Global Heritage Stone Resource: An Update

Preface

Guest Editors

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This issue of *Episodes* is a special issue dedicated to heritage stone; those stones that have special significance in human culture. Examples include some very important natural stones that have been either neglected because they are no longer extracted, or rock types that have great significance in commercial terms, but where knowledge on their international heritage is not well documented. The Heritage Stone Task Group (an IUGS Task Group) has the role to establish a new formal geological designation: the "Global Heritage Stone Resource" where a natural stone has special international significance.

The objective of this collection of papers is neither to emphasize the specific geological characteristics of the rocks with heritage attributes, or to recommend (or ban) their use for new construction. Our aim is to spread awareness of architectonic heritage and the natural stones that have been utilised. Accompanying this enhanced appreciation is the need to preserve the historical quarries that once provided the source for such stone. These quarries are linked to regional culture and local society, yet so often today, as a consequence of modern transportation, improved infrastructure, or even globalization related to imports and exports of exotic dimension stones, they lie idle. Nevertheless, due to the specific technical and aesthetical characteristics of such heritage stones, these historical quarries should be preserved and used, sometimes with restrictions, in case of the restoration of monuments and historical buildings in order to avoid the disastrous actions that have been observed in some restorations even in World Heritage Cities.

This special issue comprises papers that have been sourced from presentations to a session on Heritage Stone that was held as part of the General Assembly of European Geosciences Union, held in Vienna in April 2014, and supplemented with contributions from other authors who are enthusiastic about this concept. This issue also complements a newly issued Special Publication of Geological Society of London entitled "Global Heritage Stone: Towards international recognition of building and ornamental stones". It is our hope to provide further contributions on this subject in future issues of *Episodes*.

The Editors of this issue greatly appreciate the work of the authors and reviewers as well as IUGS support for the ongoing work of the Heritage Stone Task Group.

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The Dala (Älvdalen) porphyries from Sweden

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(Received September 1, 2014; Revised accepted October 22, 2014)

The commercial stone industry in Älvdalen, northwest of Stockholm, started in the second half of the 18th century as a social need. The region had been plagued by severe famine and there was an urgent need for additional wealth-generating industry. At that time it was already known that the porphyry in the area was similar to the "porfido rosso antico" from Egypt which had played an important role in the Roman culture. Many ups and downs followed. During one period in the 19th century, the Swedish Royal family owned the industry. At the same time, several "porphyry" objects were presented to different courts around Europe (e.g. a 4 metre tall vase to the Russian czar, although of a more granitic variety). Otherwise most products have been smaller objects like urns, vases, candelabras, etc. The very hard Stone (with variable red or black colours) can be highly polished.

Many of the porphyry varieties were sourced from glacial boulders. These had been "mechanically tested" by nature and were free from joints which otherwise was a problem in the associated quarries.

Comagmatic granites also occur. The porphyries and granites have an age around 1700 Ma, and the former are amazingly well preserved with magnificent volcanic textures.

The porphyries and granites occupy a vast area and are in part covered with red, continental sandstones, which are quarried to-day.

In the middle of the 20th century, the ignimbritic character of the porphyry was discovered. Previously, the flattened "fiamme" (collapsed pumice) had been interpreted as some kind of flow structure in lava. The porphyry manufacturing plants in Älvdalen are a part of the Swedish industrial history. Over a significant historical period the porphyry-works produced good handicrafts that catered for the poor as well as providing items of extravagant luxury.

Today a porphyry museum exists in Älvdalen. A few handicraft workers are active, and the abandoned old porphyry plants are open to visitors.

Introduction

The commercial stone industry in Älvdalen, about 350 km northwest of Stockholm, commenced in the second half of the 18th century as a consequence of social need. A severe climate, in addition to an increasing population, produced great strain on society. The region had been plagued by severe famine. When crops failed, people were starving and many died. There was an urgent need for additional wealth-generating industry.

At that time it was already known that the porphyry in the area was similar to the "porfido rosso antico" from Egypt that had played an important role in the culture of ancient Rome where porphyry was a symbol of power. Later, during the Renaissance, a renewed interest in the material took place and many old objects were reused. The shortage of good quality porphyry led to the idea that the porphyries in the region of Älvdalen were a valuable natural resource. Some Swedish 18th century scientists like Linneus, Cronstedt and Gahn, honoured later with the mineral names linnaeite, cronstedtite and gahnite, were involved in the investigations prior to establishment of the industry. Private entrepreneurs, with support from the King, ultimately launched an industry in 1788. King Gustaf III made a journey to Italy in 1783 where he visited the stone industry in Florence. Most likely this visit inspired him to support the establishment of porphyry manufacturing operations.

History of porphyry

The word "porphyry" derives from the Greek πορφυριος and means "purple". In ancient times the stone was much sought after. The oldest porphyry quarries were to be found in Egypt near the Red Sea (Maxfield and Peacock, 2001). Cleopatra of Egypt, the Emperor of Rome, the Popes of the Middle Ages, the Medici of Florence, Cardinals Richelieu and Mazarin, Napoleon and many more famous figures surrounded themselves with beautiful objects made of porphyry, where the colour of the material, purple, would give an extra stress to mark the importance of the owner. The traditional royal colour used to be blue, but Cleopatra changed the symbolic colour to red and had the walls of her banqueting hall in Alexandria adorned in porphyry. Roman Emperors continued the use of the red stone. Bathtubs of porphyry were popular. In the Eastern Roman (Byzantine) Empire the material was especially used to mark the importance of the Emperor. In the palace of Constantinople a special childbirth delivery-room was designed for the Empress where the walls and floors were covered in porphyry. A prince born in this room was bestowed with the extra title “born to the purple”.

The ancient mining of porphyry was concentrated on the Egyptian quarries, active from 20AD to 400AD. During the Middle Ages, the importation of porphyry to Europe was discontinued and alternatives had to be found leading to reuse of the existing material. Since the fashion was to bury ecclesiastical princes in sarcophagi of porphyry, a great number of Roman bathtubs were rebuilt and elevated to the new status of papal sarcophagi. The King of the Ostrogoths, Theodoric the Great, was also entombed in a porphyry bathtub. There are occurrences of porphyry in several places in Western Europe, but in the Älvdalen area in Sweden the porphyries display an unusually great variation in colour, texture, phenocryst size and content, which makes them favourable for use as ornamental stone.

The Swedish porphyry occurrences were discovered in the 1730s by a vicar in Älvdalen, but half a century was to pass before the working of porphyry objects was in progress. The Swedish counsellor of the realm formed, together with ten other men, a company for the working of porphyry. A huge grinding house (Figure 1), driven by waterpower, was constructed in 1796-97. It greatly facilitated the subsequent production. The first foreign agent was established in Hamburg, Germany, but it was soon followed by representatives in London, Paris and Vienna. A catalogue from Paris, 1805, (Sundblom et al, 1985) shows a variety of objects for sale. In France, there was also cooperation with skilful workers for bronze decorations. In

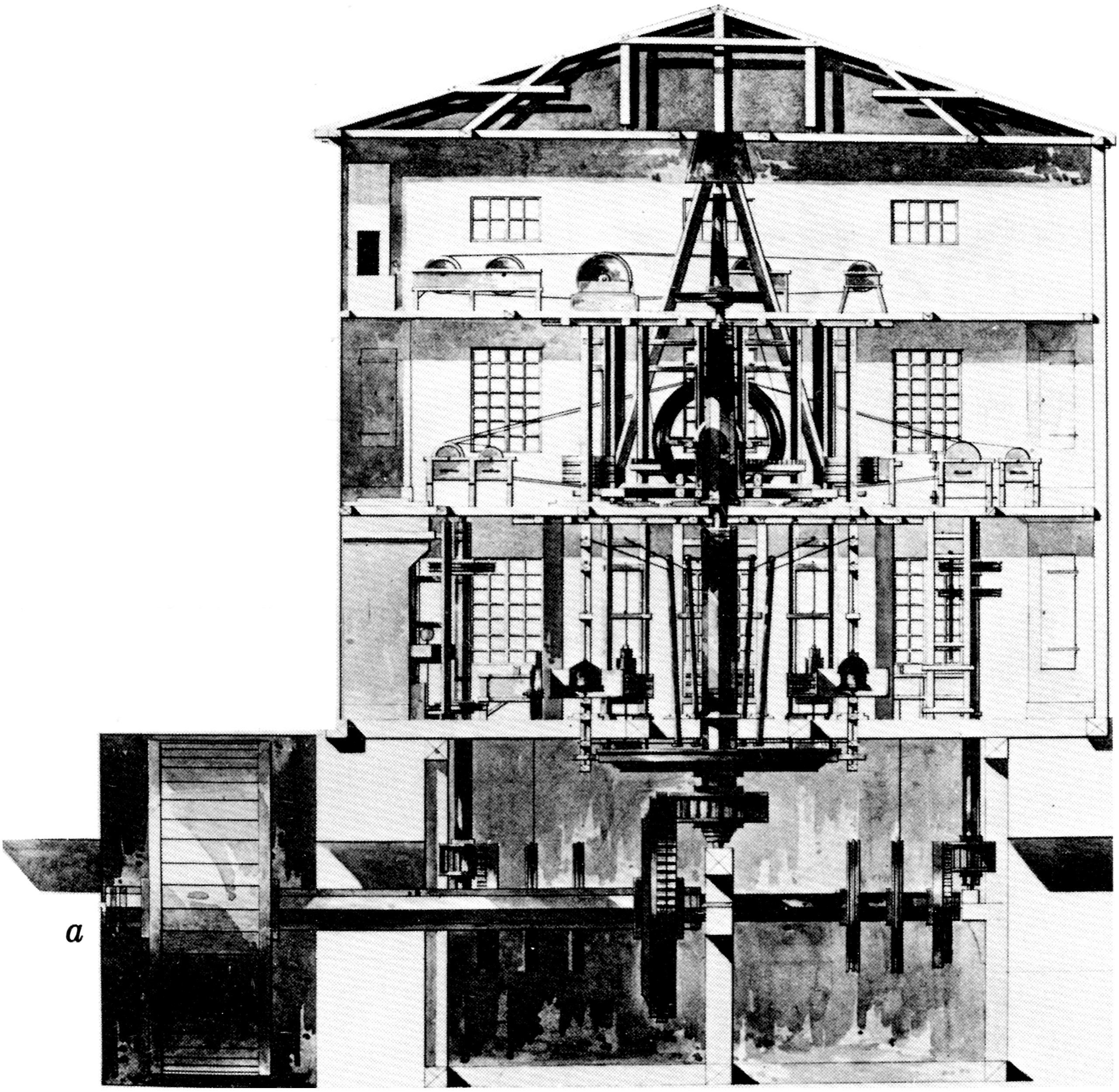


Figure 1. Sketch of the porphyry grinding house, built 1796-97, driven by water power. Destroyed by fire in 1867 (Lagerqvist and Åberg, 1984).

general, France was a good market, and Swedish porphyry objects can still be seen in French museums and homes.

Economic fluctuations were a feature of the porphyry enterprise. At the beginning of the 19th century, Napoleon´s general Bernadotte became King of Sweden under the name Karl XIV Johan. The Swedish Royal family owned the porphyry-works between 1818 and 1856 and it used porphyry items as gifts to various international luminaries. During this period, Sweden was economically poor and roads, bridges etc., were of inferior quality. Thus transportation of the larger manufactured porphyry objects created major challenges (see below).

Even though the Napoleonic wars curtailed activities between Sweden and France, the porphyry business soon recommenced after the wars. Much later in 1867, a severe fire destroyed the major grinding house and resulted in closure of the initial industrial enterprise. Soon after, it was reopened but never recovered its initial capacity.

Today a porphyry museum has been established in Älvdalen. A few handicraft workers are active, and the abandoned porphyry manufacturing plants are open to visitors. (http://www.geonord.org/shows/porph.html)

Geology

Figure 2 shows the location of Dala porphyry production area, where Dala volcanites occupy an area approximately 5000–6000 km^2 in size (Figure 3). These rocks are also present below a cover of continental sandstone (Dala Sandstone) to an unknown extent. They were subdivided into porphyries and porphyrites by Hjelmqvist (1966) where the former are mainly ignimbrites and the latter mainly lavas ranging from basalt to dacite in composition (Nyström 2004). The lavas have had limited interest for the stone industry. The continuation in Norway is known as the ”Trysil porphyries” (Wolff *et al*., 1995).

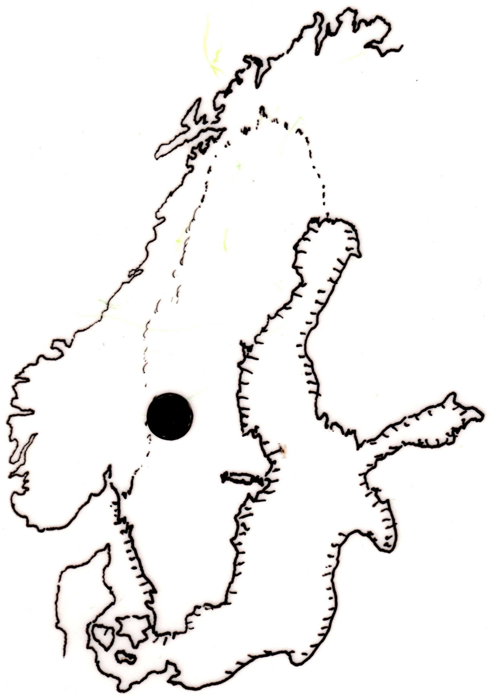


Figure 2. Map showing the location of Dala Porphyry production area.

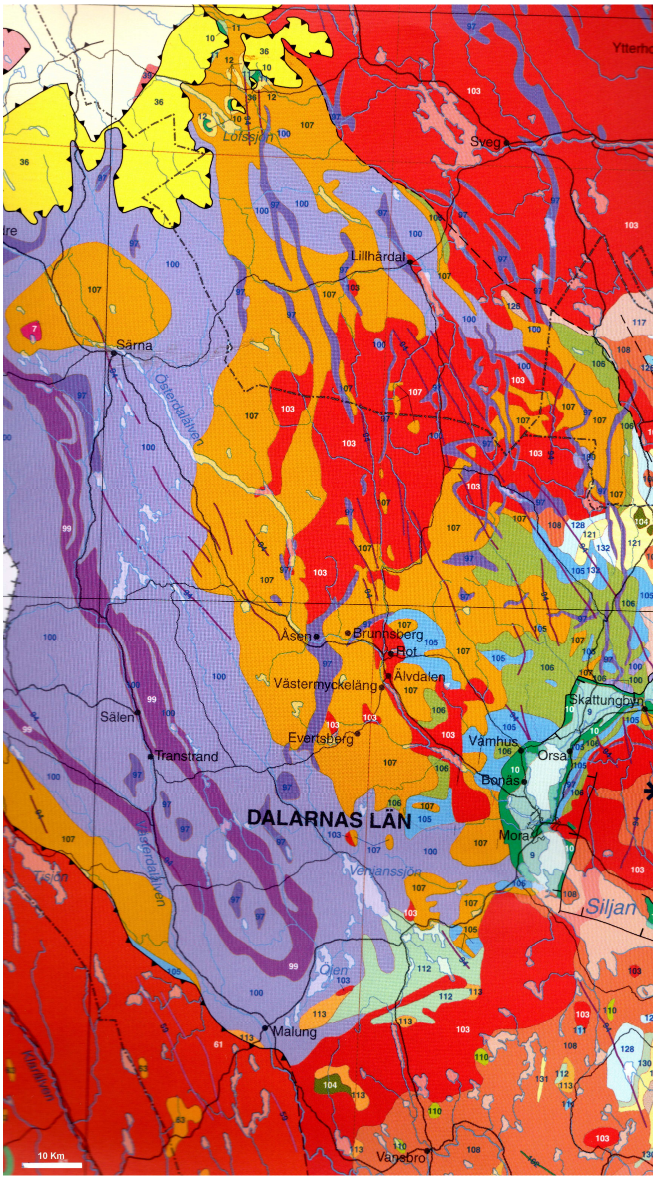


Figure 3. Bedrock map (Bergman et al. 2014). The porphyries are shown with dark yellow colour, the covering continental sandstones in pale violet colour, dolerites in dark violet, and granites in red.

In Sweden “porphyry” is the traditional rock name for well preserved (very low or low grade) felsic, porphyritic volcanic rocks and some dike rocks occurring at Älvdalen and other parts of the country. This name has earlier been widely used by geologists, but it is now often replaced by “rhyolite”, “trachyte” etc., according to modern international rules. However, since the name “porphyry” (*porfyr* in Swedish) is deeply rooted in common language in Sweden, largely because of the famous objects made at the porphyry works of Älvdalen, we think it is appropriate to use it in the context of this paper.

The ignimbritic character (Figure 4) of the porphyries was described by Hjelmqvist (1956, 1966, 1982) and Lundqvist (1968), and a general overview was given by Nyström (2004). Some of the porphyries (see for instance the Kåtilla porphyries, Figure 5) are closely associated to high-level granite intrusions and display textural similarities with a porphyritic granite called the Garberg granite. This

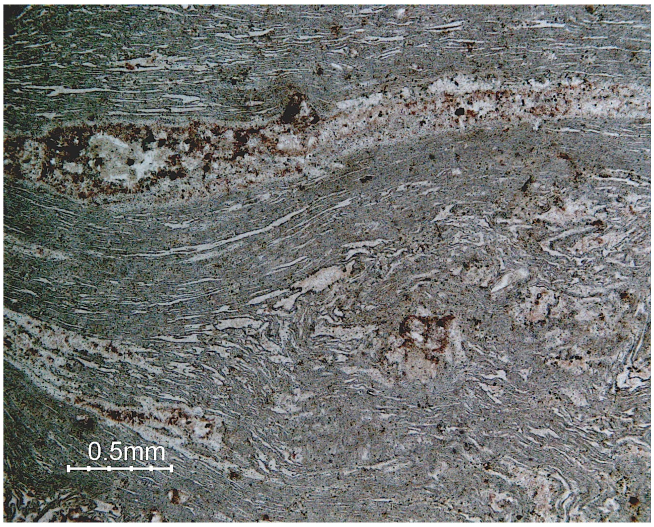


Figure 4: Microphoto of ignimbritic, rhyolitic Dala Porphyry (Rännås Porphyry) showing well preserved glass-shard texture and more coarse-grained ignimbrite flames. Rännåsarna, 12 km north-northeast of Älvdalen. Photo by Thomas Lundqvist.

has been manufactured under the name ”granitell”. The Garberg granite has many chemical similarities with rapakivi granites, including its high content of fluorine (Lundqvist and Persson 1999). Radiometric dating (U–Pb on zircon) of both porphyries and granites (e.g. Garberg granite) results in dates of around 1700 Ma (Lundqvist and Persson (1999). The metamorphic grade decreases from greenschistfacies at the base of the porphyry complex to prehnite-pumpellyite facies near the top. The burial metamorphic pattern indicates that the original thickness of the deposit was several thousand meters (Lundqvist, 1968; Nyström, 2004).

Boulders and blocks of porphyry from this part of Sweden have been glacially transported for long distances due to their hardness. Both in Sweden and Central Europe, they have acted as tracers for ice movements (Hesemann 1936). Glacial boulders of a green tinguaite, with nepheline, cancrinite and aegirine phenocrysts, also attracted the stone workers early and were sometimes considered as “porphyry”. This tinguaite is considerably younger, 280 Ma, than the true porphyries and have been further described by Lundqvist (1997).

Manufactured objects

The Älvdalen porphyries can take a high polish with a special lustre, but to attain this finish there is a need for time consuming handicraft work. As a result, prices have been very high over the years and the objects have been rated in the luxury category.

Although most of the raw materials have been extracted in bedrock quarries, much porphyry was also sourced from glacial boulders. These had been ”mechanically tested” by nature and were free from joints, which otherwise caused problems in the quarries.

Large objects, like the 4 meter tall vase presented by the Swedish King Karl XIV Johan to the Russian Czar and the large sarcophagus for this king, were manufactured from the Garberg granite. This granite is more suitable for large objects because it has a lower frequency of fissures than the porphyries.

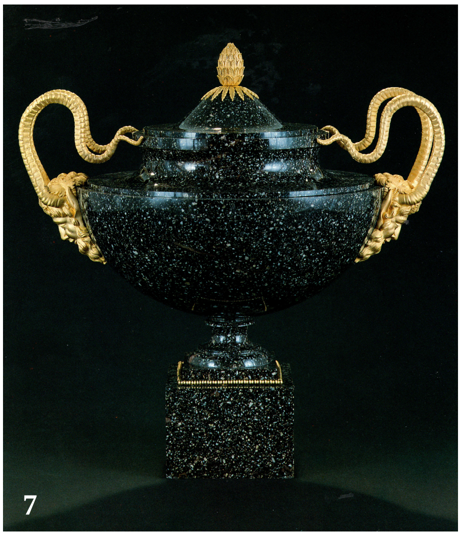
Special products included mosaic tables, often with many different porphyry varieties.

As mentioned above, the Swedish king Karl XIV Johan commenced giving porphyry gifts to prominent persons. The Royal Court continued with this custom, at least until the 1920s when the King of Siam (modern Thailand) was presented with a porphyry vase.

A list of known porphyry gifts noted from published sources, mainly Lagerqvist and Åberg (1989) follows. Large objects, manufactured from ”granitell”, are listed:

- 1838. Four meters tall vase presented to the Russian Czar Nikolaus I, installed in in the garden of the Summer Palace in St. Petersburg.
- Large urn installed outside the small pavilion of Rosendal in Djurgarden in Stockholm (Figure 6).
- Sarcophagus of Karl XIV Johan.
- 1822: two large vases presented to King George IV of the United Kingdom.
- 1837: a large vase presented to King Maximilian of Bavaria.

Figure 5: Different varieties of Swedish porphyries used in industry. From left to right and from top to bottom: Garberg granite, Blyberg porphyry with ignimbritic ”flames”, the most commonly used variety, Rännås porphyry, Kåtilla porphyry, Dysberg porphyry, Kåtilla porphyry, Rämma porphyry and Bredvad porphyry. Photos by J.-O. Svedlund.



Figures 6-8. (6) Large vase made from "granitell" between 1815 and 1825, Rosendal Castle, Stockholm. Photo from Bukowskis auctions. (7) Gilded bronze ornamented Dala Porphyry urn. Photo from Bukowskis auctions. (8) Porphyry memorial in honour to Linneus, inside Uppsala Cathedral. Photo by Björn Schouenborg.

- 1851: a large vase presented to Queen Victoria of the United Kingdom from King Oscar I.
- Unspecified porphyry gift presented to the French monarch.
- A number of urns and memorials (Figures 7 and 8).

Conclusion

Sweden's Dala or Älvdalen porphyries have had major decorative and ornamental significance at an international scale for more than 200 years.

They have been utilised in the most prestigious vases, urns, sarcophagi, mosaic tables and other ornamental works especially as gifts from the Swedish monarchy during the early nineteenth century.

Their historic importance continues to be recognised in Sweden today with the establishment of a porphyry museum in the village of Älvdalen, about 350 km northwest of Stockholm and the maintenance of handicraft manufacture.

Dala or Älvdalen porphyries deserve to be considered as a potential "Global Heritage Stone Resource" from Sweden.

Acknowledgements

We thank Jan-Olov Svedlund for supplying us with photos of different porphyry varieties. We also thank the Bukowskis auction firm in Stockholm for the permission to use two photos from their catalogues. Tom Hendal and Benno Kathol provided useful reviews and comments to improve the manuscript. Björn Schouenborg provided the picture from inside Uppsala cathedral. Project 18KBGZ/463AC01, from the University of Salamanca, and ERASMUS Intensive Programme 2012-1-ES1-ERA10-54375 are acknowledged for financial support. This is a contribution of the HSTG.

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Anders Wikstrom was born in 1937, studied at Uppsala University Sweden, (fil.kand. 1961 in mathematics, chemistry and geology, fil.lic. 1968 in mineralogy and petrology, thesis dealing with retrograde reactions in eclogites). Student at Chulalongkorn university in Bangkok 1961-62. Between 1968 and 2000 employed as state geologist and senior state geologist at the Geological Survey of Sweden.

Thomas Lundqvist worked as a geologist with regional mapping at the Geological Survey of Sweden and as a professor of Bedrock geology at the Department of Geology, University of Gothenburg. Before employment, he studied geology at Stockholms Högskola (now Stockholm University), and volcanology with Professor Alfred Rittmann in Catania, Sicily. His main interests are, besides volcanology, petrology and regional geology in the Precambrian.

Dolores Pereira is professor at Geology and Engineering Geology degrees at the University of Salamanca. She is vicepresident of the IUGS Heritage Stone Task Group for southern Europe and Member of the network CONSTRUROCK. She is adviser and reviewer for UNESCO on World Heritage Sites. Her research interests include natural stones and their use in new building and restoration of architectonic heritage.

Barry Cooper holds an MSc from theUniversity of Melbourne and a PhD from Ohio State University. During the 1980s and 1990s Barry commenced investigations first into the history of geology and later in dimension stone geology. In ‘retirement’ as Associate Professor at the University of South Australia, he has been one of the leaders in advocating formal designation of those natural stones that have achieved widespread recognition in human culture. Barry is currently Secretary General of both the Heritage Stone Task Group (HSTG) and the International Commission on the History of Geological Sciences (INHIGEO).

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Petit Granit: A Belgian limestone used in heritage, construction and sculpture

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(Received September 7, 2014; Revised accepted October 01, 2014)

Petit Granit is a Carboniferous grey-bluish crinoidal limestone that becomes shiny black when polished. The rock is known under several other names including Pierre bleue (Blue stone), but it should not be confused with other natural stones having a similar commercial name, which are superficially similar limestones. It consists of around 96% microcrystalline calcite and a high proportion of fossils, mainly crinoids. In addition some dolomite, quartz, pyrite, marcasite and fluorite are present. Around fifteen quarries are currently active, employing almost one thousand people and thus is an important part of the natural stone economy in Belgium. Petit Granit has an Appellation d'Origine Locale (Local Appellation of Origin) designation since 1999. It has been extracted in several regions of southern Belgium since the Middle Ages.

The stone characterizes many façades of the urban architecture of Brussels and other Belgian cities, and since the second half of the 19th century it has been used in various countries elsewhere in Europe and overseas. Its high density and uniformity mean that it takes an excellent polish and thus has versatile use as a dimension stone. Petit Granit has also been used widely in sculpture and architecture by several well known artists. However, deterioration has been observed when it has been used for exterior purposes, and appropriate measures need to be taken to prevent this. This stone can be considered as a possible candidate for Global Heritage Stone Resource nomination in Europe for its prominence and value both in construction and artistic uses.

An introduction to "Petit Granit"

Petit Granit is a calcareous grey-blue stone, giving rise to the local name "Pierre Bleue," characterized by an abundance of crinoids. With polishing, this stone becomes dark, but when used in exteriors, it loses its polish in a relatively short period of two to three years and becomes significantly lighter and greyer in colour. Its extraction is exclusively from Belgium, in the area around Soignies in the Hainaut province and around the Ourthe valley and in Condroz, as in the Bocq and Molignée valleys (Figure 1). The rock is Early Carboniferous in age (Tourneur, 2004; Groessens and Tourneur, 2011; Groessens, 2013) and comprises the Soignies Member of the Écaussinnes Formation. A variety exists in some of the older strata, of middle Tournaisian age, named "Petit Granit du Bocq", after the Bocq valley, a tributary of the Meuse river, to the east of the municipality of Yvoir, where it is still exploited.

The name of the stone, Petit Granit, is somewhat misleading, as it applies a term for an igneous rock to a sedimentary rock. However, the fact that this limestone encloses numerous fossil fragments of white crinoids, brachiopods and locally corals, which look superficially like feldspars in granites (Figure 2). This needs to be pointed out because a number of sculptures in museums and catalogues made with this limestone are labelled as "Black Granite", with the consequent misinformation for visitors (e.g. Hernández, 1950; Sotheby's catalogue, 2008, 2011; Museo Mateo Hernández, Béjar, Salamanca)

On freshly broken surfaces, the cleavage planes of the crinoid fragments are reflective, giving a coarse-grained appearance. The name Petit Granit is relatively old, used at least since the end of 18th century (e.g. Brard 1808: "Marbre madréporique de Mons (Petit gris, ou Petit Granit des marbriers" [p. 372], or "ce vilain marbre du département de Jemappes connu sous le nom de Petit Granit" [p. 398]).

