# Miliolite limestone – a potential global heritage stone resource

The proposal for a 'Global Heritage Stone Resource' (GHSR) was first made at the 33rd International Geological Congress in Oslo, Norway, in August 2008. Since then, GHSR has gained support from the International Union of Geological Sciences (IUGS). The International Commission on Geoheritage (ICG) of IUGS has a Heritage Stone Sub-commission (HSS), which evaluates the proposals of heritage stones from different parts of the world for designation as GHSR. As of February 2019, 14 heritage stones have been designated as 'GHSR's. Makrana marble from Rajasthan, India is Asia's first GHSR[1]. It was confirmed by IUGS in July 2019.

GHSR provides a means by which geoscientists, planners and the industry can explain the importance of some types of stones used to repair and maintain historic structures, new buildings and objects such as sculptures[2].

The defining criteria for identifying GHSR include:

(i) Wide-ranging geographical use for a significant period.
(ii) Utilization in significant industrial projects.
(iii) Recognition as a cultural icon.
(iv) Continuing availability.
(v) Potential: cultural, scientific, environmental and commercial benefits.

The miliolite limestone satisfies all the above criteria, and is a suitable candidate to be declared as GHSR.

The proposed natural stones of India for inclusion under GHSR are from diverse formations of different ages. Four potential Global Heritage Stone Provinces, one each from the North and North Western Province, the Central and Western Peninsular Province, the Southern Peninsular Province, and the Eastern and North Eastern Province have been identified in the country[3]. Stones from these Provinces have been used in heritage monuments. Makrana marble (a metamorphic rock) of Rajasthan, basalt (an igneous rock) of Maharashtra, red sandstone from the Vindhyan mountains and Jaisalmer limestone of the Jurassic age are some of the well-recognized Heritage stones of India.

Among them, Makrana marble has been used extensively as a dimension, ornamental and sculptural stone for numerous iconic buildings[1], such as the Taj Mahal of India – one of the Seven Wonders of the World and the Moti Masjid, the 17th century religious building located inside Lahore Fort, Pakistan. Red sandstone is extensively used to construct iconic buildings in North India, including the Red Fort of Delhi, Agra Fort and surrounding buildings. Sourced from the Vindhyan mountains of India, red sandstone has been proposed for GHSR status[4].

Recently, attempts have been made to declare the Alwar Quartzite of Rajasthan as a GHSR[5]. It is being reasoned that the rock has been extensively used in several stone-built monuments in Delhi and other states in North India. Several monuments of Delhi, in particular, built during the 'pre-Sultanate period' (11th century or earlier) and the British Raj in the late 19th century, have extensively utilized the Alwar quartzite.

The Golden Jaisalmer limestone, a yellow lime from Jaisalmer, Rajasthan, has been used widely in heritage monuments in India. The Jaisalmer Fort was built in AD 1156 using yellow Jaisalmer limestone. Other

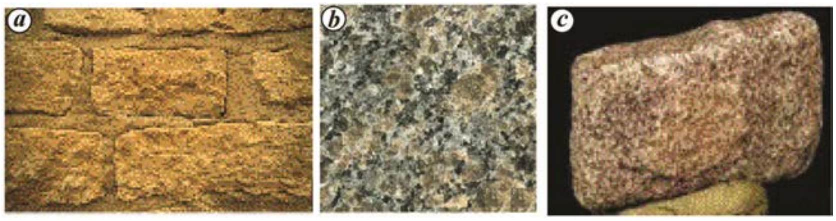


**Figure 1.** A few polished Global Heritage Stone Resource of India. ***a***, Jaisalmer limestone; ***b***, Charnokite; ***c***, Khondalite.

