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Charnockite: a candidate for ‘Global Heritage Stone Resource’ designation from India

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The first description of charnockite rock, now known to occur in all continents, became available to the world from India. Sir Thomas Holland named the tombstone of Job Charnock’s sepulchre at St. John’s Churchyard in Kolkata (erstwhile Calcutta) as ‘charnockite’ in his honour. Later, the classic memoir on charnockite by Thomas Holland appeared, where he defined charnockite as a quartz-feldspar-hypersthene-iron ore-bearing rock. Charnockite incorporates members of orthopyroxene-bearing, high-grade felsic-granulites and granitoids. It essentially contains orthopyroxene as the characteristic ferro-magnesian mineral along with quartz and feldspar. Charnockite is an excellent example of a heritage stone as it was extensively used from time immemorial on the Indian subcontinent. The Mahabalipuram temple complex (UNESCO world heritage site), Sri Padmanabha temple, Vivekananda and Thiruvalluvar memorials, Job Charnock’s tombstone etc. are just a few examples of monuments made of charnockite spread out in various parts of India. In contemporary times, Indian charnockite has a huge market in countries like Japan, Germany, Italy, Netherlands, UK, USA, Africa, Australia and so forth. The protracted history of usage of charnockite in architectural heritage in India combined with its unique geological significance makes it an exemplary candidate for the Global Heritage Stone Resource (GHSR) recognition.

Introduction

Since time immemorial, humans have always been fascinated by the varying colours and textures of natural stones, as demonstrated by the grandiose monumental depictions in numerous civilizations. The techniques of construction and decoration of the architectural heritage and monuments were essentially decided by durability, aesthetics and availability of the geological materials. In most cases, proximity and/or ease of transport of the geological material were the decisive

factors for selecting a particular stone to construct historical buildings. However, certain stones have overcome the spatial limits and have been transported across the continents to build architectural heritage in different parts of the world. Given the importance of heritage monuments and natural stones used for their construction, the International Union of Geological Sciences (IUGS) established a Heritage Stone Subcommission (HSS) to designate rocks of historical significance as ‘Global Heritage Stone Resource’ (GHSR) based on Terms of Reference of the HSS (<http://globalheritagestone.com/reports-and-documents/terms-of-reference/>). To date, twenty-two heritage stones have been designated as GHSRs from around the globe (e.g., Pereira, 2019; Kaur et al., 2020a). The famous Carrara marble from Italy (Primavori, 2015), Jacobsville sandstone from USA (Rose et al., 2017), Makrana marble from India (Garg et al., 2019), etc. are few examples of rocks that are already designated as GHSRs (<http://globalheritagestone.com/igcp-637/igcp-achievements/>). Other important rocks at international level can be found listed at <http://globalheritagestone.com/other-projects/ghsr/interim-list/>. They could well be potential candidates for the future recognition as GHSRs.

India is dotted with numerous stone-built architectural heritage and some of the distinguished Indian heritage stones have been lately proposed as candidates for designation of GHSRs (Kaur et al., 2019a,b, 2020a,b,c). This paper highlights important attributes of one more important rock from India, named charnockite, which deserves to be candidate for nomination for designation of GHSR by IUGS-HSS following their Terms of Reference. The charnockite has a wide spatial distribution across the Indian subcontinent with numerous magnificent monuments to its credit. In the following sections, geological significance, petrophysical properties and architectural use of Indian charnockite are enumerated in support of the GHSR candidature of charnockite.

The Charnockite (terminology) Problem

The term “charnockite” was coined by Sir Thomas Holland (Holland, 1893), then director of Geological Survey of India, to describe an acid variety of orthopyroxene-bearing rock found on the tombstone