The stone can be worked and polished in all common styles. It is one of the few calcareous stones that can receive flame treatment. The stone characterizes many façades of the urban architecture of Brussels and other Belgian cities, and since the second half of the 19th century it has been used in various countries in Europe and overseas. Exportation of this natural stone to Germany has led to it being known commercially there by the name of "Belgisch Granit" (Belgian Granite), thereby continuing the misunderstanding regarding its rock type, and also "Belgischer Blaustein" (Belgian blue stone).

Petit Granit has also been used widely in sculpture and architecture by several well known artists (e.g. Mateo Hernández, Michel

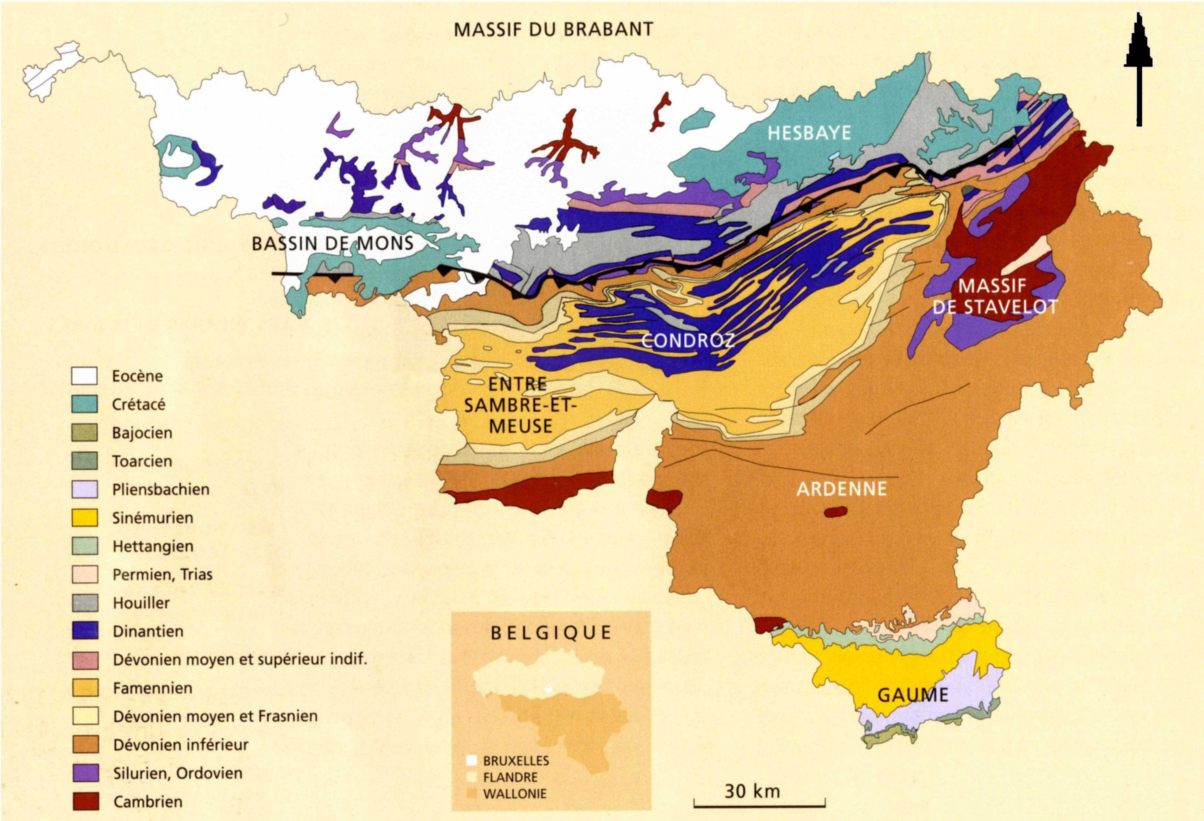

Figure 1. Map of Belgium showing distribution of lithologies. Marchi and Tourneur (2002)

Smolders, Tom Blatt, Belgischer Blaustein, Belgischer Blaustein, Santiago Calatrava, among others).

Petit Granit as Global Heritage Stone Resource

The essential characteristics of a Global Heritage Stone Resource (GHSR) are now defined (Hughs et al. 2013; Cooper et al. 2013; HSTG "Terms of Reference" approved by IUGS at its Executive Committee Meeting in San Sebastian, Spain in February 2012 (http://www.globalheritagestone.org/home/ghsr-proposals). An approved GHSR nominee must have a cultural history encompassing a significant period of time and needs to have been utilised in significant works, either in buildings, sculpture or utilitarian applications. Wide geographical use, extending if possible to numerous countries, is important. In addition, recognition as a cultural icon, potentially including association with a national identity or a significant individual contribution to architecture, is also valuable. In the case of Petit Granit, all these characteristics are accomplished. Contemporary quarrying and therefore the on-going availability of a GHSR for construction can increase the status of a GHSR and hence is also beneficial. As a consequence of this availability, technical investigations are encouraged, and continued use of the GHSR stone is promoted. With contemporary quarrying, GHSR designation may safeguard the resource from future inaccessibility resulting from quarry closure. Such inaccessibility has long been a problem given the common close proximity of dimension stone quarries to other human activities.

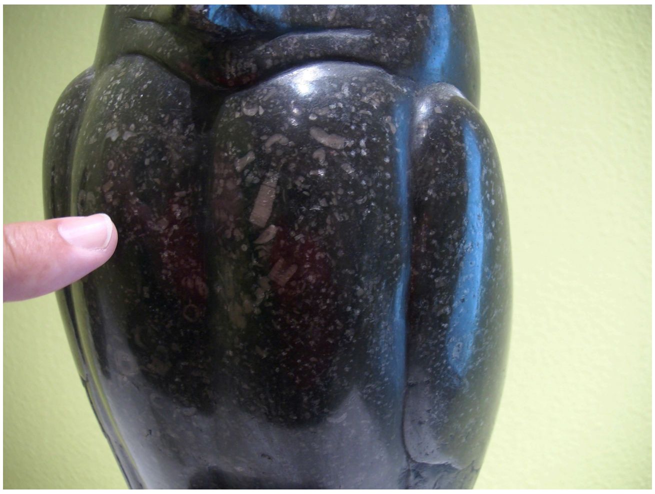

Figure 2. Mateo Hernández's "Owl", made on Petit Granit where the white fossils against the black background explain the controversial name for a limestone. Reference on the material at the museum: Granito Negro (Black Granite). Photo by D. Pereira.

Required GHSR Nomination/Citation data

For the purpose of GHSR nomination, the HSTG Terms of Reference state that citations shall contain specific information (Cooper et al. 2013), as follows.

Formal Name: Petit Granit.

Other Names: Pierre Bleue de Belgique, Blue Stone, Belgian Blue Stone (not to be confused with Chinese Bluestone or Irish Bluestone), Belgian Limestone.

Place of Origin: Southern Belgium.

Resource Location: Petit Granit is exclusively extracted in Belgium. Four regions are known for having quarries (Figure 1):

- Hainaut province: Soignies and Neufvilles, formerly Écaussinnes, Feluy, Arquennes
- Condroz area: Sprimont, Chanxhe, Anthisnes, Clavier, Modave, Ouffet, Pailhe, Les Avins
- Valley of the Bocq: Dorinne, also in Yvoir and Spontin for the variety Petit Granit du Bocq
- Valley of the Molignée: for the moment, no active exploitation, formerly Denée

Today there are two major production regions:

- Hainaut (approximately 80 % of the total)
- The Ourthe–Amblève region, south of Liège.

Quarrying: Petit Granit has been extracted in several regions of southern Belgium since the Middle Age (Figure 3a and 3b). Around fifteen quarries are active these days, employing almost one thousand people. A map with specific locations of present-day quarries is at http://www.pierresetmarbres.be.

Heritage issues: The quarries are being considered within the European Quarry Landscapes project, which considers historic quarries and landscapes formed by quarrying across Europe (http://www.quarrylandscapes.teruel.es/)

Victor Hugo mentioned the Petit Granit in his travel writings (e.g. "Ces roches de la Meuse contiennent beaucoup de fer; mêlées au paysage, elles sont d'une admirable couleur: la pluie, l'air et le soleil les rouillent splendidement; mais, arrachées de la terre, exploitées et taillées, elles se métamorphosent en cet *odieux granit gris bleu dont toute la Belgique est infestée*. Ce qui donnait de magnifiques montagnes ne produit plus qued'affreusesmaisons. Dieu a fait le rocher, l'homme a fait le moellon." (Rouvez, 1909)

Petrographic Name: Crinoidal limestone (bioclastic packstone [Dunham, 1962]; biomicrite [Folk, 1959])

Mineralogical composition: The mean composition is of 96 to 99 % carbonate (with a minimum of 88 % calcite), 0 to 1 % quartz, 0,1 to 0,4 % iron (mainly as pyrite) and 0,2 to 0,4 % of organic carbon (which gives the dark colour in fresh surfaces).

Colour: Grey-bluish, dark-grey on freshly broken surface, to light-grey with a slight bluish shade as a patina.

Natural variability: The strata of Petit Granit are well known for their homogeneity and uniform character. There is a slight variability in the size and density of crinoid ossicles, and also a slight variation of colour, somewhat darker ("bancs noirs") or lighter ("bancs gris"). The many different finishing possibilities for the rock, smooth or rough ones, alter the colour appearance.

Suitability: The Petit Granit is covered by a technical agreement referred to "Agrément technique avec certification", under the authority of the Union belge pour l'agrément technique dans la construction, (http://www.ubatc.be), where all the geological and technical data are given. Its high density and uniformity mean that it takes an excellent polish and thus has versatile use as a dimension stone. It can be used in nearly every kind of applications in architecture, garden and landscape architecture, decoration and sculpture. However, some finishing styles are not long-lasting in external uses and are reserved for inside decoration.

Stratigraphy: Different varieties are found in early Carboniferous strata, from middle to late Tournaisian age. Petit Granit s.s.is of middle Tournaisian age. The limestone was formed in a shallow-marine depositional environment, in tropical conditions, inhabited by many invertebrate organisms, such as crinoids, corals and brachiopods. For a complete geological explanation: http://www2.ulg.ac.be/geolsed/geolwal/geolwal.htm

Commercial designation: "Pierre Bleue de Belgique®", a registered name.

Figure 3 (a) *Quarries at Hainaut. Past. At the beginning of XXth century, the landscape looks more "industrial' with many travelling cranes, but with still old installations. Collection Bertels, Brussels.* ***(b)****. Quarries at Hainaut. Present. The position of strata in Soignies, with a gentle slope of 12-13°, allows exploitation in huge terraces and production of very large blocks of good stone.*

Physical properties:

Extracted from http://www.pierrebleuebelge.be/images/biblio/biblio-74-710.pdf

Water absorption (%)	0.11
Mean Density (kg/m³)	2687
Mean Porosity (%)	0.28
Mean Compressive Strength (MPa)	157.90
Mean Flexural Strength (MPa)	16.70
Wear resistance (mm)	18.80
Static Elastic module (GPa)	86.90
Dynamic Elastic module (GPa)	86.90

Vulnerability and maintenance of supply: Petit Granit is only quarried in Belgium.

Production figures for 2006 were 38.000m^3 at Clypot site and 17.000 m^3 at Gauthier and Wincqz site (extracted from: http://www.pierrebleuebelge.be/key-figures.45-uk.html)

The annual turnover for all Petit Granit quarries in Belgium is 65,000,000 euros at present, including 30 % of exports. The quarries employ 650 people (400 only at 'carrières du Hainaut'). This data guarantee the maintenance of extraction activity for the future.

Historic Use: Petit Granit has an Appellation d'Origine Locale (Local Appellation of Origin) designation since 1999. It has been extracted in several regions of southern Belgium since the Middle Ages. Architects and sculptors have been using this stone since at least the 12th century.

Buildings

Historical (with date of construction in brackets):

- Cathedral of Funchal, Madeira (15th c.)
- Collegiate church of Sainte-Waudru, Mons, Belgium (interlaid with sandstone) (15th–16th c.)
- Other churches and private houses in Mons and region, Belgium (15th–19th c.)
- Garden pavilion, parc d'Arenberg, Enghien, Belgium (17th c.)
- Castle of Seneffe, Belgium, by the architect L.B. Dewez (mid-18th c.)
- Flooring, Panthéon, Paris, interlaid with French stones, by architect Rondelet (beginning of 19th c.)
- Galeries Royales Saint-Hubert, by architect Jean-Pierre Cluysenaer, Brussels, Belgium (1846-1847)
- Palais du Gouverneur (neogothic), Liège, Belgium (1850)
- Saint Catherine´s church (Figure 4a), central Brussels, Belgium, designed by Joseph Poelaert (1854)
- Palais du Cinquantenaire (Figure 4b) Brussels, Belgium (1880)
- Palais du Centenaire, Brussels, Belgium (1930)
- Maison du Roi (Grand-Place), neogothic restoration, Brussels, Belgium (1890)
- Many Art Nouveau private houses, including that of Victor Horta (UNESCO). Brussels, Belgium (1892–93)
- Pont de Fragnée, Liège, Belgium (for Universal Exhibition of 1905)
- Entrance of Canal Albert, Liège, Belgium (International Exhibition of 1930)
- Art Deco town hall, Charleroi, Belgium, by the architects J. Cézar & J. André (1936) (interlaid with French limestone)

Recent buildings

- 'Amphithéâtre de l'Europe' at the University of Liège (Sart-Tilman) (Figure 5)
- Brussels airport, Belgium
- Leipzig airport, Germany
- Belgium embassy in Berlin, Germany
- Belgium embassy in Tokyo, Japan
- Chartres town centre, France
- Design centre, Saint-Etienne, France
- Factories Leblan Lafont, Lille, France
- Granite Tower, Paris, France
- Place d'Armes, Valenciennes, France
- Liège-Guillemins railway station, Belgium (Figure 6)
- Maastricht station, Netherlands
- The Hague station, Netherlands
- The Hague town hall, Netherlands

And many newer commercial buildings (e.g. Figure 7)

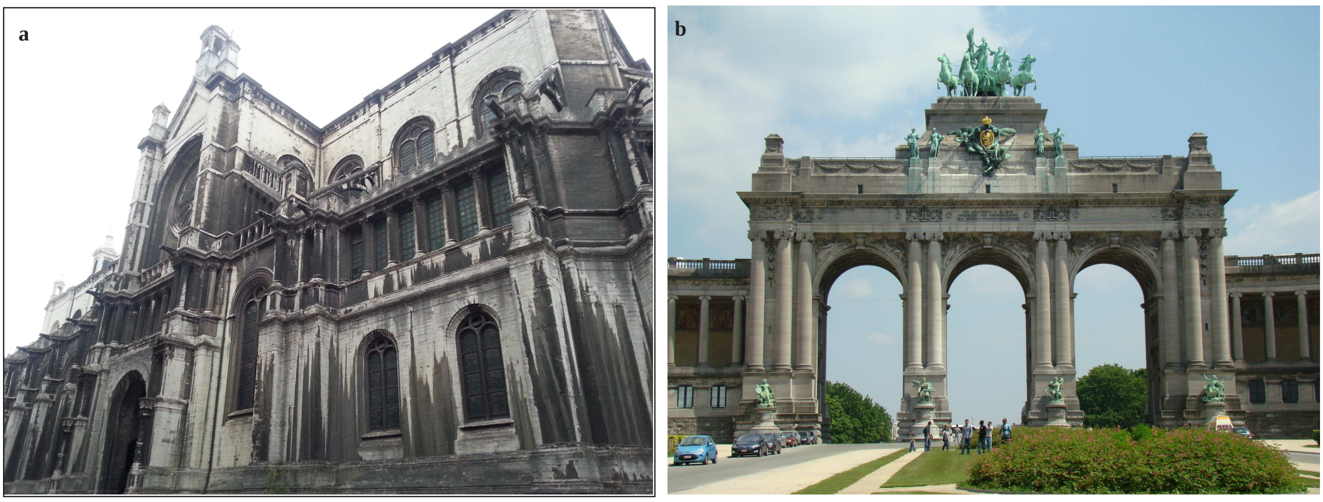

Figure 4. (a) Sainte-Catherine church, Brussels. 1854-1874 by architects Joseph Poelaert and Wynand Janssens. (b) Palais du 'Cinquantenaire' in Brussels and its 'Arc de Triomphe', architect Charles Girault, 1905.

Figures 5-8. (5) 'Amphithéâtre de l'Europe' at the University of Liège (Sart-Tilman), architect Daniel Dethier, 1996. (6) 'Gare (Station) des Guillemins' at Liège, architect Santiago Calatrava, 2009. (7) Petit Granit in façade of commercial building in central Brussels. (8) Mateo Hernández (Hernández, 1954). In the original: "Groupe de Chimpanzés, en granit noir". Notice the misnomer in giving the nature of the stone.

***Sculptures*:** Petit Granit has also been used widely in sculpture and architecture by a number of well-known artists. The list is long, but included is a selection of some sculptors, starting with Mateo Hernández (Figure 8), whose works appear in a dedicated museum in Béjar, Salamanca (Spain).

- Mateo Hernandez (Hernández, 1950; Bernáldez Villarroel and Brasas Egido,1998; BernáldezVillarroel, 2000)
- Käthe Kollwitz
- Michel Smolders
- Elise Delbrassinne
- Benoît Luyckx
- Eugène Dodeigne
- Florence Freson
- Félix Roulin
- Philippe Ongena
- Tom Blatt
- Santiago Calatrava

Other characteristics: Because the depositional environment was one of high water-column productivity which led to mostly reducing conditions in the sediment, sulphide minerals (pyrite) were created and the limestone contains a high percentage of organic carbon. For this reason it is also called "coal lime". One characteristic of this rock is the smell it produces when broken or scratched due to the hydrogen sulphide released, which explains the nickname "stink lime".

Conclusion

Petit Granit fulfils all the requirements to be presented as candidate for designation as a GHSR, both for construction and artistic purposes, but especially for its widespread use as a dimension stone for building exteriors.

Acknowledgements

This work was sponsored by the ERASMUS Intensive Programme 2012-1-ES1-ERA10-54375 and it was done within the framework of Heritage Stone Task Group activities. University of Salamanca funding program supports this publication. Brian Pratt is acknowledged for his review and useful comments on the paper. The city council of Béjar is acknowledged for the support received in visiting Mateo Hernández museum.

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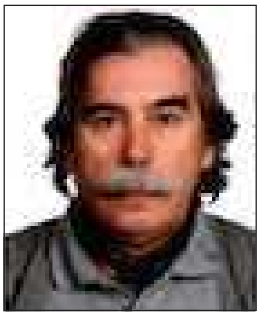

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Ana García Blázquez. Student of Engineering Geology in her last year. Her final year project is related to the Petit Granit, together with other natural stones used by the sculptor Mateo Hernández. She was student in practice for the Spanish Geological Survey during the first stage of the final project.

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Lede Stone: A potential "Global Heritage Stone Resource" from Belgium

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(Received December 12, 2013; Revised accepted May 28, 2014)

Lede Stone is an important dimension stone with major relevance for Belgian and Dutch cultural heritage. It is sourced from the Eocene (Lutetian) Lede Formation, mainly in the region to the southeast of Ghent in Belgium. The oldest known use dates back to Roman times. With the rise of Gothic architecture during the middle ages, the use of Lede Stone increased substantially. Quarries arose at different locations at different times. Today only one active quarry remains, after a period of non-production during the 20th century. Current production is mainly used for restoration purposes. A major concern is the use of alien stones as a substitute for Lede Stone in cultural heritage restoration. In the light of the establishment of the "Heritage Stone Task Group", this paper deals with requirements of its "Terms of Reference" and illustrates the stone's nature, technical properties, utilization and associated issues. It should contribute to the cultural appreciation and preservation of this stone.

Introduction

Lede Stone is an important historic building stone from northwestern Belgium. It combines the unique aesthetic quality of a pale, workable sandy limestone with petrophysical values typical of high-strength rocks. The stone represents a valuable part of the built cultural heritage of northern Belgium and the Netherlands. In the light of the recent establishment of the "Heritage Stone Task Group" (HSTG), this paper deals with the proposed "Terms of Reference" for Lede Stone to be designated as "Global Heritage Stone Resource". Not only would this recognize the value of the Lede Stone in the built heritage of northern Belgium and the Netherlands. Moreover, designation of Lede Stone as Global Heritage Stone Resource would be beneficial for conservation of geological outcrops, preservation of Lede Stone in the built environment and would invigorate the importance of ongoing production.

Lede Stone has long been used as a dimension stone for buildings, artwork and other constructions. The stone is closely associated with specific architectural styles and the socio-economic history of its source and application regions. It is strongly intertwined with the charming appearance of several historical centres of cities such as Ghent, Brussels, Bruges and many others.

Despite existing active quarries, the introduction of alien stones as replacement can be seen as a threat to cultural heritage. This is an issue which has concerned specialists for more than a century. It may be addressed by the recognition of Lede Stone as a heritage stone of international significance.

Geology and petrography

Lede Stone is a sandy limestone quarried from the Lede Formation. The shallow marine sands from the Lede Formation were deposited during the Lutetian (Eocene) in a southern North Sea bight (Jacobs and Sevens, 1993; Jacobs and De Batist, 1996). These sands are interpreted as a stepwise transgressive deposit with correlative unconformities overlying a ravinement surface. Some lithified horizons, commonly up to three, within these sands gave rise to the natural building stone resource. Fobe and Spiers (1992) recognised 3 facies types in the Lede Formation. They describe the most important Meldert facies as a shallow marine facies with storm deposits. This facies includes the principal building stone resource (see below). A deeper marine facies without storm beds is found to the north, where these NNE-dipping layers are buried by younger Cenozoic sediments, and to the west, where outcrops can be found in the hill flanks of some outliers. The third facies from the southernmost outcrop represents more near shore deposits. The latter two facies are less relevant as a stone resource.

Lede Stone is mainly quarried between the Rivers Scheldt and Dyle (Fobe, 1990), with its principal production centre to the southeast of Ghent (Figure 1). Its major resource location is the town of Balegem (Oosterzele) and its surrounding communities. Therefore, the alternative name Balegem Stone is not uncommon. Lede Stone, on the other hand, is a more correct reference to its lithostratigraphical

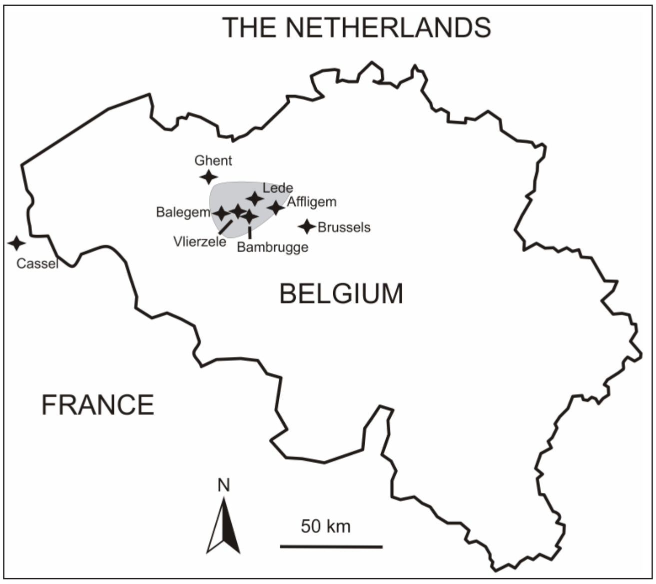

Figure1: Map with geographical locations mentioned in the geological description. The main production centre is marked by the shaded area.

status, which was first described in Lede where there was also historic production. Some outliers of the Lede Formation occur in the hills to the east and west of this region, as far as Cassel in France and east of Brussels. In the latter, Lede Stone was quarried in underground galleries.

Lede Stone is a mixed siliciclastic-carbonate rock, consisting of a quartz fraction together with other detrital grains of glauconite and carbonate allochems with a matrix/cement (Figure 2). Therefore it has been classified either as a sandy limestone or as a calcareous sandstone. Since the amount of carbonate exceeds 50 vol-% of the rock, this rock can be preferably classified within carbonate rock classifications. In general, it can be determined as an 'arenaceous sparry packstone' (Dunham) or a 'poorly washed sandy biosparite' (Folk) or a 'sandy allochem limestone' (Mount). Given the natural variability in the stone, more precise denomination is best provided to individually assessed stone blocks.

The nature of the bioclasts indicates a shallow marine fauna. The most diagnostic fossils are the foram *Nummulites variolarius* and the serpulid *Ditrupastrangulata*. Echinoderms, bivalves, gastropods and shark teeth are the most common macrofossils, which are commonly deposited as shell beds. The microfauna is predominantly milliolid and textulariina forams. The siliclastic composition is dominated by a bimodal quartz population (up to 40 vol-%) of subangular very fine sand fraction supplemented with rounded medium sized sand. Glauconite is commonly present in 2-3 vol-%. Accessory minerals are feldspars, zircon, tourmaline, micas and opaque minerals (e.g. pyrite).

Matrix may be present, but is sometimes washed away. Epitaxial crust can occur around echinoderm fragments and not uncommonly around nummulitids. Cement is most commonly present, from fine grained microsparite to coarse grained sparite in some cases, and is mostly rich in iron. There is no silicification.

The porosity is mainly defined by intergranular and intragranular porosity; however moldic porosity can considerably contribute to porosity and appearance.

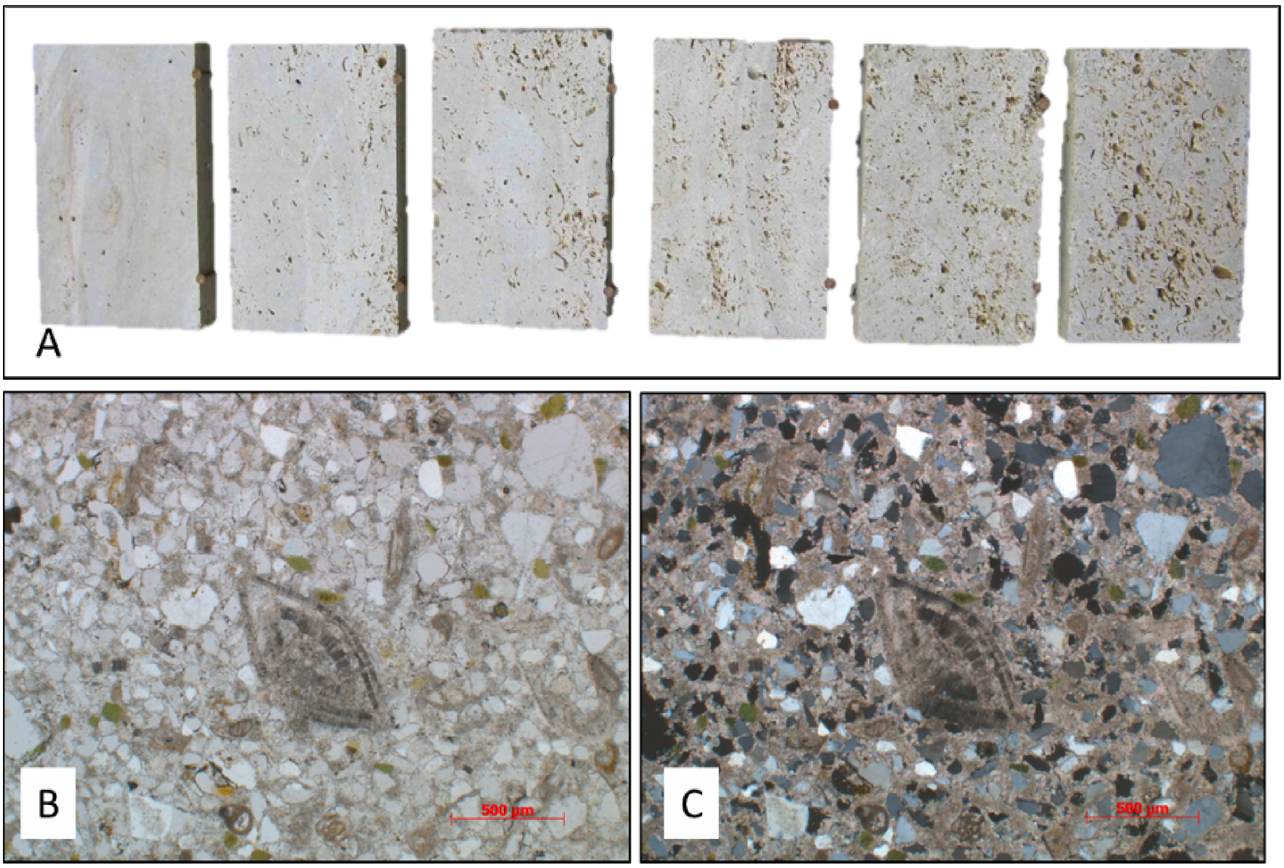

Figure 2. (A) Natural variability within the Lede Stone. (B) PPL micrograph of Lede Stone. (C) XPL micrograph of Lede Stone.

