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THE BLUE QUARTZITES AND SYENITES FROM BAHIA, BRAZIL – GEOLOGY AND TECHNOLOGICAL CHARACTERISTICS

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The Blue Quartzites and Syenites from Bahia, Brazil — Geology and Technological Characteristics

Maria Heloisa Barros de Oliveira Frascá[1] · Nuria Fernández Castro[2]

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This paper focuses on two rare types of blue-coloured, world-famous natural stones: the blue dumortierite quartzites 'Blue Macaúbas', 'Blue Boquira', and 'Imperial Blue', and the sodalite syenites 'Blue Bahia' and 'Blue Sodalite' — all from the Brazilian state of Bahia. The blue quartzites belong to a metasedimentary sequence, deposited in a lagoon-and-coastal environment around 1 Ga ago. Ranging from pure to slightly micaceous, they present cross laminations and bedding, and are mainly composed of quartz, kyanite, and dumortierite in acicular radial aggregates, either concentrated in lenses or disseminated in the matrix. The blue sodalite syenites are products of the differentiation of a nepheline–syenitic magma, occurring as stocks and dykes. Their main composition is sodalite, feldspar, biotite, and nepheline, with remarkable structural and textural differences amongst the two commercial lithotypes. 'Blue Bahia' is homogeneous, exhibiting a granite-resembling texture, while 'Blue Sodalite' has a gneissic–migmatitic structure and variable grain size. Several companies have exploited and exported these quartzites and syenites since the 1960s. These blue stones have technological properties suitable for any use as a natural stone but, due to their rarity, they are expensive and therefore consumed by an upscale international market, and especially used in interior-design projects and high-value artworks. The geological and technical characteristics together with the small but continuous international use, for more than 50 years, of these unique building materials make them good candidates for Global Heritage Stone Resource (GHSR) designation.

Keywords Blue syenites · Blue quartzites · Natural stone · Neoproterozoic · São Francisco Craton · Bahia

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Introduction

Blue-coloured rocks are relatively uncommon in nature, as they derive from the special petrogenetic conditions that favoured the formation of rare rock-forming minerals responsible for their colour. Sodalite ($Na_8(AlSiO_4)_6Cl_2$), a sodium aluminium silicate; kyanite (Al_2SiO_5); lazurite ($(Na,Ca)_8(AlSiO_4)_6(SO_4,S,Cl)_2$) and dumortierite, a boron silicate ($Al_7O_8(BO_3)(SiO_4)_3$); and lazulite ($(Mg,Fe_2)Al_2(PO_4)_2(OH)_2$), a phosphate (Klein and Dutrow 2008), stand out among these minerals.

This article is part of the Topical Collection on Global Heritage Stone Resource: The sustainable way forward

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The main rare rock types containing them to be cited are the sodalite syenites, leading Brazilian natural stones, with other few occurrences or deposits reported elsewhere around the world, such as in Bancroft (James 1965) and British Columbia (Pell 1994), Canada; Litchfield, USA (West et al. 2016); Cerro Sapo, Bolivia (Schultz et al. 2004); Swartbooisdrif, Namibia (Drüppel et al. 2005); and in the Ilímaussaq Alkaline Complex in South Greenland, where sodalite was first described (Friis 2011), although exhibiting pink colour.

Another rock type — also an important natural Brazilian stone — is dumortierite quartzite, with few references of further occurrences besides those in Mozambique and Madagascar, reported by Borghi et al. (2004), and India (Mahapatra and Chakrabarty 2011).

Although not found in the Brazilian territory, another blue stone worthy of mention is lapis lazuli — composed of lazurite with calcite, pyrite, diopside, and wollastonite — a semi-precious stone, highly valued since at least the fifth millennium B.C.E, traditionally extracted in Afghanistan,

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and nowadays also coming from Siberia, Chile, and California (Gambardella et al. 2016).

Historically, natural stones were chosen as building materials based on the proximities of their source quarries. Nonetheless, because of their cultural significance or aesthetic characteristics (texture and colour), stones have travelled to distant places since ancient times, especially from the middle of the nineteenth century (Cassar et al. 2014). Building stones — local or imported — can be considered ex situ geodiversity elements (Brilha 2016) and, in some cases, significant geoheritage (Brocx and Semeniuk 2019).

Natural stones are also accessible resources for enhancing geological education (De Wever et al. 2017; Del Lama 2018) and may exhibit characteristics of high scientific value, such as in the case of the stromatolites of the Aurora Pérola metalimestone, commercialised in the twentieh century in Brazil and no longer being quarried (Del Lama and Costa 2022). Moreover, they can have cultural or social values linked to the object they are part of, so providing information on a stone's intrinsic characteristics is helpful for the conservation of those objects, especially for heritage monuments, buildings, or sites (Pereira et al. 2015). The Heritage Stones Subcommission of the International Commission on Geoheritage of the International Union of Geological Sciences (IUGS) created the Global Heritage Stone Resource (GHSR) designation to acknowledge and give visibility to natural stones of significance for humankind to aid the conservation of cultural heritage (Cooper et al. 2013).

The blue Brazilian rocks focused on here — sodalite syenite and dumortierite quartzite — have been exploited and exported to many countries for more than fifty years. Appreciated for their beauty and durability in the natural stone market, blue stones are labelled as "exotic" and their price varies with their aesthetic pattern. In general, the more saturated the blue tone, the more expensive the stone. They are primarily used in small quantities, as decorative stones, in buildings and monuments, indoor and outdoor.

The characteristics and usage of these rocks, examples of the geodiversity of natural stones, allow us to presume their potential as GHSR candidates. From this perspective, the two types of blue rocks exploited as ornamental stones in the State of Bahia, Brazil, are subject of this article, in alignment with the IUGS-HSS HerStones Project (IGCP 637), the main goal of which is to promote heritage stones from emerging countries. This manuscript is aimed at giving publicity to these Brazilian natural stones of widespread use, following the terms of reference of GHSR, which includes their geological setting and petrographic, technical, and architectural attributes, quarries, and the current maintenance of stone-built heritage, among other things (Kaur et al. 2021).

The Blue Stones of Bahia

Although rare occurrences around the planet have already been reported in the literature, it is worth noting the important occurrence of two distinct types of blue rocks (dumortierite quartzites and sodalite syenites) in the crystalline basement of the State of Bahia, Brazil (Fig. 1) — both economically exploited as valuable natural stones since the middle of the last century (Iza and Magalhães 2019).