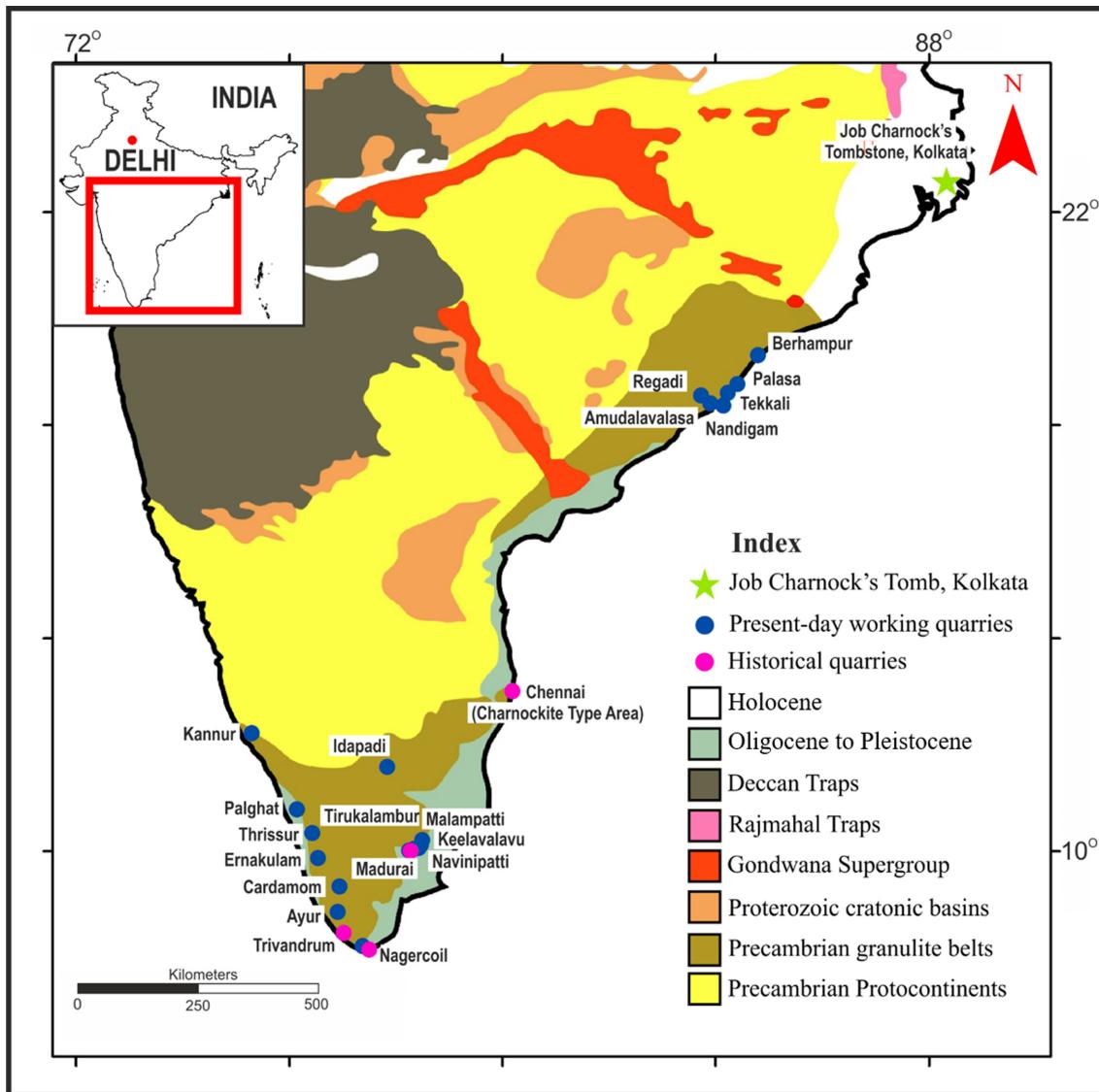


Figure 1. Charnockite province of southern India showing historic as well as present quarry sites of charnockite (Map modified after Roy, 2014). The type area of charnockite at Chennai, southern India and Job Charnock Mausoleum at Kolkata are also marked for reference.

of Job Charnock (1630-1693) at St. John's Churchyard in Kolkata (then Calcutta) City. Thus, the charnockite has been privileged with a rare incidence of having its name originated from a monumental stone. Based on the mineralogical composition, Holland concluded that the Job Charnock's tombstone rock was transported from St. Thomas Mount, near Pallavaram in Chennai (then Madras) (Fig. 1). Later, in his classic memoir on charnockite, Holland (1900) defined charnockite as a quartz-feldspar-hypersthene-iron ore-bearing rock, and suggested that the name should not be used for any hypersthene-granite occurring outside the type-area at St. Thomas Mount in southern India.