Historic production and use

The oldest evidence of quarrying and use of Lede Stone dates back to Roman times. Archeological finds prove the mining and use of Lede Stone around Balegem during the 2^{nd} and 3^{rd} century. Such records are considered at the Provincial Archeological Museum (PAM) in Velzeke (Nijs, 1990). Since the 11^{th} century, Lede Stone has been quarried and used for larger constructions. The production of 'white', workable Lede Stone benefited from the emerging Gothic architecture. Many production sites arose at different towns during the Middle Ages (De Smet *et al.*, 2003). These were exploited by the abbeys, stonemasons or private owners. The Abbey of Affligem was one of the first commercial producers in the 12^{th} and 13^{th} century; they probably exported stones to the Netherlands and Germany (Groessens, 2011). Nearby, quarrying delivered stone for constructions in Aalst, Gent and Antwerp.

By the beginning of the 14^{th} century Lede Stone was sought by architects for prestigious buildings. Architect Jan van Haelst ordered the stone from Vlierzele for the building of the Belfry and St Michael's Church in Ghent (Van der Kelen, 1996; De Smet *et al.*, 2003) and architect Peter Appelmans, working on the Our Lady's Cathedral of Antwerp visited the quarries owned by the Abbey of Affligem (Groessens, 2011).

It is impossible to determine the production rate or total volume. The total volume of Lede Stone for constructing the 15^{th} century St Walburga Church in Oudenaarde amounted 1108 m^3 (Van der Kelen, 1996). A small recalculation demonstrates that this is equivalent to a quarry pit with a surface area of more than 1000 m^2, assuming a useable total thickness of 1 m for the typical occurrence of three stone banks. The total surface over which stone has been quarried over the centuries must therefore be reasonably high.

During the 16^{th} century, the centre of gravity of quarry production shifted towards Balegem (De Smet *et al.*, 2003). The "House of the Free Boatsmen" and the "Guildhouse of the Bricklayers" in Ghent are magnificent examples of late Gothic constructions in stone from Balegem.

Since the 17^{th} century, Lede Stone was increasingly used as a decorative element in combination with brick masonry. Quarries in the area of Brussels remained important during the 17^{th} and 18^{th} century, but had disappeared by the 20^{th} century (Gulinck, 1949). By this time, Lede Stone was being used for restoration, with only limited use for new constructions, such as the St Peter Railway station in Ghent. In the area of Balegem, production ceased and by beginning of the 20^{th} century, the last quarry closed in Bambrugge (Figure 3).

The production of such large volumes of Lede Stone was and remains dependent on quarrying at many locations with only limited volumes of stone being sourced from the subsurface. This contrasts with many other natural resources, where quarries produce large volumes from one location.

Contemporary availability and issues

In 1966, Verlee BVBA started to produce Lede Stone as by-product from a sandpit in Balegem. In 2011, Balegro BVBA took over the sand pit and the associated stock of Lede Stone. Production continues today and Lede Stone remains available for restoration works. However, because of low quantity, diverse stones have been imported as replacement material for Lede Stone, both in Belgium (De Kock *et al.*, 2014) and in the Netherlands (Quist *et al.*, 2013). This was already an issue more than hundred years ago, as a consequence of the actions of architects Mortier in Belgium and Van der Veen in the Netherlands (Quist and Nijland, 2013). Mortier, charged with the restoration of the "House of the Free Boatsmen", investigated the resources in an abandoned quarry wall in Balegem (Mortier, 1898). Van der Veen often travelled to Belgium to purchase Lede Stone from the remaining quarry in Bambrugge or utilised stone recovered from the demolition of buildings in Belgium for restoration in the Netherlands (Quist and Nijland, 2013). By the end of the 20^{th} century, replacement of Lede Stone in monuments was so drastic, that architect Breda described the use of dissimilar foreign stones in a metaphor as a disease (Breda, 2005). This awareness suggests that the use of authentic materials is not only beneficial for aesthetic purposes, but also for stone compatibility and durability.

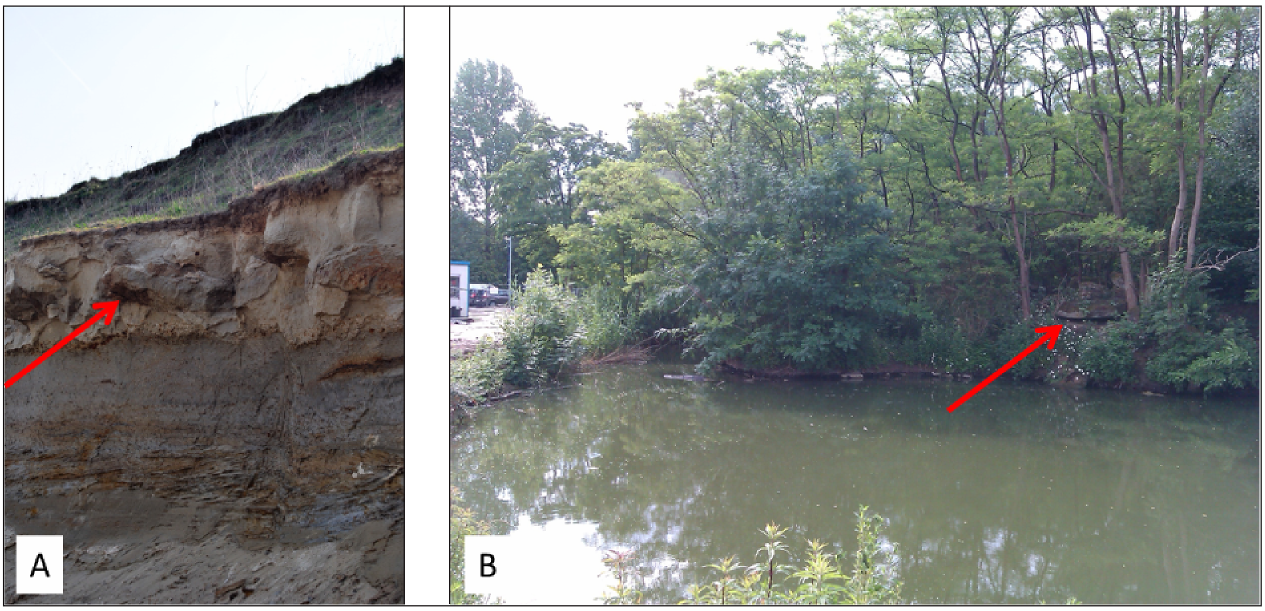

Figure 3: (A) Occurrence of Lede Stone as discrete stone banks (arrow) in Balegem quarry in 2010. (B) Remnants of quarry pit in Bambrugge. Arrow indicates remnantstock.

Technical publications and illustrations

More technical information about Lede Stone has been incorporated in several professional magazines and books published in Belgium and the Netherlands. These works also illustrate its use in some prominent buildings. Among the most leading publications have been Berends *et al.*, 1982; van Hees *et al.*, 2005; Cnudde *et al.*, 2009 and Dusar *et al.*, 2009. New technical tests have been performed recently at Ghent University on the demand of and delivered to the Balegro BVBA company (Table 1).

A non-exhaustive illustrative list of Lede Stone in buildings can be found at http://www.belgiumview.com. An illustration of Lede Stone as building stone in a historic building in Belgium (Fig. 4), historic bas-relief (Fig. 5), modern house (Fig. 6), modern sculpture (Fig. 7) and as building stone in a historic building in The Netherlands (Fig. 8) is provided in this paper.

Figures 4-8. (4) St Bavo's Cathedral (Ghent) with Lede Stone and other white stone types such as Brussels stone, Gobertange Stone and Euville Stone. (5) Bas-relief in Lede Stone above the entrance of the House of the Free Boatsmen (Ghent). (6) Modern house in Lede Stone (Leeuwerikstraat, Zottegem). (7) Sculpture 'De Schepenbrief' in Lede Stone in Dikkelvenne; monument for a charter from 1249: 'Schepenbrief van Bochoute'. (8) City Hall Veere (the Netherlands), built by the end of 15th century with masonry in Lede Stone.

Table 1: GHSR Nomination/Citation requirements

Formal Name	Lede Stone
Other Names *Historical* *Regional*	 witten ordu(y)n Balegem Stone, Dender Stone, Afflig(h)em Stone, Houtem Stone
Place of Origin	northwestern Belgium
Resource location *Principal* *Secondary*	 Balegem (Oosterzele) and surrounding communities underground in and around Brussels
Quarrying	Since 11th/12th century by stone masons and abbeys, mainly in open air except for Brussels. Since 1966 at Balegem in open air sand pit, before by Verlee BVBA, nowadays by Balegro BVBA
Heritage issues	No outcrops or quarries are currently protected or preserved. Some legacy of old quarrying can be seen in the landscape, although always overgrown. The holostratotype was defined by Mourlon (1887) in the Balegem sandpit, but is no longer visible. Many buildings in Lede Stone are listed as cultural heritage. Lede Stone is also prominent in the Grand Place of Brussels, which is inscribed by UNESCO World Heritage.
Petrographic Name	Sparry arenaceous packstone (Dunham), Poorly washed sandy biosparite (Folk), Sandy allochem limestone (Mount)
Colour	Greenish-gray or yellowish-gray in reducing conditions, yellow-brown to orange or ochre in oxidizing conditions
Natural variability	From compact and low-porous to coarse moldic high-porous; high differences in concentrated fossil content
Suitability	Durable dimension stone, used for ashlars and for sculpting
Stratigraphy	LedeStone belongs lithostrati-graphically to Lede Formation, which is of Eocene (middleLutetian) age, nannofossil zone NP15b
Commercial designations	Only one commercial stone type. Distinctions are sometimes made for shell beds and associated stone with elevated porosity called 'lumachelles'. Historical designations can refer to the quarry location.
Physical properties (Mean)	
Apparent density (NBN EN 1936:1999)	2448 ± 29 kg/m³
Open Porosity (NBN EN 1936:1999)	8,27 ± 1,09 vol.%
Mean Saturation coefficient	0,75 ± 0,07
Capillary absorption coefficient (NBN EN 1925:1999)	11,98 ± 4,07 g/(m²vs)
Compressive strength (NBN EN 1926:1999)	48,4 ± 12,6 Mpa
Flexural strength (NBN EN 12372:1999)	17,6 ± 3,9 Mpa
Ultrasound velocity (NBN EN 14579:2004)	4359 ± 41 m/s
Abrasion resistance (NBN EN 1341:2001)	19,00 ± 1,19 mm
Frost resistance (NBN EN 12371:2010)	Nc 168
Vulnerability & maintenance of supply	Lede Stone is suitable for use as dimension stone and is only produced at Balegem, Belgium. Supply issues result from the limitations of quarry sites and the need for new resource extraction locations given competition with residential expansion and nature conservation areas. The occurrence of Lede Stone as discrete stone banks results in a relatively low quarry production efficiency.
Historic use:	Lede Stone has been used since Roman times and has been utilised extensively since the 11th century in Belgium and The Netherlands. Lede Stone has been used for major architectural buildings in both countries. Since the end of the 20th century, its resources mainly supply restoration projects.
Illustrations: *Belgium* *The Netherlands*	 Saint-Bavo Cathedral (Ghent); St Peter's Abbey (Ghent); St Martinus Church (Aalst) City Hall (Veere); St-Lievensmonster Tower (Zierikzee); Church of Our Lady (Breda); City Hall (Hulst)

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by V. Cardenes, V. Cnudde, J.P. Cnudde

Iberian roofing slate as a Global Heritage Stone Province Resource

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(Received March 23, 2014; Revised accepted September20, 2014)

The Iberian Peninsula is, nowadays, the main producer of roofing slate of the world. Most of the outcrops are located in the NW of the Iberian Peninsula, in the regions of Galicia, Leon, and in Portugal. The technique of working and roofing with slate was brought from Flanders by King Felipe II by the second half of the XVI century. The most representative building from this period is the Monastery of El Escorial, N Madrid. However, the Spanish slate industry remained incipient until the 1960s, when Galicia and Leon suffered an accelerated industrialization process which greatly enhanced the volume of production. Additionally, the Portuguese slate industry was well developed by the second half of the XIX century. Most of the Portuguese production was exported, mainly to the United Kingdom. By the second half of the XX century, the Spanish, and in a lesser extent, the Portuguese roofing slate spread all over Europe, forcing most of the existing European quarries to close. Nowadays, different varieties of roofing slates are quarried, mainly in Spain, being used indistinctly in new residential construction and for restoration of historical buildings. The main importing countries are France, Germany and the United Kingdom. This work presents an overview of the history and main varieties of the Iberian roofing slate, in order to propose its inclusion as a Global Heritage Stone Province.

Introduction

Roofing slate is the commercial term for a wide variety of rocks that have in common their ability to be split into thin, large and plane tiles. The metamorphic degree of the Iberian roofing slates ranges from the greenschist to the amphibolite facies. Nowadays, the largest roofing slate outcrops over the world are located in the Iberian Peninsula, which produces about 60% of the slate tiles sold in the world (Fig. 1). However, there are also other countries with important slate outcrops like Brazil and China.

Most of the Spanish slates come from the Ordovician terrains of the Truchas Syncline (Martínez Catalán et al., 1992), a macro structure located between Valdeorras, La Baña and El Bierzo, located in the South-East of Orense and the North-West of Leon, in the NW of Spain. However, there are other important outcrops outside this area which played an important role as slate source areas in the past, creating a local economic motor for the population. Thus, Iberian slate lithotects can be divided into 12 districts, following historical and geographic criteria (Fig. 2). This division is widely used today in the slate sector (Cárdenes et al., 2008).

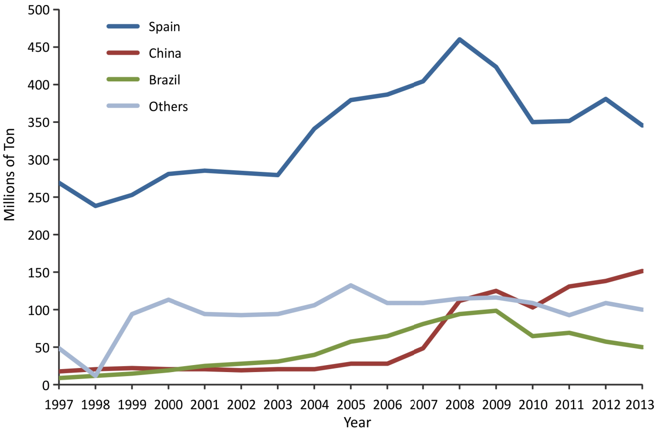

Figure 1. World's exportations of roofing slate for the period 1967-2013. Data: UNSTATS, United Nations Comtrade

Checklist for Global Heritage Stone Province (GHSP) citation

Historic use and geography

The first uses of slate in the Iberian Peninsula can be found during the Chalcolithic period, as material for making arrow heads and similar tools (Fabregas, 2008) at the archeological outcrop of Trabazos de Aliste (Zamora). Later, during the VI-VII centuries, slate is used as a writing base for the so-called "Visigothic numeral slates" (Cordero and Martin, 2012) in the area of Montijo, Badajoz. In both archeological sites, the slates documented come from actual roofing slate districts. Slate was used over the centuries by the inhabitants from settlements close to the outcrops. However, the modern slate industry in the Iberian Peninsula begins during the XIX century.

Portugal

Historically Portugal had a good relationship with the UK. The

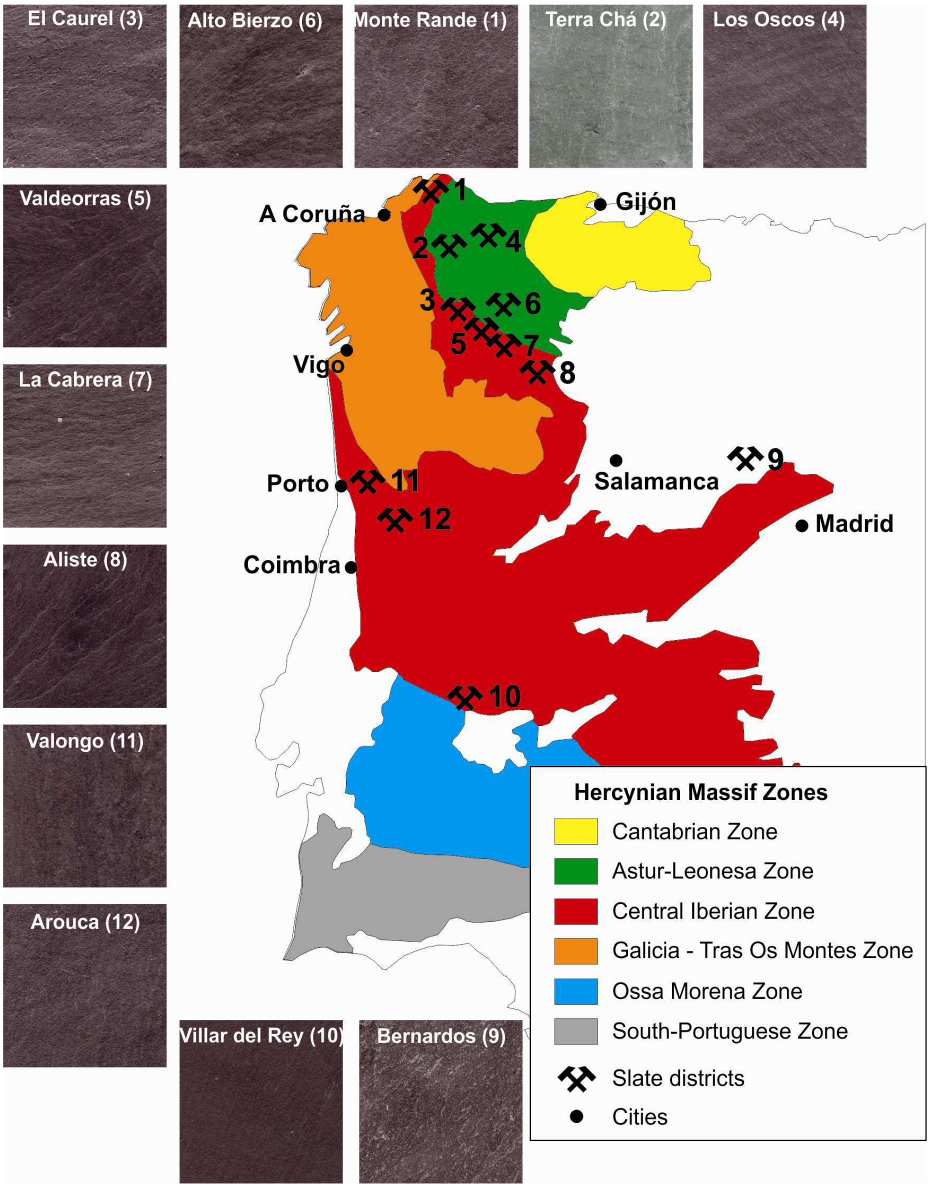

Figure 2. Location of the slate quarries on the Iberian Peninsula and districts classification.

development of the slate industry was done on their first stages by Englishmen. The modern slate mining began in 1865, with the foundation in the region of Valongo of the English company *The Vallongo Slate & Marble Quarries* (Santos de Oliveira, 1997). The English company owned the mines in Galinheiro, Cardósias, Valle de Amores and Susão.In 1874, these slates were appointed as the main supplier of the Royal House. At the end of the 19thcentury the company exported over 40 tons of slate todifferent countries such as Brazil, Russia, and Denmark and mostly to Great Britain, and it employedover 500 workers. As new applications (billiard tables, pavements, chimneys, etc.) for the slate were created, the industry increased. In 1930, *The Vallongo Slate & Marble Quarries* is absorbed by the new company *Empresa das Lousas de Valongo S.A.* The new company reached up to 1.600 workers, but in 1939, the beginning of WWII marks a negative point of inflexion for the slate business (Santos de Oliveira, 1997). During the years of the war, the business decreased dramatically, since most of the production was exported to the UK. Neither after the war the exportations recovered, since national governments protected their local industries. Thus, UK consumed only its own slate. In the 50's, the slate business suffered a deep restructuration, diversifying the offer and focusing in other slate products. Nowadays, the Portuguese slate industry, led by the company *Pereira Gomes & Carvalho, Lda.*, is highly mechanized, with an average production of 7.000 ton/year, of which 80% is exported. East of Valongothe slate district of Aroucacan be found. The quarries, reopened in 1990, are much smaller, with a reduced production. However, the great value for these quarries is not the slate itself, but the exceptional trilobite outcrop (Gutiérrez-Marco et al., 2009).

Spain

During the Spanish Renaissance, the urban architecture experienced a growth that brought an extensive use of roofing slate. The milestone for this slate development was 1559, when King Felipe II ordered to build "*with slate covers and in the same way as in Flanders*" (Nieto et al., 2001). King Felipe II was very influenced by the architecture of Central Europe, since his father, Emperor Carlos V, abdicated several territories to him, among which were the Netherlands. Qualified Flemish slate roofers were sent to Spain to teach the slate roofing techniques. The maximum exponent was obtained with the construction in the 16th century of the Royal Monastery of San Lorenzo de El Escorial (known as El Escorial), about 45 km North of Madrid, one of the most important buildings in the Spanish Heritage and sepulcher of the Spanish Kings. The slate supplied for this construction was quarried at Bernardos (Segovia), located about 75 kilometers North of San Lorenzo de El Escorial. The outcrops were seized by order of the King in order to secure the supply of slates. During the Spanish Baroque period, the use of slate consolidated.

At the same time, the mining industry developed in order to satisfy the demands of the building industry. Bernardos quarries provided most of the slates needed for the construction, since the Valdeorras and Villar del Rey outcrops were still not exploited to their fullest potential. At that time, in the second half of the 16th century, Valdeorras was rather isolated from the rest of Spain. The first mentioning of slate quarrying in Valdeorras is found in the 18th century (García Tato, 1994). The first Valdeorras slate quarries were located along the valley of the Casaio river. These quarries were worked only by locals. There was no machinery, and the mining labors had to be done only using *blood power*, or the strength of men and animals. This task was especially hard since most of the outcrops were located in mountain areas, with altitudes over 1800 m.

The slate from Valdeorras was only used locally until the beginning of the 20th century, when an English company, Cantabrian Slate

Figure 3. The beginning of the modern slate industry in Valdeorras. (A) Splitting of a slate block just in the middle of the mountai, Valley of Casaio. Photograph courtesy of Manuel Fernandez, Casaio. (B) Load of tiles directly in a truck. Photograph courtesy of Pizarras SAMACA, S.A.. This method caused many tiles to broke before arriving to destiny.

Quarries Ltd, opened a quarry in Congosto, located in El Bierzo, the neighboring region to Valdeorras, also located in the Truchas Syncline. However, the lack of experience made this company to exploit one of the poorest outcrops of Northern Spain and finally they were forced to close in 1931 (The London Gazete, 07/31/1931). It took several years before they tried again to exploit slates from these areas. At thistime French technicians prospected the area and discovered the high resources potential. In the 60's, an accelerated industrialization process took place in these areas. French, and later Germans, used their know-how in the manufacturing of slate tiles, especially in dimensioning the tiles following their own templates. Before that, slates were cut without following any normalized template, so each piece had different dimensions. With the introduction of hand dies that could dimension the tile into regular shapes in seconds, the production increased in quality and quantity. This industrialization process was also favored by the rupture of the agrarian communities due to the emigration (San Román Rodriguez, 2000). However, the new promising slate industry reverted the emigration tendency in some areas (Fig. 3A). Tools used at that time were the same as for agriculture.

In 1962, an engine of a dismantled truck was the first compressor to be working in the Valdeorras slate industry and the first mechanical shovel arrived at the end of that decade. Black gunpowder cardtriges were stuck by hand in order to pull out the big blocks of slate(García Tato, 1994). This process caused a high number of cracks in the blocks, but continued to be used until the early 90's, when the Italian technology of diamond wire saw allowed to increase enormeously the explotation ratio of the slate outcrops. This technology brought also a secondary advantage for geologists and engineers. Because now it became possible to clearly see the relationships between the main structures in the slate, sedimentation S_0 versus slaty cleavage S_1 and they better understood the regional geology.

Transportation was done by lorries to the port or directly to the warehouses. The slates were stuck inside two types of crates, *road crates* or *ship crates*, depending on the method of transportation. Sometimes tiles were directly stuck on the truck (Fig. 3B). Nowadays, only *ship crates* are used, because they are more solid and appropiate for the sucessive changes of transportation, up to 12 times a crate might suffer before arriving to its destination. In these years, the slate industry in Villar del Rey (Badajoz, Fig 1-10) and Terra Cha (Lugo, Fig 1-2) took its first steps. In Villar del Rey slates had been used for construction for at least 300 years. Due to its proximity with the Portugal border, some British-Portuguese investors saw the potential of the outcrops and opened the first quarries. On the other hand, the green phyllites from Terra Cha never had been quarried since a slate company with Italian and Spanish founding (*IPISA*) opened the first quarries during the 60's.

During the 70's, the sector consolidated and the first cooperative societies were formed (*Pizarras SAMACA* and *Cupire Padesa*, nowadays named *CUPA PIZARRAS*). Today, these two companies are still the leading companies of the world slate production. The Spanish slate irrupted in the European market, especially in France helped by the strikes of the French slate workers of the late 70's.

In the 80's, first pneumatic cuters were introduced and the legislation of the dumps began. Before that they were dumped without governmental criteria, only using the quarrymen criteria. In the 90's, the sector was shaken by numerous strikes that lasted for several months, making the situation very hard for both workers and owners. During the second half of this decade and the first half of the 21st century, the exportations increased continuosly year after year. This period was the most profitful for the slate industry. Finally, in 2008 the global crisis began to hit hard in the sector, leading many companies to close and putting the rest in a very difficult situation. Nowadays, several slate districts have closed their quarries (Villar del Rey, Terra Cha, Aliste, El Caurel, La Cabrera) and many others are threatened by the current economicalcrisis.

Compared to Portugal, the Spanish slate industry was developed much later, and with a considerably lower degree of industrialization. However, the Spanish outcrops are much bigger than the Portuguese, so nowadays Spain is leading the slate sector, but with some challenges needed to face urgently, like the competition with the emerging countries such as Brazil and China, and the neccesary restructuring of the sector, that still suffers from some handicaps inherited from the past.

Formal Name for this proposed GHSP

Iberian slate province

Origin of name

Roofing slates from the Iberian Peninsula

Other names

None

Area of occurrence

Spanish Provinces of A Coruña, Lugo, Ourense and Leon, in NW Spain, Segovia, center of Spain, and Badajoz, SW Spain. Portuguese provinces of Arouca and Valong, N Portugal.

List of constituent GHSP designations that are included within this designated Province

As pointed before, there are 12 slate districts in the Iberian Peninsula (Fig. 2):

1. Monte Rande slate, Ortigueira, in A Coruña. Dark-grey slate. Two active quarries at this moment.
2. Terra Cha phyllite, Pol, in Lugo. Light-green phyllite with abundant pyrite cubes. No active quarry at this moment.
3. El Caurel, Quiroga, in Ourense. Light-grey slate with characteristic crystals of chloritoid. Not working at this moment.
4. Los Oscos, Fonsagrada, in Lugo. Light-grey slate. One active quarry.
5. Valdeorras, in Ourense. This district is the largest one,of all, with more than 50 quarries. Slates from Valdeorras range from dark to light grey colors. Several varieties can be recognized (IGME, 1991):
    a. Casaio
    b. Castañeiro
    c. Mormeau
    d. Rozadais
    e. Los Molinos
    f. Domiz
    g. Vianzola
    h. PenedoRayado
    i. San Vicente
    j. Forna
6. Alto Bierzo, Laciana, in Leon. Light-grey slates, no quarry working at this time.
7. La Cabrera, in Leon. This is the second district in order of importance, with about 20 quarries working. These slates are mainly greyish. As for Valdeorras, there are several varieties:
    a. San Pedro de Trones
    b. Benuza
    c. La Baña
    d. Odollo
8. Aliste, Bercianos de Aliste, in Leon. Dark-grey slate, no quarry working at this time.
9. Bernardos, in Segovia, N Madrid. Light grey phyllites. There are two quarries, owned by the same company, that are still working.
10. Villar del Rey, in Badajoz. Dark slate with abundant iron sulphides and organic matter, no quarry working at this time.
11. Valongo, Portugal. Light grey slate, two active mines.
12. Arouca, Portugal. Dark slate, one active quarry.

