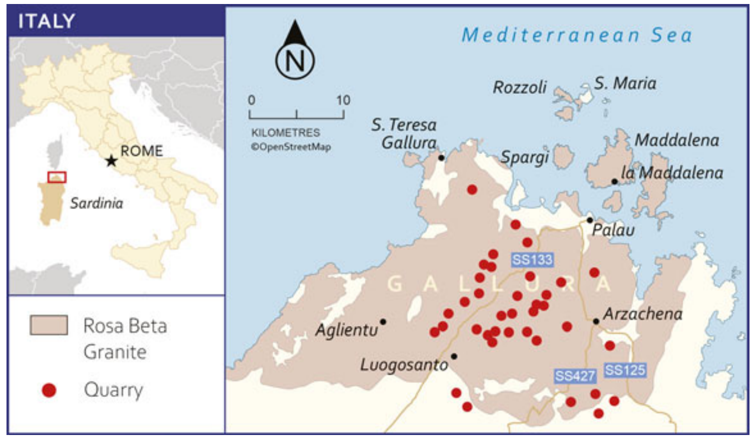
Occurrence
Gallura, NE Sardinia, Italy

Petrography

Rosa Beta is an equigranular quartz-monzogranite (or pink monzogranite) "Arzachena facies".
Generally speaking, the Sardinian pink granites show a color ranging from dotted-pale to diffuse pink, to intense pink, with a medium-small uniform grain having size between 0.5 and 2 cm.
This pinkish coloration is driven by the abundance of pink K-feldspar crystals.
Thin section studies show mainly plagioclase feldspar, quartz and orthoclase feldspar with minor biotite mica.

Location and geology

Rosa Beta granite is sourced from the Gallura region (North of Sardinia), where 32 quarries were in operation twenty years ago. Currently, due to the “granite crises” only 5 quarries are operating.
Granitoids are related to the Sardinia-Corsica Batholith that is a huge set of calcalkaline plutons emplaced between 340 and 280 Ma ago, at the end of the Variscan Orogenesis.
Within these plutons many facies often occur having different texture, composition, color etc.
The large heterogeneity in Batholith composition matches up with the lithological variety ranging from gabbros, quartzdiorite to granodiorites, monzogranites and leucogranites.
With regard to color, this was deter-mined by the color of the dominant mineral.



Quarries

Almost all of the Rosa Beta granite quarries are hill-side; they are quarried by using the open-cast method, single or multiple bench configuration, and descending development.
The classic quarrying scheme provides for the isolation (primary cut) of large parallel-piped rock volumes (benches), which are subsequently divided into smaller volumes (slices).
The squaring of the slices results in the production of the final blocks (commercial blocks). It should be noted that the quarrying cycle does not always result in the division of the bench into slices; for example, in dome-shaped deposits, typical of Gallura, it is preferable to have a primary cut to directly obtain the vertical slices.
Diamond wire is the most used technology during the primary cut of the main bench and subsequent slicing.
On the other hand, the block cutting to commercial size is mainly performed by using the traditional method of drilling and wedge-splitting.

Sardinian pink granite quarry near Luras (Gallura).

Architectural and cultural impact

In Sardinia, wherever massive granite formations are found, the landscape is dotted with ancient stone monuments, which blend harmoniously with the solitude of nature that surrounds them.
First utilization of granite started in the prehistoric age during the pre-Nuragic and the Nuragic culture (the latter dates from the 18th century B.C.) which main manufacts and buildings are menhir, dolmen, Giants’ graves and Nuraghi.
From the Roman Age, the extensive use of granitoids rocks as building and dimension stones characterized the region of Gallura, where abundant traces of their historical, cultural and economic significance are widely exposed in the territory.
In the so-called ‘Granite towns’ of Sardinia granite was the building material of first choice for one millennium.
In the 19th century, an export company exported the pink granite in Italy and worldwide (Brazil, Egypt, etc.); in Gallura and its northern small islands (Santo Stefano and La Maddalena), for about half a century there was a large, close-knit community of quarrymen and stonemasons which lead, in the late 20th, the quarrying and processing of Rosa Beta granite to be the most thriving industry of northern Sardinia.
However, the company was affected by the consequences of the Great Depression that had overtaken the American economy. For the next few decades, the Island’s stone production consisted mainly of building stone for the local market.
After that period of stagnation, thanks to its high technical and aesthetic properties, its excellent finishing qualities, as well as the new architecture of the American school, granite soon achieved great success on both national and international markets from the 1960s until 2000, Rosa Beta granite (together with other granitoids) conquered international markets (90 % of Italian granite was quarried in Sardinia at that time) with several iconic buildings around the world.

Arab Organizations’ Headquarters Building, Kuwait City (1996)
Photo:: from almullaengineering.com

Main reference

Careddu N., Grillo S., 2015. Rosa Beta granite (Sardinian Pink Granite): a heritage stone of international significance from Italy. From: Pereira, D., Marker, B.R., Kramar, S., Cooper, B.J. & Schouenborg, B.E. (eds) 2015. Global Heritage Stone: Towards International Recognition of Building and Ornamental Stones. Geological Society, London, Special Publications, 407, 155–172.