The sodalite syenite of Itajú do Colônia, one of the first ornamental rocks quarried in Bahia, was found in the

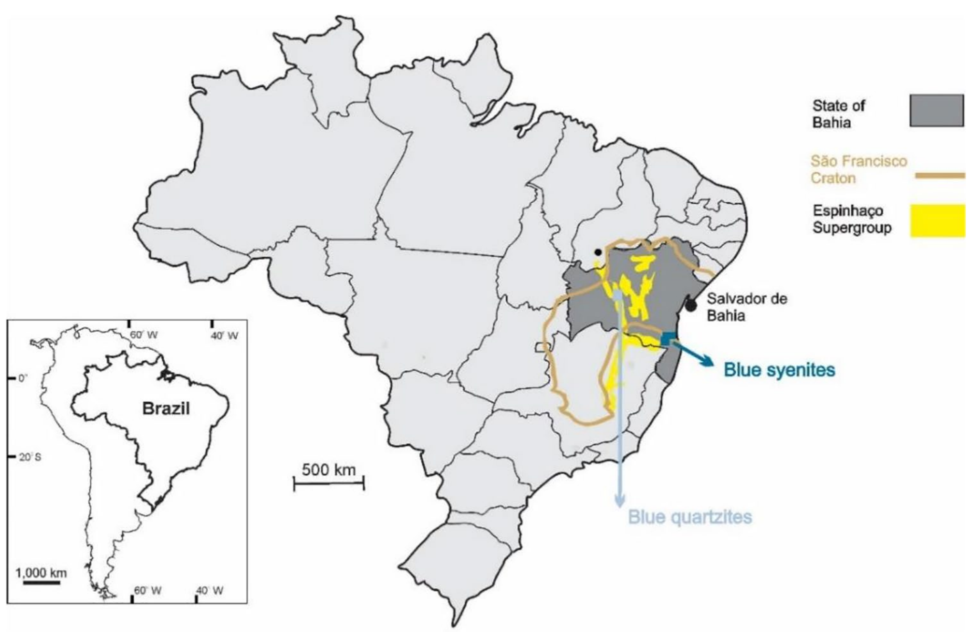


Fig. 1 Bahian blue natural stones approximate location map (Modified from Rosa et al. 2007; Caxito et al. 2008; Uhlein and Noce 2012; and Franz et al. 2014)

early 1960s (Fujimori 1967), and, already mined in 1967 as ‘Azul Bahia’ (Iza and Magalhães 2019) rapidly reaching the international market mainly due to the chromatic uniqueness of the rock.

Soon after, in the early 1970s, the other type of blue rock occurring in the Bahian territory was discovered — the dumortierite quartzite designated ‘Azul Macaúbas’ — the quarrying of which began in 1972 (Iza and Magalhães 2019). Demonstrating the progress in the stone sector’s technical accuracy, as can be seen analysing these authors report, it was initially marketed as ‘marble’, then as ‘granite’, being today correctly referred to as ‘quartzite’, concurring with the increasing value of this rock type in the international market.

Blue Quartzites

Several natural-stone companies commercialise their dumortierite quartzites under different names (Fig. 2). The most traditional, quarried close to the city of Oliveira dos Brejinhos from the 1960s, is ‘Imperial Blue’. This quarry was the first and only in Brazil, during the first decade of the twentieth century, to cut stone blocks by underground mining (Fig. 2c). However, due to structural stability risks, that method was abandoned (Vidal et al. 2014). Other important types are ‘Blue Boquira’ and ‘Blue Macaúbas’ — both named after the closest cities, located about 700 km away from Salvador (capital of the State of Bahia). The above names are used even when extracted in other areas of the region.