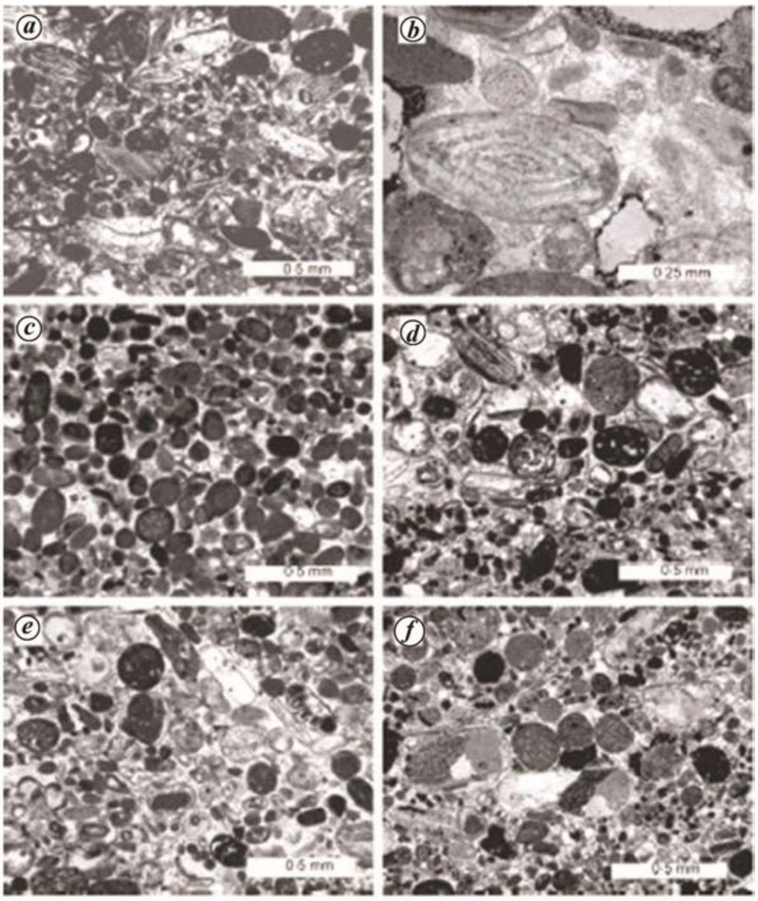


**Figure 2.** Photomicrographs of different varieties of carbonate aeolianite. ***a***, Typical biopelsparite; ***b***, well-rounded clast of foraminifera; ***c***, typical pelsparite; ***d***, ***e***, pelbiosparite; ***f***, pelsparite[34].

monuments of great antiquity built using Jaisalmer limestone include Patuon ki Haveli (1805), Salim Singh ki Haveli (1815), Gadisar Lake Temple and Chhatris (AD 1156), Amar Sagar Jain Temple (1871) in Jaisalmer area (Figure 1 *a*).

The tombstone of Job Charnock in the vicinity of St John's Church compound in Kolkata, was made of a quartz–feldspar–hypersthene–iron ore-bearing rock named as charnockite by Thomas Holland[6]. This world-famous rock incorporates orthopyroxene-bearing, high-grade felsic-granulites and granitoids[6]. The Mahabalipuram Temple complex (UNESCO World Heritage Site), Sri Padmanabha Temple, Vivekananda and Thiruvalluvar memorials and Job Charnock's tombstone are just a few examples of monuments made of charnockite/granite spread out in various parts of India (Figure 1 *b*). Today Indian charnockite has a huge market in countries like Japan, Germany, Italy, the Netherlands, UK, USA, Africa and Australia. The protracted history of the usage of charnockite in architectural heritage in India combined with its unique geological significance, makes it an exemplary candidate for recognition as a GHSR.

Yet another stone proposed to be designated as a GHSR from India is khondalite[7] (Figure 1 *c*), which has been used for building most ancient temples in Odisha, for example, the Konark Sun Temple and the Jagannath Temple of Puri.

Khondalite is dominantly found in the Eastern Ghats between Vijayawada and Cuttack. The term 'Khondalite' is also used to describe other rocks of similar composition found elsewhere in India, as well as in Burma, Sri Lanka and the Inner Mongolia region of China.

Miliolite limestone, also known as Porbandar stone, is a carbonate rock found in the Saurashtra and Kachchh regions of Gujarat. The name was given by Carter[8] (1849) as he found *Miliola* (Foraminifera, family Miliolidae) in the thin section of Porbandar stone. Later, Chapman[9] (1900) examined the microfossil in detail. The Quaternary carbonate sequences of Saurashtra consist of Miliolite Limestone Member and Chaya Member[10]. The Miliolite Member includes petrographic types biopelsparite, pelsparite, biosparite, biosparrudite, intrasparrudite and micrite[11] (Figure 2), while the Chaya Formation includes mainly biosparrudite and shell limestones[10,12,13].

From the stratigraphic relationship, palaeontological studies and geomorphological data, the age of the miliolite limestone is considered as Late Pleistocene to Early Holocene[14,15].

As mentioned earlier, miliolite limestone occurs along the Saurashtra coast of Gujarat[16,17]. In the interior highlands, it occurs overlying the Deccan Traps, Mesozoic and Tertiary sediments (Figure 3). In Kachchh, it occurs as isolated, patchy outcrops in the central plateau[14]. The aeolian obstacle dune deposits of miliolites occur at an elevation of 200 m amsl. Miliolite limestone also occurs as thick aeolian deposits in Diu island[16]. The origin of miliolite limestone is