SARDINIAN BASALT

Italy

The most famous nuragic settlement `Su Nuraxi´ (XV-VII cent. B.C.), located in Barumini (South Sardinia).
Photo: from imagomuse.it

A rediscovered stone

Nicola Careddu
Stefano Columbu

Since the neolithic age, Sardinian basalt has been used thanks used thanks to its good technical features and wide availability in the territory, especially in the Central and North-Western sectors of Sardinia.easy workability. Nevertheless, it has been used mainly in the areas of its occurrence, the evidences of the uses of this stone are found in the whole island. Surely the most important historical monument, built by using the Sardinian basalt is the complex of circular defensive towers, known as "Su Nuraxi di Barumini" which was included in the World Heritage List by UNESCO in 1997.
Now, thanks to its „rediscovery", Sardinian basalt is in great demand as dimension stone (outdoor paving with various formats, „rustic" facade cladding) and other building elements such as jambs, window sills, architraves and street furniture both in the island and in Europe.

classic Sardinian basalt

"Black prestige"

Red-wine basalt

Petrography
Basalt, trachy-basalt, basaltic trachy-andesite, andesitic basalt

Geological setting
Cenozoic – Plio-Pleistocene volcanism

Occurrence
Central-western Sardinia (e.g., Montiferro volcanic complex, and Planargia, Campeda, Abbasanta plateaux), central-southern part of the island (e.g., Monte Arci complex, Gesturi and Serri jars), and minor eastern sectors (e.g., Dorgali-Orosei, Capo Ferrato), Italy

Petrography

The Sardinian basalt used in the historical and recent times as construction materials and as a tool mainly belong to the subalkaline, transitional and alkaline series of Plio-Pleistocenic volcanism (~5-0,1 Ma) that is well represented in the central-western sectors of Sardinia.
According to the classification scheme of igneous rocks adopted in the IUGS classification, the Sardinian basalt can be mainly classified between the alkaline series as (1) from alkali-basalt, to trachy-basalt, to trachy-andesite for potassic series and as (2) basanite for sodic series; between the subalkaline series the "basalt rocks" can be classified as: basalt, to andesitic basalt, (to the less frequent basaltic andesite).
The color of this stone shows variations that belong to three main dominants: grey, brown grey-black, and brown-amaranth-red (rarest).

Location and geology

The “basaltic rocks” of Sardinia (including not only the commercial Sardinian basalt in s.s.,) are related to the Cenozoic magmatic activity in Sardinia, which is divided into two phases (Late Eocene-Miocene and Pliocene-Pleistocene) constituting two distinct petrographic provinces.
The two different phases, which show very different geochemical characteristics, led to the formation of the important volcanic complexes of Montiferru and Monte Arci (central-western Sardinia) and the setting up of important volcanic coverings which represent a large portion of the Sardinian territory, both as pyroclastic/ignimbritic products and as „basaltic“ lavas.
The second phase (mainly occurred in the Plio-Quaternary) is an intraplate continental volcanism with alkaline, transitional and sub-alkaline character that has produced most of the common “basaltic rocks” in Sardinia, developing mainly in the central-western part of the island from which the “basalt rocks” most utilised in historical and recent times belong.
The simplified map shows the sectors where the lithologies of the Plio-Pleistocene Sardinian volcanism outcrop, in which territory the main mining and processing activities for basaltic stone materials used in construction are located.

Quarries

Although many archaeologic evidences of ancient quarrying have been found in the island, the current basalt quarrying activities are located exclusively in the central-western sectors of Sardinia.
Sardinia is currently the main production area of raw basalt in Italy. Moreover, compared to other Italian productions, it is characterized by a greater uniformity about the petro-physical features of the stone.
As almost all the basalt quarries, the quarrying method is generally based on the separation of boulders.
However, there is a unique basalt quarry in Norbello where the quarrying method used involves the complete classic cycle, from the isolation of a large volume (bench), to obtain the commercial block.

Quarry located in Norbello (inside the Abbasanta plateau in central-western Sardinia), where basalt known commercially as ‚Nora basalt‘ is extracted.

Architectural and cultural impact

The improved craftsmanship and the introduction of more specialised tools resulted in the production of higher quality stone works during the nuragic period (1500–500 B.C.).
Nuragic civilization takes its name from the distinctive megalithic constructions (towers called „nuraghes“) that featured Sardinia’s history.
Another important archaeological site is the Nuragic sanctuary of Santa Cristina, located in the area of Paulilatino, in the southern part of the plateau of Abbasanta (West-Central Sardinia). The most known and investigated area of this site is the temple, which is a sacred well built during the nuragic age using processed basalt blocks (Lilliu 1988).
The nuragic of Santa Cristina is thought to have been built for religious rituals: it was architected so that the moonlight would be reflected on the water when the moon reached its zenith (directly above the well) in the sky.
The use of basalt as a building material as well as ornamental stone is further found both in the Roman and Medieval ages. Numerous groups of buildings scattered throughout the Island, and especially in its Central-Northern part, where churches were built with basalt, often along with limestone and trachyte.
The most widely used `basalt rocks´ belongs to the of Plio-Pleistocene volcanism phase, which were used up until the 1950s, for construction and architectural purposes.
Following the market penetration of new stone and non-stone materials, the use of basaltic stone decreased considerably; however, basalt lived a new phase for nearly two decades, and it has now acquired new appeal especially in the production of street furniture and decorative parts used for public and private buildings, during the restoration of several civic centres.
The famous sculptor Pinuccio Sciola (1942-2016) often used Sardinian basalt to create his “sounding stones”.

External paving made in Sardinian basalt. Rome. Photo: courtesy of GMC Pietre.

Main references

Careddu, N., Grillo, S.M., 2019. Sardinian Basalt—an Ancient Georesource Still En Vogue. Geoheritage (2019) 11:33-45;

Columbu S, Garau AM, Carboni D, Ginesu S, Macciotta G, Marchi M, Marini C, Corazza G (2011) Manuale sui materiali lapidei vulcanici della Sardegna Centrale e dei loro principali impieghi nel costruito. ISKRA (ed.), Ghilarza (OR), Italy (in Italian);

Columbu, S.; Palomba, M.; Sitzia, F.; Carcangiu, G.; Meloni, P. 2022. Pyroclastic Stones as Building Materials in Medieval Romanesque Architecture of Sardinia (Italy): Chemical-Physical Features of Rocks and Associated Alterations. International Journal of Architectural Heritage, 2022, 16(1), 49–66.;

TEZOANTLA WHITE TUFF

Mexico

Panteón inglés (English Cemetery) of Mineral del Monte. This cemetery of the 19th century represents a relevant English legacy in Mexico. Many gravestones and monuments were made out with Tezoantla Tuff and possess a symbolism from Anglicanism, ancient Celtic and masonry traditions. Photo: Daniel Acosta

Monuments and vernacular architecture in the mining heart of Mexico

Carles Canet
Elizabeth Lozada Amador
Laura Itzel González León
Ilia Alvarado Sizzo
Francisco O. Lagarda-García

The cultural importance of this stone lies in its continued use during the last four centuries in the construction of monuments and as a material for sculpture, as well as in vernacular architecture and in mining buildings.