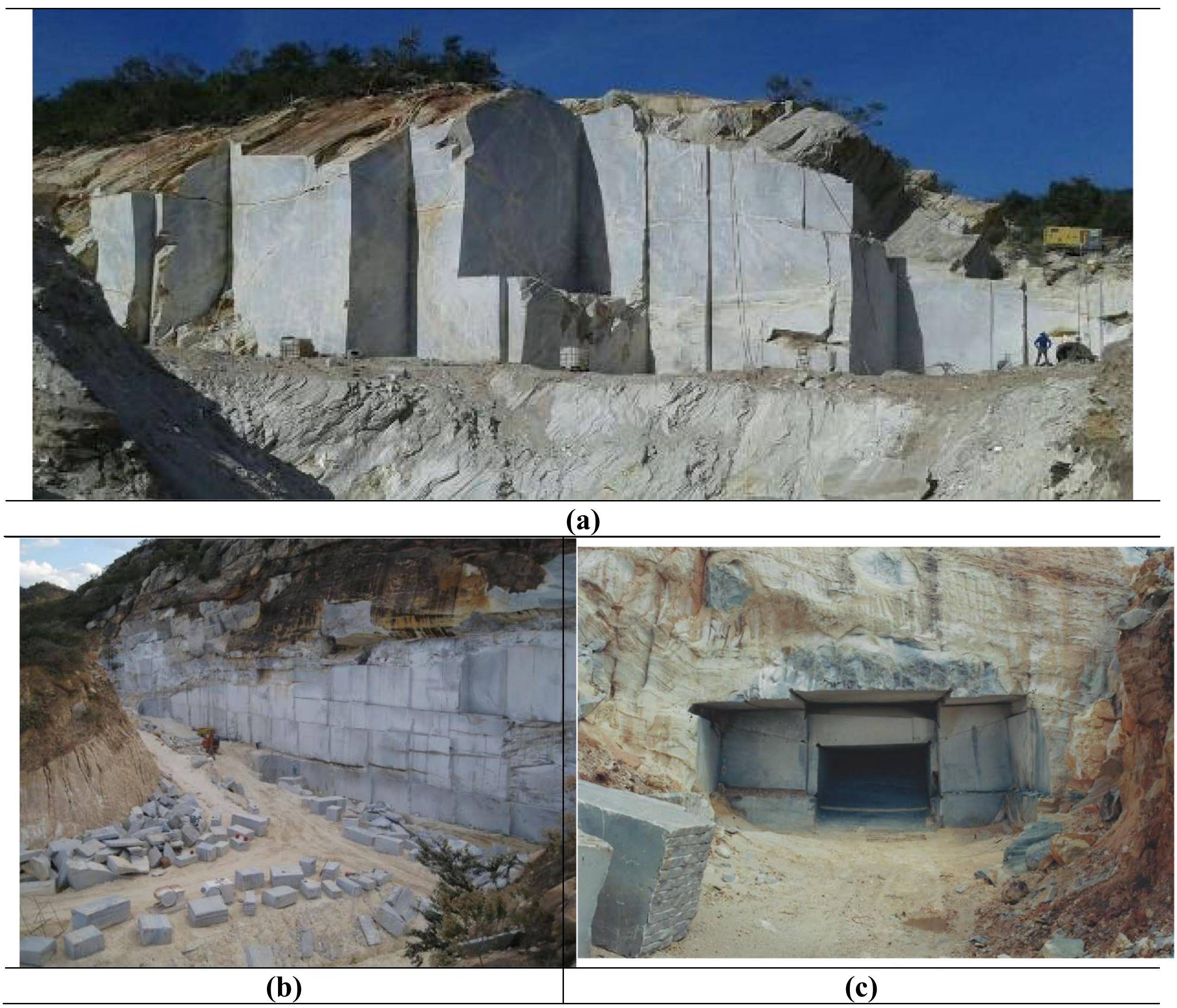


Fig. 2 Some blue quartzite quarries (Bahia, Brazil). **a** ‘Imperial Blue’ quarry (Photo: Graniti Export); **b** 'Blue Macaúba's quarry (Photo: Blue Stones/GM Granitos e Mármores); **c** ‘Imperial Blue’ abandoned attempted underground quarry (Photo: Maria Heloisa Frascá)

Geology

The blue quartzites occur in the northern portion of the Espinhaço Supergroup (Fig. 1), a Precambrian cover of the São Francisco Craton, consolidated in the Transamazonic event, circa 2.0 Ga (2032 ± 31 Ma according to zircon dating using laser-ablation inductively coupled plasma mass spectrometry) together with the Congo Craton (Franz et al. 2014). The Espinhaço Supergroup extends in the NNW–SSE direction for about 600 km and is constituted by a Paleo/Mesoproterozoic sequence of continental and marine metasedimentary and metavolcanic rocks accumulated between 1.75 and 1.0 Ga (Barbosa 2012). Their colour is due to the presence of dumortierite.

The quartzite mainly occurs in the Serra das Veredas Formation, an intermediary sequence of the Santo Onofre Group (Barbosa 2012), the last great sedimentation cycle of the Espinhaço Supergroup.

However, the lithostratigraphic unit and designation differ according to different researchers. Caxito et al. (2008), Jordt-Evangelista and Danderfer Filho (2012), and Franz et al. (2014) label the dumortierite quartzite occurring stratigraphic unit as the 'Veredas Formation' and place it at the bottom of the Sítio Novo Group (Fig. 3). This group fills an NNW–SSE axis asymmetrical rift, and the Veredas Formation represents the rift's initial filling stage in a continental and coastal environment.

According to Jordt-Evangelista and Danderfer Filho (2012), the bluish lithofacies, characterised by cross-laminated metasandstones and interstratified mudstones, may be interpreted as the initial filling product of a Mesoproterozoic rift. The boron that generated dumortierite would then be related to the deposition of boron-rich evaporitic salts (borates), mainly in fine sediments (mudstones), possibly in lagoon environments or in tidal flats located in the posterior part of the barrier islands (Jordt-Evangelista and Danderfer Filho 2012).

The occurrence of dumortierite as centimetric bands irregularly distributed in a meta-quartz sandstone or concentrated in fractured zones is described by Couto (2000) apud Barbosa (2012) to the west of the municipalities of Boquira and Macaúbas.

In the region between Macaúbas and Canatiba, Caxito et al. (2008) found several types of pure-to-slightly micaceous quartzites, sometimes strongly silicified, showing cross laminations and bedding, with the blue-coloured silicified quartzite occurring in its intermediate segment, with an average thickness of 10 m.

Dumortierite-rich quartzites, in layers extending over 15 km with thicknesses of approximately 30 m, were also found on the eastern flank of the Serra da Veredas (Horn et al. 2014).

Although dumortierite quartzites are the main rock type exploited as natural stone, in the Veredas Formation, Jordt-Evangelista and Danderfer Filho (2012) also identified the presence of lazulite–trolleite quartzites, which have an intense bluish-green colour due exclusively to the homogeneously distributed aluminium phosphates present — lazulite and trolleite ($Al_4(PO_4)_3(OH)_3$).

Franz et al. (2014) carried out isotopic studies in four natural-stone quarries in the Veredas mountain ridge, mostly located west of Macaúbas and south of Boquira, where some quartzite types also bear lazulite: lazulite–dumortierite quartzite (Conservice quarry), dumortierite–hematite quartzite (São Marco quarry), lazulite quartzite + hematite/

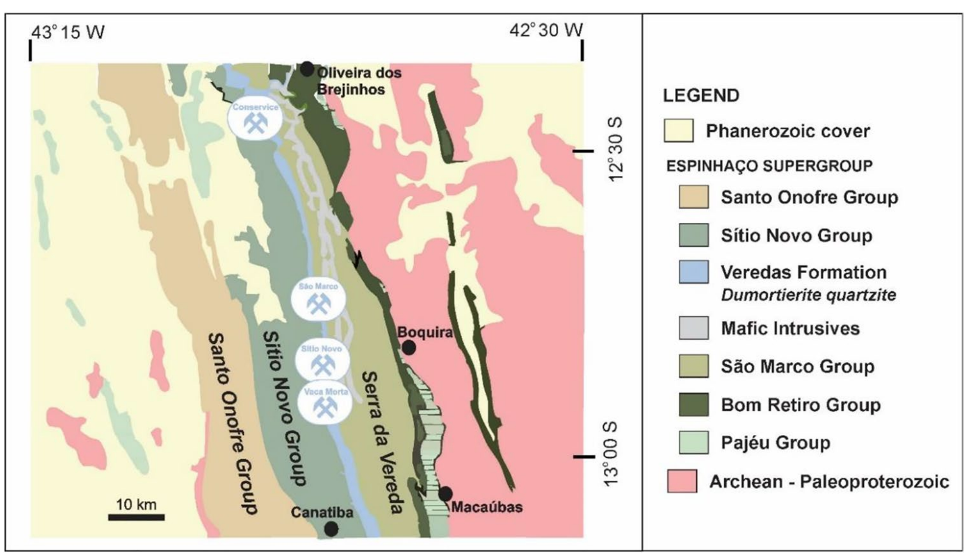


Fig. 3 The Veredas Formation in the Espinhaço Supergroup in eastern Brazil (modified from Franz et al. 2014)

magnetite layer (Sítio Novo), and massive lazulite in contact with quartzite (Vaca Morta quarry).