List of other known constituent heritage stone types

No other significative heritage stones are quarried in this proposed GHSP.

Geological setting

The proposed GHSP is located at the Hercynian terrains of the Iberian Peninsula (Fig. 2). Most of the slate outcrops can be found on Ordovician terrains (Table 1, Fig. 4).

Table 1. Geological settings of the slate districts from the Iberian Peninsula

	Slate districts	Formations / Geological structure / Age
1	Monte Rande	Luarca slates / W of the Ollo de Sapo Anticlinorium / Upper Ordovician
2	Terra Cha	Cándana slates / Mondoñedo Thrust / Lower Cambrian
3	Caurel	Luarca slates / Truchas Syncline / Middle Ordovician
4	Los Oscos	Luarca slates / Mondoñedo Thrust and Narcea Anticlinorium / Middle Ordovician
5	Valdeorras	Luarca slates, Casaio, Rozadais and Losadilla formations / Truchas Syncline / Ordovician
6	Alto Bierzo	Luarca slates / Truchas Syncline / Ordovician
7	La Cabrera - La Baña	Luarca slates, Casaio, Rozadais and Losadilla formations / Truchas Syncline / Ordovician
8	Riofrio	Luarca slates / Alcañices Syncline
9	Bernardos	Santa MariaBeds / Santa María la Real Massif / Precambrian
10	Villar del Rey	GevoraUnit / San Mamed - La Codosera Synclinorium / Devonian
11	Valongo	Valongo slates / Valongo Syncline / Middle Ordovician
12	Arouca	Valongo slates / Valongo Syncline / Middle Ordovician

From a stratigraphic point of view, the productive formations are as follows (Cárdenes et al., 2013):

- Santa María Beds, from the Santa María la Real Massif (Álvarez, 1982), belonging in turn to the Schists Greywacke Complex. Quarries are located to the North of Madrid, in the province of Segovia. The slates are slightly sandy, greenish-grey colored, with numerous sandstone and quartzite levels, more abundant to the top and bottom of the stratigraphic section. These are the roofing slates of the Iberian Peninsula which present the highest metamorphic grade, reaching the biotite isograde.
- Formation Cándana Green Slates (Compte, 1959), from the Group Middle Cándana. These are green slates and schists with abundant carbonates and centimetric cubic crystals of pyrite. The characteristic mineral for these slates is clinochlore, which gives them the green color. Outcrops are located in the province of Lugo, N Spain, in MondoñedoThrust Domain. These slates have a low fissility grade, being used mostly for flooring.
- Luarca Slates Formation (Barrois, 1882) is the largest roofing slate lithotect in the Iberian Peninsula. Main outcrops are found in the Truchas Synclinorium (Fig. 5)and El Caurel Domain (Marcos, 1973), covering the provinces of Lugo, Orense and León. It consists of a monotonous sequence of black slates with thin sandy levels. To the bottom and top of the stratigraphic section there are volcano-sedimentary levels, and to the middle part there is an iron nodule level, which in some localities have been quarried. The slate is black, fine grained, with abundant iron sulfides to the top. In the slates from El Caurel Domain is usual to find chloritoid well developed, visible with naked eye. In N Portugal, the equivalent lithotect is the Valongo Slates Formation (Romano and Diggens, 1974).

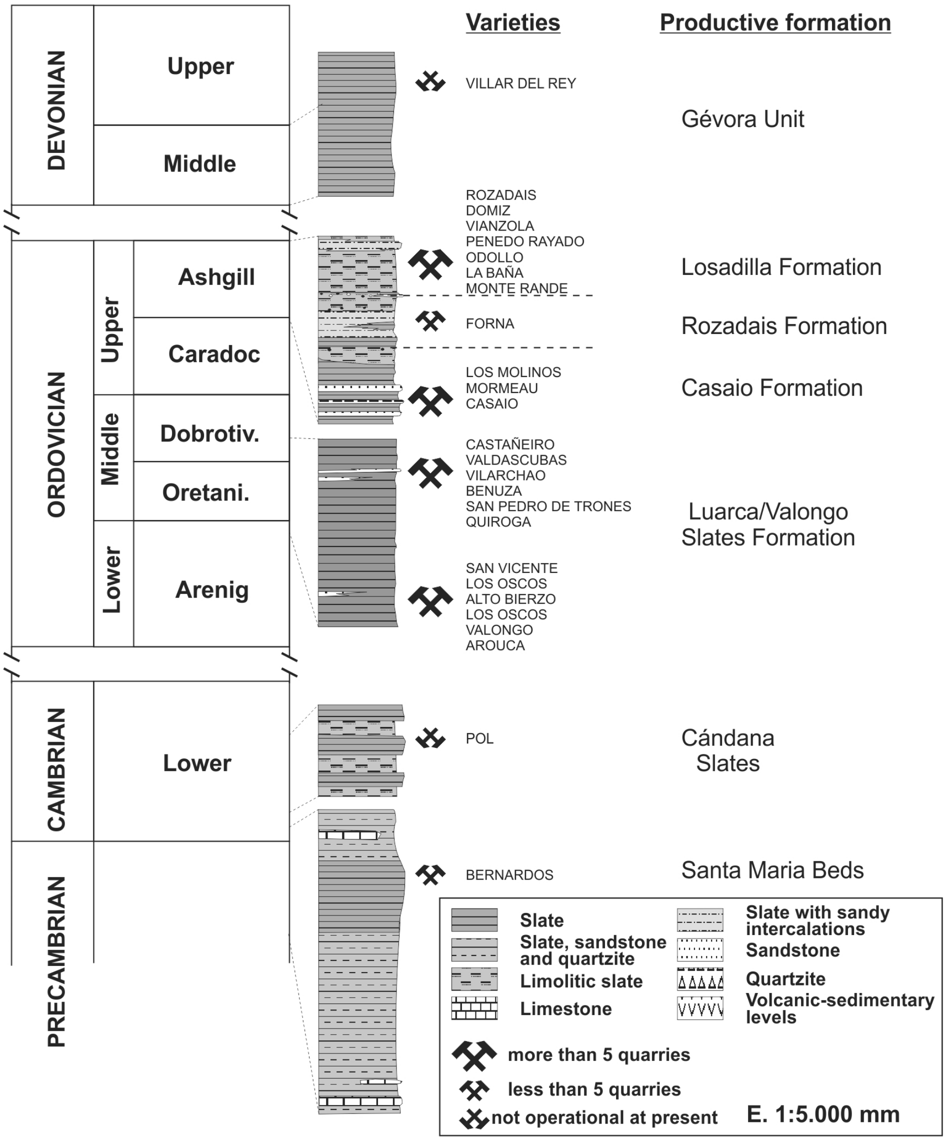

Figure 4. Stratigraphic column for the Iberian Peninsula slate varieties.

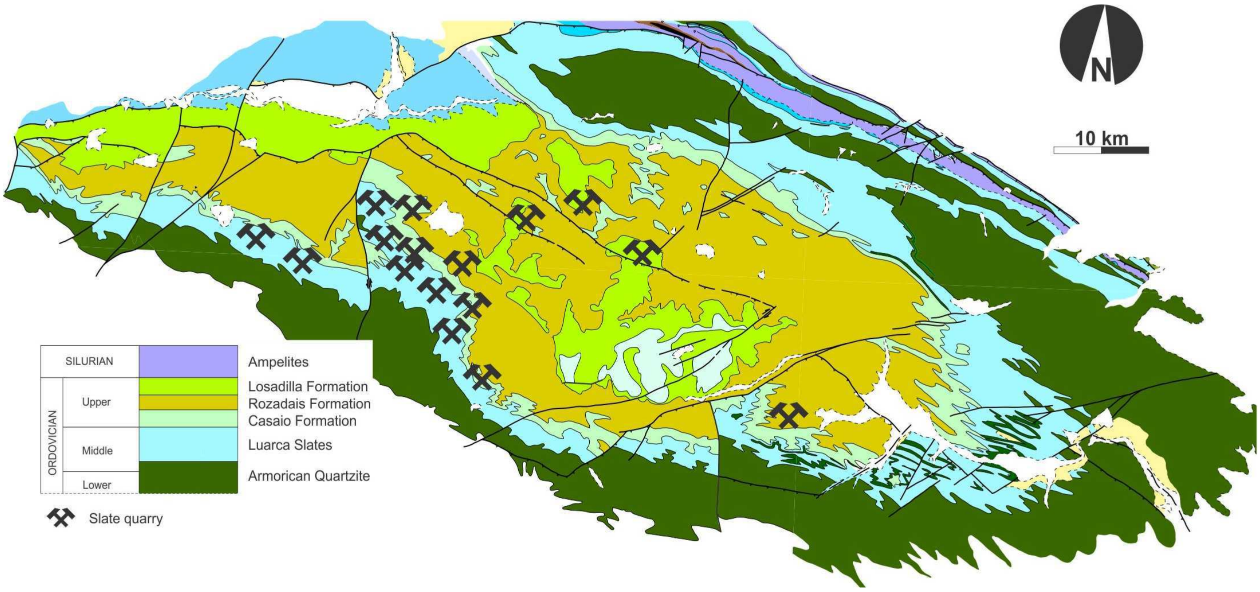

Figure 5. Geological map of the Truchas Syncline, with the main slate outcrops represented. Modified from Heredia et al., unpublished.

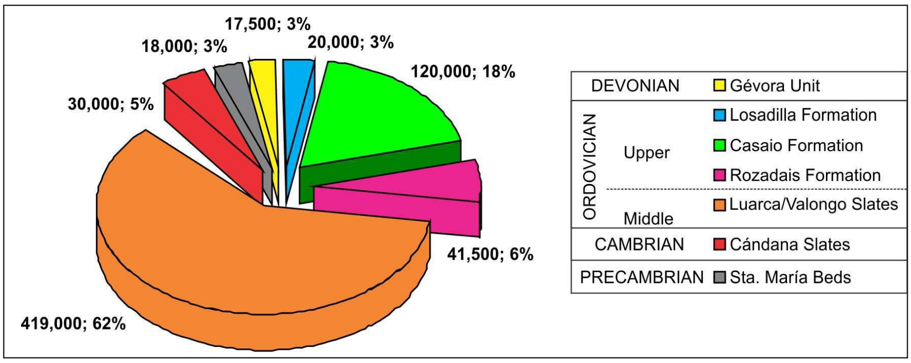

Figure 6. Slate production by Formations. Data from UNSTATS, United Nations Comtrade, 2009.

- Casaio, Rozadais and Losadilla formations (Barros, 1989) for the Truchas Syncline Domain, and Agüeira Formation (Marcos, 1973), outside the Syncline. Casaio Formation consists of light grey slate, with coarse detritic lithologies and iron sulfides. Most of the quarries are placed in this formation. Rozadais Formation has predominance of slaty terms, with some quartzite intercalations, and fragments of limestone and sandstone to the top. These pelite fragments (pelítes à fragments) can be recognized in other localities of the European Hercynian chain. Finally, Losadilla Formation, the less productive, is represented by light grey slates with sandy laminations, with high quartz content.
- Gévora Unit (Santos-García and Casas, 1979), in the southern area of the Central Iberian Zone, in the province of Badajoz. The outcrops are located in the La Codosera-Puebla de Obando Synclinorium. These slates are black, medium grained, homogeneous, with abundant inclusions of cubic pyrite and organic matter.

The main, by far, productive formation is the Luarca Slates, from Middle Ordovician (Barrois, 1882), mainly quarried at the Truchas Syncline (Catalan et al., 1992). Other Ordovician formations (Casaio, Rozadais and Losadilla) are quarried at the Truchas Syncline, with a considerable volume of production (Fig. 6).

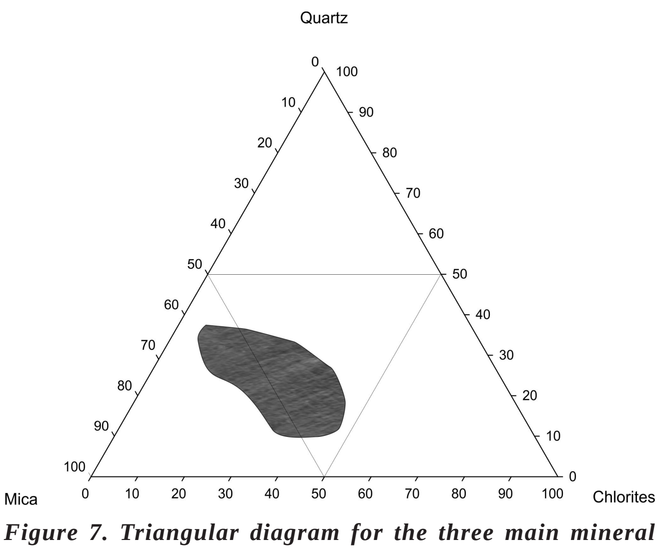

Figure 7. Triangular diagram for the three main mineral components. The shadowed area represents the average values for Iberian roofing slates.

Unifying characteristics of this province

The proposed GHSP comprises the roofing slates from the Iberian Peninsula. By definition, roofing slates are a fine grained group of stones which have the ability to be split into thin, plane and large tiles. In the Iberian Peninsula two types of rocks agree with these conditions, slates *s.s.* and phyllites (Arkai et al., 2007). Technical characteristics of these rocks are very similar. As a general condition, they fulfill the requirements of the European Norm for roofing slates EN 12326 (AEN/CTN_22, 2011). The main characteristics that together form a good slate tile are mineralogy and geochemistry (weatherability) and petrographic texture (fissility).

Iberian roofing slates are very uniform in mineralogy, with three main minerals (quartz, mica and chlorites, Fig. 7) and some accessories like chloritoid, iron sulphides, carbonates, organic matter, rutile and tourmaline.

Regarding to the geochemistry, the elemental composition of the Iberian slates is rather homogeneous (Fig. 8). The average values and standard deviation (in brackets) for the major elements are SiO_2: 56.03(3.35), Al_2O_3: 22.09 (1.97), Fe_2O_3: 8.06 (1.33), MnO: 0.09 (0.03), MgO: 2.37 (0.52), CaO: 0.44 (0.23), Na_2O: 1.29 (0.73), K_2O: 4.05 (0.73), TiO_2:1.15 (0.22), P_2O_5: 0.16 (0.16).

From a petrographic point of view, the texture of the slates is very characteristic, lepidoblastic or porfiro-lepidoblastic (Fig. 9). This texture always shows a penetrative slaty cleavage, with clear alignments of the clasts. There is a special requirement of the EN 12326 for roofing slates regarding to petrography, that is the calculation of the Mica Stacking Index (MSI). This index calculates the density and thickness of the mica levels that form the slaty cleavage planes, and it is related with the fissility(Cárdenes et al., 2010).

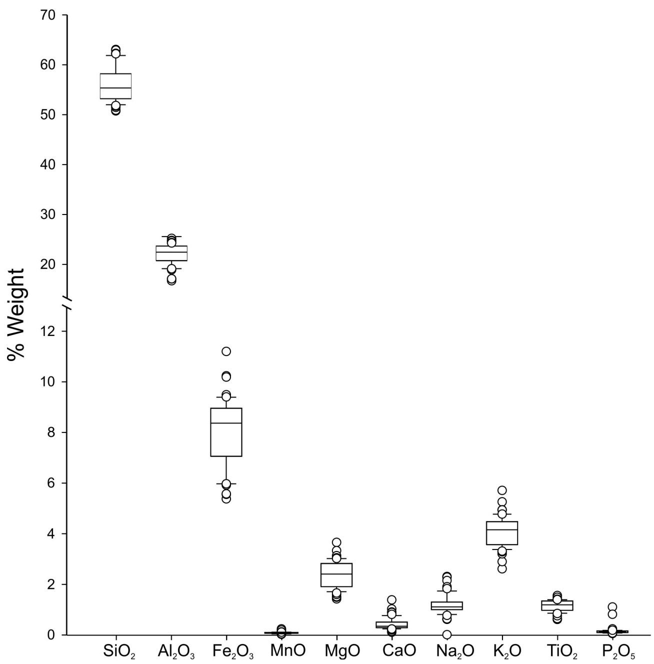

Figure 8. Major elements composition for Iberian roofing slates.

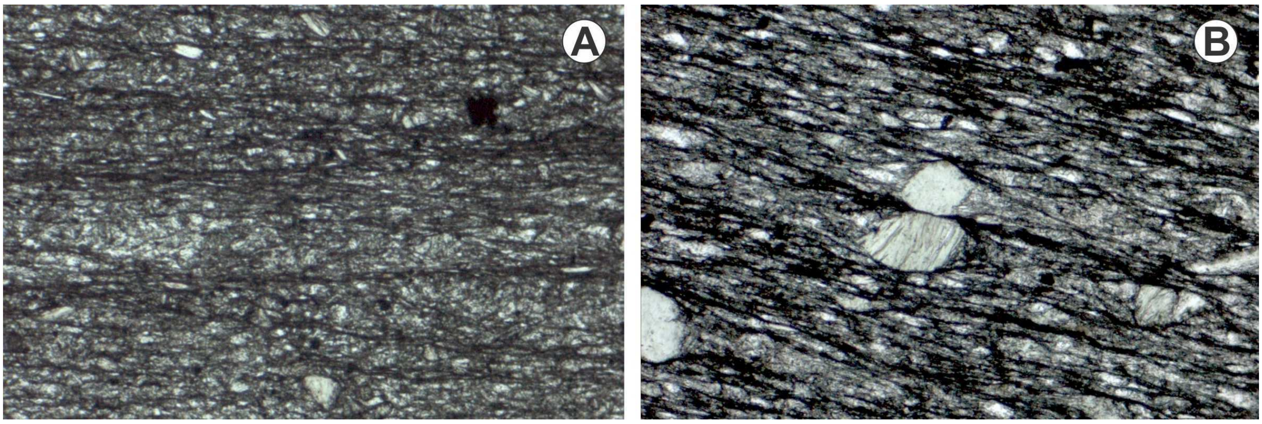

Figure 9. The two characteristic microscopic textures for Iberian roofing slates. (A) Lepidoblastic texture, Luarca Slates Formation, Valdeorras. (B) Porphyro-lepidoblastic texture, Rozadais Formation, Valdeorras. Both microphotographs taken with parallel nichols, 200x magnification.

Natural variation of geology within this province

The geology of the different areas that form the proposed province falls within the Hercynian of the Iberian Peninsula. However, all these areas have some important geological features in common. All of them are located in the Hercynian terrains of the Iberian Peninsula, showing none or very slight deformation; otherwise it would be impossible to obtain regular tiles. The metamorphic range is rather short, from 200 to 400 °C of temperature and 20 to 40 MPa of pressure. The original sediments were in all cases pelites (Cárdenes et al., 2013).

Vulnerability

There are enough reservoirs in all the districts, with the exception of the district of Bernardos. This district has been quarried from more than 500 years, and now it is close to its exhaustion. However, there is always the possibility to continue the works by opening a mine, like in other countries (France, Germany) that have been quarrying slate for hundreds of years. This option has been taken into account by several companies in Bernardos but also in other districts, such as Valdeorras and La Baña. In case there would be needed substituting slate from a heritage building with a different source slate, a protocol of acting has been developed (Cárdenes et al., 2014; Prieto et al., 2011), taking into account the mineralogy and aesthetics of the slate.

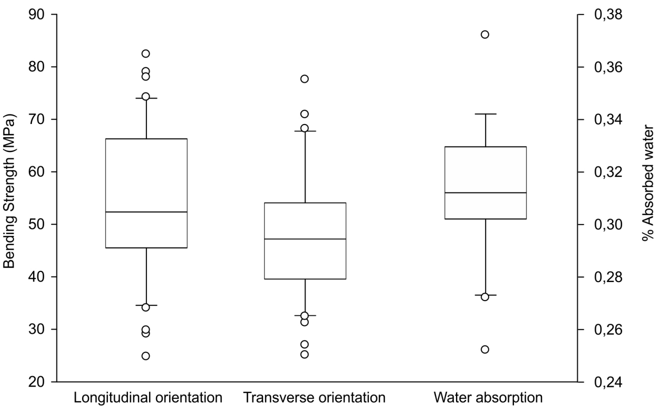

Figure 10. Average values for bending strength (right) for both longitudinal and transverse orientations. On the left, average values for water absorption. Data from the Technological Center of Slate, Sobradelo de Valdeorras, Spain.

Construction

Nowadays, about 80% of recent buildings in Europe with slate covershave Iberian slate. Also, many buildings from the European heritage have been restored with Iberian slate, or still keep the original slate, as in the case for El Escorial Palace in Spain.

Technical and aesthetic characteristics for Iberian roofing slates are very similar. The tests needed for commercializing, according to EN 12326, are bending strength (calculated in both longitudinal and transverse orientations respect of the tile), water absorption (Fig. 10), freeze-thaw resistance, oxidizability by thermal cycling and petrographic characterization. This set of tests is focused on the requirements of a roofing material. From a durability point of view, roofing slates can be affected by two main pathologies, oxidation and gypsification. The oxidation is the result of the weathering of the iron sulphides (mainly pyrite and pyrrhotite) that the slate may content, while gypsification is the transformation of the carbonates to gypsum. The relative abundances of the potentially harmful minerals are between 0 and 4% for iron

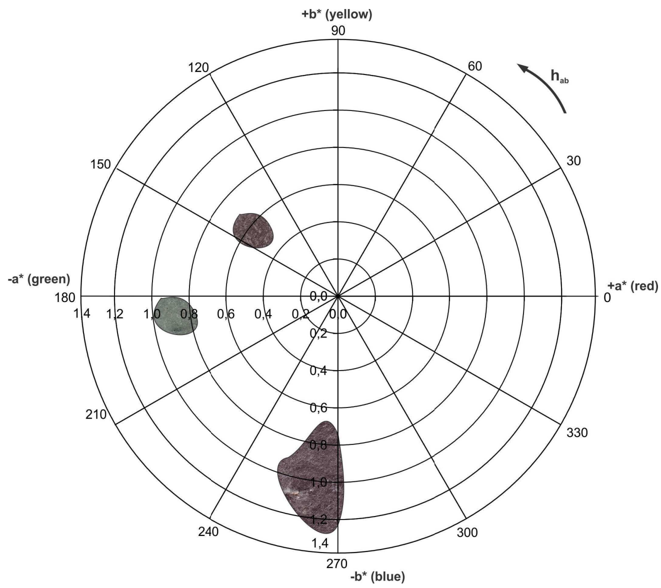

Figure 11.CIELAB color space: representation of the area in which the chromatic parameters: a*, b*, C*ab and hab of the slates studied are included. Shaded area corresponds to the average coordinates for Spanish roofing slates.

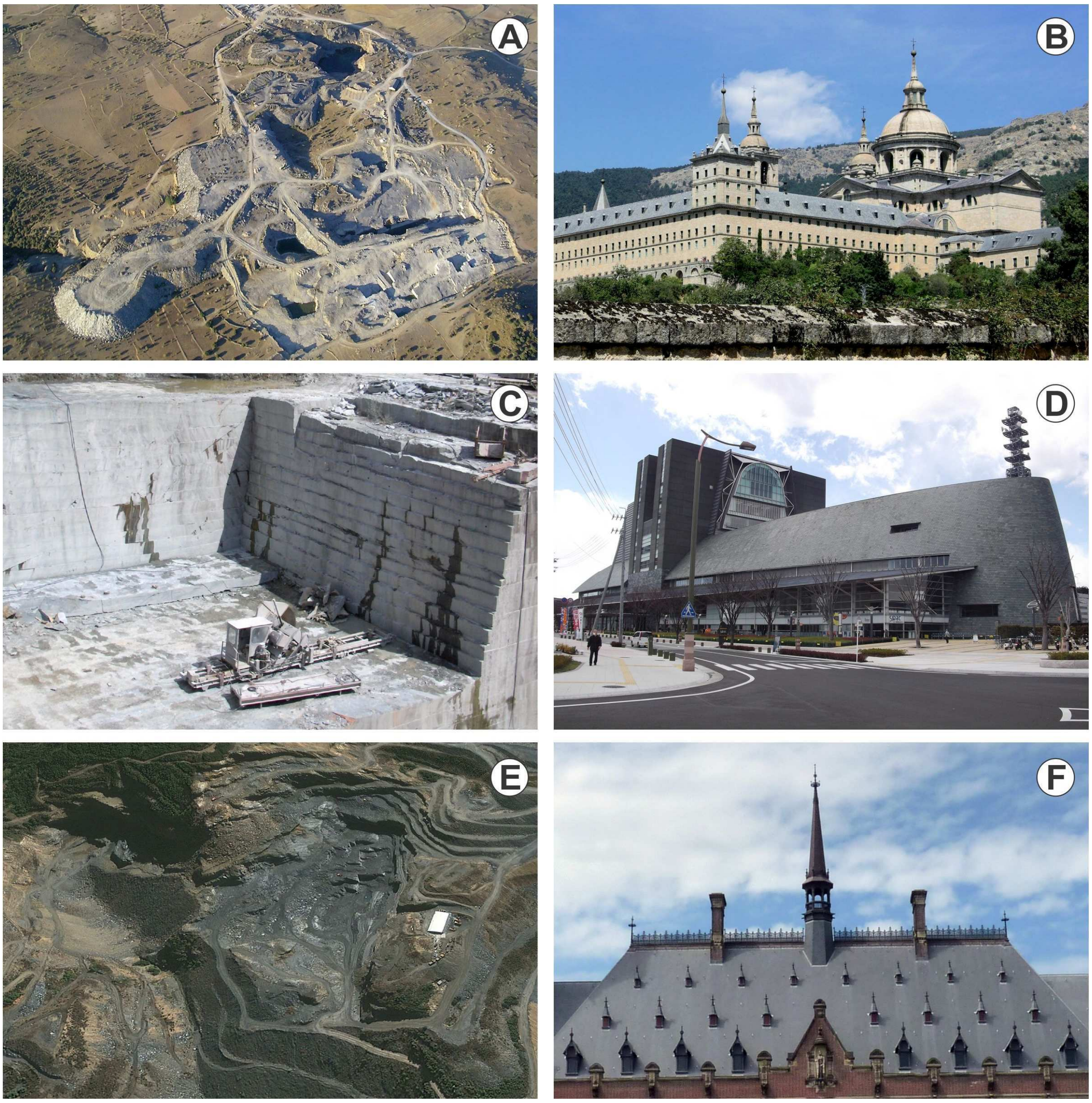

Figure 12. Some of the most important representative Iberian slate quarries, together with emblematic buildings made with their slate: A. Quarry from Bernardos, Segovia, Spain.Image: Pizarras J. Bernardos. B. Royal Monastery of San Lorenzo de El Escorial (1563-1584), Spain, one of the most important buildings in Spanish Heritage constructed by and for King Felipe II, originally covered with slate from Bernardos. C. Quarry for the variety Verde Pol, in Lugo, Spain. D. Shizouka Convention and Arts Center (1999), Shizouka, Japan, made with Verde Pol Photo: IPISA. E. Quarry from Los Molinos, Ourense, Spain. Image: Google maps. F. Peace Palace (1907 – 1913), The Hague, The Netherlands, place for the International Court of Justice, slate from Los Molinos quarry.Image: CUPA Pizarras.

sulphides and between 0 and 2% for carbonates.

Regarding to aesthetics, slates have colors ranging from black dark to light grey, with the exception of the phyllites from Lugo, that are light green (Fig. 11).