During the 16th, 17th and early 18th centuries, this stone was used in several Baroque religious buildings. During the 19th and 20th centuries, it was notably used in mining architecture throughout what is now the Comarca Minera UNESCO Global Geopark (UGGp).

The use of this stone is noticeable in the chimneys (chacuacos), a conspicuous element of the iconic Cornish engine houses. However, the most notable monuments done with this stone correspond to the Neoclassical and eclectic styles, dating back to the 19th and early 20th centuries. The use of this stone is not limited to Hidalgo, as it also can be admired in buildings of Mexico City.

Field appearance of the Tezoantla White Tuff, Photo: C. Canet

Petrography

The Tezoantla White Tuff is an ash tuff affected by low-temperature hydrothermal argillic alteration (zeolite alteration).

Under the petrographic microscope, the texture of this stone is micro-cryptocrystalline, pyroclastic (fragmental texture).

It has subhedral quartz, albite and sanidine micro-phenocrysts (<1 mm), embedded in a fine matrix that corresponds to 60-65% (modal) of the rock, and disseminated biotite, Fe-oxides, illite and smectite clays, as well as subangular lithic fragments of basic to intermediate rocks.

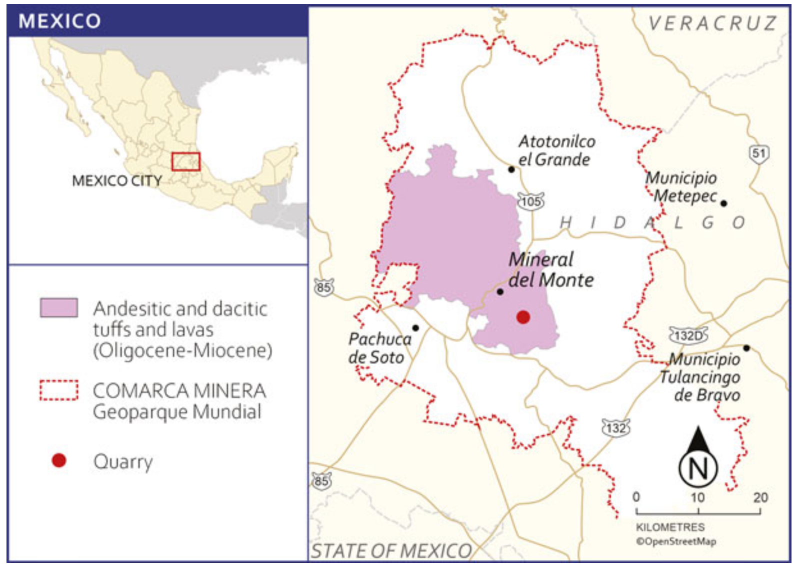
Petrography
Tuff; ash tuff, affected by low-temperature argillic hydrothermal alteration

Geological setting
Cenozoic - Miocene - Pachuca Group

Occurrence
Tezoantla and Santa Rosalía villages, Mineral del Monte municipality, Hidalgo State, Mexico

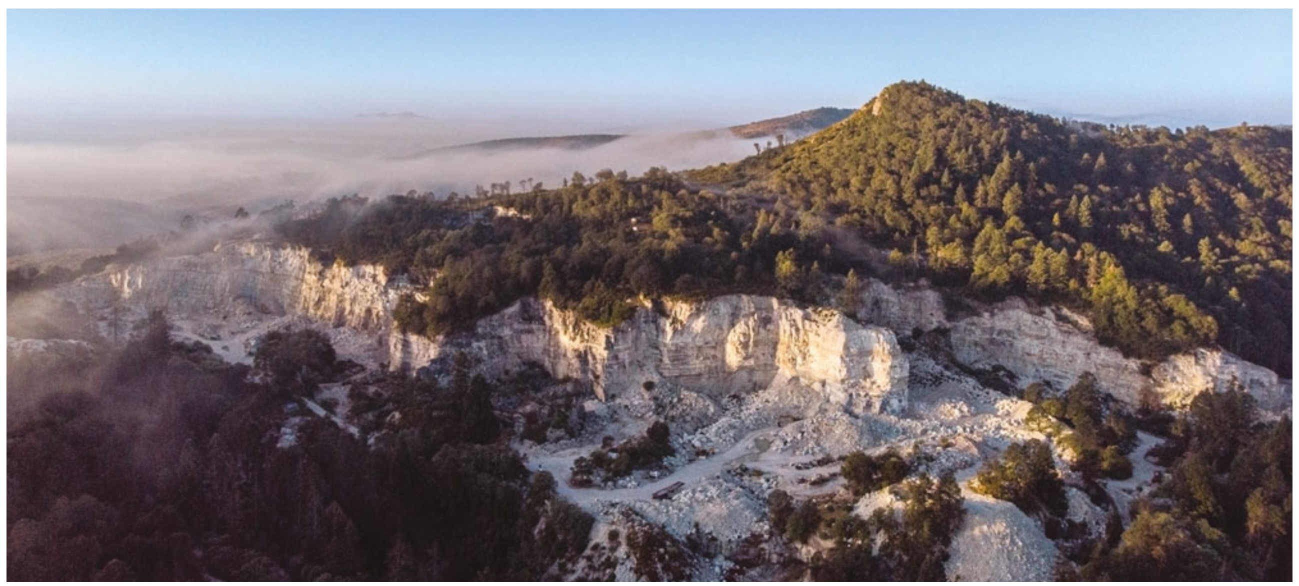
Location and geology

The Tezoantla White Tuff is mostly exploited at a quarry located 1 km to the southeast of Tezoantla and at a similar distance from Santa Rosalía, both villages belonging to Mineral del Monte municipality of the Comarca Minera UGGp.
It occurs at the top of the Sierra de Pachuca range, consisting of Oligocene-Pliocene intermediate and acidic volcanic rocks. Several units are identified: (a) Pachuca Group, mostly of Oligocene age and andesitic; on whose top, of Miocene age, lie the (b) Vizcaína, Cerezo, Tezoantla and Zumate formations, ranging between rhyolitic and dacitic; and (c) rhyolite domes with obsidian and pumice, of Pliocene age.
This stone is assigned to the Miocene interval of the Pachuca Group; in particular, to the Tezoantla Formation. Conspicuous low-temperature hydrothermal alteration sets apart it from the other units of the Pachuca Group.