Caxito et al. (2008) consider the dumortierite quartzites a product of greenschist facies metamorphism of boron-rich sediments, probably deposited under an arid climate in a sabkha-type environment, i.e., in a coastal evaporation plain. Jordt-Evangelista and Danderfer Filho (2012) estimated metamorphic conditions ($P \geq 3.5$ kbar and $T = 475$–560 °C) consistent with higher greenschist to lower amphibolite facies.

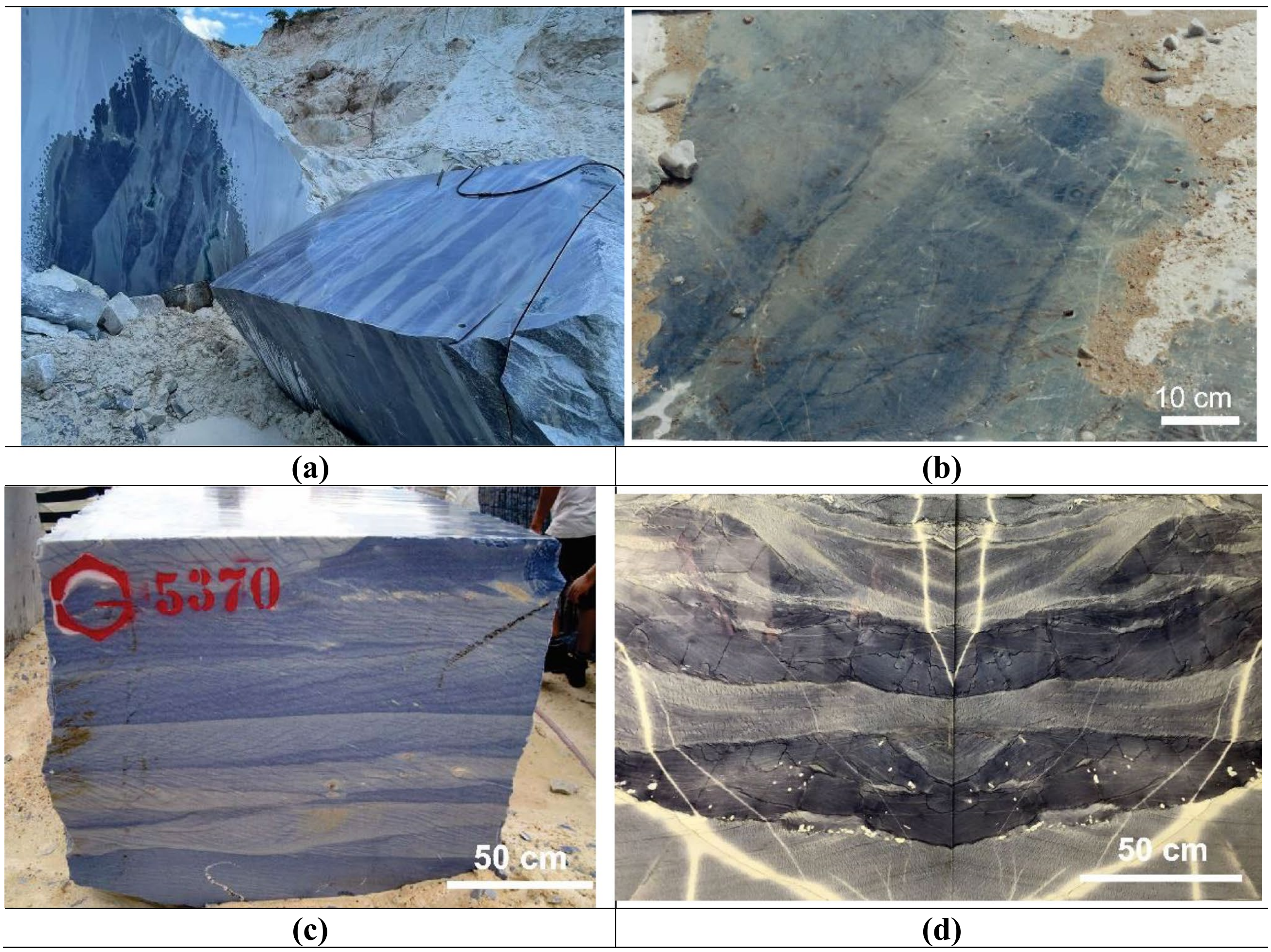
According to Franz et al. (2014), the most prominent metamorphic minerals in these quartzites are lazulite and, in the presence of boron, dumortierite. They dated the major metamorphic event (recorded by reprecipitated zircon) as Neoproterozoic (634 ± 19 Ma), corresponding to the Brasiliano remobilisation of the São Francisco Craton.

Main Petrographic and Technological Characteristics

Slight mineralogical variations give the dumortierite quartzites different hues and saturations – one of the reasons why they are marketed under different names. Figure 4 illustrates some textural and chromatic characteristics of blue quartzites.

In a microscopic examination of dumortierite quartzites of the Veredas Formation, Caxito et al. (2008) observed that dumortierite's euhedral to subhedral crystals or acicular radial aggregates may appear concentrated in millimetric bands or lenses, or disseminated in the matrix. Kyanite is subordinate, generally concentrated in greenish bands.

The average mineralogical composition of the Veredas-Formation blue quartzites found by Jordt-Evangelista and



(a) (b)
(c) (d)

Fig. 4 Main macroscopic aspects of some dumortierite quartzites of the Veredas Formation (Bahia, Brazil). **a** 'Blue Macaúbas' block showing the blue colour coinciding with stratification (Photo: Thor Granitos), **b** 'Blue Imperial' outcrop showing dumortierite remobilisation (Photo: Maria Heloisa Frascá), **c** Cross-bedding in a 'Blue Macaúbas' block (Photo: Blue Stones/GM Granitos e Mármores), and **d** 'Blue Boquira' slabs bookmatch (Photo: Liliane Defruili)

Table 1 Main mineralogical composition of blue quartzites

	'Blue Macaúbas' (Vaca Morta quarry)[a]	'Imperial Blue'[b]	'Imperial Blue'[c]
Quartz (%)	80	75	90
Dumortierite (%)	10	~5	5
Kyanite (%)	5	15	<5
Muscovite (%)	5	~5	<5
Monazite (%)	-	-	tr
Petrographic classification	Dumortierite quartzite	Kyanite quartzite	Dumortierite bearing quartzite

Sources: [a]Azevedo and Costa (1994), [b]Zagôto et al. (2017), [c]CETEM (2018a)

Danderfer Filho (2012) is quartz (50–85%), dumortierite (15–20%), kyanite (≤30%), and white mica (10–15%). Dumortierite and kyanite are mostly concentrated in millimetre-wide, parallel-to-crossed sedimentary strata, and dumortierite-filling discordant fractures demonstrate the high mobility of boron during metamorphism (Jordt-Evangelista and Danderfer Filho 2012).