However, regardless of the caution on the usage of terminology, researchers from around the globe have recognised its presence in Precambrian orogenic roots all around the globe with similar mineralogical composition and petrological characteristics (e.g., Groves, 1935; Prider, 1945; Quensel, 1951; Wilson, 1959; Howie, 1964). Since then, a magmatic versus metamorphic origin of charnockite became a mat-

ter of debate because the orthopyroxene-bearing quartz-feldspathic assemblages are common in rocks of granitic compositions of igneous as well as metamorphic origin (Field et al., 1980; Friend, 1981; Wentlandt, 1981). Le Maitre (2002) described charnockite as a rock with orthopyroxene and often with perthite, mesoperthite or antiperthite. Based on modal mineralogy, charnockite plots within the fields of granite-granodiorite to tonalite in the QAPF classification (Streckeisen, 1976).

Distribution of Charnockite and Architectural Monuments

The geological distribution of charnockite is restricted to exposed lower crustal segments of high-grade granulite-facies terrains. Charnockite and its variants have been reported in high-grade terrains all around the globe, namely, Southern Granulite Terrain (SGT), Eastern



Figure 2. A few of the prominent charnockite monuments around the globe: (a) Ruins of Lagoinha in Brazil, (b) Bank of Brazil, São Bento Street branch, (c) the Christ the Redeemer statue in Brazil, (d) Canadian War Memorial in Green Park, London, (e) life-size statue of Oscar Wilde at Dublin, Ireland and (f) Australian War Memorial in Hyde Park Corner, London (Photo courtesy: [d-f] Wikipedia).

Ghats Mobile Belt (EGMB), Aravalli Mountain Belt and Meghalaya Massif (India); Green Ubatuba and Venda Nova (Brazil); Mozambique and Limpopo Belts (Africa); Minto terrain (Canada); Bamble Sector (Norway); Bjørnesund (Greenland); Ivrea Zone (Italy); Adirondacks and Wyoming (USA); Musgrave Block (Australia); north China Craton; Antarctica etc. (e.g., Howie, 1964; Bohlender et al., 1992; Newton, 1992; Frost et al., 2000; Mikhalsky et al., 2006).

Charnockite has also been extensively used as a building stone in different parts of the globe. Some world-famous charnockite monuments are Mahabalipuram temples, India; Ruins of Lagoinha, Christ the Redeemer, José Bonifácio, Banco do Brasil building and base of the Peace Landmark, Brazil; famous sculpture of Oscar Wilde, Ire-

land; Canadian and Australian War Memorials, United Kingdom and statue in memory of Douglas Mawson, flanked by a charnockite boulder, Australia, are just a few of the many examples (Figs. 2a-f).

Charnockite Occurrence in India

In southern India, charnockite is widely distributed within SGT and along EGMB, regionally termed as Precambrian granulite belt (Fig. 1). On outcrop scale, charnockite occurs either as massive-type (pluton or mega-scale units) (Figs. 3a-b) or as patches and veins, usually describing the stone as incipient charnockite. Of these, massive-type charnockite, excavated as dimension stones and/or as rough stones



Figure 3. Field relationships of charnockite from southern India: (a) mesoscopic view of massive-type charnockite, (b) quarrying of massive, pluton-type units, (c) charnockite being excavated as dimension stones and (d) panoramic view of large scale quarrying of charnockite.

(Figs. 3c-d) is best sought for construction purposes around the world.

In high-grade terrains of southern India, wide spread distribution of massive-type charnockite can be seen either as isolated large hillocks or as bands and lenses of several meters thickness within garnet-biotite and/or hornblende-biotite gneisses. Charnockite displays a wide range of composition from tonalitic-granodioritic to granitic (Ravindra Kumar and Sreejith, 2016). The samples from type-area at St. Thomas Mount, Chennai (Fig. 1) depict average mineral mode typical of granitic composition (Rajagopalan, 1946). The rock is usually granoblastic and it is occasionally foliated.

The age groups of southern Indian charnockite comprise Early- to Meso-Archaean to the north of Palghat–Cauvery shear zone and Neo-Proterozoic (related to Pan-African orogeny) to the south (Ravindra Kumar and Sreejith, 2016). Similar kinds of mineralogical, petrological and geochemical signatures as that of Indian charnockite are identified across charnockite terrains around the globe (e.g., Groves, 1935; Prider, 1945; Quensel, 1951; Wilson, 1959; Howie, 1964; Newton, 1992).