Quarries

In the study area there are six quarries, the main of which is found at coordinates 20°06'54.61"N / 98°3820.87"W (elevation: 2914 m asl), covering an area of about ~80 ha. Industrial exploitation —albeit by artisanal methods— of this stone began in the late 19th century by the arrival of miners, technicians and capitals from Cornwall, Great Britain; however, this stone had already been quarried and locally used since the beginning of New Spain's colonization (16th century).
Nowadays the exploitation is undertaken with gunpowder, backhoes and hand tools like hammer, wedge and bar.



At an elevation higher than 2900 m above sea level, the main quarry of Tezoantla is shown in an aerial image in a foggy winter morning.
Photo: Daniel Acosta

Architectural and cultural impact

Due to its aesthetic value (appreciated for its resemblance to marble) and physical properties (suitable for carving), this volcanic stone has been used as building and sculpture material in monuments of eclectic and Neoclassical styles of Hidalgo and the historic center of Mexico City (19th to early 20th centuries).
In addition, it has been widely used in vernacular architecture and in industrial constructions that are part of the outstanding mining heritage of the Comarca Minera UGGp, with Cornish engine houses (19th century) standing out.
Heritage buildings play an important role in Mexico's collective memory and cultural identity. In this regard, Tezoantla White Tuff is of great cultural significance because it has been extensively used in vernacular architecture (particularly in manor houses), in mining constructions (engine houses), and for religious and civil buildings, including some iconic monuments. Particularly, in the Comarca Minera UGGp there are three Pueblos Mágicos ('Magical Towns', namely: Mineral del Chico, Mineral del Monte and Huasca de Ocampo), a celebrated label given by the Tourism Secretariat of Mexico. In these three towns the Tezoantla White Tuff is widespread, being an integral part of the local identity.
In Mineral del Monte, there is the famous cemetery Panteón Inglés (English Cemetery), a relevant English legacy in Mexico. Its origin dates back to the 19th century, when entrepreneurs and workers arrived in what was once the world's most productive silver mining district. Many gravestones and sculptures found here were made out of Tezoantla White Tuff.
Stonemasonry is deeply-rooted in various communities scattered throughout the state of Hidalgo. Highly-skilled quarrymen work not only in Tezoantla, but also in the western part of the state.

Reloj Monumental (Clock Tower, built in 1910), the most renowned monument of Pachuca de Soto, the Hidalgo state capital.
This Neoclassical monument was inaugurated in 1910 to commemorate the centennial of Mexico's independence.
Photo: Daniel Acosta

Main reference

González-León, L.I., Canet, C., Lozada-Amador et al. (2023): Tezoantla Tuff («Cantera de Tezoantla», Hidalgo state): the first Mexican "Heritage Stone". Episodes (https://doi.org/10.18814/epiiugs/2023/023016)

TEZONTLE OF THE BASIN OF ANÁHUAC

Mexico

Pyramid of the Moon (Pirámide de la Luna) in the Mesoamerican city of Teotihuacan, State of Mexico, today an archaeological site registered in the UNESCO World Heritage List. Tezontle is found throughout the structure of the pyramid, in which blocks of mainly tezontle and basalt are combined.
Photo: S. Domínguez

Volcanic Scoria

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María Guadalupe Dávalos Elizondo
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Used in construction for at least 20 centuries, tezontle can be considered the most representative building stone of Mexico. Its earliest use dates back to 1st-7th centuries, a long period during which was built the holy city of Teotihuacan, inscribed in the World Heritage List (WHL) since 1987. Centuries after the fall of Teotihuacan (14th century), tezontle was used massively for the construction of temples in the island-city of Tenochtitlan.

After the conquest of Mexico, tezontle continued to be used in the colonial, Baroque-style buildings, especially during 17th and 18th centuries. Many of these buildings are within the area of Mexico City inscribed on the WHL.

The most recent use of tezontle in a WHL site can be seen in some architectural elements of the Central Campus of the Universidad Nacional Autónoma de México, built between 1950 and 1952.

Close-up of a façade showing the chromatic diversity of tezontle.
Photo: J. Miros

Petrography
Basaltic to basaltic-andesitic volcanic scoria

Geological setting
Cenozoic – Pleistocene; eastern sector of the Trans-Mexican Volcanic Belt

Occurrence
Basin of Anáhuac – Hidalgo, State of Mexico and Mexico City

Petrography

«Tezontle» is the name given in Mexico to basaltic to basaltic-andesitic volcanic scoria, i.e. glassy, highly vesicular solidified mafic (to intermediate) lavas, formed from explosive Strombolian eruptions, usually occurring in cinder cones —also known as 'scoria cones'.