Some examples of representative buildings (Fig. 12) made with Iberian roofing slate are:

- The Peace Palace (1907-1913), The Hague, The Netherlands.
- Merlemont Castle (17th century), Val d'Hermeton, Philippeville, Belgium.
- Baelen Castle (17th century), Welkenraedt, Belgium.
- Mitsubishi Ichigokan Museum of Arts (1864), Tokyo, Japan.
- Church Notre Dame, Laeken, Brussels, Belgium (1854).
- Kerfily Castle (1858-1863), Elven, Morbihan, France.
- Pontevedra Auditorium, Spain.
- Shizouka Convention and Arts Center (1999), Japan.
- Royal Monastery of San Lorenzo de El Escorial (1584), Madrid, Spain.
- Royal Mint House (1580), Segovia, Spain.
- Palace of Cardenal Espinosa (1572), Segovia.
- Santa Cruz Palace (1629-1643), Madrid, Spain.
- Parish church of Santa Bárbara (former Royal Monastery of La Visitación, 1757), Madrid, Spain.

Conclusions

The Iberian Peninsula is, nowadays, the main producer of roofing slates of the world. As pointed before, about 80% of the world's production comes from the Iberian Peninsula. Roofing slates from the Iberian Peninsula are rather homogeneous both from constructive and petrological points of view, with only some differences among them in color and mechanical performance. They are present in many of the European building heritage and also in actual buildings. These facts give sense to the proposal of a *Global Heritage Stone Province* for the Iberian roofing slate.

Acknowledgements

Victor Cárdenes is grateful to the Foundation for the Scientific Research (FWO) from the Flanders Government, Belgium, for his Pegasus Marie Curie Fellowship.

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Alpedrete granite (Spain). A nomination for the "Global Heritage Stone Resource" designation

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(Received September 12, 2014; Revised accepted November 01, 2014)

Alpedrete granite is a monzogranite quarried in the Sierra de Guadarrana *(Spanish Central System) foothills in and around Alpedrete, in the province of Madrid, Spain. Used as a building material since the Neolithic, it is one of the most representative of heritage granites of Madrid.*

Alpedrete and the surrounding region are characterised by a quarrying culture that has been maintained for centuries. The area is strewn with historic quarries, along with the one presently in operation. Traditional stone cutters who produce hand-finished granite ashlars are still to be found, while others use more modern techniques to achieve new types of products.

Representative monuments including Royal Palace of Marid, Alcalá Gate and the National Library owe their good conservation state largely to the petrophysical properties and durability of Alpedrete granite. In addition to its use in a substantial number of heritage buildings in Madrid, this stone is also found in most of the city's housing, urban furniture and cobble-stoned streets and nearly all the rural architecture in the Alpedrete area.

This paper discusses the petrological and petrophysical properties of Alpedrete granite, as well as its durability, historic use and quarries, in support of its nomination for the "Global Heritage Stone Resource" designation.

Introduction

The granite in Madrid's *Sierra de Guadarrama*, traditionally commercialised under the name *Piedra Berroqueña*, has been the building stone most widely used in central Spain throughout the region's history. Specifically, a Carboniferous (302 M.a) (Villaseca et al., 2012) monzogranite with cordierite as an accessory mineral (Figure 1), has been quarried for centuries at Alpedrete, a town approximately 45 km north of Spain's capital city. This was the stone most frequently chosen for Madrid's built heritage due to the abundance and quality of the material and proximity of the quarries (Fort et al., 2013). Its role in the city's heritage, along with its petrography, petrophysics, mechanical and aesthetic properties and durability make this granite a worthy nominee for the Global Heritage Stone Resource (GHSR, Cooper, 2010; Cooper et al., 2013a) designation. The present account of the history and usage of Alpedrete granite and its traditional and modern quarries aims to establish its distinctive identity.

This paper discusses the characteristics and legacy (Table 1) of the stone in sufficient detail for GHSR assessment by the Heritage Stone Task Group (HSTG) Board, as specified in the Task Group's Terms of Reference. HSTG establishment is narrated by Cooper et al. (2013b). Alpedrete granite might be regarded as the first of several dimension stones that could contribute to the *Piedra Berroqueña* region's designation as a "Global Heritage Stone Province".

Alpedrete granite, a grey stone that may contain microgranular mafic nodules (Villaseca et al., 1998), has left its imprint on Madrid's architectural personality and forms part of most of the city's buildings and streets.

Criteria for GHSR recognition

The following description of Alpedrete granite addresses all the features required of GHSR nominations (Cooper et al., 2013a; Hughes et al., 2013).

The importance of granite in the villages around Alpedrete (Figure 2) is mirrored in the stone-related etymology of some of their toponyms. Examples are *Alpedrete* itself (stone in Spanish is *piedra*) and *Berrocal* (in Spanish, an outcrop of granite boulders), names such as *Moralzarzal* are based on the pre-Roman roots *mor(r)* or *mur(r)*, meaning a pile of stone. These and other villages made stone quarrying their way of life: for centuries with the area's economic activity revolving around granite quarrying, hewing and transport. This long quarrying tradition led to the founding of many small historic, family-run quarries (Figure 3A) where the trade was and still is deeply rooted. The many monuments to the quarryman also attest to the determination to keep stone quarrying traditions alive (Figure 3B).

Alpedrete granite is regarded as a traditional building stone (Fort et al., 2008, 2013). Any number of scientific articles have been published on its origin (Villaseca et al., 1998, 2009, 2012; Villaseca

Table 1. Representative monuments in the Madrid region built with Alpedrete granite and other types of stone

Building	Year built	Fountains	Year built
Dolmen at Entretérminos	2500-3000 BCE	F. of Titans	1657
El Beneficio-Miaccum Roman archaeological site	Before the 4th century	F. of Fame	1731
Asunción de Nuestra Señora Church at Alpedrete	12th-13th centuries	F. of San Antón	1770
Toledo Bridge	1719-1732	Artichoke F.	1781
Madrid's Royal Palace	1738-1764	Galapagos F.	1832
Façadeon San Nicolás de los Servitas Church	1740 aprox.	King Philip IV F.	1843
Prado Museum	1785-1808	Fallen Angel F.	1880
Alcalá Gate	1770-1778	F. of the Shell	1969
House of the Five Major Guilds	approx. 1789	**Sculptures**	**Year sculpted**
Royal Theatre in Madrid	1830-1850	Hercules and the Lernean Hydra	1650
National Library	1866-1892	Obelisk to the 2nd of May	1821
Bank of Spain	1884-1891	Queen Isabel	1883
Cervantes Institute	1925-1929	Monument to King Alfonso XII	1901
Joint Ministry Headquarters	1933-1942	Miguel de Cervantes	1916
Valley of the Fallen Monument	1940-1958	Princess Isabel de Borbón	1953
Addition to the Bank of Spain	2003	Jacinto Benavente	1961

and Herreros, 2000, historic quarries (Fort et al., 2010, 2013), petrology (Gómez-Heras et al., 2008), petrophysics (Fort et al., 2011), technical properties and durability (Gómez-Heras, 2005; López-Arce et al., 2010, 2011; Fort et al., 2011), as well as the buildings on which it is found (Fort et al., 2004, 2010, 2013; Menduiña and Fort, 2005; Pérez-Monserrat et al., 2013).

Alpedrete granite properties

Petrography, petrographic name and commercial designation

Alpedrete granite is an equigranular, medium- to fine-grained monzogranite (Figure 1) consisting of interlocking plagioclase aggregates (20-30 vol. %), quartz (2–5mm 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.

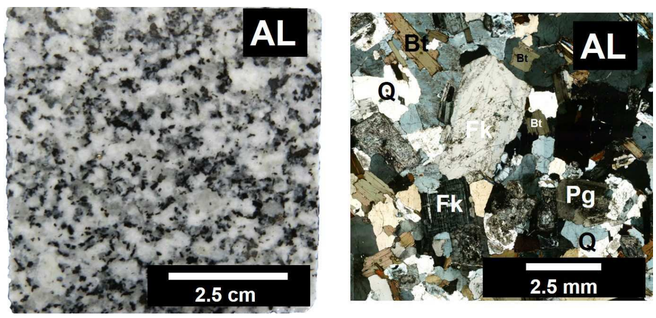

Figure 1. Alpedrete granite from historical quarries: left, macroscopic image; right, thin section petrographic image: Bt: biotite, Pg: plagioclase, Q: quartz, FK: potassium feldspar.

Alpedrete granite have micro-granular mafic enclaves, usually with a tonalite composition show fine-grained porphyritic textures, with phenocrysts commonly of millimetric size. (Gómez-Heras et al., 2008).

Chemical composition

The standard chemical analysis of Alpedrete granite given in Table 2 reveals its homogeneity.

Table 2. Mean chemical composition of Alpedrete granite (Villaseca et al., 1998).

Chemical analysis: majority elements in Alpedrete granite (wt%)										
SiO_2	TiO_2	Al_2O_3	Fe_2O_3	FeO	MnO	MgO	CaO	Na_2O	K_2O	P_2O_5
69.6	0.4	15.02	2.97	1.54	0.05	0.96	2.45	3.32	3.89	0.16

Colour

Alpedrete granite is grey, with slight variations in tone. Its chromatic parameters are listed in Table 3. The colour values given are based on the CIELAB scale (1976): lightness (L*), chromatic coordinates a* and b*, whiteness index (WI) and yellowness index (YI), as set out in standard ASTM E313-73.

Table 3. Chromatic parameters

	Alpedrete granite
L*	67.4 ± 3.5
a*	-0.7 ± 0.3
b*	1.0 ± 0.8
YI	1.8 ± 1.6
WI	34.5 ± 3.8

Natural Variability

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.

Physical properties

Alpedrete granite owes its long durability and resistance to weathering to its physical properties. Table 4 lists the values of these properties as reported by several authors.

Table 4. Physical properties in Alpedrete granite (AL). (1) Mendiuña and Fort., 2005, (2) Fort et al., 2011, (3) Fort et al., 2013.

Property	Value
Impact strength (cm)	68±14 (1)
Compressive strength (MPa)	136.9±41 (1)
Bending strength (MPa)	8.88±3.69 (1)
Bulk density (Kg/cm^3)	2669±17 (2)
Water absorption (%)	0.3±0.0 (2)
Capillary absorption coefficients ($g \cdot m^{-2} \cdot s^{-0.5}$)	1.523 to 3.1983 (2)
Porosity accessible to water (%)	0.8±0.1 (2)
Mercury intrusion porosity (%)	0.5 (3)
Frost resistance (%)	0.01 (1)
Ultrasonic P-wave velocity (m/s)	4601±204 (2)
Total anisotropy (%)	5.8 (3)

Durability

Alpedrete granite is found in heritage buildings that have resisted weathering for centuries. Decay in this stone adopts the form of cracking, surface scaling (Figure 4J), efflorescence, stains or granular disintegration and resulting volume loss. These weathering forms are due primarily to climate, air pollution or the presence of salts (López-Arce et al., 2010; Pérez-Monserrat et al., 2013), in conjunction with factors such as vandalism (Figure 4K). Where microgranular nodules are present (Figure 5D), differential decay may be observed between the nodule and the surrounding rock (Gómez-Heras et al., 2008).

To quantify the decline in petrophysical values, freeze-thaw testing was conducted as specified in European standard EN 12371: 2001 (140 cycles), while salt crystallisation trials were performed further to Spanish and European standard EN 12370:1999 (30 cycles) (López-Arce et al., 2010). The variations observed in the stone's petrophysical properties after these ageing tests are given in Table 5.

Laboratory-accelerated decay included surface cracking, generated especially in the feldspar (freeze/thaw test) and biotites (salt crystallisation). Severe decay has been observed in ornamental elements carved from Alpedrete granite on heritage buildings. Such decay is induced by human action: pollution, urination, rust in the iron anchorages used to join ashlars, breakage of downpipes, conservation treatments (Fort et al., 2004; Varas et al., 2007) or the use of inappropriate mortars (Muñoz, 2003).

Table 5. Petrophysical properties in Alpedrete granite before and after 140-cycle freeze-thaw and 30-cycle salt crystallisation testing. Vp: ultrasonic P-wave velocity; Δ : property variation, measured in percentage (Source: López-Arce et al., 2010)

Property	Initial value	After 140-cycle freeze-thaw test	Δ (%)	After 30 cycle-salt crystallisation test	Δ (%)
Porosity accessible to water (%)	0.8±0.08	-	-	1	25.0
Bulk density (kg/m^3)	2668±18	2666±12	0.06	2 660	-0.3
Vp (m/s)	4620±163	4525±139	2.0	4445	-3.8
Mercury intrusion porosity (%)	0.44	0.62	40.9	1.01	129.5
Microporosity < 5 µm (%)	0.31	0.48	54.8	0.32	3.2
Macroporosity > 5 µm (%)	0.13	0.14	7.7	0.69	430.8

Quarrying, resource location and supply

Around 400 historic, generally small, shallow quarries (Martín, 1994) (Figures 2 and 3A), where the stone 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 whale-back 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 (Figure 2). Beginning in the 1980s, as a result of their inability to adapt to new environmental regulations, many of the small traditional quarries have been closing.

Figure 2. Location of the historic Alpedrete granite quarries: (1) Alpedrete, (2) Collado Mediano, (3) Becerril de la Sierra, (4) Mataelpino, (5) El Boalo, (6)Cerceda, (7) El Berrocal, (8) Moralzarzal (modified after Fort et al., 2013a).

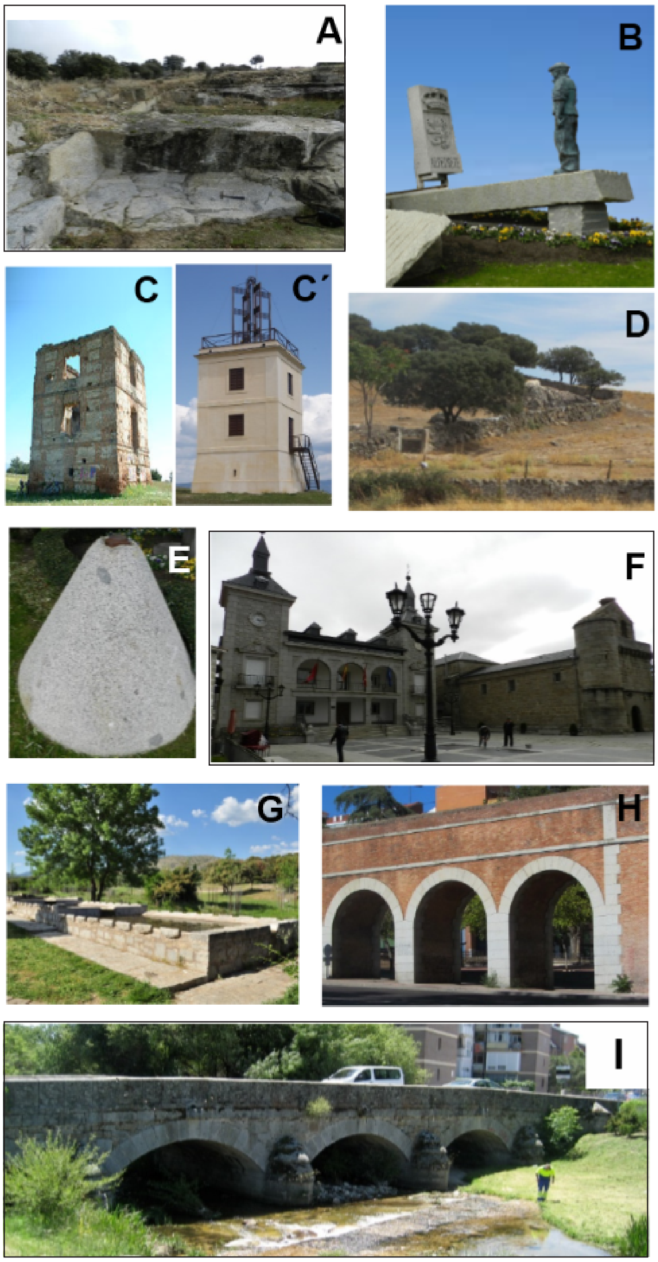

Figure 3. (A) Alpedrete historic quarry, front, (B) Monument to the quarryman, Alpedrete, (C) Optical Telegraph Tower at Collado Mediano before conservation-restoration works, (C´) After conservation-restoration works, (D) Typical granite boundary wall in Alpedrete, (E) Cone for crushing olives, (F) City Hall, Alpedrete (1959) and Asunción de Nuestra Señora Church (12^{th}-13^{th} centuries); (G) Washing place, Alpedrete, (H) Amaniel aqueduct, (I) Rosario Bridge, second half of 17^{th} century.

One quarry at Alpedrete whose operations can be traced back for over 100 years is still active. Its 6000-m^3 yearly outputs guarantee the supply of dimension stone.

Historic use

The Neolithic dolmen at Entretérminos between Alpedrete and Collado Villalba, whose remains are still standing was one of the first structures in which Alpedrete granite was used as a building stone. Part of a Roman granite building is preserved at the El Beneficio-Miaccum archaeological site in Collado Mediano. No monumental works were built during the Visigoth period (4^{th}-8^{th} centuries) or none has survived (Menduiña and Fort, 2005). The Muslim era was characterised by the development of materials such as brick and the reuse of the stone from Roman buildings. It was not until the Christian reconquest of Toledo in 1085 that Churches started to be built in central Spain (Figure 3F) with, among other materials, Alpedrete granite. Since building materials were sourced from nearby locations during the Middle Ages (8^{th}-15^{th} centuries), Alpedrete granite was used in the entire area. Widespread use of *piedra Berroqueña* began after King Philip II moved the court to Madrid in 1561. Quarrying was nonetheless most intense at the time in the area around Zarzalejo, SW of Alpedrete, which while forming part of the same pluton (Villaseca et al., 2012), is characterised texturally by larger grain size and mineralogically as a different stone lacking cordierite. It was not until the 18^{th} century that Alpedrete granite became the stone most widely used in and around Madrid and when most of Alpedrete area quarries started to work (Fort et al., 2011). This material was used in many works during the reign of Charles III (1759-1788). It was used to cobble stone avenues and lay gutters, as well as to build monuments such as Madrid's Royal Palace (Figure 4A), Alcalá Gate (Figure 4B), Artichoke Fountain, Prado Museum (Figure 4D) and hospitals such as the one presently bearing the name Queen Sofia. One of the most prominent monuments outside Madrid is the Guadarrama (or Rosario) Bridge (Figure 3I). In the $18^{th}$and 19^{th} centuries, Alpedrete granite was generally used in conjunction with the Colmenar limestone quarried in the Madrid basin (Fort et al, 2014), yielding the grey stone - white stone contrast so typical of Madrilenian architecture (Figures 4A, 4B, 4D, 4J and 5F).

The mid-19^{th} century construction of the Isabel II Canal that carries water to Madrid from the *Sierra de Guadarrama* spurred activity in the Alpedrete area quarries, whose granite was in constant demand to build waterworks (Unceta, 2005) in Madrid such as the Amaniel aqueduct (Figure 3H). Likewise in the 19^{th} century, Alpedrete granite was used in the new city quarters built to accommodate Madrid's expansion. To meet the strong demand, for 73 years (1883-1956), an 11-km railway line (Aranguren, 1990) operated exclusively to ship Alpedrete granite 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 (Figure 2). From there it was hauled to Madrid together with granite from other nearby quarries, simplifying and lowering the cost of transport.

With the founding in 1914 of the Sociedad de Sacadores de Piedra de la Sierra (society of stone extractors), whose membership included most of the quarrying villages, and the Sociedad Construcciones Hidráulicas y Civiles (Hydraulic and Civil Construction Society), Alpedrete became the area's leading building stone producer. With the return of the quarries to individual management when these two societies disappeared in 1925, output declined.

Work in the quarries was suspended during the Spanish Civil War (1936-1939). While Alpedrete granite resisted the ravages of war, the bullet holes are visible on the ashlars in some of Madrid's heritage buildings (Figure 4I).

In the 1940s and 1950s, Alpedrete granite was used to rebuild Madrid and, along with other types of granite, the 'Valle de los Caidos' (Valley of the Fallen) monument. The output of Alpedrete granite rose in the 1960 showing boom, driven by Madrid's rapid population growth.

Figure 4. Monuments built with Alpedrete granite. (A) Façades, Royal Palace at Madrid, (B) Alcalá Gate, (C) Portal, San Nicolás de los Servitas Church, (D) Façade, Prado Museum, (E) Bank of Spain, (F) Chimney, Royal Palace at Aranjuez, (G) Detail of window ornament, (H) Façades, Cervantes Institute, (I) Ashlars damaged by bullets during the Spanish Civil War, (J) Surface scaling on enclosure wall, (K) Ashlars soiled by graffiti.

Today this stone is used primarily in flooring (García del Cura et al., 2008). Other uses include cobblestones, funeral art, and building and monument restoration and rehabilitation across the region of Madrid. The Bank of Spain, rehabilitated in 2003, is but one example (Figure 4E).

Heritage issues

Many of the surnames of the inhabitants of Alpedrete and surrounding quarrying villages can be traced back to other quarrying areas in northern Spain. Because of the huge demand for Alpedrete granite, many workers from the north migrated to the mountains around Madrid to work in the quarries there.

Examples of Alpedrete granite in industrial heritage include grinding stones for flour mills, cones to crush olives (Figure 3E) and mining infrastructure in the former silver mine at Moralzarzal (Soto, 2011). Along with brick masonry and granite rubble, Alpedrete granite is one of the materials that was used to build the grid of optical telegraph towers (1844). An Alpedrete granite tower has been conserved at Collado Mediano, although the 2008 restoration concealed the original masonry bond (a mix of brick and coursed rubble masonry) (Figures 3C-C'). Many examples of traditional rural architecture are also well preserved, including sheds, washing places (Figure 3G), drinking troughs, irrigation canals and boundary walls (Figure 3D). The Alpedrete granite-related heritage has been turned to value in the form of Geomonumental routes (*http://www.madrimasd.org/English/Science-Society/scientific-heritage/Geomonumental-Routes/default.asp)*, a platform that introduces the general public to the geological characteristics and cultural value of buildings bearing Alpedrete granite. These socially beneficial activities

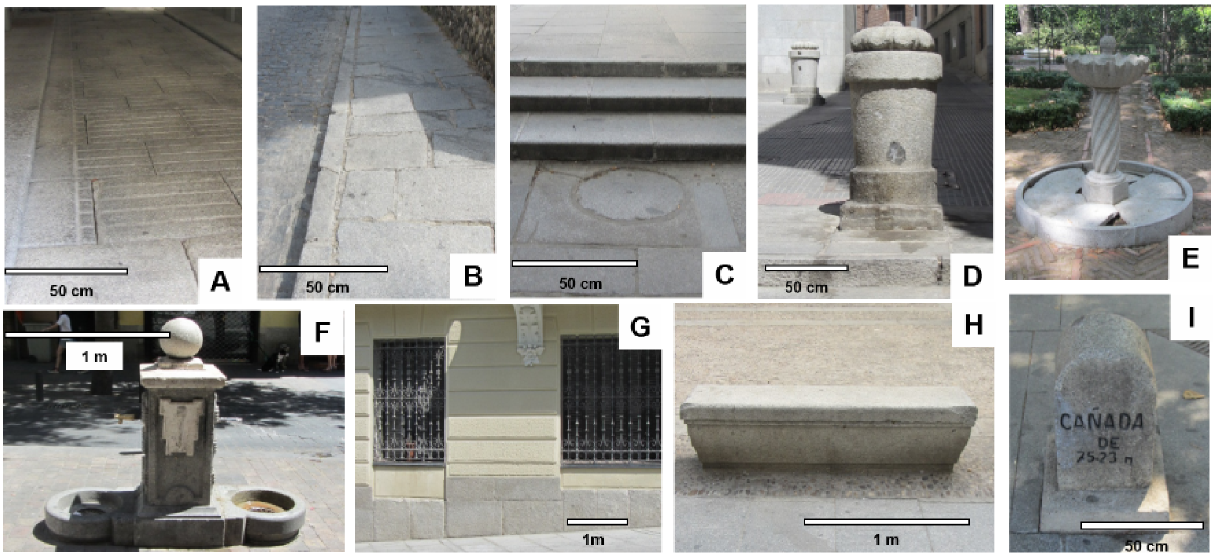

Figure 5. Alpedrete granite on Madrid streets and thorough fares: (A)Walkways, kerbs and carriageway, (B) Walkway, curb and cobblestones, (C) Staircase, street paving and sewage system cover, (D) Spur stone with nodule, (E) Ornamental fountain, (F) Functional fountain (Alpedrete granite and Colmenar limestone), (G) Dado on traditional building, (H) Bench, (I) Milestone on cattle route, Madrid.

have been conducted on site in recent years in the framework of Madrid's Science Week.

Buildings

Alpedrete granite is found in 75% of Madrid's cultural heritage assets. It was also used in nearly all heritage industrial buildings, housing in the city's traditional quarters, indoor sit was used in steeps of stairs, chimneys and outdoors, in dados or window frames, walkways, statues, fountains, milestones and urban furniture (Figures 4 and 5). Table 1 lists the most representative monuments built with Alpedrete granite, together with other types of building stone (Fort et al., 2002; Gómez-Heras and Fort, 2004).

Alpedrete granite vulnerability and maintenance

Thanks to its petrological and petrophysical characteristics, Alpedrete granite is highly resistant to the agents of decay (and consequently durable), usable with a variety of finishes and readily cleaned.

Pre-quarrying decay, gloss (micro-roughness), finish and position on buildings, however, condition the type of maintenance or cleaning required. The method used should not roughen the granite surface and special care should be taken in aged *piedra Rubia* quarried from very shallow tors where the feldspars and micas may have been significantly altered by the action of fluids and concomitant hydrolysis. In this process, potassium feldspar is replaced by kaolinite, plagioclase is converted to sericite and chloritization of biotite. Hydrolysis may also release iron from biotite. Cordierite alteration, in turn, yields pinite or micaceous clusters that decay more quickly, although cordierite is only rarely present in Alpedrete granite (Fort et al., 2013).

Suitability

The low anisotropy, capillary water absorption, porosity and high mechanical strength and durability (Tables 4 and 5) characterising Alpedrete granite render the stone exceptionally moisture-resistant. For that reason it has traditionally been used in pedestals, dados (Figure 5G) and building facades. Its scantly fractured outcrops are particularly suitable forcarving very large columns and lintels (Figure 4). It is used not only in structural members, but also in ornamental elements, especially around doors and windows (Figures 4C, 4G), chimneys (Figure 4F), pinnacles atop buildings, and to make bollards. This stone has also been used for cobblestones (Figure 5B), walkway kerbs (Figures 5A, 5B) (Martín, 1994), manhole lids (Figure 5C), wells, spur stones (Figure 5D), retaining walls, corner protectors, decorative (Figure 5E) and functional (Figure 5F) fountains, benches (Figure 5H) and milestones (Figure 5I) that are present throughout Madrid.

As may be deduced from the foregoing, Alpedrete granite meets all the requisites for a GHSR nomination. Its designation would contribute to raising awareness of historic and modern features essential to its conservation, while furthering more efficient use of this dimension stone as a restoration material in the heritage monuments it was used to build.

Acknowledgements

This study was funded by the Community of Madrid under the GEOMATERIALS 2 project (S 2013/MIT-2914). The authors are members of the Complutense University of Madrid's Research Group: "Alteración y Conservación de los Materiales Pétreos del Patrimonio" (ref. 921349). The petrophysical assessments were run at the IGEO Petrophysical Laboratory, affiliated with the Moncloa Campus of International Excellence (UCM-UPM) Heritage Laboratory Network (RedLabPat). The assistance, input and support provided by laboratory technicians Carmen Vázquez and Blanca Gallardo are gratefully acknowledged.

Manuscript edited by Margaret Clark, professional translator and English language science editor.

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by A. Bulakh

"Porphyries" from Russia and Sweden used in St Petersburg and Russian "porphyry" used in Paris: misuse of a geological term for some possible candidate as a Global Heritage Stone Resource

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(Received July 22, 2014; Revised accepted September 22, 2014)

The term "porphyry" has a specific geological meaning but has been used freely by sculptors and art historians to name many types of stone that are not, geologically, porphyries. "Porphyries" have been associated with nobility and Imperial Monuments since Roman times. This paper discusses some examples from Karelia in Russia and from Sweden used in St Petersberg and the use of Russian Shoksha "porphyry" in Paris, France. It highlights several types of stone that have been referred to as porphyries but are not. The Shoksha stone has been of architectural and artistic importance both nationally and internationally for some 300 years. This might qualify it as a candidate for Global Heritage Stone Resource status.

Introduction

The term "porphyry" has a specific geological meaning but has been used freely by sculptors and art historians to name many types of stone that are not, geologically, porphyries just as the term "granite" has been used for a wide variety of durable stones that take a good polish. This paper discusses some examples from St Petersburg in Russia and from Sweden.