Other petrographic results are presented in Table 1 and illustrated in Fig. 5.

The knowledge of the technological characteristics — especially weight, porosity, and mechanical resistance — is relevant not only for the determination of the best application of the rock, but also for the selection of the most suitable stone materials in restoration work. The main technological properties of 'Blue Macaúbas', with data from the Bahia Natural-Stone Catalogue (Azevedo and Costa 1994) and 'Imperial Blue', from Graniti company (CETEM 2018b) — all determined according to Brazilian standards that correlate to European and US standards — are presented in Table 2.

Blue Syenites

In the early 1980s, although little known and studied, Ulbrich and Gomes (1981) recognised eight geochemically different magmatic alkaline associations in Brazil and grouped the undersaturated and essentially persodic association in the so-called 'Type VIII', the main rock types of which are alkali syenites, sodalite syenites, and litchfieldites. Those researchers described only two known examples of Type-VIII blue rocks: one in Canaã, Rio de Janeiro, and another in Itajú do Colônia, Bahia.

Table 2 Main technological properties of 'Blue Macaúbas' (Azevedo and Costa 1994) and 'Imperial Blue' (CETEM, 2018b) and respective test methods

Properties	'Blue Macaúbas'	'Imperial Blue'	Test method
Apparent density (kg/m^3)	2683	2700	ABNT (2015a)
Apparent porosity (%)	0.30	–	ABNT (2015a)
Water absorption (%)	0.11	0.03	ABNT (2015a)
Compressive strength (MPa)	210.2	241.6	ABNT (2015b)
Modulus of rupture (MPa)	20.39	17.06	ABNT (2015c)

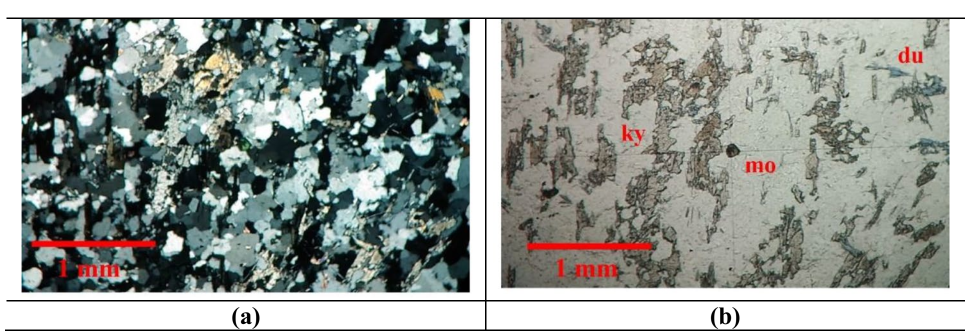


Fig. 5 Petrographic aspects of dumortierite quartzite. **a** cross-polarised light; **b** plane-polarised light (du: dumortierite, mo: monazite, ky: kyanite) (Source: CETEM 2018a)

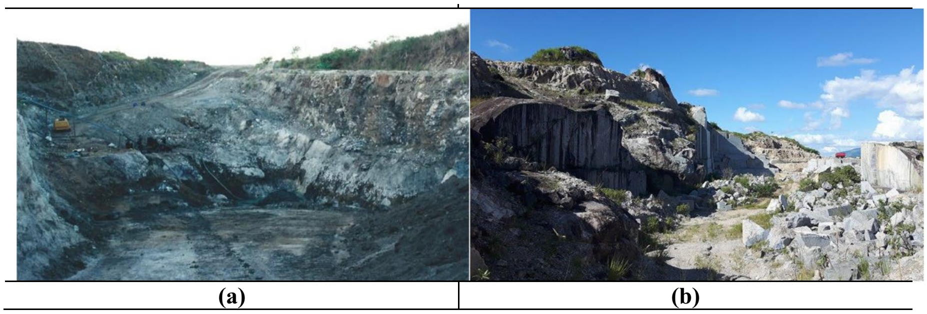


Fig. 6 Quarry with exploitation of sodalite as a gemstone, in 2000 (**a**) and after its exhaustion, in 2018 (**b**)

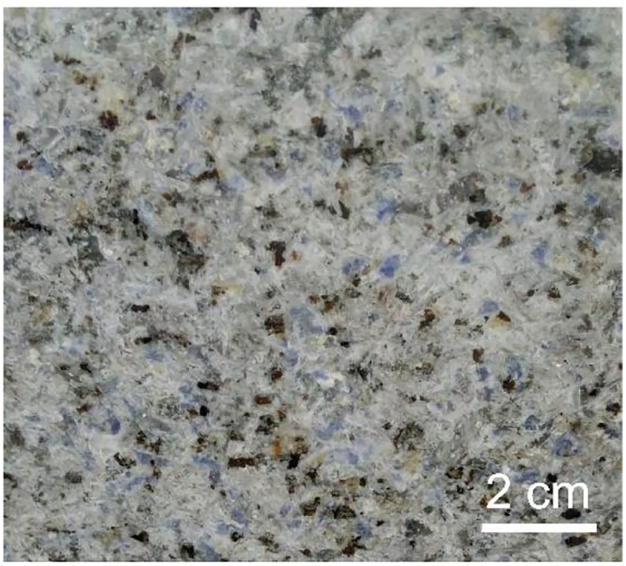


Fig. 7 'Blue Guanabara' syenite commercialised in Rio de Janeiro in the twentieth century

Although some worldwide deposits may become exploited as natural stones, most are (or were) sources of sodalite as a precious stone, which happened in some areas of Itajú do Colônia until the beginning of this century, where the local sodalite concentration allowed it to be separated and marketed as a gemstone (Fig. 6).

The other blue rock mentioned by Ulbrich and Gomes (1981) was exploited during the twentieth century from a 15-m-wide syenitic dyke 40 km north-west of Rio de Janeiro, Brazil. It was a sodalite–cancrinite–nepheline syenite, called 'Blue Guanabara' (Fig. 7) — a light-blue-coloured rock, equigranular, medium-sized, and of a less saturated blue than the sodalite syenites of Bahia (Motoki et al. 2015).