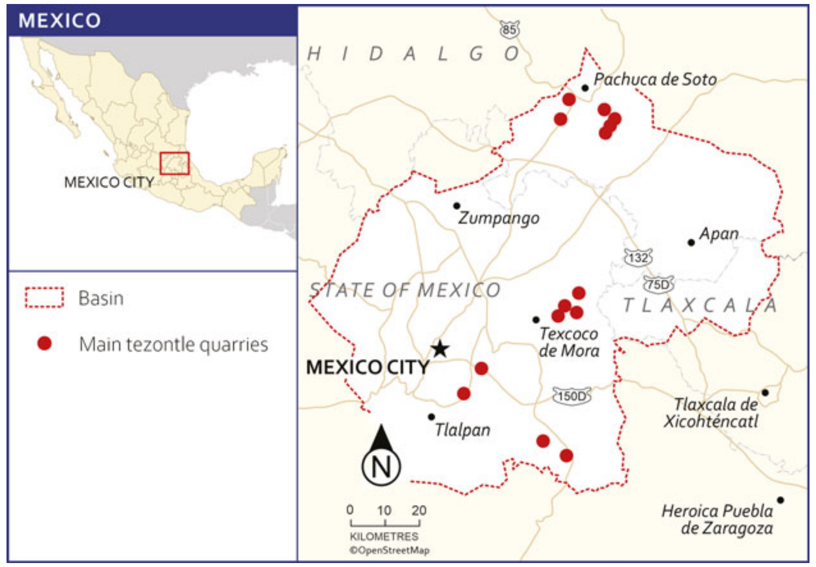
Under the petrographic microscope, tezontle shows typical porphyritic textures, with phenocrysts (less than 20% modal) within a glassy groundmass.

Phenocrysts, mostly of plagioclase and pyroxenes (ortho- and clinopyroxene), are up to 3 mm across and usually occur randomly oriented.

Iron oxides are abundant, conferring the characteristic reddish coloration that is observed macroscopically.

Location and geology

Tezontle is found in all monogenetic volcanic fields throughout Mexico. It has been exploited from the numerous cinder cones that dot the former lacustrine Basin of Anáhuac.
This basin, once the heart of Mesoamerica, is today the most populated area of the country, with ~22 million inhabitants.
It is a highland (2200 m) depression of the eastern sector of the Trans-Mexican Volcanic Belt, a Neogene continental arc that runs through central Mexico.
In addition to massive stratovolcanoes and calderas, there are a huge number of cinder cones. In the Basin of Anáhuac, these small, short-lived volcanoes are about 2 Ma to 1700 yr in age.
The Basin of Anáhuac was closed (becoming endorheic) during the Pleistocene, as a result of the volcanic activity whose products (andesites) blocked the fluvial drainage.
Until the conquest of Mexico, it hosted a large brackish lake known as Lake Texcoco.



Map or the Basin of Anáhuac, a large lacustrine and volcanic basin in the central highlands of Mexico. Very characteristic of the built cultural heritage of this area is tezontle, whose source can be found at the numerous monogenetic volcanoes (cinder cones) scattered throughout the basin.
The Basin of Anáhuac includes Mexico City in its whole and extends over parts of three neighboring states (State of Mexico, Hidalgo, and Tlaxcala), encompassing the Metropolitan Area of the Valley of Mexico.

Quarries

In the Basin of Anáhuac tezontle has been exploited since time immemorial, so the total number of quarries is difficult to determine.
There are declared active tezontle quarries towards the north of the basin (municipalities of Pachuca de Soto, Mineral de la Reforma, and Epazoyucan, in Hidalgo) and to the southeast of the basin (municipalities of Chalco and Tlalmanalco, State of Mexico).
Additionally, about 150 quarries operated during the previous decade in the east of the State of Mexico, particularly in the municipalities of Tezoyuca, Papalotla, Tepetlaoxtoc, and Texcoco, to satiate the huge demand of raw material for the runway pavements.
As for Mexico City, many former quarries are well-known conspicuous elements of today's urban landscape; many of them are mentioned in chronicles and technical documents of the 16th and 17th centuries.

Panoramic views of the Yuhualixqui volcano (~2400 m asl at the top; 19°18'57.9"N / 99°3'9.8"W), currently a mine of tezontle producing construction aggregate in southeast Mexico City.

Architectural and cultural impact

The widespread utilization of tezontle in the Basin of Anáhuac is not only because it was the most readily available and easy-to-extract stone in the area; beyond that, its constructive properties made it suitable to build on the unfavorable, sinking ground of the lacustrine basin.
In particular, its lightness (low density) was an advantage from a constructive point of view since it did not add excessive load. Due to its unique properties, tezontle was considered a gift of providence.
As recorded in technical documents of the late 18th century, tezontle was called «divino material» (divine material), an epithet that stems from its mystical character and at the same time points to how highly valued this stone was among the architects of the time.
On the other hand, tezontle was widely used for decorative purposes. Because it is a porous and fragile material, tezontle is in principle not suitable for elaborate carving; however, in pre-Columbian times this stone was worked with mastery so that innumerable sculptures and magical-religious pieces of particular beauty were elaborated.
The esteem of tezontle for its reddish color and rough appearance transcended the conquest of Mexico. Hence, it was also widely used in colonial buildings as façade cladding for embellishment.
The careful combination of reddish-dark tezontle and clear tuffs in Baroque architecture —seeking of an effect of contrast between both stones— provides a particular aesthetic to the historic districts of Mexico City.
In fact, the special appearance of this stone, so different from the stones used in European capitals, is seen as unique and provides identity to Mexico City.
The rare beauty of tezontle, whose color is for many an allegory of blood, is part of the modern imaginary of Mexico City.

Choir vault built with tezontle to achieve a weight-reducing effect- a constructive innovation of the 17th century in Novo-Hispanic architecture-.
The ornaments on the cusp are carved in clear tuff. Example from the Baroque-style San Lorenzo Mártir temple, Mexico City.