Petrography

The strength, durability and aesthetic significance of stones are generally influenced by microstructures (textures) and mineral assemblages. Charnockite is a mesocratic rock characterized by medium- to coarse-grained texture and inequigranular, interlobate to polygonal granoblastic textures with mutual interlocking of grains (Fig. 4a). It

exhibits dark blue to greenish colour in fresh exposures and tend to have a pink or light brown color when altered. Charnockite exhibits a massive to foliate structure, the latter being less frequent.

The most common mineral assemblages in charnockite include K-feldspar + plagioclase + quartz + orthopyroxene (En_{40-60}) \pm clinopyroxene \pm hornblende \pm biotite \pm garnet (Fig. 4b). Ilmenite, magnetite, zircon and monazite are accessory phases in charnockite. Feldspar (30–60%) is micro and mesoperthitic with typical antiperthitic (K-feldspar lamellae in plagioclase) and perthitic (plagioclase lamellae in K-feldspar) textures and sometimes exhibits tartan pattern of twinning (Fig. 4c). Phenocrysts of feldspar reach up to a few centimetres. Plagioclase (15–35%) has composition of An_{30-35} . Quartz (15–30%) presents wavy extinction. Mafic minerals represent 3 to 10% of the total volume of the rock. Orthopyroxene is abundant in most samples and usually forms subidiomorphic crystals, with composition En_{40-60} and occurs associated with hornblende and biotite (Fig. 4d). Biotite is found in small amounts. Clinopyroxene and amphibole are rarely found in charnockite and when present, occur either as subidiomorphic crystals or as rims around orthopyroxene.

Based on mineralogy and geochemistry, Ravindra Kumar and Sreejith (2016) have classified charnockite into three broad groups, namely, tonalitic, granitic and augen charnockite. The major difference between tonalitic and granitic varieties is the modal abundance of plagioclase over K-feldspar in tonalites, whereas K-feldspar forms the major phase in granitic varieties. Augen charnockite is essentially granitic in composition with augen (eye-) shaped megacrysts of K-feldspars. The tex-