Description of colour is also an issue because both "purple" and "scarlet" were both used in referring to colours of tunics and robes of nobles in Ancient Rome. It is understandable that stone in the continuum of colours from "purple" to "scarlet" should have become associated with nobility and Imperial monuments.

The most famous antique ornamental porphyry came from Gebel Dokhan in the Province of Egypt in the Roman Empire (Fig. 1) and has attracted names such as "Red Antique" and "Imperial" porphyry. Sculptures and the busts of Roman Emperors, sarcophagi (Fig. 2) and other masterpieces were cut from this stone, especially in extensive quarrying operations between the 1st and the 4th centuries A.D. From a petrographic point of view, this rock is a dacite-andesite porphyrite (Price, 2007, p. 203) which contains feldspar phenocrysts in a fine grained or glass-like groundmass (Fig. 3). Fine-grained piemontite gives colour to the stone.

Porphyries in St Petersburg

At the end of 18th century and during the 19th century "porphyry" became fashionable in decorating the facades and interiors of palaces and mansions in St Petersburg.

The first to be used was the Schoksha porphyry (Bulakh *et al.*, 2010, 2014). In 1801, this stone was used in friezesin the main façade of St Michael Castle (Fig. 4), a residence of the Russian Emperor Paul I. The same stone was used to design the interior of St Isaac's Cathedral (1818-1848). Steps to the altar and the bottom part of the iconostasis were hewn out of dark-red Schoksha stone. The same rock type was used for cornices topping walls as well as in the wide frieze of that stone that fringes the periphery of the floor of the cathedral. A bust to Auguste de Montferrand (Fig. 5), the architect of St Isaac's Cathedral, stands inside. The sculptor A. Foletti created the bust from the many kinds of stones that were used by Montferrand in building the cathedral. The face was carved from white Carrara Marble,

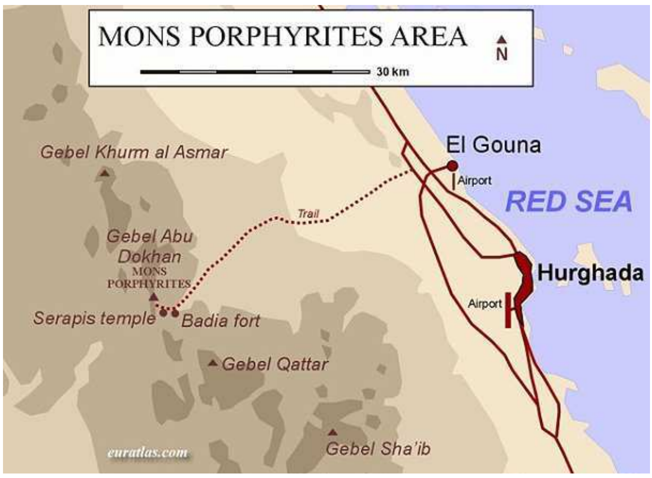


Figure 1. Location of Gebel Abu Dakhan.

Figures 2-6. (2) Sarcophagus of St Helen. Imperial porphyry from Egypt. (3) Texture of imperial porphyry. (4) Red porphyry-like stone in facade (St. Petersbury, St Michael Temple, 1797-1800). (5) Porphyry-like stone in the cloak of A. Montferrand . (6) Monument to Nicholas I. Red porphyry-like stone is a frame for high reliefs

the hair from grey granite, the collar of the uniform from slate, the cloak from crimson Schoksha stone, the cordon of green marble, and the orders from yellow Siena marble and also crimson Shoksha stone. Pink Tivdiya Marble from Onega Lake, Karelia, Russia, served for the pedestal of the bust.

The most memorable example of the use of this stone is the pedestal of the Tsar Nicholas I monument (Fig 6). Montferrand designed the monument and decorated it with red Schoksha porphyry, pink Rapakivi Granite, grey Serdobol Granite, and white Carrara Marble. The sculptor, P. Klodt, created the monument in an equestrian form.

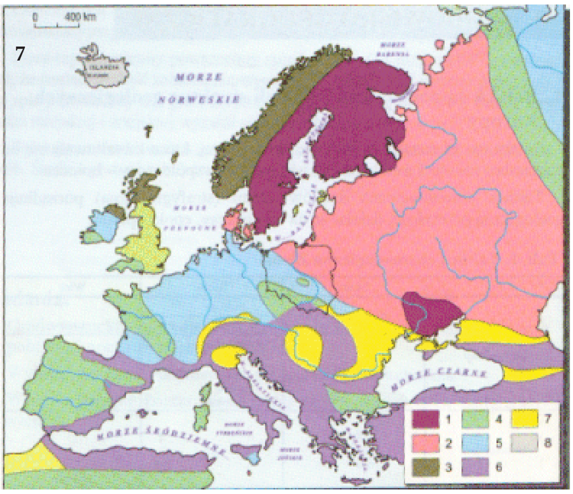
Superficially, Schoksha "porphyry" closely resembles the antique imperial porphyry from Gebel Dakhan but is, in fact, a Proterozoic quartzite. The only source is located in the Fenno-Scandian Shield, on the south-east coast of Lake Onega (Fig. 7). Many color varieties of Schoksha quartzite have been quarried here since the18th century. The stone is layered (Figs. 8, 9) and fine grained (Fig. 10)

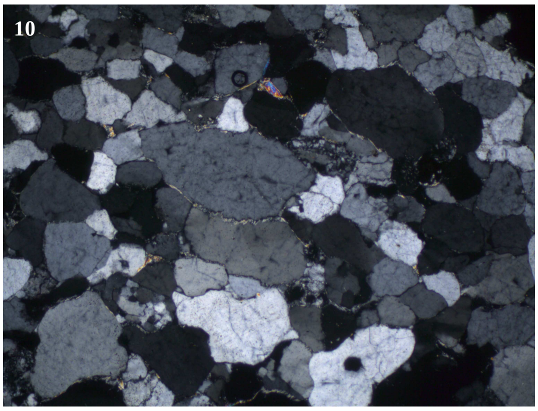
Secondly, there are many and varied examples of "porphyry" vases (Fig. 11), craters, amphora, bowls, obelisks, table-desks and other goods in collections of the State Hermitage (Mavrodina, 2007). These were manufactured by Russian masters at the Peterhof, Yekaterinburg and Kolyvan lapidary factories from 1790-1860. The majority of these masterpieces were manufactured from greyish-violet and grey stone taken from the River Korgon, in the Altai Mountains in Siberia. This is a fine-grained almost glass-like rock sometimes with flow texture and with fine phenocrysts of feldspar and quartz together with chalcedony and has been described as a "silicified porphyry" (Samsonov and Turinge, 1984, p.158-159), but the meaning of the word "porphyry", in this context, has not been stated clearly.

Swedish"porphyries" in St Petersburg

However, "porphyries" were also brought to St. Petersburg from elsewhere. Three stone vases that stand in the city of St Petersburg were worked by the Royal Porphyry manufacturing factory in Älvdalen, Sweden in 19th century. A pair of greyish-black vases (craters) arrived in 1830s. They firstly stood, together with two bronze lions,on the flanks of granite staircase to the Winter Palace (a residence of Russian Emperors) on the Neva River (Fig. 13). In 1914-1916, these vases were moved to flank another granite staircase, between the Admiralty and the Bronze Horseman (Bulakh *et al.*, 2014). The "porphyry" used is, geologically,a coarse-grained diabase (Bulakh *et al.*, 2006) locally known as Åsbo diabase after a village near the extraction site in Sweden (Hjelmquist, 1982). The vases are hollow and stoppered but broke into many pieces due to internal accumulation and freezing of water in the past decade. The Russian Master A. Androkhanov restored them, and they were returned to their place in May 2014 (Fig. 14).

The third vase was presented to the Russian Emperor Nicholas I by King Carl XIV Johan Bernadotte of Sweden. It was placed in the Summer Garden in 1839 and consists of four parts (Fig. 15), the neck, body, stem, and plinth, cut from Garberg granite (Bulakh *et al.*, 2006; Hjelmquist, 1982). In 1825, this stone was used to manufacture the famous Rosendal vase in Stockholm. The total height of the vase in the Summer Garden with its pedestal is 4.85 metres. The pedestal is made of Blyberg porphyry, and "porphyry" is a geologically





Figures 7-10. (7) Location of the Schoksha Deposit. 1-8 – different tectonic zones of Europe. (8) The Schoksha quarry. (9) Schoksha quartzite Sedimentary layering. (10). Schoksha quartzite. Microscopic structure.

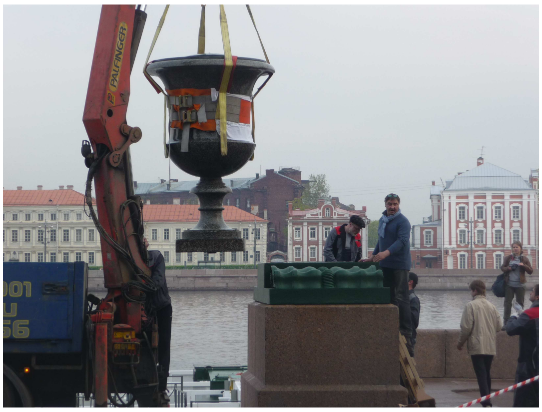
appropriate term here (Hjelmquist, 1982). In the frost of January 2008, this vase developed a crack and fell apart due to gradual accumulation of water in original natural cracks in the stone and inside the vase (Bulakh *et al.*, 2011). Carl XIV had planned to present a pair of vases, but one of the two manufactured vases cracked just after it was produced, showing that weaknesses were present at the outset although, even so, the vase remained intact for many years. This vase was restored by A. Androkhanov (Fig. 16) and put back in position in May 2013.

Stone of the Napoleon's sarcophagus in Paris

The use of Russian "porphyry" is not limited to the Russian Federation. As is well known, the tomb of Napoleon I Bonaparte is located in the central crypt of the Église du Dome church at the Hotel des Invalides, in the City of Paris. The remains of the Emperor, inside the sarcophagus, are protected by six concentric coffins, made from different materials, including mahogany, ebony, and oak, one inside the other. The tomb itself (Fig. 12) was crafted in red "porphyry" placed on a green "granite" base.It is circled by a crown of laurels with inscriptions, which act as reminders of the Emperor's great victories (http://www.paris-france.me.uk/napoleon's_tomb.htm.)

This red porphyry is, in fact, Schoksha quartzite. Moscow, the capital of Russia, is listed between laurels in a circle on the monument. Tsar Nicholas I is reputed to have said that this was strange fate for Emperor Napoleon because he lost his glory in a struggle with

Figures 11-13. (11) Korgon porpyry Vase. The Hermitage. (12) Napoleon's sarcophagus. (13) Black Swedish vase near the Winter Palace. 1847. Water-colour, by L.Bonshtedt



Figures 14-16. (14) A black Swedish vase being returned after restoration. May 11, 2014. (15). A pink Swedish vase in the Summer Garden. 2007. (16) Master A. Androkhanov and a split pink Swedish vase

Russia but Russia presented stone for his tomb. The reality was that architect Luis Visconti was not able to find large blocks of antique Egyptian porphyry from the old quarries and selected Schoksha quartzite as an alternative. A special quarry was developed to secure massive stone blocks of raspberry color with almost unnoticeable sedimentary layering. Twenty seven blocks totaling forty tons were sent to France in 1847. The largest was about 4x2x0.8 meters in size.

Conclusions

The examples presented in this paper highlight the misuse of the term "porphyry" in old literature on history of art. In books on art and architecture it can refer to many different types of rock of superficially similar appearance and properties. Many of these are not, geologically, porphyries. Careful examination of old documents and petrographical examination of the stone in monuments and sculpture are needed to properly identify stone required for repairs.

Secondly the examples demonstrate the cultural importance of the "porphyries" from Karelia and the Urals both within and outside the Russian Federation as well as those imported from Sweden. The artistic and architectural significance of the Shoksha quartzite over the past 300 years might qualify it as a candidate for Global Heritage Stone Resource status.

Acknowledgements

The paper went through an extensive editing by B. Marker and B. Cooper in preparation for publication. The author greatly thanks them for their kind help. The author visited the Natural History Museum in Stockholm and Älvdalen. He again thanks Mr Jan Olav Nyström, Mrs Monica Sjö, Mr Jan Westling, and Mr Alex Schebanov for their assistance.

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Bath Stone and Purbeck Stone: A comparison in terms of criteria for Global Heritage Stone Resource Designation

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(Received September 12, 2014: Revised accepted October 22, 2014)

Two limestone resources from the Mesozoic strata of south-west England, Bath Stone and Purbeck Stone, are compared in terms of criteria proposed for designation of Heritage Stone Resources. Both have been used locally for some 2000 years and have had significant wider use in the past 350 years. Bath Stone has been used widely in the UK and to some extent elsewhere. Its use throughout the city of Bath provides an overall architectural integrity that contributed to it achieving World Heritage City status. Purbeck Stone, with the exception of a variety known as "Purbeck Marble", has been mainly used locally. It was used to build several structures now designated as Ancient Monuments but Purbeck Marble has been used extensively for interior ornamental work in many ancient and important buildings. Bath Stone has been widely recognised as a "cultural icon" but there is less awareness of Purbeck Stone. Both are still quarried, and have an assured future, subject to continuing demand. However, for both, Heritage Stone Resource designation might help to reinforce their status. Overall, the case for designation of Bath Stone appears to be stronger than that for Purbeck Stone.

Introduction

Criteria for designating Global Heritage Stone Resources (GHSR) and Global Heritage Stone Provinces (GHSP) have been developed by the Heritage Stone Task Group (HSTG) of IUGS and Commission C-10 of IAEG (Cooper, 2014). These can be summarized as:

a) historic use for a significant period;
b) wide-ranging geographic application;
c) utilisation in significant public or industrial projects;
d) common recognition as a cultural icon;
e) ongoing quarrying and availability; and
f) providing potential benefits (cultural, scientific, environmental and/or commercial).

It is important to test the criteria for designation of GHSR using real examples before any stones are formally considered for designation to establish whether any modifications of clarifications of the criteria are needed (Marker, 2014). With those criteria in mind, this paper compares two limestone resources from the Mesozoic of England: Bath Stone and Purbeck Stone.

Bath Stone

The Middle Jurassic strata of England contain several major horizons of oolitic and bioclastic limestones that have long provide high quality freestones for construction locally as well as for prestigious buildings through much of southern England or more widely. One of the most important is found in south-west England in an area between the City of Bath and the town of Corsham.

The Great Oolite Group (Upper Bathonian) consists mainly of limestones interbedded with clays and includes two important freestone horizons, the Combe Down and Bath Oolites. These are known commercially as Bath Stone but the term has also been used generally for some other oolites from the southern part of the Jurassic "stone belt". Bath Stone (*sensu stricto*) consists mainly of current bedded and/or shelly oomicrites that are white, pale cream or buff. They are readily workable on extraction but weather to an attractive honey colour and toughen on exposure (Geddes, 2011; King, 2011). Some technical properties are summarized in Table 1. The stone is suitable for a wide range of uses including masonry, retaining walls, ashlar, cladding, columns, lintels, copings,

Table 1: Bath Stone – some technical properties

Property	Value(s)
Bed height	20-160 cms
Length	80-350 cms
Block size	0.2-2.8 m^3
Porosity (CEN) by volume	23.4 – 26.1%
Saturation coefficient (BRE141)	0.80-0.83
Water absorption by weight	9.02-10.9%
Bulk specific gravity	2066kg/m^3
Density (BSEN 1936)	2010kg/m^3
Compressive strength	15.0-24.6 MPa
Flexural strength (CEN) dry	3.7-4.1 MPa
Thermal conductivity (BSE12524)	1.50kg^3

Sources: Hanson Bath and Portland Stone plc and The Bath Stone Group plc

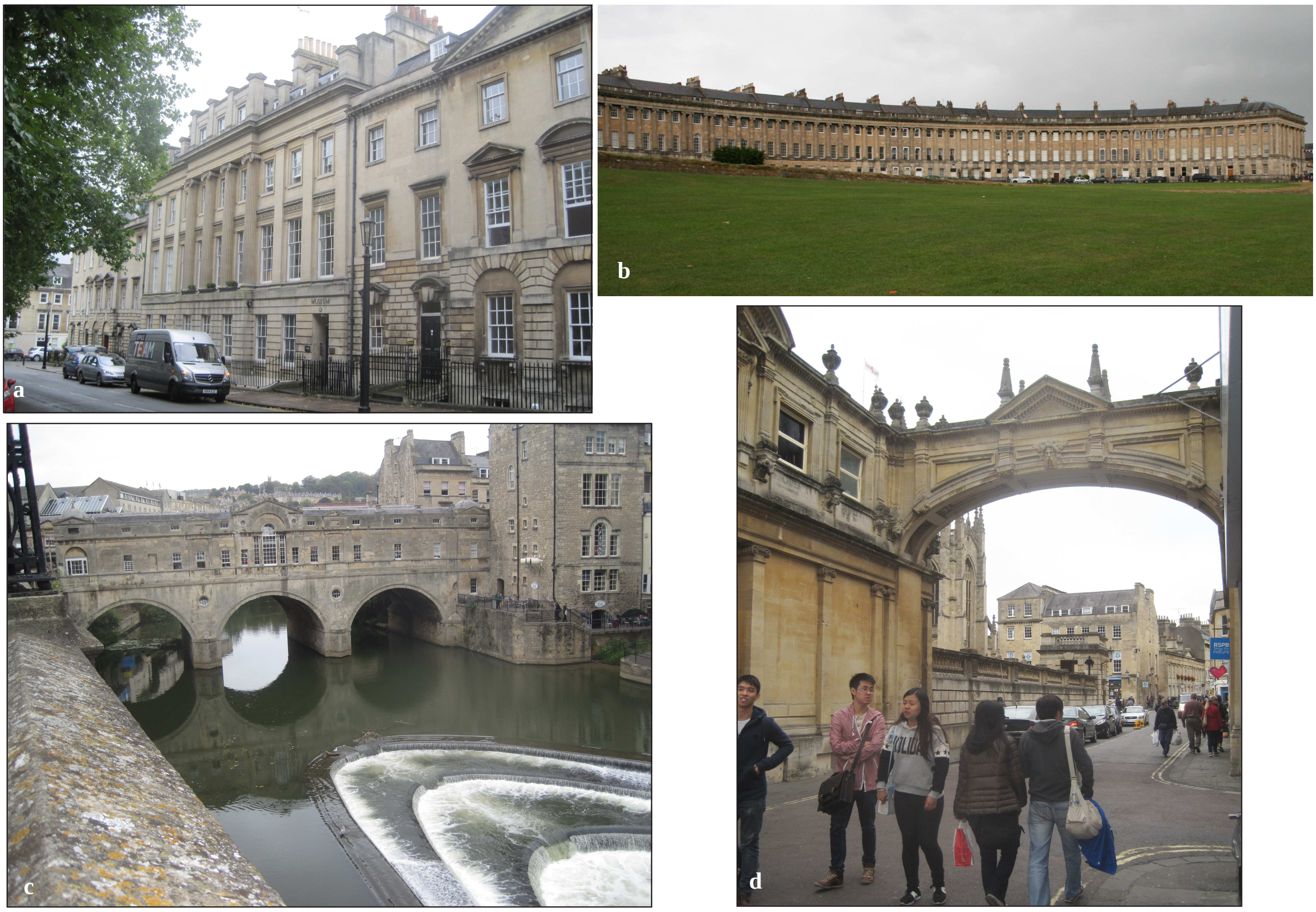

Figure 1. Examples of the use of Bath Stone in the City of Bath. (a) Queen Square, Bath, (b) Royal Crescent Bath, (c) Pultney Bridge, Bath, (d) York street, Bath with the Victorian surroundings to the Roman Baths to the left.

thresholds, paving, flooring, fireplaces, carvings, mouldings and sculpture.

From late 1st century AD a Roman city was constructed around thermal baths (almost unique in the United Kingdom) and Bath Stone was used for the major municipal buildings. The City fell into decay after the Romans left in the early 4th century AD and the remains of their settlement now lie at depths of 3-5m (Cunliffe, 2000). Following the Norman Conquest in 1066AD nearby religious and defensive buildings and transport infrastructure were built from Bath Stone, including an important abbey and cathedral, but most other buildings still consisted of wood, wattle and daub. In later medieval times, prosperity based on the wool trade supported the construction of prestigious stone houses in the vicinity of Bath. But reduction of trade due to competition from elsewhere led to decline and, by the early 17th century, Bath remained essentially a small walled city with poorly maintained buildings mostly built of wood (Hudson, 1971).

In the early 18th century the thermal baths became popular as a resort for the wealthy and famous leading to a revival of the economy of the city and a building boom. Extensive redevelopment took place from about 1727 at a time of increasing interest in Roman and Greek culture and antiquities and attracted important British architects, notably John Wood, his son also named John, John Eveleigh and Robert Adam (Colvin, 1997). John Wood the elder worked in Palladian style while John Wood the younger perfected English Georgian style. They worked mainly in Bath Stone from underground mines operated by Ralph Allen at nearby Combe Down and Bathampton Down (Perkins et al. 1983; Price, 1984; Willies et al. 2011). Some major achievements were the Thermal Baths and a Mineral Water Hospital (founded in 1738) now the Royal National Hospital for Rheumatic Diseases; Queen Square (commenced in 1739); Pulteney Bridge based on the Rialto Bridge in Venice (1770); and the spectacular Royal Crescent (1767-1774) (Forsyth and Bird, 2003; Hudson, *op.cit.*). Some examples are shown in Fig. 1. A less important structure, Trim Bridge, contained the office of canal engineer and pioneer geologist William Smith from 1802 to 1804 (Torrens, 2003). Indeed, Smith's 1799 map of the vicinity of Bath is believed to be the earliest map accurately showing strata in an ordered stratigraphical sequence (Hobbs and Jenkins, 2008). The opening of the Kennet and Avon Canal connecting the Rivers Avon and Thames stimulated wider use of the use of the stone.

The popularity of Bath as a resort continued among the rich and famous into the early 19th century but it gradually fell out of favour by the mid 19th Century except for visitors to the spa for health reasons (Eglin, 2005). In 1871 a new King's Bath was built during which the remains of the Roman spa were rediscovered and partly incorporated into the new baths. However economic decline led to poor maintenance of many buildings and all became discoloured by smoke from coal fires. Extensive bomb damage was suffered by buildings, particularly near the Abbey, in 1941. After 1945, there were plans to redevelop the damaged areas but also, in the interests of urban renewal, to replace large areas of the less prestigious buildings and some were demolished. By the 1960s this led to a major national campaign for

Figure 2. Examples of the use of Bath Stone elsewhere. (a) Apsley House, London, (b) Royal Pavilion, Brighton, (c) Temple Meads Railway Station, Bristol, (d) Guildhall, Bristol.

preservation of the city (Ferguson, 2011). From the 1970s onwards, extensive repair, renovation and cleaning of buildings took place. Local authority planning policies required new buildings to be faced with Bath Stone to be compatible with their surroundings. The widespread use of this stone gives the City an architectural integrity that partly led to its designation as a World Heritage City. Bath is now a major tourist destination.

Bath Stone was used more widely in England contributing to numerous major historic buildings of which a few are: the Royal Pavilion (1812) in Brighton; civic buildings such as Bristol Guildhall (1843); the Dartmouth Naval College (1905) in Devon; churches and cathedrals such as Truro Cathedral (1880) in Cornwall; engineered structures, notably the large Dundas Aqueduct (1795) on the Kennet and Avon Canal; major palaces and mansions such as Buckingham Palace and Apsley House (1828) in London and Gatcombe Park (1771-1774) and Tyntesfield (1860s) in Somerset; and early railway stations and structures including parts of Temple Meads Station, Bristol, built for Isambard Kingdom Brunel's Great Western Railway (1839-1841). Some examples are shown in Fig. 2. More widely, Bath Stone has been used in Union Station in Washington DC; Toronto Bible College; the Town Hall at Cape Town, South Africa as well as recent development at Turkey Creek, Dallas, USA and the Waterford Medieval Museum in the Irish Republic.

Over the years the city grew across the stone mines operated by Ralph Allen and these have sometimes presented subsidence problems. This led to a shift of extraction in both quarries and mines to the east of Bath notably at Limpley Stoke to the east of Bath and around the village of Box in the neighbouring county of Wiltshire. From the late 1930s until relevantly recently many of the underground workings were commandeered for military use which limited the potential; for further extraction (Hawkins, 2011; Tye and Muir, 2012). Reserves permitted for extraction in both local planning authority areas are substantial and resources are extensive so the stone will be accessible in the long term. There is steady demand for stone for maintenance and repair of structures but also for new building in compatible materials so the future of the industry seems secure (North Somerset Local Authority, 2007; Wiltshire County Council, 2001).

Purbeck Stone

The Purbeck Group of uppermost Jurassic to lowermost Cretaceous age (Tithonian- Berriasian) outcrops mainly in the Purbeck and Portland areas of Dorset, England. The succession consists largely of thinly bedded limestones, mudstone and calcareous clays which were deposited in shallow freshwater to brackish lagoons with occasional marine incursions (Ensom and Turnball, 2011). Most of

Figure 3. Examples of the use of Purbeck Stone in the Purbeck area. (a) Village of Worth Matravers,.(b) Langton Matravers Parish Church, (c) Chapel at St. Aldhelm's Head, (d) font in the parish church at Kingston – upper part of Purbeck Stone and lower part of "Purbeck Marble"

the usable limestones are collectively known as Purbeck Stone but the succession also contains an unusual type of limestone known commercially as Purbeck Marble.

Limestones, mainly biosparites that are thick enough to be useful occur at six main levels. Some technical properties are shown in Table 2. Colours vary from almost white to shades of brown and bluish grey and textures from smooth to fairly rough. The fairly thin bedding places limitations on the range of uses but the variations in thicknesses make individual beds suitable for different purposes including dimension stone, monumental and ornamental stone, roofing tiles, paving and flooring and rockery stone for garden features (Pennell, 2012).

Purbeck Stone has been extracted to some extent at least from Roman times (1st century AD) but fell into disuse when the Romans withdrew from Britain in the early 4th century. Following the Norman conquest of England in 1066AD there was an upsurge in stone building. There was a revival in the medieval period especially in the 12th to 15th centuries (Leach, 1975). Quarrying expanded greatly from about 1700 reaching a peak in the late 18th and 19th centuries (Stannier, 1996). The stone was initially used locally or was transported by sea principally to ports on the south and south-east coasts of England. Local use gave an important element of local character to villages and towns many of which are now regarded as

Table 2. Purbeck Stone – technical properties

Property	Value(s)
Bed height	20-80 cms
Length	80-120 cms
Block size	02.-2.8m3
Porosity (EN1341) by volume	8%
Saturation coefficient (EN1341)	0.77
Water absorption by weight	2.43%
Density (BSEN 1936)	2.24-2.56
Bulk specific gravity	2498 kg/m3
Compressive strength (EN1342)	98.2 MPa
Flexural strength (EN1341)	11.5 MPa

Source: Building Research Establishment for Purbeck "Spangle Bed"

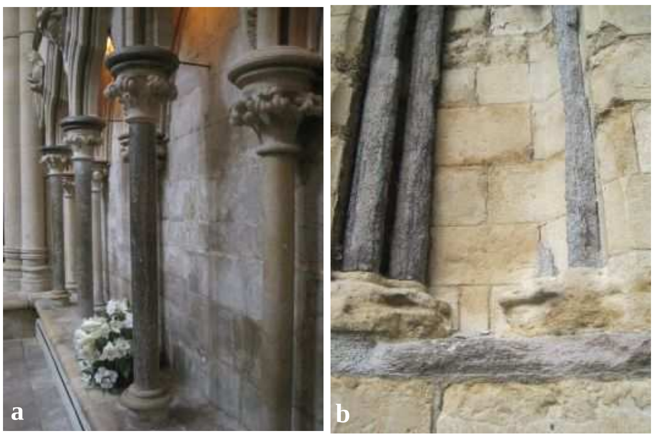

Figure 4. Interior use of "Purbeck Marble" and weathering on exposure at Lincoln. (a) dark coloured pillars of polished "Purbeck Marble" in Lincoln Cathedral. (b) similar pillars of "Purbeck Marble" exposed to weathering in a ruined section of the Bishop's Palace, Lincoln.