Main reference

Rodríguez Morales, L. (2011): La práctica constructiva en la ciudad de México. El caso del tezontle, siglos XVIII-XIX. Boletín de Monumentos Históricos (22), 155–178. https://revistas.inah.gob.mx/index.php/boletinmonumentos/article/view/2168

TSUKUBA MASSIF GRANITE

Japan

State Guest House Akasaka Palace; Tokyo

The foundation of Modern Japanese architecture

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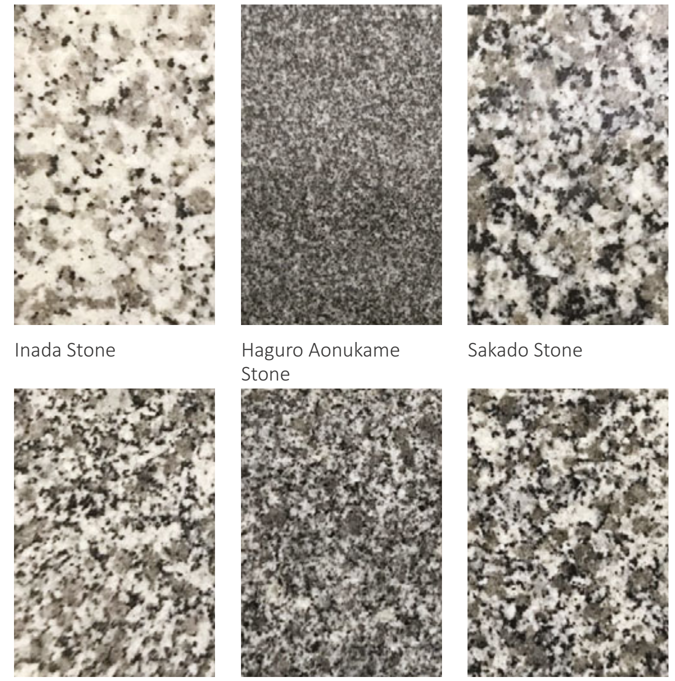
The granite of the Tsukuba Massif, consisting of Inada Granite in the north, Kabasan Granite in the northwest, and Tsukuba Granite in the south, was formed from the Late Cretaceous to the Paleogene.
The large and unusual rocks of the Tsukuba Massif have been protected by local people since ancient times as a place of mountain worship. In the 13th century, stone Buddhas and Gorinto (five-ring pagodas) began to be made using these granites.
With the modernization of Japan around the turn of the 20th century, Inada and Kabasan Granites were transported by rail to Tokyo as the high-quality and abundant Inada and Makabe Stones. These stones were used in many representative stone buildings of Japan, such as the State Guest House Akasaka Palace, Nihonbashi Bridge, and the Bank of Japan.



Inada Stone; Haguro Aonukame Stone; Sakado Stone
Yasato Mikage Stone; Makabe Stone (Kome); Makabe Stone (Chūme)

Varieties (presented by Haguro Stone Industry Cooperative Federation)

Petrography
Granite, biotite granite to granodiorite

Geological setting
Late Cretaceous – Early Paleogene

Occurrence
Tsukuba Massif in central and southern Ibaraki Prefecture, North of Tokyo, Japan

Petrography

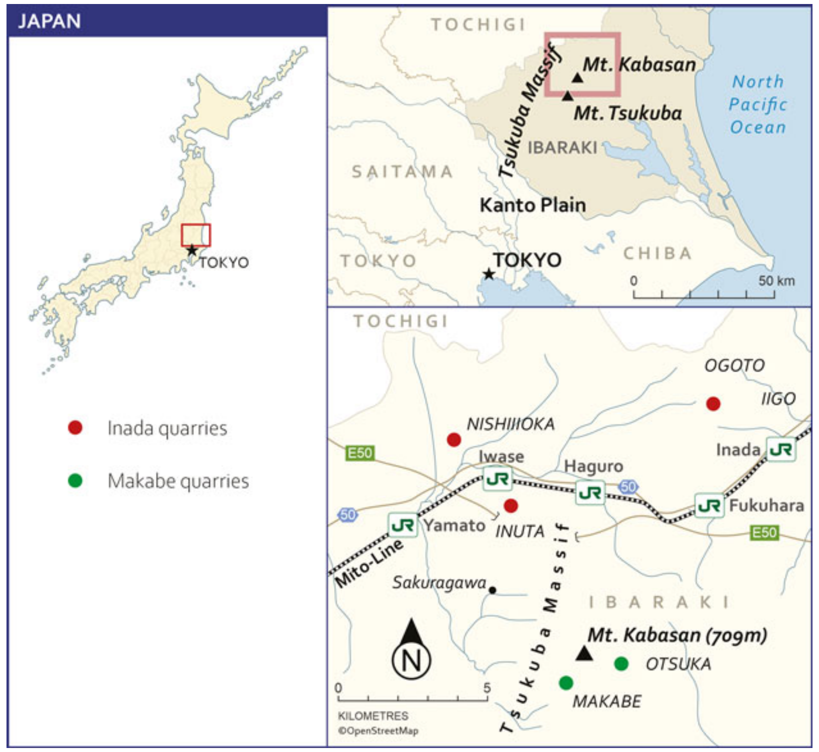
There are several varieties of Tsukuba Massif Granite, which may differ in petrography.

Inada Granite (Inada Stone) consists of:
1) Coarse-grained hornblende-bearing biotite granite
2) Medium-grained hornblende biotite granodiorite
3) Fine-grained muscovite biotite granodiorite

Kabasan Granite (Makabe Stone) consists of:
1) Medium-grained biotite granite
2) Fine-grained muscovite-bearing biotite granite
3) Leucocratic fine-grained garnet-bearing muscovite biotite granite
4) Very fine-grained biotite granodiorite

Tsukuba Granite consists of:
1) Porphyritic biotite granodiorite
2) Foliated biotite tonalite
3) Muscovite biotite granite
4) Fine-grained granites

Location and geology



The Tsukuba Massif in central and southern Ibaraki Prefecture harbors granites from the Late Cretaceous to early Paleogene. These are mainly classified into Inada, Kabasan, and Tsukuba Granites based on their intrusive patterns, characteristics, and relations to metamorphic parent rocks. Inada Granite, yielding Inada Stone, consists of coarse-grained hornblende biotite granite, spreading in the north from Iwase to Haguro and Inada, formed between 63Ma-59Ma.