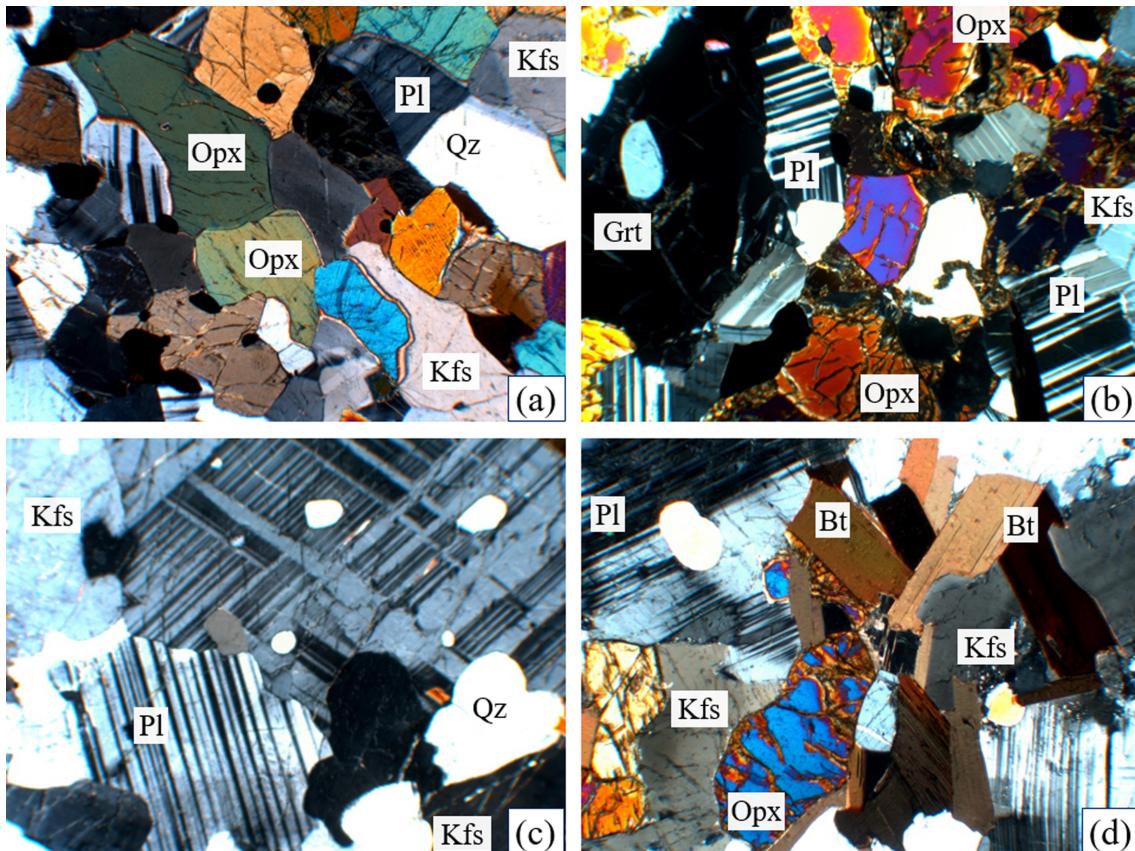


Figure 4. Photomicrographs of southern Indian charnockite with crossed polarizers (scale = 4x magnification) showing: (a) polygonal granoblastic microstructure with mutual interlocking of grains, (b) common mineral assemblages, (c) textures exhibited by feldspars and (d) Opx-Bt-Kfs assemblages in charnockite (mineral abbreviations after Whitney and Evans, 2010).

tural and mineralogical evidence of the charnockite is indicative of high-temperature and intermediate- to high-pressure transformation of precursor plutonic rocks under granulite-facies conditions, giving rise to a compact crystalline rock with isotropic fabric. Similar kinds of textures and mineralogical compositions are identified for charnockite elsewhere in the world (e.g., Touret and Huizenga, 2012).

Petrophysical Characteristics

The microstructures influence petrophysical characteristics of the rocks. The important petrophysical characteristics defining the strength, durability and resistance to deterioration of rocks, which are key factors for designing engineering structures are: compressive strength (capacity to withstand loads), tensile strength (stress threshold for crack initiation limits), bulk density (mineralogical makeup, porosity and moisture content), Young's modulus (stiffness of materials), compressional and shear wave velocities, porosity, density, water absorption, permeability, Poisson's ratio (deformation) etc. In general, charnockite is entirely crystalline, composed chiefly of closely compacted crystals of quartz and feldspar and acquires an excellent surface polish, which reinforce the recommendation of their use as dimensional and decorative stones. The charnockite exhibits high values for compressive and tensile strength and bulk density with low porosity, low water content and isotropic distribution of minerals indicating their ability to withstand

load and crack initiation. The petrophysical characteristics of Indian charnockite are summarized in Table 1.

The average specific gravity of charnockite is ~2.7 and water absorption capacity values range between 0.13 and 0.24% by weight (Table 1), which falls under the recommended standard value of water absorption capacity (ASTM, 2018). Similarly, unconfined compressive strength of charnockite falls into very strong category of the strength classification (GSEG, 1977). The petrophysical parameters reported for different commercial varieties of Indian charnockite such as Black granite, Vizag Blue, Seaweed Green, Lavender Blue etc. corroborate these values (CDOS, 2002; Rao et al., 2006; Ravindra Kumar and Sreejith, 2013).

Heritage Monuments Made of Indian Charnockite

The charnockite terminology proposed by Holland (1893) to the geological lexicon celebrated its Quasquicentennial Jubilee (125th year) in the year 2018. However, heritage made of charnockite is even far more ancient. Some renowned historical sites such as the group of monuments at Mahabalipuram (UNESCO world heritage site since 1984), Madura Meenakshi temple and Sri Padmanabha temple are Indian examples for ancient heritage made of charnockite. On the other hand, modern usage of charnockite in monument construction in southern India is depicted by Vivekananda and Thiruvalluvar memo-

Table 1. Petrophysical properties of Indian charnockite

Property	Value (Average)	Reference
Compressive Strength (MPa)	156	CDOS, 2002
Tensile Strength (MPa)	10.30	CDOS, 2002
Bulk Density (kg/m ³)	2740	Ravindra Kumar and Sreejith, 2013
Specific Gravity	2.70	CDOS, 2002
Water Absorption Capacity (% by weight)	0.19	CDOS, 2002
Flexural Strength (N/mm ²)	14.48	CDOS, 2002
Young's Modulus (GPa)	84.05	Rao et al., 2006
Compressional Wave Velocity (m/s)	5920	Rao et al., 2006
Shear Wave Velocity (m/s)	3571	Rao et al., 2006
Poisson's Ratio	0.21	Rao et al., 2006

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

Indian Monuments

The Mausoleum of Job Charnock (Figs. 5a-b), wherfrom the rock attained its name, was erected more than 300 years ago and forms one



Figure 5. (a) The Mausoleum of Job Charnock at Kolkata, (b) inscriptions on charnockite inside the Mausoleum and (c) charnockite monument at St. Thomas Mount, Chennai, wherfrom the tomb stone of Job Charnock had been excavated (Photo courtesy: Geological Survey of India).