Table 3. Bath Stone and Purbeck Stone – comparison on terms of criteria for GHSR designation

Criteria	Bath Stone	Purbeck Stone
Historic use for a significant period	Major use for about 350 years but locally for about 2000 years	Significant use for over 350 years but locally for about 2000 years
Wide-ranging geographic application	Widespread use in the UK and some use elsewhere	Mainly local use – "Purbeck Marble" more widespread
Utilisation in significant public or industrial projects	Major use in a World Heritage city and many other designated ancient monuments and historic buildings	Mainly small scale but includes some designated Ancient Monuments. "Purbeck Marble" used for ornamental purposes in many major buildings.
Common recognition as a cultural icon	Widely recognised	Less widely recognised with the exception of "Purbeck Marble"
Ongoing quarrying and availability	Currently quarried and future assured subject to continuing strong demand	Currently quarried and future assured subject to continuing moderate demand
Potential benefits (cultural, scientific, environmental and/or commercial)	Reinforcement of present status	Reinforcement of present status

conservation areas. Some examples are shown in Fig. 3. From the mid 19th century rail transport promoted wider use within the UK. Initially the stone was taken from quarries but was later mined. However, the number of operating companies declined from 15 to 5 over the past 40 years, leaving only 10 active small quarries (Benfield, 2011).

Near the top of the sequence is an unusual dark grey to greenish or bluish easily carved gastropod biosparite known as "Purbeck Marble". This was used in Roman times but also from the time of the Norman Conquest, particularly in narrow stone columns known as shafts, and was the most widely used British decorative stone in both periods (Clifton-Taylor, 1972; Haywood, 2009). By the 12th Century it was widely employed for ornamental and decorative purposes especially in churches and cathedrals for fonts, tombs, flooring and facings on columns, for example in the Medieval cathedrals of Salisbury, Exeter, Durham, York, Wells, Lincoln and Worcester as well as in Westminster Abbey in London (Clifton-Taylor, *op.cit.*). In the 13th century it was used for a time in effigies and memorial floor slabs. It was used formerly for both interior and exterior purposes but was found to weather badly in northern and exposed positions and has largely been replaced in outside situations (Benfield, *op. cit.*) (Fig. 4). Use of Purbeck Marble declined until the 19th century when working was revived for church widespread restoration (Clifton-Taylor, *op.cit.*).

Outputs of Purbeck Stone are from few hundred tonnes to a few thousand tonnes per annum meet the continuing demand for repair and maintenance of historic structures and building in locally compatible styles. About 9 to 12 years of permitted reserves remain but only 1 quarry still produces Purbeck Marble. It is not easy to find new sites for future quarrying in south Dorset because potential extraction sites are in an Area of Outstanding Natural Beauty (Bristow et al., 2002). But the Planning Authority recognises quarrying as a traditional industry of the area and has policies requiring repair, maintenance and new building using local stone in conservation areas (Dorset County Council, 2013). The quarries are also geologically significant and are close to the internationally significant Jurassic Coast World Heritage Site.

But Purbeck Stone is not limited to the Purbeck area. It occurs also on the nearby Isle of Portland. The Purbeck Group immediately overlies the Portland Stone which was formerly extracted for building stone in both areas but is now only worked for aggregate in Purbeck. There is a strong case for designation of Portland Stone as a GHSR (Hughes et al., 2013) but a weaker case in respect of Purbeck Stone. However the juxtaposition of both raises the possibility that the two, together, might constitute a Global Heritage Stone Province.

Discussion and conclusions

Both Bath and Purbeck Stone have been used for about 2 millenia, initially in Roman times but mainly since the 16th century, and were major extractive industries in the 18th and 19th centuries. Both are of heritage significance with continuing supplies being needed for repair and maintenance of important buildings as well as building in locally compatible styles. Both are high quality stones. They are still extracted and the future of their extraction seems to be secure but much of the demand is for sporadic repair and maintenance contracts while, to be economically viable, extractive operations also depend on contracts for new building to give steadier levels of sales.

A comparison with GHSR criteria is in Table 3. Bath Stone has been used for many major buildings designed by noted architects particularly around Bath but also widely through England and to some extent overseas. It contributed strongly to the case for designating the City of Bath World Heritage Site. In contrast, Purbeck Stone had significant local use for more modest structures although many of these are now collectively recognised as being worthy of conservation. However the unusual "Purbeck Marble" has had exceptional use for ornamental and artistic works in historic buildings and might be regarded as more significant than Purbeck Stone in general. The obvious conclusion is that there is a stronger case for designating Bath Stone as a GHSR.

Acknowledgement

Thanks are due to Dr Ian A Thomas who made useful comments on the initial draft of this paper.

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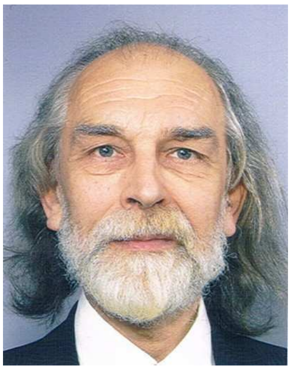

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Sydney sandstone: Proposed 'Global Heritage Stone Resource' from Australia

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(Received October 10, 2014: Revised accepted November 11, 2014)

This paper suggests Sydney sandstone as the first Global Heritage Stone Resource to be nominated from Australia. Sydney sandstone underlies much of the city of Sydney. It is also the most widely utilised dimension stone in the city. Its use in Sydney has extended over 200 years and it continues to be quarried today for Australian domestic use as well as for export. Existing documentation ranges from extensive technical assessment of the stone, heritage lists with abundant illustrations, as well as a Wikipedia entry. Its earliest international use was probably in New Zealand during the 1830s.

Introduction

Sydney is Australia's oldest and largest city, having being founded in 1788. The city is fortunate to have been established on an extensive and a relatively undeformed layer of Triassic-age sandstone that has proved to be an excellent construction material. These are the most conspicuous building stones in Sydney, but have also been drawn upon for breakwater stone, concrete aggregate, road base and marine ballast. Recent historical reviews of Sydney sandstone are provided by Branagan (2013) and Franklin *et al.* (2014).

The uppermost and conspicuously cliff-forming sandstone in the Sydney Basin sandstone has long been known to stratigraphers as the Hawkesbury Sandstone, because a rock unit using the name, Sydney, and occurring in Nova Scotia, Canada, has been considered to have name precedence (Clarke, 1878; Branagan 2000a). However, the term "Sydney sandstone" has long been informally used (for example by Baker. 1915), even to the extent of being the feature of several published books, including the title (Deirmendjian 2000). In stratigraphic terms, the Sydney sandstone comprises not only the Hawkesbury Sandstone, until recently the predominant source of dimension stone within the region, but also the upper part of the underlying Narrabeen Group, that outcrop to the north of Sydney (see Fig.1).

This contribution formally nominates Sydney sandstone as a 'Global Heritage Stone Resource' (GHSR). The nomination has been modelled on the published proposal for Portland Stone from the United Kingdom (Hughes *et al.* 2013). This formal designation as a heritage stone will technically formalise the term, "Sydney sandstone". Cooper (2014) and Cooper & Kramer (2014) have already suggested that "Sydney sandstone is Australia's most prominent potential Global Heritage Stone Resource and details are readily available in publication to make the nomination."

This paper makes abundant use of McNally and Franklin (2000), an important collection of 28 technical papers on Sydney sandstone published by the Environmental, Engineering and Hydrogeology Specialist Group of the Geological Society of Australia. Also of significance are the dedicated volumes of Baglin and Austin (1980) and Deirmendjian (2000). These are popular publications with profuse colour images of Sydney sandstone use, plus important heritage information. There is also a useful summary article on Sydney sandstone in Wikipedia at *http://en.wikipedia.org/wiki/Sydney_sandstone*. Another recent book (Jones, 2013) examines the sandstone landscapes of the Sydney region and the artists who depicted these.

Rock character

The Hawkesbury Sandstone is a massive stratigraphic unit of Triassic age, 100-200 metres thick, composed largely of quartz sandstone with ~5% shale. It covers an area of approximately 12,500 square kilometres within the Permo-Triassic Sydney Basin (Branagan, 2000a, b). Figure 2 shows an example of coastal outcrop adjacent to Sydney Harbor. Branagan and Packham (2000) provide excursion itineraries that direct participants to abandoned quarries at Pyrmont and Bondi as well as to heritage Sydney sandstone buildings.

The Hawkesbury Sandstone originated in a Triassic braided stream system carrying sand from the south-south-west. This was subsequently weakly lithified, uplifted and mildly deformed over the past 250 million years. Its most distinctive feature is its inclined cross laminations and lenticular beds, resembling flattened pillows, 1-10 metres thick and 100-500 metres in lateral extent (Standard 1964, 1969; Conaghan, 1980).

When fresh, the colour of Sydney sandstone is often grey, cream or white. When aged it is typically yellow, buff or brown due to the presence of iron oxides. Detailed geological studies by Wallace (1971),

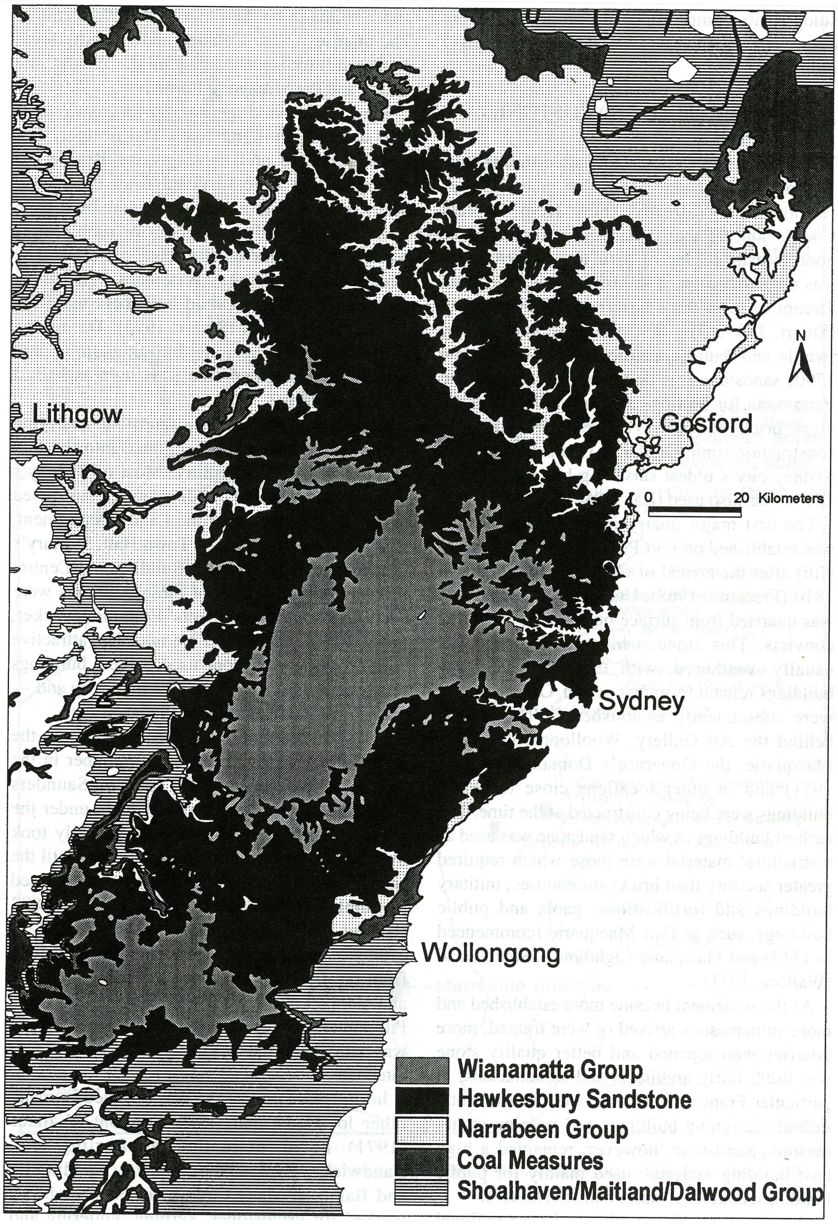

Figure 1. Generalised geological map showing Sydney Basin sediments in the region around Sydney. The city of Sydney is centred on the south side of the coastal inlet (Sydney Harbor) immediately above the Sydney label (reproduced from Ray, 2000).

Spry (2000) and Franklin (2000) have determined six types of Sydney sandstone that are used as dimension stone. These are:

1. Grey Sandstone
2. 'Yellow Block' sandstone
3. White sandstone
4. Quartz-rich sandstone
5. Colour-banded sandstone
6. Typical surface Hawkesbury Sandstone

The so called "Yellow Block" sandstone – actually pale pink to pale orange in colour due to siderite oxidation – is the most prized type in heritage construction. However the quartz-rich sandstone is the most abundant in the greater Sydney area and is now the most extensively quarried variety.

Australian heritage

The earliest use of Sydney sandstone was undoubtedly by Australia's indigenous aborigines, who utilised the stone for grinding, sharpening tools and carving as well as for shelter (Baglin and Austin, 1976; Ray, 2000). However cutting and spear point artefacts had to be quarried from harder rock distant from Sydney so the region's aborigines have been described as a 'stone-age people without good stone'.

Following foundation of the city of Sydney in 1788, the use of sandstone for building was well recorded by the time of Governor Lachlan Macquarie (1810-1821) and the convict architect Francis Greenway (Wallace, 1971; Franklin *et al.*, 2014). A very early geological description of the Sydney sandstone by Russian naturalist, Fedor Ivanovich Stein, in 1820 has been translated into English and published in Branagan (2010). A few years later, in 1839-1840, eminent US geologist J.D. Dana provided much more geological information on the same stone (Dana, 1849).

Subsequently in the late 19th century, most prominent public buildings in Sydney including the Town Hall, General Post Office (Fig 3), Art Gallery of New South Wales and State Library of New South Wales were all constructed using Sydney sandstone.

Also in the late 19th and early 20th century, Sydney sandstone was used for major construction in most other major Australian cities especially Melbourne, Adelaide and Brisbane to the extent that complaints were expressed that suitable local stone materials were being neglected (Cooper, 2012, p. 24).

Innumerable sculptures utilising Sydney sandstone also embellish Australian heritage constructions ranging from decorative friezes and capitals to significant monuments (Baglin and Austin, 1976; Deirmendjian, 2002, Fig.3).

Quarries

Branagan (1996) notes that a map prepared by a convict in June 1788 shows a quarry, most likely in Sydney sandstone, near the site of the present Sydney Opera House. Gibbons in Franklin *et al* (2014) noted that there is an 1823 painting of stone quarrying at State Library of New South Wales (Mitchell Library). The same author also recorded that a valuable "freestone" resource had been recognised by the late 1820s and 1830s and that major sandstone quarries were established in the inner Pyrmont area of Sydney, probably by the late 1840s. It was here that the famed "Yellow Block" sandstone was extracted.

Quarrying continued in this, now inner urban area, until the early 20th century. These quarries are now largely built over, although attempts were made to extract further "Yellow Block" in the 1980s. An early description of sandstone quarrying at this locality in an international journal was provided by "Scientific American" in the late nineteenth century (Anonymous, 1884).

Quarrying of Sydney sandstone continues today. In 2000, there

Figure 2. Outcropping Hawkesbury Sandstone at the The Gap, Watsons Bay at the entrance to Sydney Harbor

were 33 significant operating sandstone quarries, including dimension stone and aggregate operations around the city (Ray, 2000). Quarrying today also occurs at active building sites where stone is removed to facilitate Sydney construction. However Sydney building sandstone is now mainly sourced from the upper Narrabeen Group in the Gosford area more than 50 km north of Sydney. Smaller dimension stone quarries are located in the lower Blue Mountains to the northwest and in the Bundanoon area to the southwest. Quarries in the outer suburbs of Sydney supply sandstone for road base, filling, residential and landscaping purposes. "Yellow Block" sandstone for remedial stone masonry is now obtained from recycling yards, since the last quarry closed in 1970.

GHSR Nomination/Citation requirements

For the purpose of GHSR nomination, the HSTG Terms of Reference state that citations should contain specific information. This is further discussed in Cooper *et al*. (2013) where a Check List of requirements is provided. Consequently in order to nominate Sydney sandstone as a GHSR the following definitive details are summarised below.

Formal Name

Sydney sandstone (using small 's' for sandstone as suggested by McNally, 2000).

Origin of Name

From the Australian city of Sydney

Stratigraphic (or Geological) Name

McNally (2000) has suggested that the term "Sydney sandstone" is a convenient collective name for a number of sandstones that outcrop around Sydney of which the stratigraphic unit Hawkesbury Sandstone is the "most important by far". Spry (2000) accepts this definition of Sydney sandstone and refines the term further to include related, but not identical, Triassic sandstones in the Sydney-Gosford region thus allowing the less commonly quarried sandstones from the Narrabeen Group also to be included in the Sydney sandstone.

Other Names

Sydney sandstone is also known as "Yellow Block" or "Pyrmont Freestone" in specific reference to quarries in the Pyrmont area of Sydney.

Commercial Designations

Other past and present names used for Sydney sandstone often used regional locality or quarry names include Debden, Wondabyne, Gosford, Kurrajong, Kariong, Somersby, Bondi, Wilton, Maroubra, Bundanoon, Piles Creek and Mount White. The sandstones from these quarries are marketed under a wide range of commercial names.

Area of Occurrence

Despite the large, near-surface outcrop area of sandstone, the earliest large quarries was in the immediate city area, primarily at Pyrmont. Sandstone is now mainly sourced from the Kariong area north of Sydney, and to the northwest and southwest of Sydney.

Excellent outcrop occurs across much of the Sydney Basin notably in coastal cliffs, for example at the entrance to Sydney Harbor (Fig.2), and in road cuttings around Sydney.

Principal Location of Quarry or Quarries

Some currently operating dimension stone quarries in and around Sydney include:

Bundanoon	Bundanoon Sandstone International Pty Ltd
Mount White	Gosford Quarries Pty Limited
Piles Creek, Kariong	Gosford Quarries Pty Limited
Somersby	Gosford Quarries Pty Limited
Wondabyne	Gosford Quarries Pty Limited
East Kurrajong	Gosford Quarries Pty Limited
Glenorie	Gosford Quarries Pty Limited
Cattai	Gosford Quarries Pty Limited
Kurrajong	Sydney Sandstone Pty Ltd
Glenorie	Sandstone Sales Pty Ltd
Wollombi	Wollombi Sandstone
Central Mangrove	Mangrove Mountain Quarries Pty Ltd

Numerous smaller quarries supply sandstone to the commercial, residential and landscaping markets.

Geological Age and Geological Setting

Hawkesbury Sandstone is a Lower Triassic (Anisian) age deposit that occurs stratigraphically in a sedimentary succession within the Sydney Basin, underlain by the Narrabeen Group and overlain by the Wianamatta Group, these adjacent units being more diverse in lithology.

Petrographic Name and detail

The abundant "Quartz-rich sandstone" contains 70-85% quartz and 8-15% clay (Franklin *et al.* 2014). Minor constituents include 0-3.5% mica, 0-2% feldspar/lithics, and 0-1.2% iron oxides (adapted from Franklin, 2000).

The more limited "Yellow Block" is made up of 55-68% quartz, 18-25% clay, 2-10% siderite with 2-7% voids (adapted from Franklin, 2000).

Primary Colour(s), Aesthetics and Natural Variability of Stone

'Yellow Block' sandstone is considered to be a "self-colouring" sandstone. It is grey when quarried but oxidises and darkens on exposure to a warm-yellow brown colour. When aged, other varieties of Sydney sandstone are more stable, retaining their colour or aging to a pale yellow or buff hue (Franklin, 2000).

Most Sydney sandstone varieties are grey, white and cream when fresh, but rarely orange red and brown. The abundant quartz-rich sandstone variety may be pale yellow or dark brown or banded. In outcrop, Sydney sandstone may possess all colours ranging from white, grey, orange, deep brown and banded.

Technical Properties

The overall engineering geology of the Sydney Basin has been comprehensively considered by Pells (1985a) with a specific paper on the Sydney sandstone (Pells, 1985b).

Heiman (2000) tested three samples, with the "best results" in terms of technical properties being obtained with his "Sample A" of Hawkesbury Sandstone quarried near the top of the unit. Selected results are as follows:

Water Absorption (% weight)	3.1
Density (kg/m³)	2290-2420
Apparent Porosity (% weight)	7.4
Uniaxial Compressive Strength – Dry (MPa)	76
Modulus of Rupture (dry), MPa	11.9

Spry (2000) summarised the properties of "Yellow Block" from Pyrmont as follows

Water Absorption (%)	3.0-4.2
Density (kg/m³)	2.29-2.42
Porosity (%) mean	8.7
Compressive Strength – Wet (MPa)	13-31
Flexural Strength –Wet (MPa)	1.8
Modulus of Rupture MPa Wet	1.7-4.3
Durability (%) Loss Salt Crystallisation	0.6-2.2

Suitability

Sydney sandstone has, for more than 150 years, been utilised in major load-bearing construction and sculpture including significant public buildings in Sydney. Valuable geotechnical properties are homogeneity, durability and stiffness of the material (McNally, 2000). As a consequence, it has also been significantly utilised in the Sydney region for domestic housing (mainly foundation courses), retaining walls, dams ('cyclopean masonry'), bridge piers, monuments, road pavements, kerb stones, wharves and sea walls. Baglin and Austin (1976) illustrate many of these utilitarian uses which include fireplaces, steps, chairs and slab paving.

Vulnerability and Maintenance of Supply

The major impediment to the supply and availability of Sydney sandstone is the continuing expansion of Sydney city and adjoining urban areas, and the desired environmental protection of outcrop areas. With respect to the latter, much iconic scenery in National Parks in the Sydney region has formed on Sydney sandstone.

The supplies of "Yellow Block" sandstone for heritage conservation are limited to recycled stone, and at least two other varieties of sandstone used for heritage conservation are extracted from single quarries. Little information on resources of high quality sandstone in existing quarries is publicly available. There are few, if any, provisions for ensuring availability of stone from some of the more significant quarries for conservation work after the quarries cease commercial operation.

Nevertheless there remain huge geological reserves of Sydney sandstone, though not "Yellow Block" for new construction as well as for export for the foreseeable future.

Historic Use and Geographic Area of Utilisation

Sydney sandstone is the building stone most strongly identified with the city of Sydney. Sydney is also Australia's largest city and the city arguably most identified with Australia. However, it has also been used in other Australian cities, notably in buildings dating from the second half of the nineteenth century.

The oldest international usage of Sydney sandstone was probably in the "Stone Store" at Kerikeri, New Zealand (1832-1836), the oldest stone building in New Zealand. Wikipedia supplies further information at *http://en.wikipedia.org/wiki/Stone_Store*. Notably Sydney sandstone was also exhibited at the International Exhibition in London in 1862 (Baker, 1915).

Over the past 20 years, Sydney sandstone has had significant exports as documented by quarrier, Gosford Quarries, at their website (*www.gosfordquarries.com.au/export.html*). Recent international projects, supplied by Gosford Quarries, include Mishima Golf Club in Japan, Al Awadi Tower in Kuwait, New World Resort in China and a Hard Rock Café in Florida, USA. Bundanoon Sandstone International Pty Ltd also advises at its website that "they are leading merchants and manufacturers taking Australian sandstone to the world" with "Discerning clients across Australia, US and Asia" (*www.bsint.com.au*). Sandstone is exported from their Bundanoon quarry.

Undoubtedly there are other international applications of Sydney sandstone, but confirmation has been difficult to locate.

Buildings etc

In the inner and central parts of Sydney, Sydney sandstone has been utilised in religious, educational, public (Fig.3) and commercial buildings. In addition, it can be found used for domestic housing, gate posts, walls, bridges (Fig.5), monuments, pavements gutters, wharves and sea walls. A summary list of the major use of Sydney sandstone follows.

Buildings in Sydney: Places of worship

- St Mary's Cathedral (Architect: William Wardell from 1865) (Fig. 4)
- Garrison Church, Millers Point (1840)
- Great Synagogue (Architect: Thomas Rowe, from 1878)

Figure 3. Sydney General Post Office (1874), 1 Martin Place Sydney, excluding small granite columns and associated white marble sculpture

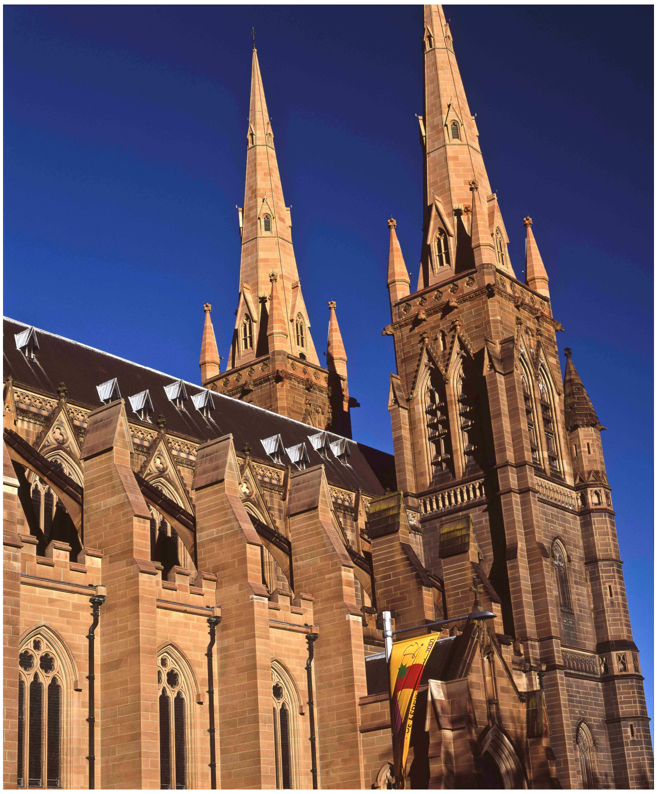

Figure 4. St Mary's Cathedral (1868), 2 St Mary's Road, Sydney

- St Andrew's Cathedral (Architect: Edmund Blacket from 1868)
- St Stephen's Uniting Church, Sydney (1875-1935)
- Scots Church, Sydney (Architect: Rosenthal, Rutledge and Beattie 1929)
- St Philip's Church, Sydney (Architect: Edmund Blacket, 1856)

Buildings in Sydney: Educational buildings

- Newington College (Architect: Thomas Rowe 1877)
- Saint Ignatius' College, Riverview, Main building (1880)
- St Joseph's College, Hunters Hill Main building and Chapel (1882)
- Sydney Grammar School, Main building (Architects Edward Hallen, Edmund Blacket 1832, 1857)
- University of Sydney - Great Hall; main quadrangle; original Fisher Library (Architects: Edmund Blacket, James Barnet and W.L. Vernon from 1868); Anderson Stuart Building; St John's College; St Andrew's College; St Paul's College (Architect: Edmund Blacket from 1854)

Buildings in Sydney: Galleries and Museums

- Art Gallery of New South Wales (Architect: Walter L. Vernon 1885)
- Australian Museum (Architects: Mortimer Lewis, James Barnet, 1846, 1864)
- Museum of Contemporary Art, Sydney (Architects W.H. Withers and D. Baxter 1947)
- Museum of Sydney (Architect: Denton, Corker Marshal 1993)

Buildings in Sydney: Public buildings

- Callan Park Hospital for the Insane now Sydney College of the Arts (Architect James Barnet 1883)

- Central Railway Station, Sydney (Architect: W.L. Vernon, 1901)
- Chief Secretary's Building (Architects: James Barnett and Walter Vernon 1873)
- Customs House, Sydney (Architects: Mortimer Lewis, James Barnet, Waklter L. Vernon 1845, 1885, 1903)
- Darlinghurst Gaol, now the National Art School (Architects: Mortimer Lewis, James Barnett 1836, 1885)
- Department of Lands building, including the statues in the niches (Architect: James Barnet from 1876)
- Department of Education Building (Architect: George McRae from 1912)
- Frazer Fountains, one in Albert Road, the other in Hyde Park (Architect: Thomas Sapsford 1884)
- Fort Denison (1841, 1855-1857)
- Gladesville Mental Hospital (Architect: Mortimer Lewis 1836-1838)
- Government House, Sydney (Architect: Edward Blore 1846)
- General Post Office (Sydney) (Architect: James Barnet, from 1864) (Fig 3)
- New South Wales Club, Bligh Street (Architect: Wardell and Vernon, 1884)
- Registrar-General's building (W.L. Vernon, architect, from 1913)
- Suspension Bridge, Northbridge (Designers J.E. F. Coyle & W.H. Warren, 1892) (Fig. 5)
- Sydney Observatory (1856)
- Sydney Town Hall (Architect: J.H. Wilson, T.E. Bradbridge, from 1868)
- "Saunders' Terrace" in Pyrmont (unknown designer, 1870s)
- Treasury building, Sydney (second stage)(Architect: W.L. Vernon from 1896)
- Hyde Park Barracks, Sydney (Architect: Francis Greenway 1819
- Campbell's Warehouses, The Rocks (1844)

Buildings in Sydney: Commercial buildings

- AMFI building, King and Pitt Streets (Architect: G.A. Morell, 1881)
- AMP building, Pitt Street (architects Reed & Barnes 1860s) (now demolished)
- Burns Philp building (Architects: McCredie & Anderson, from 1898)
- City House, Pitt Street (now Skygarden complex) (Architect: G.A. Mansfield, 1893)
- Queen Victoria Building (QVB) (formerly Queen Victoria Markets) (Architect: George McRae from 1893)
- Radisson Plaza Hotel (formerly Fairfax Printers Building) (Architects: Manson & Pickering 1922) (Fig 6).