Kabasan Granite, from around Mt. Kabasan in the northwest, produces Makabe Stone, which is mainly medium-grained biotite granite or fine-grained biotite-containing muscovite granite with an age of 77Ma-58Ma. Tsukuba Granite, characterized by spotted biotite granite diorite, is found in the south towards Mt. Tsukuba, aged 63Ma-53Ma.

Quarries

Currently operating granite quarries in the Tsukuba Massif include 10 locations mining Inada Stone (Inada Granite) and 14 locations mining Makabe Stone (Kabasan Granite), totaling 24 sites. These granite bodies commonly develop three directions of joint systems and sheeting joints.

In the past, quarrying methods utilized these joints to break the stone into smaller pieces. Later, techniques such as rock drilling, rock blasting, and directly cutting the rock with jet burners became common. Recently, mining with diamond wire saws has also been adopted. The vast rock surfaces created by carving out Inada Stone have come to be locally called the Stone Cutting Mountain Range (Ishikiri Sanmyaku).

Inada Ishikiri Sanmyaku Quarry, Kasama, Ibaraki

Architectural and cultural impact

Inada Stone, also known as Inada Shiromikage Stone, is characterized by its large and uniform particle size of constituent minerals, including abundant quartz and feldspar, which give it a distinctively beautiful and durable white appearance.

Additionally, the appearance of the stone can be varied through different processing techniques such as polishing and heating. Among Inada Stones, those with a bluer hue are marketed as Sakado Stone, while those with finer particle sizes are known as Haguro Aonukame Stone. On the other hand, Makabe Stone, mined in the northwestern part of the Tsukuba Massif, is known by various names based on its characteristics and origin, such as Hitachi Komikage Stone, Yasato Mikage Stone, and Taki Stone. Compared to Inada Stone, it has a pale blue hue and is easier to shape due to its smaller mineral particle size. Since the Meiji era, when Western culture entered Japan, these stones have been widely used in the construction of stone buildings such as the Bank of Japan and the State Guest House Akasaka Palace, as well as for paving around the National Diet Building and Tokyo Station, and for bridges like Nihonbashi Bridge and tramway tracks. These stones remain popular nationwide as materials for gravestones and monuments. Makabe Stone, being easily carved, has been used since the Kamakura period for making stone Buddhas, gorinto (five-ring pagodas), and lanterns. Especially Makabe Stone Lanterns, which originated in the Edo period, have been officially designated as a Traditional Japanese Craft.

Graves of the Makabe Clan ((gorinto five-ring pagodas)

Main references

Takahashi, Y., Miyazaki, K. and Nishioka, Y. (2011) Plutonic Rocks and Metamorphic Rocks in the Mount Tsukuba. Journal of the Geological Society of Japan, Vol. 117(Supplement), 21-31.; https://www.jstage.jst.go.jp/article/geosoc/117/Supplement/117_117.S21/_pdf

Inui, M. (2012) Inada-granite and other granitic building stone quarries in Japan. Journal of Science and Engineering, Transactions of the Kokushikan University science and engineering, no. 5, 74-80.; https://kokushikan.repo.nii.ac.jp/record/5452/files/1882_4013_005_06.pdf;

Kawamata, M. (2017) Development of Ibaraki Prefecture's Granite Stone Industry in the Meiji Era: Focused on Sakuragawa City and Kasama City. Ibaraki Prefecture Modern History Research, 40-53.

Wang, J.Y., Santosh, M., Tsunogae, T., Kim, S.W., Dong, Y.P., (2022). Arc building through bimodal magmatism: The Tsukuba Igneous Complex, Japan, and its correlations and connections. International Geology Review, 64(16), 2339-2358.

VIROLAHTI PYTERLITE

Finland

The Pro Patria monument, Valkeala, Finland (2007). Photo: Paavo Härmä

Finnish red rapakivi granite used in historic and modern architecture

Paavo Härmä
Olavi Selonen

The construction of the old historic city of St. Petersburg in Russia, which is one of UNESCO World Heritage Sites, has mainly been built from Virolahti pyterlite as no hard rocks were available in the near vicinity. The large-scale extraction of Virolahti pyterlite started during the late 1700s.
The total amount of stone exported from the Virolahti area was over one million m^3.
Virolahti pyterlite has been used in several remarkable objects of the historic St. Petersburg and in the applications as: foundations and stairs of buildings, embankments, walls, bridges and railings of rivers, paving of streets, fortress structures and decorative stones. Nowadays, Virolahti pyterlite can be quarried from eleven quarry areas and is known by the commercial name Carmen Red.

Virolahti pyterlite as a polished slab.
Photo: Geological Survey of Finland

Virolahti pyterlite in an outcrop with round K-feldspar megacrysts (ovoids) measure 1-3 cm in diameter but lack a plagioclase rim.
Photo: Paavo Härmä

Petrography
Rapakivi granite, pyterlite

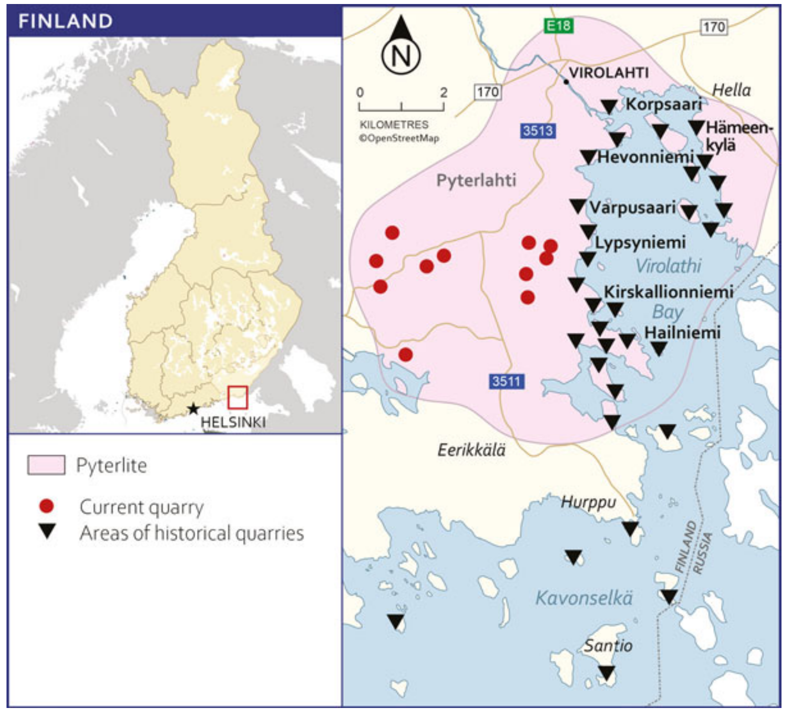
Geological setting
Mesoproterozoic (around 1.634 Mrd years);
Wiborg rapakivi batholith

Occurrence
Around Virolahti Bay, SE Finland.