Figure 6. (a) Monolithic charnockite carved temple of Mahabalipuram, Chennai and (b-c) examples of exquisite rock-sculptures carved in charnockite exhibited in Mahabalipuram temple (Photo courtesy: Wikipedia).

of the important charnockite monuments in India (Hyde, 1893). It is also interesting to note that the charnockite used in the monument was quarried and transported from Chennai (more than 1500 km far south of Kolkata; Fig. 1), which became the type-area for this rock group and has been preserved as a geological monument presently (Fig. 5c).

The UNESCO world heritage site (Ref: 249/1984) at Mahabalipuram, Chennai, represents nowadays a world-renowned heritage made of charnockite (Fig. 6a). The exquisite rock-sculptures (Figs. 6b-c) exhibited in the Mahabalipuram dates back to the 7th Century (AD 650-700), during the rule of Pallava dynasty (Babington, 1829; GIJ, 2017). In Mahabalipuram, four different types of Pallava architectural designs have been noticed: (1) cave temples, (2) monolithic temples, (3) structural temples and (4) excavated remains. The uniqueness of the monument lies in the fact that the sculptures are carved *in situ* on dense, hard rocks, using traditional hammer and chisel techniques. This traditional carving pattern has now been granted with the geographical indicator tag of Intellectual Property Rights, India, under exceptional handcrafted stone carving products (GIJ, 2017).

Madura Meenakshi and Sri Padmanabha temples are virtuous examples of architectural masterworks on charnockite from southern India. The Madura Meenakshi temple spans over 45 acres (approx. 180,000 sqm) and forms one of the largest temple complexes in Tamil Nadu. The construction of the temple was completed during the 17th Century under the patronage of Nayak rulers (Fergusson, 1972). The temple encompasses 12 gateways (*Gopuram*), which are 45 to 60 metres in height and are made of charnockite blocks as high as 9 metres. The tallest amongst these on the southern side is about 61 m high (as high

as a nine-storey building). Charnockite has been widely used to build the magnificent structures and pillars of the temple.

The Sri Padmanabha temple (Fig. 7), situated in Trivandrum, southern India, is an excellent example of architectural grandeur built of charnockite, gneiss, and laterite. The temple is run by a trust headed by the royal family of Travancore and considered the world's wealthiest temple, with the value of treasure reaching more than one trillion dollars. The time period of construction of the temple and consecration of the idol is lost in antiquity. However, recorded remarks about the temple in the narratives of 'Sangam' period (500 BCE to 300 CE) indicate its construction in the pre-historic times. The temple structure suggests a complex combination of 'Chera' (300 BCE to 300 CE) and 'Dravidian' styles of architecture featuring high-walls made of charnockite blocks (Sarkar, 1978). All these ages indicate archaic usage of charnockite in construction of giant structures. Extensive usage of charnockite in the construction of the temple is also evidenced by the lengthy corridors supported by 365 and one-quarter sculptured pillars with elaborate carvings and the pavements made of charnockite slabs.

Other prominent monuments in southern India made of charnockite in the 20th Century are the Vivekananda and Thiruvalluvar memorials (Fig. 8a), constructed atop small monolithic (charnockite) rocky islands situated approximately 250 m away from the southern tip of Indian mainland, the confluence of Indian Ocean, Bay of Bengal and Arabian Sea. This location is particularly significant in global geology, because this is the region where the Indian subcontinent was assembled with Africa, Madagascar, Sri Lanka, and Antarctica in the Gondwana supercontinent period.



Figure 7. Panoramic view of Sri Padmanabha temple in Trivandrum. The gold covered “Gopura” of the temple is built of charnockite.



Figure 8. (a) Panoramic view of Vivekananda and Thiruvalluvar memorials constructed on monolithic charnockite islands situated at the meeting point of Indian Ocean, Bay of Bengal and Arabian Sea, (b) Vivekananda memorial constructed using polished blocks of charnockite and (c) the 41 m (133-feet) tall sculpture of Tamil poet Thiruvalluvar. The statue is made entirely of charnockite blocks.