Geology

The Neoproterozoic alkaline magmatism in the southern region of Bahia, named by Silva Filho (1974 apud Gomes et al. 1998) as the Southern Bahia Alkaline Province (SBAP) or Intrusive Itabuna Suite by Oliveira et al. (1980) and Lima et al. (1981) (apud Gomes et al. 1998), was an anorogenic

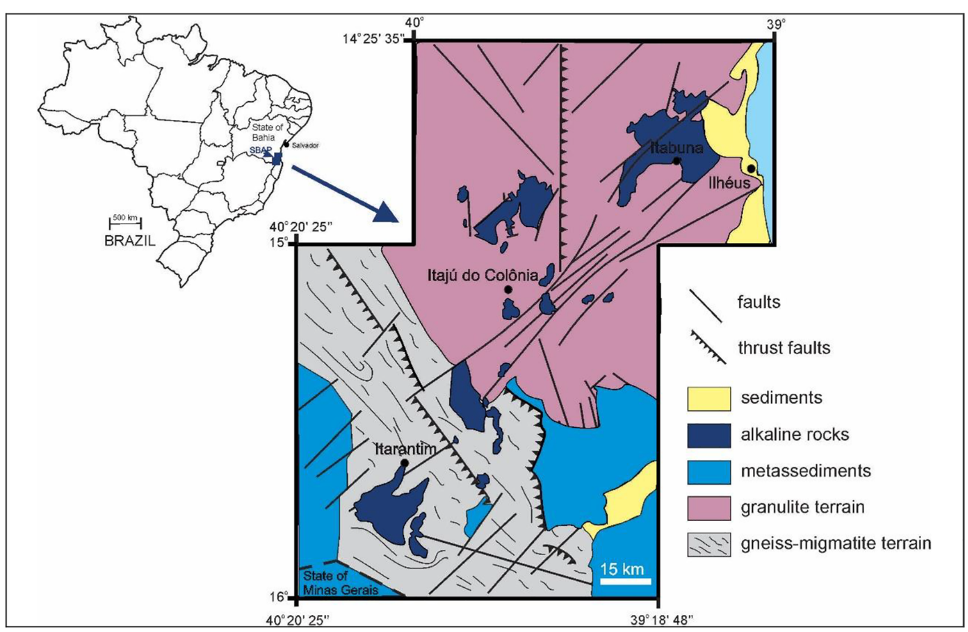


Fig. 8 Simplified geological map of the Southern Alkaline Province of the State of Bahia and its location in the Brazilian territory (Modified from Rosa et al. (2007))

Fig. 9 **a** The 'Blue Bahia' quarry near Itajú do Colônia and **b** the blue–white–black-'painted' appearance of the rock, resembling granite in texture, with a local concentration of sodalite

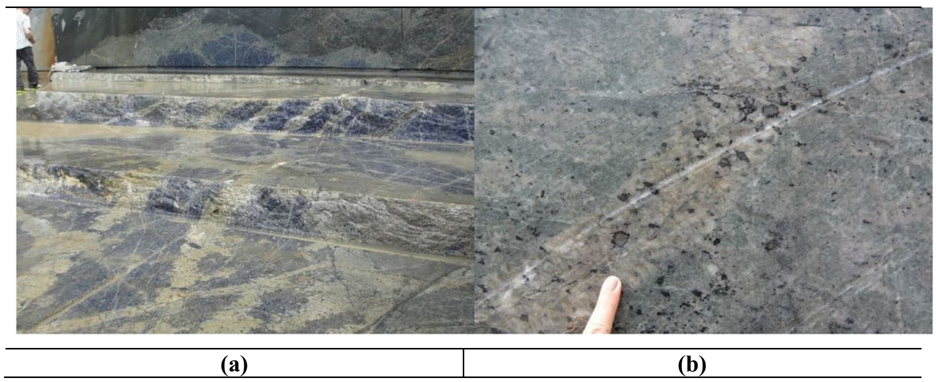


Fig. 10 **a** 'Blue Sodalite' quarry near Potiraguá. Note the rock heterogeneity given by irregular greenish discontinuities cutting sodalite-rich areas, and **b** local concentrations of cancrinite (pink) and mafic minerals (hornblende, biotite, and aegirine)

magmatism inferred to be active for approximately 60 Ma (Rosa et al. 2004, 2007).

The alkaline province is constituted by bodies arranged in a NW–SE regional direction for about two hundred kilometres and distributed across an area of about 12,500 km^2 (Fig. 8), intrusive in Archean–Paleoproterozoic rocks, mostly granulitic in its north-eastern part and gneissic–migmatitic in the southwest.

The province includes syenitic batholiths (Itabuna, Floresta Azul, Serra das Araras, and Itarantim), several stocks, some of them containing sodalite (e.g., Rio Pardo, Itajú do Colônia, Morro da Santa), and many dykes, some mineralised (Conceição et al. 2009). Geologically, it may be divided into two areas: one to the northeast, between the cities of Ilhéus and Itabuna (Itabuna–Floresta Azul alkaline suite), and another to the southwest, around the city of Itarantim (Itarantim–Potiraguá alkaline suite).

The boundaries of the Itabuna and Floresta Azul bodies are partly controlled by NE–SW faults, although they are also affected by other fault directions and joints. Potiraguá limits are adjusted to NW–SE parallel thrust faults. The Itarantim body, on the other hand, seems not only to combine the two fault directions, but also to be involved in the regional folding and refolding systems (Moreira et al. 2004).

The geochronological data (Rosa et al. 2007) for the economic deposits show that blue sodalite syenites were formed during an interval of at least 36 Ma: between 696 ± 3 Ma (Pb–Pb, carried in zircon) for the Floresta Azul Complex and 732 ± 8 Ma (U–Pb, carried in titanite) for Itajú do Colônia. As the ages of the sodalite syenite and nepheline syenite host rocks were similar, Rosa et al. (2007) concluded that the sodalite genesis was part of the crystallisation processes and that it would either crystallise directly from the magma or by magmatic fluid interaction with previous minerals (metasomatism).

Moraes Filho and Lima (2007) described the syenitic elliptical bodies, 1350 m long by 500 m wide (approximately 1 km^2 in area), mined since the 1960s as natural stones (Fig. 9). They occur southwest of the city of Itajú do Colônia, intruding in the Archean–Paleoproterozoic granulites of the Itabuna Belt.

These rocks are described as sodalite syenite composed of tabular orthoclase with interstitial sodalite, in addition to aggregates of aegirine, biotite, and opaque minerals (Moraes Filho and Lima 2007) with textural relationships indicating that sodalite crystallises directly from magma after nepheline, followed by K-feldspar, titanite, calcite, and aegirine (Rosa et al. 2005, 2007).