Petrography

The formal technical petrographic name of the rock is syenogranite. According to the texture and mineral composition, the name is rapakivi granite (pyterlite).
The traditional rapakivi texture comprises large round K-feldspar megacrysts (ovoids) surrounded by a plagioclase mantle and this rock type is named “wiborgite”. The rapakivi granite type in which the K-feldspar ovoids lack a plagioclase rim is called “pyterlite”. The colour of the fresh surface of Virolahti pyterlite is red. The large K-feldspar megacrysts are surrounded by mineral grains of quartz and plagioclase which size is less than 10 mm. The main minerals of Virolahti pyterlite are quartz, K-feldspar, plagioclase and biotite. The texture of Virolahti pyterlite is homogeneous and the rock itself is massive without orientation.

Location and geology



The Finnish rapakivi granites occur as four major batholiths (Wiborg, Laitila, Vehmaa and Åland) in southern Finland.
The Wiborg rapakivi granite batholith occupies an area of approximately 18 000 km^2 in southeastern Finland (Härmä 2020).
Virolahti pyterlite forms a distinct intrusion around Virolahti Bay in the southeastern part of the Wiborg batholith, having a size of 67.6 km^2.
The age of the Virolahti pyterlite is 1634.5 ± 3.0 Ma defined from the ovoid. The historical quarries for Virolahti pyterlite are located both on the islands and along the coastline of Virolahti Bay in the Gulf of Finland.
Altogether 126 historical quarry sites have been identified around the Bay.

Quarries

The size of the 126 historical quarries around the Virolahti Bay in southeastern Finland varies from 21 to 52 000 m^2.
The quarries with the largest surface area are located in Hämeenkylä, Korpisaari, Hevonniemi (Huvisaari), Lypsyniemi, Kirskallionniemi and Hailniemi.
The number and size of the quarries decrease towards the south and towards the contacts of the pyterlite intrusion.
Therefore, homogeneous red pyterlite was probably the main target in old quarrying and the selection based on quality was carried out. Today, the pyterlite can be quarried from eleven licenced quarry areas in the Virolahti area and they are situated in the same pyterlite intrusion as the historical ones but located further west around the villages of Pyterlahti and Ala-Pihlaja.

The historical Hevonniemi quarry for Virolahti pyterlite, which the famous column of Alexander I was extracted from. Photo: Paavo Härmä

Architectural and cultural impact

Virolahti pyterlite has been used in several significant objects in historical St. Petersburg, as embankments buildings and monuments.
Examples of the objects: The Alexander Column consists of the tallest monolith in the world of Virolahti pyterlite extracted from the Hevonniemi quarry. In the St. Isaac's Cathedral, the pyterlite has been applied as 112 monolithic columns in the building.
Other examples: The walls of the Spit (Strelka) at the eastern end of Vasilyevsky Island, the Stock Exchange House, Academy of Arts, the Peter and Paul Fortress, the Marble Palace building, Kazan Cathedral, the St. Petersburg Academy of Sciences, the buildings for the Senate and Synod, the House of Laval, the Narva Triumphal Arch and the monument to Emperor Nicholas I.
In modern time, Virolahti pyterlite (Carmen Red) has been applied in Europe and the USA, as well as in countries of the Far East, mostly in the façade of buildings. Examples of objects: The Central Daily Newspaper Building, in Seoul, Korea and the Travellers Express Tower in St. Louis Park, Minnesota, USA.
Examples in Germany: The Lurgi House in Frankfurt-am-Main, the Landesarbeitsamt Saarbrücken in Saarbrücken and the Goethe University in Frankfurt.
In Norway: The Kaibygg 1 building, Aker Brygge in Oslo.
In Finland: the SYP Bank building in Oulu and the Pro Patria monument in Valkeala.
The importance of the Virolahti pyterlite quarries to the economy of the region was very large. The quarries annually brought in tens of thousands of roubles to the Virolahti region.
The stone production defined prosperity, because it employed personnel in extractive operations and complementary services such as transportation, accommodation, catering, maintenance, health and education services.
The population of the Virolahti area doubled and reached 10 000 inhabitants in 1887.

The monolith and the pedestal of Alexander Column (1829–1834) are made of Virolahti pyterlite. Photo: Paavo Härmä.

Main references

Bulakh, A.G., Abakumova, N.B., and Romanovsky, J.V. 2010. St Petersburg – A History in Stone. University Press, St Petersburg, Russia, 173 p.;

Härmä, P. 2020. Natural stone exploration in the classic Wiborg rapakivi granite batholith of southeastern Finland – new insights from integration of lithological, geophysical and structural data. Monograph: Academic dissertation. Geological Survey of Finland, Bulletin 411, 90 p. https://doi.org/10.30440/bt411;

Härmä, P. and Selonen, O. 2024. Red pyterlite from Virolahti in southeastern Finland: a unique heritage stone with a classic rapakivi texture applied in historic and modern architecture. Episodes 47 (1), 53–64. https://doi.org/10.18814/epiiugs/2023/023021

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" An IUGS Heritage Stone is an IUGS designated natural stone that has been used in significant architecture and monuments, recognized as integral aspects of human culture."

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