The Vivekananda memorial (Fig. 8b), completely made with charnockite blocks is built on a dome-shaped, massive-type charnockite island, covering an area of 150×120 m. The idea behind the rock memorial was to commemorate the Birth Centenary of Swami Vivekananda (1863-1902), who inspired the whole world through his iconic speech on 11th September 1893 at the Chicago Convention of Parliament of Religions, USA. The construction of this awe-inspiring memorial was completed in 1970 and stands as an architectural chef d'oeuvre illustrating various architecture styles. At present, it is one of the most popular tourist locations in southern India. The monument exhibits distinctive architecture styles from all over India. The Vivekananda rock island is a part of the Nagercoil charnockite block. A petrological description and geochemistry of the rocky island is provided by Bhattacharyya and Tickha (2012) and suggested granulite-facies metamorphism of a magmatic protolith in the Pan-African period.

Towards the western side of Vivekananda memorial, on another rocky island of charnockite, stands a giant sculpture of Thiruvalluvar made entirely of charnockite blocks weighing more than 7,000 tons (Fig. 8c). Thiruvalluvar was a celebrated Tamil poet and philosopher, best known for his work "Thirukkural", widely considered as the most cherished work of Tamil literature (Zvelebil, 1975). Construction of the monument involved a great effort as 3,681 large blocks of charnockite had to be carried to the rocky island through rough sea. The largest of these stones were 4 m long and weighed over 15 tons. Similar styles of stone proportions were previously found only in Mayan temples of South America. The statue (29 m), combined with its pedestal (12 m) is approximately 41 m (133-feet) tall, denoting the 133 chapters of the Thirukkural. An interesting fact about the sculpture is that the shaping of different parts of the sculpture was carved by hand. The statue

was unveiled on the millennium day of 1st January 2000.

Use of Indian Charnockite in Global Monuments

The life-size statue of Oscar Wilde, built in 1997 in Dublin, Ireland, is a geological wonder, which is carved in five beautifully colourful and exotic rock types from three different continents (Fig. 2e). Oscar's famous smoking jacket is carved in nephrite jade (from British Columbia); the pink collar and cuffs are of thulite (Western Norway); trousers are of larvikite (Oslo Fjord in Norway); and his shoes and socks are of charnockite from southern India. Due to the use of varied geological materials in its construction, the monument has been a focus of interest to geologists since its inception (Stillman, 1999). This sculpture is particularly interesting because it is made of different stones of heritage significance transported from various continents to its present place in Dublin. This indicates global interest in southern Indian charnockite as a heritage stone resource. Similarly, Siddall (2015), Siddall et al. (2017) and Pereira (2019) testified varied uses of charnockite from India for the construction of historical and contemporary buildings of United Kingdom and across other European cities indicating demand of Indian charnockite in global markets.

Contemporary Use

The strength, durability, and resistance to weathering has made charnockite one of the most sought heritage and/or building stone among hard rocks. In the present day, charnockite and its variants used for commercial purposes are referred to by different names, such



Figure 9. (a-d) Various types of handicrafts and sculptures crafted from charnockite in India.

as Black and Green granites, Vizag Blue, Seaweed Green, Lavender Blue etc. Since charnockite has wide spread distribution in most of the Indian orogenic belts, fresh quarries are still in operation (Fig. 1), where these rocks are extracted either as dimension or raw stones for building, carving, sculpture, artefact making etc. The sculptures (Figs. 9a-d) and memorials made of charnockite in India are so exquisite that they are exported to countries like Japan, Germany, Italy, Netherlands, UK, USA, Africa, Australia etc. (GIJ, 2017; <https://eurasian.com/>). Indian charnockite, due to its strength and durability, has also been extensively used as a basement stone for residences and other buildings around the world.

Summary and Conclusions

Charnockite is a unique rock among the list of heritage stones that received its name after a tombstone from India. It has been persistently used in the monuments of historical past and recent day buildings in different parts of India. Indian charnockite has also been exported to various parts of the globe and has been extensively used as building and monumental stones in different countries. Thus, charnockite from India fulfills all the essential criteria defined at present by the Heritage Stone Subcommission, such as prolonged cultural history, utilization in significant works, wide geographical use etc. and thus it is proposed as a candidate for designation of Global Heritage Stone Resource (GHSR).

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