Rosa et al. (2005) carried out radiometric studies in these rocks providing the already mentioned age of 732 ± 8 Ma, interpreted as the crystallisation age of sodalite syenites of the Itajú do Colônia stock.

In the Itarantim massif, blue sodalite syenite occurs in the form of dykes, cutting nepheline syenites (Fig. 10), and its placement caused metasomatic transformations in the enclosing syenitic rocks (Rosa et al. 2004). Thus, with the

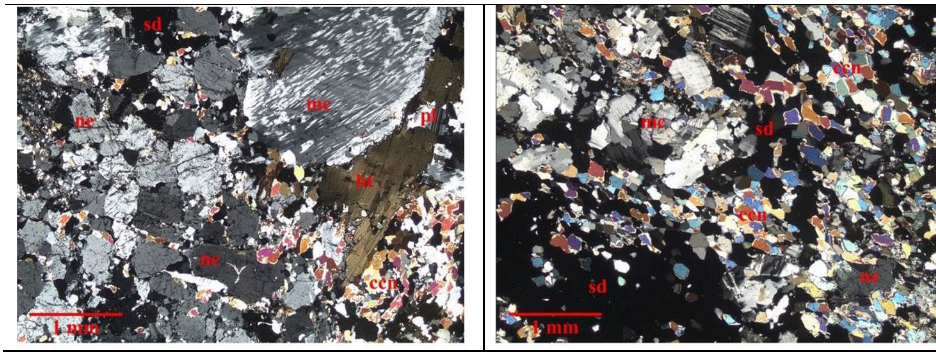


Fig. 11 Petrographic aspect of nepheline-sodalite syenite of Potiraguá (sd: sodalite, mic: microcline, ne: nepheline, bt: biotite, pl: plagioclase, ccn: cancrinite). Cross-polarised light. (Source: IPT 2012)

Table 3 Main technological properties of Bahia blue syenites and respective test methods

Properties	'Blue Bahia'[a]	'Blue Sodalite'[b]	Test method
Apparent density (kg/m^3)	2545	2465	ABNT (2015a)
Apparent porosity (%)	0.10	-	ABNT (2015a)
Water absorption (%)	0.04	0.09	ABNT (2015a)
Compressive strength (MPa)	169.2	154.7	ABNT (2015b)
Modulus of rupture (MPa)	16.64	10.14	ABNT (2015c)
Flexural strength (MPa)	-	9.98	ABNT (2015d)

Sources: [a]Azevedo and Costa (1994), [b]IPT (2012)

increase of the metasomatic process, alkali feldspars were partially replaced by sodalite. At the final stages, cancrinite and calcite occasionally replaced sodalite. Biotite remained after metasomatism but acquired a stronger brown colour, suggestive of the action of the peralkaline and chloride-rich fluids.

Geochronological studies conducted by Rosa et al. (2007) indicated an age of 722 ± 5 Ma (Pb–Pb) for the Itarantim Batholite, suggesting that they represent a highly evolved product from differentiation of the nepheline syenitic magma.

Main Petrographic and Technological Characteristics

Sodalite syenite's primary economic exploitation as a natural stone is from the Itajú do Colônia stock, commonly commercialised as 'Blue Bahia', and the Itarantim massif, commercially named 'Blue Sodalite'.

'Blue Sodalite' is a structurally heterogeneous rock (Fig. 9a) of variable grain size (medium to coarse, between 1 and 10 mm) in which the volume of sodalite may reach 40% (Rosa et al. 2004). Blue syenite exploited by Somibrás, in the Potiraguá region (IPT 2012) is a nepheline–sodalite syenite essentially composed of perthitic microcline (25%), sodalite (20–30%), albite (15%), nepheline (10–20%), biotite (10%), and cancrinite (5–10%) with opaque minerals (magnetite, ilmenite), zircon, calcite, and apatite as accessory (< 5%) (Fig. 11). Rosa et al. (2004) also mentioned the presence of aegirine and fluorite.

On the other hand, 'Blue Bahia' is a structurally more homogeneous rock, resembling granite in texture (Fig. 9b), showing a 'painted' aspect, blue (sodalite)–white (feldspar)–black (biotite, aegirine, amphibole, titanite, sulphide and carbonate) (Rosa et al. 2005). The main mineralogical composition of sodalite syenites of Itajú do Colônia, as reported by Azevedo and Costa (1994), is microcline (50%), sodalite (30%), cancrinite (10%), plagioclase (5%), with aegirine, biotite, and opaque minerals (5%) as accessory.

Technological properties of Bahia blue syenites are listed in Table 3.

Uses

The exploitation of natural blue stones in Bahia has continued since the middle of the twentieth century until today, always carried out by a small number of companies. These stones' high commercial value has been sustained by careful production, seeking to maintain the market and reserves as much as possible.

Technological properties of blue stones of Bahia are quite good compared to the main rock groups to which they belong ('quartzites' and 'granites'), making them suitable for use as natural stone in most applications in the built environment, including indoor and outdoor walls and floor coverings.