Buildings outside Sydney

- Stone Store, Kerikeri, New Zealand (1832-1836).
- Jervois Wing, State Library of South Australia, Adelaide (1879–84)
- E S & A Bank (now called "the Gothic Bank") (Architect: William Wardell, 1883), Melbourne
- Savings Bank Building, King William Street, Adelaide (1902)
- National Mutual Building (now the Bank of New Zealand) (Architect: Wright, Reed and Beaver, 1903) Melbourne

Figure 5. Northbridge Suspension Bridge (1892), Strathallen Avenue, Northbridge, metropolitan Sydney

Figure 6. Radisson Plaza Hotel (formerly Fairfax Printers Building) (1922), 27 O'Connell Street, Sydney

- St John's Cathedral, Brisbane external facings (Architect: J.L. Pearson and others, 1909–11)
- St Paul's Cathedral, Melbourne, tower and spires (Architect: James Barr, 1926)
- Union Bank, Brisbane (1916)
- National Parliament Canberra – Courtyard Sculpture by Ewa Pachuka entitled "Fossilised Architectural Landscape" (1988) utilising "Gosford Grey Sandstone" (Mayer 2009)

A more extensive list is provided by Deirmendjian (2002).

Other Heritage Issues

Three outcrop localities of Sydney sandstone, viz Cape Banks, North Bondi and Cut Rock near Kurrajong, are included in the compilation of the geological heritage of New South Wales (Percival, 1985).

In 2013, a decision was made to invite each Australian State to contribute "Federation Rocks" in order to inaugurate the "National Rock Garden" in the Australian National Capital of Canberra (www.nationalrockgarden.org.au). Sydney Sandstone or more specifically

"Yellow Block" sandstone was selected to represent the State of New South Wales as a Federation Rock (Fletcher 2013; Pillans 2013).

Acknowledgements

Greg McNally reviewed the article in detail and made numerous helpful suggestions.

The images were made available courtesy of the City of Sydney Archives.

The image photography is by Gary Deirmendjian, who first published the images in his book entitled "Sydney Sandstone" published by Craftsman House in 2002.

The School of Natural and Built Environments, University of South Australia provided excellent working facilities for BJC.

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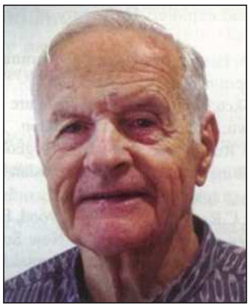

David Branagan is an Honorary Research Associate in the School of Geosciences, University of Sydney, where he was a teacher and researcher between 1959 and 1989, mainly in engineering geology and photo-interpretation. He has published a number of books and papers on aspects of Australian geology and its history. David was foundation editor of "The Australian Geologist" (1974-1984) and is an Honorary Life Member of the Geological Society of Australia. He was President of the "International Commission on the History of Geological Sciences" (1992-1996) and was awarded the Tom Vallance Medal by Geological Society of Australia in 2012 for his contribution to the history of geology. David was also awarded an Honorary DSc by the University of Sydney in 2007.

Brenda Franklin holds an MSc and PhD from the University of New South Wales. Until 1996 she was Head, Department of Applied Geology, University of Technology, Sydney. Since then, she has been a consulting geologist and currently, also a member of the Australian IGCP committee. Brenda's main academic research has been in mineralogy and petrology. With consulting she has specialised in industrial minerals, including gemstones and building stone. Her recent research has often focussed on the conservation of heritage sandstone buildings in Sydney. This work involves selection and technical evaluation of the sandstone and research on weathering mechanisms affecting Sydney sandstone.

Helen Ray is a geologist with more than 20 years' experience with the Geological Survey of New South Wales. She now works for consultancy "Geos Mining". She has also completed many investigations and reports on dimension stone and industrial mineral resources, including a comprehensive study of the dimension stone resources of NSW. She has advised government, industry and individuals on dimension stone, heritage sandstone, industrial minerals and mineral exploration management. Her more recent dimension stone work has included advice on supplies of heritage sandstone and independent technical reports on dimension stone resources in Australia, Vietnam and China.

The International Working Group on Man-Made Strata and Geo-pollution (MMS & GP) International Union of Geological Science (IUGS) Commission on Geoscience for Environmental Management (GEM) March 11, 2015

Geological Hazard Prevention Measures Learned from the 2011 Earthquake off the Pacific Coast of Tohoku and the International Declaration on Man-Made Strata and Geo-pollution

Four years have passed since the Great East Japan Earthquake of March 11, 2011. We, international researchers on man-made strata and geo-pollution, pray for the victims of the earthquake to rest in peace and for a much faster, science-led, recovery of the affected areas. We also hope and pray for the health of the victims of the radiation pollution following the associated nuclear power plant accident and for science-led revitalization of the affected areas in future that we can be proud of for years to come.

The MMS & GP Working Group of IUGS-GEM released the "International Declaration for Deterring the Geological Hazards occurring in the 2011 Earthquake off the Pacific Coast of Tohoku" on June 18th, 2011. That declaration made the following three points. (1) The need for investigation of, and measures against, damage from liquefaction-fluidization and ground wave (known in Japan as "Jinami") phenomena. (2) The need for evacuation plans and measures against tsunami damage. (3) The need for investigation and measures against the radiation pollution resulting from the Fukushima Daiichi Nuclear Power Plant accident.

We acknowledged it to be an obligation of this international working group to summarize and report that earlier declaration for deterring geological hazards at the Third United Nations World Conference on Disaster Risk Reduction (March 14th to 28th, 2015 in Sendai, Japan). Even though four years have passed since the disaster, all three points listed above remain very true today. Thus, that international declaration continues to be a valid and important declaration for the prevention and mitigation of earthquake damage world-wide, and for the investigation and planning of measures against radiation pollution resulting from the nuclear power plant accident.

Since the birth of human civilization, the magnitude of disasters has been increasing with the expansion of settlements exposed to potential damage. With extensive developments on, and utilization of, land and coastal areas, the distribution of man-made strata in those areas has been expanding and accelerating. Those man-made strata are not only more physically and chemically varied than natural strata, but the range of associated effects is also rapidly increasing. Furthermore, the Jinji Unconformity (as the base of man-made strata is termed in Japan) and variability of man-made strata also gives rise to complex groundwater flows.

Investigations undertaken in the four years since the Great East Japan Earthquake have taught us that areas containing man-made strata distributed were affected by many complex disasters and complex pollution events. For example, (1) the destruction of breakwaters and tsunami evacuation roads along the coast by liquefaction, fluidization, or ground waves before the arrival of the tsunami and the subsequent arrival of huge tsunamis resulted in a complex disaster; (2) the transport and spouting out at the ground surface of pollutants contained in man-made strata due to liquefaction, fluidization, or ground waves caused local as well as dispersed pollution adding to the complex disaster; and (3) the man-made strata distributed areas along the coast polluted by high concentrations of radioactivity from the Fukushima Daiichi Nuclear Power Plant accident were also found to have sustained damage from liquefaction and fluidization, and tsunami, as well as the pollution from radioactive substances. Therefore the complex disaster was caused by three factors.

The MMS & GP Working Group of IUGS-GEM, in research focusing on man-made strata and geo-pollution, has been able to confirm the close association of characteristics of the Jinji unconformity and the composition of man-made strata with the geological hazards and damage at the time of the earthquake. In addition, the Working Group was also able to confirm that secondary sedimentation of layers containing radioactive substances from the Fukushima Daiichi Nuclear Power Plant took place during the formation processes of man-made strata.

Since the Holocene, the expansion of man-made strata throughout the globe has been unavoidable. On the occasion of the Third United Nations World Conference on Disaster Risk Reduction in Sendai, Japan, we stressed the increasing importance of the research on both the formation process of man-made strata and Jinji unconformity in connection with disasters so that people around the globe will, some day, be able to avoid or reduce the impacts resulting from these causes.

New IGCP Projects Accepted and Starting in 2015

Project number: 637. Heritage Stone Designation

Countries involved: Albania, Argentina, Armenia, Australia, Austria, Belgium, Brazil, Cambodia, Canada, Chile, China, Croatia, Cyprus, Czeck Republic, Denmark, Egypt, Finland, France, Germany, Greece, Hungary, India, Indonesia, Ireland, Italy, Japan, Korea, Malaysia, Malta, Mexico, New Zealand, Netherlands, Norway, Panama, Papua New Guinea, Portugal, Romania, Russia, Slovenia, South Africa, Spain, Sweden, Switzerland, Thailand, Timor Leste, Turkey, UK, USA, Uruguay, Vietnam.
Project leaders: Barry J. Cooper (Australia), Björn Schouenborg (Sweden), Dolores Pereira (Spain), Sabina Kramar (Slovenia), Jan Elsen (Belgium), Joseph T. Hannibal (USA), Brian R. Pratt (Canada), Nelson R. Shaffer (USA), Fabiano Cabañas Navarro (Brazil), Hirokazu Kato (Japan), M. Jayananda (India), Phil Paige-Green (South Africa), Brian R. Marker (UK)
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This project aims to firmly establish the first international standard for building and ornamental stones via extensive documentation of those stones that have been significant in human culture.

Suitable nominations will be sought world-wide in an initiative that will aim to record the following characteristics for each stone type:

- Formal name
- Other names
- Area of occurrence
- Location of quarry/quarries
- Geological age and setting
- Primary color(s) and aesthetics
- Natural variability
- Composition
- Technical properties
- Nature of use (eg sculpture)
- Vulnerability of supply
- Historic use
- Geographic utilization
- Related stones

The project will enhance the capacity of Heritage Stone Task Group (HSTG), which was established by International Union of Geological Sciences (IUGS) in 2012, to undertake this work. This group has become the largest international group representing natural stone geoscientists.
International heritage stone designation will have social benefits by:

- promotion of increased awareness of natural stone and its positive attributes in terms of sustainability and regional economic development.
- facilitation of preservation/restoration of extant stone heritage using appropriate material.
- its encouragement to safeguard important heritage stone resources from subsequent sterilization where there is pressure for alternative development.
- promotion of precise specification of stone in the same way that regional designation of foodstuffs has occurred in the European Union.

Project number: 640. S^4LIDE (**S**ignificance of Modern and Ancient **S**ubmarine **S**lope Land**SLIDE**s)

Countries involved: Australia, Belgium, Brazil, Canada, China, Colombia, Costa Rica, Fiji, France, Germany, Greece, India, Indonesia, Ireland, Israel, Italy, Japan, Malta, New Zealand, Norway, Pakistan, Republic of Korea, Russia, Spain, Sri Lanka, Switzerland, Turkey, United Kingdom, USA.
Project leaders: Lorena Moscardelli (USA), Aaron Micallef (Malta), Michael Strasser (Switzerland), Jason Chaytor (USA), Joshu Mountjoy (New Zealand), David C. Mosher (Canada), Sebastian Krastel (Germany), Claudio Lo Iacono (UK), Maarten Vanneste (Norway), Yasushiro Yamada (Japan)
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It has been widely recognized that subaquatic landslides are of common occurrence in lacustrine and marine environments. These units have commonly been referenced to as submarine landslides in the literature. They pose a risk to coastal communities and offshore infrastructure. During the past decades geoscientists have made important contributions towards the improved understanding of submarine landslides. Efforts by the geo-modelling community have helped fill the gap between submarine landslide occurrence, dynamics and tsunami genesis. However, our lack of understanding of the causal mechanisms and timing of submarine landslides has hampered progress in the prediction effort, which is essential to implement appropriate mitigation measures.

Complex issues like these can only be addressed via a multidisciplinary approach. Interest in the study of submarine landslides spans a wide range of sub-disciplines: geologists studying the link between climate change and gas hydrate dissociation, planetary geologists using submarine landslides as terrestrial analogs, petroleum geologists evaluating the seal/reservoir capacity of ancient submarine landslides, and engineers evaluating geotechnical risks. This project seeks to create an international and multidisciplinary platform allowing geoscientists from academia and industry to sustain a dialogue conducive to the integration of findings from different fields into a more cohesive understanding of submarine landslides.

Project number: 641. Deformation and Fissuring caused by exploitation of Subsurface fluids

Countries involved: China, Egypt, India, Iran, Italy, Mexico, Spain, The Netherlands, USA
Project leaders: Dora Carreon-Freyre (Mexico), Devin Galloway (USA), Pietro Teatini (Italy), Shujun Ye (China)
Duration: 2015-2019
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Ground ruptures (earth fissures and reactivation of pre-existing surface faults) caused by extraction of fluids from the subsurface have been observed in hundreds of sedimentary basins worldwide, mainly in USA and in semiarid areas of developing countries such as Mexico, China, India, Libya, Iran, Saudi Arabia. Unexpected fissure generation and fault activation associated with anthropogenic land subsidence strongly impact on the development of urban settlements, industrial centers, agricultural and other economic activities. In this project we propose a scientific cooperative program between institutions and researchers to improve the understanding of the processes involved in ground rupturing. M3EF3 plans to use an integrated approach made by in-situ **M**onitoring of surface deformation, remote sensing techniques, hydro-**M**echanical laboratory characterization, and mathematical **M**odeling (**M3**). The significant amount of geological and hydrogeological information already available in Mexico, California, and China will be used initially. Then, the approach will be transferred to sites in other developing countries. M3 will be used to produce an effective tool to manage the geological risk associated with earth fissuring and reactivation of surface faults. Recommendations will be released for urban development and the sustainable exploitation of subsurface fluid resources considering faulting and earth fissuring as constraints, especially in developing countries.

Project number: 643. Water Resources in Wet Tropics of West-Central Africa

Countries involved: Benin, Cameroon, Ivory Coast, France
Project leaders: Bamory Kamagate (Ivory Coast), Lionnelle Mandem-Bitom (Cameroon), Nicaise Yalo (Benin), Luc Seguis (France)
Duration: 2015-2020
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The sub-Saharan regions submitted to the African monsoon are vulnerable to climate variability and land use change that affect the water cycle. In this context in accelerating change, it is imperative to improve knowledge about causality between climate and anthropogenic forcing and variability of water resources.

The main objective of this project is to carry out thematic workshops focusing on water resources under climate and anthropogenic stress. Specifically, during four years, we'll make one thematic workshop per year focused on key elements of the hydrological cycle in order to improve the capacity of partners involved in the project (Benin, Côte d'Ivoire and Cameroon). The main aim of these workshops is to enhance the knowledge of participants to better contribute to sustainable water access and support for agriculture, natural resource conservation, food security and human health. A review workshop will be conducted at the fifth year in order to establish the synthesis of workshops, the evaluation of the project and its impact on the target laboratories and consider prospective.

This project leans on the LMI PICASS' EAU which associates different laboratories from West-Central Africa and France. These laboratories study hydro (geo)logical variability in relation with climate and land-cover changes. They have built a strong background in international collaboration.

Project number: 646. Dynamic Interaction in Tropical Africa

Project leaders: Kankeu Boniface (Cameroon), Izuchukwu Mike Akaegbobi (Nigeria), Asiedu Daniel K. (Ghana), R.O. Greiling (Germany), Jurgen Runge (Germany)
Countries involved: Brazil, Cameroon, Central Africa Republic, France, Germany, Ghana, Nigeria
Duration: 2015-2018
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At the northern border of Archean Congco-craton the regional significance of Pan-African strike-slip shear zone and compressional structures and the genetic links between the geodynamic processes and ore formation still to be clarify. How deep Precambrian structures do reactivate, and its precise influence on the location, type and evolution of Mesozoic-Cenozoic fault bounded sedimentary basins of WCA-Rifts System and within plate Cenozoic magmatic activity along the Cameroon Volcanic Line is still controversial . The spatial association of historical and recent earthquakes and pre-existing lithospheric structures still a matter of debate. Degree and extend of regional or local climate fluctuation/change and its influence on weathering depths and decomposition of rocks, option available to population remain poorly know.

The proposed new IGCP project aimed to maintain the existing team build upon precursor IGCP 616 young project and to continue to carry out multi-disciplinary investigations on crustal architecture, clarified and quantified the link between basement studies, neotectonics, climate change and landscape evolution. We aim to exploit existing interest and activity and especially work to involve more isolated scientists and teams, fill the remained gaps and introduce all previous and new data into a single holistic pattern of dynamic interaction in tropical environment.

Project number: 648. Supercontinent Cycles and Global Geodynamics

Countries involved: Argentina, Australia, Belgium, Botswana, Brazil, Canada, Czech Republic, China, Egypt, Finland, France, Germany, India, Japan, Mexico, New Zealand, Norway, Portugal, Russia, South Africa, South Korea, Spain, Sweden, The Netherlands, Turkey, USA
Project leaders: Zheng-Xiang Li (Australia), David Evans (USA), Shijie Zhong (USA), Bruce Eglington (Canada)
Duration: 2015-2019
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Rapid recent progress in supercontinent research indicates that Earth's history has beendominated by cycles of supercontinent assembly and breakup. New developments in geophysical imaging power and computer simulation have provided increasingly clearer views of the Earth's interior, and how the moving plates on the Earth's surface interact with the deep planetary interior. In this project, we will bring together a diverse range of geoscience expertise to harness these breakthroughs in order to explore the occurrence and evolution history of supercontinents through time, and the underlying geodynamic processes. As part of this project, we will establish/improve global databases of geotectonics, palaeomagnetism, mineral deposits, and the occurrences of past mantle plume events, and examine how the supercontinent cycles interacted with the deep mantle to produce episodic and unevenly distributed Earth resources. The project builds on the success of a series of previous IGCP projects. It will not only lead to major scientific breakthroughs, but also develop user-friendly GIS-based databases that can be used by anyone who wants to reconstruct palaeogeography, test geodynamic models, model major climatic events such as Snowball Earth events, and predict exploration targets for Earth resources.

Project number: 649. Diamonds and Recycled Mantle

Countries involved: Australia, Canada, Cuba, France, Germany, Japan, Myanmar, Sweden, The Netherlands, Turkey, UK, USA
Project leaders: Jingsui Yang (China), Yildirim Dilek (USA), William L Griffin (Australia), Paul T. Robinson (Canada), Ibrahim Milushi (Albania), Mohamed Metwaly Abu Anbar (Egypt)
Duration: 2015-2019
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Recent studies of ophiolites show the presence of diamonds in both chromitites and peridotites. These "*ophiolite-hosted diamonds*" represent a new occurrence of ultra high-pressure (UHP) minerals, whose estimated pressure-temperature conditions indicate crystallization at mantle depths of 150-300 km or more. Current models of oceanic lithosphere production presume shallow mantle depths (~60-80 km) of partial melting, and therefore the discovery of *ophiolitic diamonds* poses a significant conundrum. Relevant questions include: (1) Are diamonds ubiquitous in the mantle, or do they only exist in isolated mantle domains? (2) Where did the carbon for diamonds come from? (3) How did diamonds and other UHP minerals reach the surface? Answers to these questions require global studies, and would contribute significantly to our understanding of mantle dynamics and recycling, and the operation of the Earth as a heat engine. Our project is designed to address these questions. Our research team is a leader in the study of *ophiolite-hosted diamonds* and has *in-house* access to the necessary instrumentation to do this research. We will undertake systematic sampling of peridotites and chromitites in different ophiolites with a range in ages and geochemical affinities, to document the extent of diamond occurrence in the mantle.

Trace element–isotope geochemistry and precise geochronology will help us address Questions 2–3. We will organize thematic meetings and training workshops for students and early-career researchers as venues for knowledge transfer, international collaboration, and capacity building. These activities will contribute to training the next generations of geoscientists and will provide them with opportunities to utilize modern instrumentation and to acquire quantitative skills.

Project number: 650. 3rd Pamir High Elevation International Geophysical Expedition (HEIGE)

Project leaders: Vladimir Aizen (USA), Paul Mayewski (USA), Christoph Mayer (Germany), Frank Wilhelms (Germany), Pascal Bohleber (Germany), Nozomu Takeuchi (Japan), Koji Fujita (Japan).
Countries involved: Germany, Japan, USA
Duration: 2015-2019
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Seasonal snow and glaciers of the Pamir Mountains supply water to over 60 million people in Tajikistan, Uzbekistan, Turkmenistan, Afghanistan and north-west China. The proposed international collaborative research project: "3rd Pamir's High Elevation International Geophysical Expedition" (HEIGE), will advance evaluation of the past, present, and future climate and water resources in the Pamir Mountains by assessing impacts of natural variability and modern human activity. The proposed research will estimate the potential for abrupt climate and water resource change via major climate drivers such as changes in solar activity, greenhouse gases, atmospheric circulation and atmospheric aerosols, water/nitrogen cycles, and sea surface temperature. HEIGE will plan to recover surface to bedrock ice cores from the glaciers in central and eastern Pamir, mainly in the territory of Tajikistan, including an ice-core drilling site up to 1km deep at the Fedchenko Glacier. This will be the deepest ice-core ever drilled outside of the Polar Regions, thus providing climate records at a uniquely high-resolution time scale. The results of HEIGE are critical for the development of adaptation and mitigation practices required to maximize socio-economic sustainability in Tajikistan and surrounding Central Asia countries in a changing climate and will answer the following science questions:

(1) Will climate thresholds be crossed that change the current state of water resources, and if so where, how fast, and how much?
(2) How will local and regional changes in climate, snow cover, glaciers, and permafrost impact the regional hydrology, land degradation, and ecosystem?

International collaborative efforts with the Central Asian countries, and in particular the Republic of Tajikistan, is also being facilitated by UNESCO through joint coordination and support by the International Hydrological Programme (IHP) and International Geoscience Programme (IGCP) in a regional context of scientific advancement and capacity building activities in Central Asia.

Other IGCP Projects

No. 589 Development of the Asian Tethyan Realm

Project leaders: Xiaochi Jin (China), Katsumi Ueno (Japan), Graciano Yumul JR (Philippines), Pol Chaodumrong (Thailand)
Duration: 2012-2016
Website in process

No. 591. The Early to Middle Palaeozoic Revolution

Project leaders: Bradley D. Cramer (USA), Sivile Sigaitë (Lithuania), Thijs R.A. Vanderbroucke (France), Kathleen Histon (Italy), Renbin Zhan (China), Guillermo L. Albanesi (Argentina), Michael J. Melchin (Canada), Mikael Calner (Sweden)
Duration: 2011-2015
Website: http://igcp591.org/

No. 592. Continental construction in Central Asia

Project leaders: Inna Safonova (Russia), Reimar Seltmann (UK), Min Sun (China)
Duration: 2012-2015
Website: http://www.iagod.org/igcp/

No. 596. Climate Change and Biodiversity Patterns in the Mid-Paleozoic

Project leaders: Peter Königshof (Germany), Thomas J. Suttner (Austria), Iliana A. Boncheva (Bulgaria), Nadezhda G. Izokh (Russia), Phuong Ta Hoa (Vietnam), Thasinee Charoentitirat (Thailand), Johny A. Waters (USA), Wolfgang Kiessling (Germany)
Duration: 2011-2015
Website: http://www.senckenberg.de/root/index.php?page_id=14651

No. 597. Amalgamation and Breakup Pangæa: the Type Example of the Supercontinent Cycle

Project leaders: J. Brendan Murphy (Canada), J. Duncan Keppie (Mexico), Cecilio Quesada (Spain), Bill Collins (Australia)
Duration: 2011-2015
Website: http://www.wix.com/declan_15/test

No. 604. Groundwater and Wetlands in Ibero-America

Project leaders: Emilia Bocanegra (Argentina), Gerdon Cardoso (Brazil), Emilio Custodio (Spain), Teresita Betancur (Colombia), Marisol Manzano (Spain)
Duration: 2011-2015
*Website:*http://www.mdp.edu.ar/hidrogeologia/IGCP604/description.php

No. 608. Asia-Pacific Cretaceous Ecosystems

Project leaders: Hisao Ando (Japan), Xiaoqiao Wan (China), Daekyo Cheong (Korea), Sunil Bajpai (India)
Duration: 2013-2017
Website: http://igcp608.sci.ibaraki.ac.jp/

No. 609. Cretaceous Sea-Level Changes

Project leaders: Michael Wagreich (Austria), Xiumian Hu (China), Silke Voigt (Germany), Julleh J. Rahman (Bangladesh), Ismail O. Yilmaz (Turkey), Svethana Zorina (Russia)
Duration: 2013-2017
Website: http://www.univie.ac.at/igcp609/

No. 610. From the Caspian to Mediterranean Environmental Change and Human Response during the Quaternary

Project leaders: V. Yanko-Hombach (Ukraine), N. Panin (Romania), Mehmet Celal özdoðan (Turkey), Olena Smyntyna (Ukraine), T.A. Yanina (Russia)
Duration: 2013-2017
Website: http://www.avalon-institute.org/IGCP610/index.php

No. 618. Paleoclimate information obtained from past-recharged groundwater

Project leaders: Dioni I. Cendón (Australia), Jianyao Chen (China), Jason J. Gurdak (USA), Ofelia Tujchneider (Argentina), Emerit. Sylvi Haldorsen (Norway), Ir. M.J (Martine) van der Ploeg (The Netherlands), Rein Vaikmäe (Estonia), Roland Purtschert (Switzerland) Najiba Chkir Ben Jemâa (Tunisia)
Duration: 2012-2016

No. 624 OneGeology
Project leaders: A Malahoff (New Zealand), G. Schneider (Namibia), S. M. Kimball (USA), A. Tsukuda (Japan), M. van der Meulen (Netherlands)
Duration: 2013-2017
Website: http://www.onegeology.org/

No. 628. The Gondwana Map Project

Project leaders: R. Silva Schmitt (Brazil), M. De Wit (South Africa), A. Collins (Australia), P. Rossi (France), C. Reeves (Netherlands), E.J. Milani (Brazil)
Duration: 2013-2016
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Income and Expense for the year 2014 compared with 2013.

	Amount (USD)			
	2014		2013	
Income				
Membership Fees				
Previous years	59,256.68		84,500.76	
Current year	306,337.46		351,434.64	
		365,594.14		435,935.40
Contribution from UNESCO				
final payment for last year	16,834.00		10,941.00	
1st payment for current year	24,962.00		44,954.00	
		41,796.00		55,895.00
Contribution from BGS				21,843.31
Contribution from Episodes Beijing				8,000.00
Other Income		8,750.24		704.00
Total Income		**416,140.38**		**522,377.71**
Expenditure				
IGCP		96,000.00		142,000.00
Joint Programmes		37,995.90		53,203.30
IUGS Commissions		83,000.00		64,300.00
IUGS Task Groups		17,000.00		13,300.00
Initiatives		58,680.02		15,000.00
Committees		8,418.99		7,441.92
Affiliated Organizations		28,555.66		19,000.00
Contributions		-		13,632.49
Episodes		28,000.00		28,000.00
Contingency		10,000.00		5,000.00
Secretariat expenses		15,000.00		15,000.00
Russian Reserve expense				
Other expenses		49,488.91		73,175.04
Total Expenditure		**433,809.48**		**449,052.76**
Net Income		**-17,669.10**		**73,324.95**

Note: The funds paid to RFG and PC both exceeds the allocated amount, which increased the expenditure in "IUGS Commissions" and "Initiatives' lot in 2014.