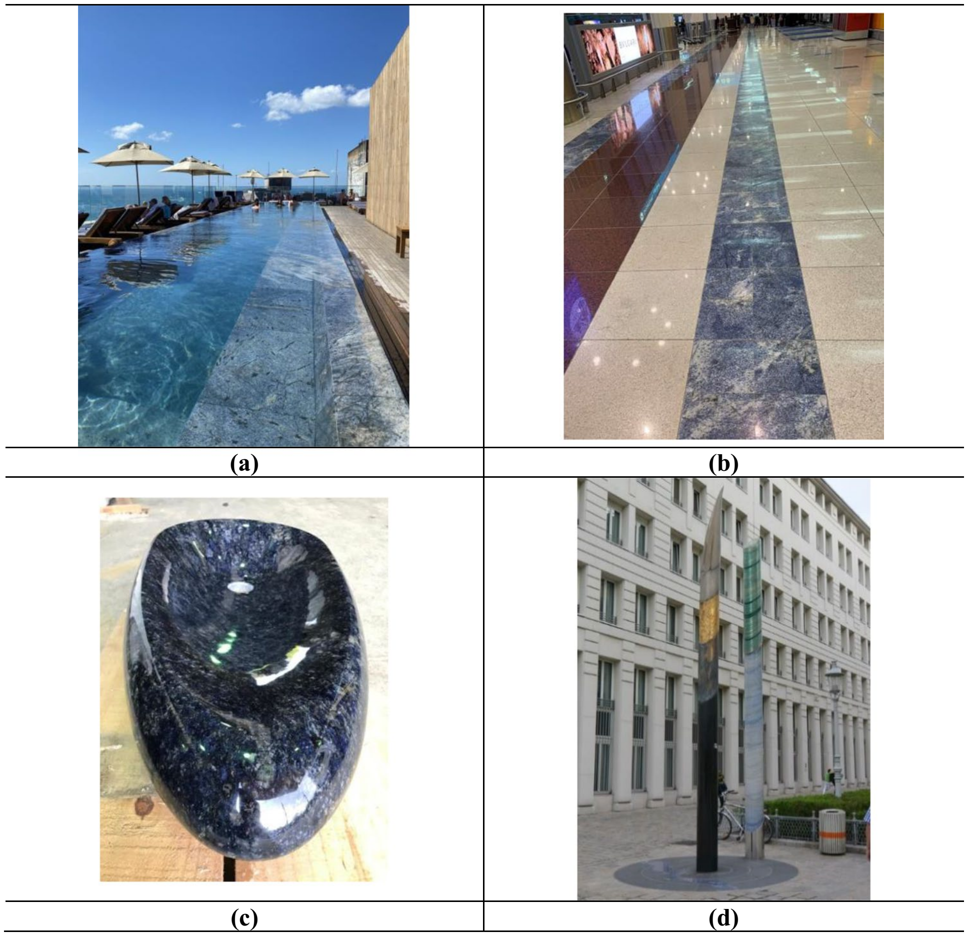


Fig. 12 **a** ‘Blue Bahia’-tiled pool at the Fasano Hotel, in Salvador, Bahia (Photo: Ana Pimenta/Nosso Blog de Viagem), **b** ‘Blue Bahia’ flooring at Dubai Airport (Photo: Maria Heloisa Frascá), **c** ‘Blue Sodalite’ sink (Photo: Somibrás), and **d** Erde Wasser Feuer Luft sculpture, by Robert Margreiter, at Minoritenplatz, Vienna, using ‘Imperial Blue’ (stele) and a ‘Blue Bahia’ ribbon (undulated piece on the floor; photo: Maria Heloisa Frascá)

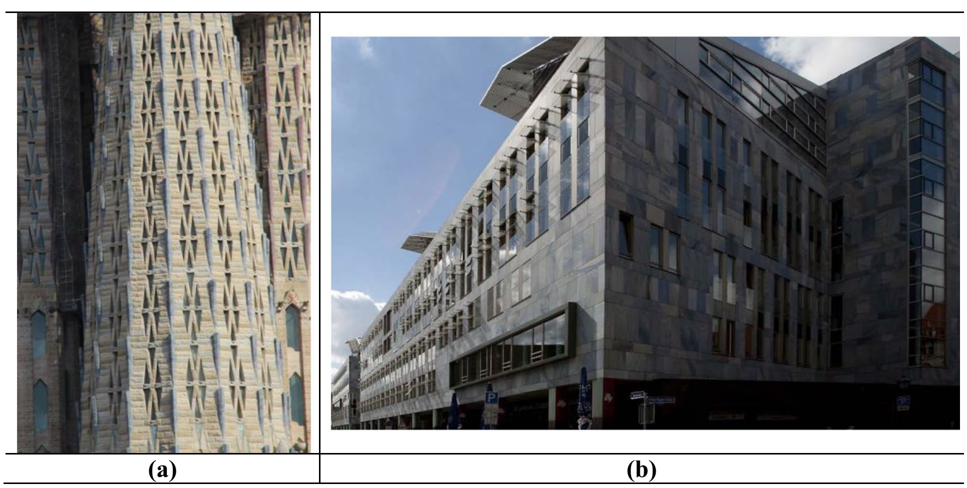


Fig. 13 **a** ‘Blue Bahia’ in Sagrada Familia Towers (Barcelona, Spain; photo: Elena Fernández), and **b** ‘Blue Macaúbas’ cladding of the Nord/LB Magdeburg branch (Germany; photo: Blue Stones/ GM Granitos e Mármores)

Although no studies or reports on deterioration or conservation of these rocks were found, their characteristics indicate they are durable with appropriate use and maintenance.

Exported since the 1960s to many countries, mainly as rough blocks to Italy, Spain, Germany, and Middle-Eastern countries, they are currently also exported in slabs, highly valued in the USA.

However, due to their high price (around US$ 2000/m^3 and US$ 500/m^2), these blue rocks are usually used in small volumes, combined with other lithotypes or materials in luxury hotels (Fig. 12a), airports (Fig. 12b), and high-income residences, as kitchen countertops and bathroom decoration (Fig. 12c), as well as in art objects or sculptures (Fig. 12d).

They can also be found in valued architectural projects, such as the Hereford Cathedral Apse and the Kensington Ismaili Centre façade details and interior decor (UK), the Sagrada Familia's new towers (Spain) (Fig. 13a), and the Nord/LB Magdeburg branch (Germany), which has a 28-m-high façade covered with 'Blue Macaúbas' quartzite (Fig. 13b).

Conclusions

Rare in nature, the blue stones presented here are beautiful examples of rock uniqueness in global geodiversity.

Belonging to the domain of the São Francisco Craton, they represent either a sedimentary cover (Supergroup Espinhaço) or an alkaline magmatism associated with rift zones in an intraplaque tectonic environment (SBAP). Both differentiate from other syenites and quartzites by the presence of rare elements in the formation environment — boron in the case of the dumortierite quartzites and chlorine in the sodalite syenites.

Blue syenites are exploited in the south of the State of Bahia, and their colour is given by blue sodalite. Blue quartzites occur around 700 km west of Salvador, capital of the State of Bahia, and owe their colour to the mineral dumortierite.

They have been continuously quarried since the 1960s by a small number of stone companies that keep their reserves and high value with controlled production and commercialisation.

Both types of natural stones have technological properties suitable for all uses, but the main uses are in exclusive decoration or art projects due to their high price. Because of their rarity, as well as their aesthetic and technological characteristics, the blue syenites and quartzites from Bahia are some of the world's most valued natural stones.

The geological and technical characteristics, together with the small-volume but continuous international use — for more than 50 years — of these unique building materials from Bahia, make them candidates for the designation as GHSRs of Brazil. It is important to point out that some characteristics of these lithotypes, such as their scientific and aesthetic value, could also configure them as geosites in a geoheritage context (Brilha 2016), which could be the subject of future detailed works.

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This manuscript does not involve any studies in humans or animals.

Declarations

Conflict of Interest The authors declare no competing interests.

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