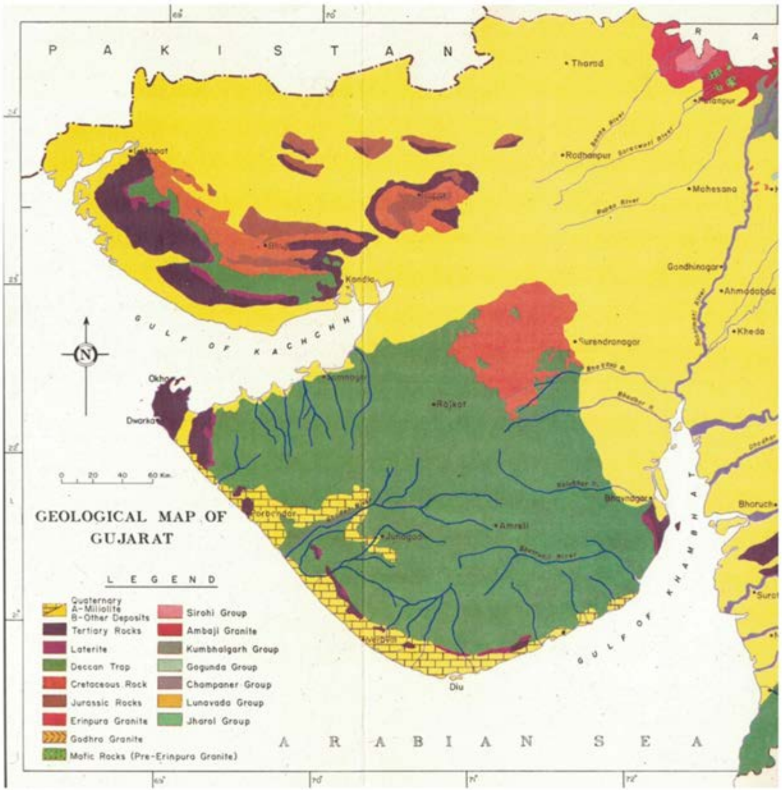


**Figure 3.** Geological map of Saurashtra peninsula showing coastal miliolites in yellow brick pattern, Gujarat, India (source: Merh, S. S., *Geology of Gujarat*, 1995; ISBN No: 81-85867-14-3).

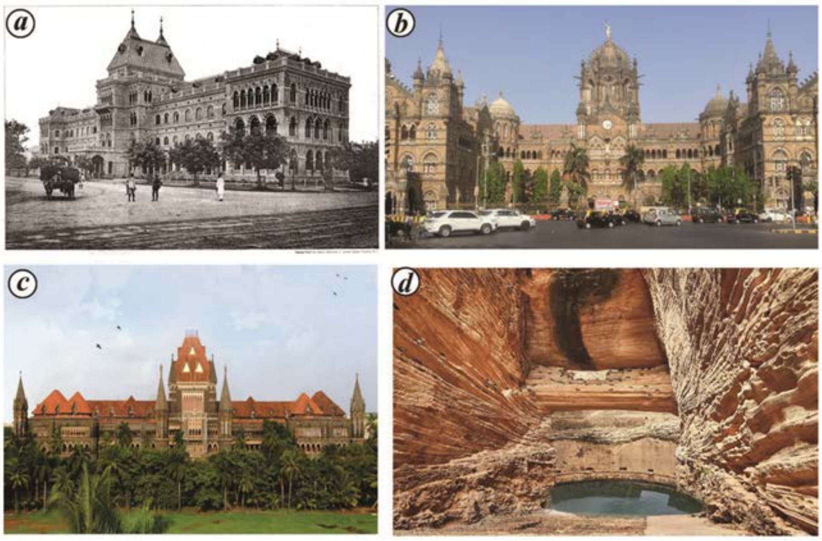

**Figure 4.** A few iconic structures made of miliolite limestone. ***a***, PWD building, Mumbai, built in 1870, the facade of which features miliolite limestone. ***b***, Iconic buildings of Victoria Terminus, Mumbai built in 1877 using miliolite limestone. ***c***, Iconic buildings of the High Court, Mumbai built in 1862 using miliolite limestone. ***d***, The 15th century Adi Chadi Vav (a step-well), Uparkot Fort, Junagarh district, Gujarat, carved entirely in miliolite limestone.

controversial and has been discussed by many workers[11,14,16–24]. According to one theory, it is considered to be of marine origin, while according to another it is of aeolian origin.

Most miliolite rocks occur on hill slopes and in valley depressions which are natural barriers and serve as traps for the wind-borne sediments. They also occur as barchan fossil dunes[25]. These characteristics indicate an aeolian origin for the miliolite rocks.

Miliolite limestone has been used to make buildings and other structures for a long time. One of the unique structures carved entirely out of miliolite limestone is a 15th century 41 m deep, circular step-well named as Adi Chadi Vav, in Uperkot Fort, Junagarh district, Gujarat[26] (Figure 4). A group of Junagarh Buddhist caves comprising Khapra Kodiya Cave and Baba Pyara Cave were excavated in miliolite limestone during the 3rd–4th century BCE, during the rule of Emperor Ashoka. The Khapra Kodiya Buddhist Cave is the most beautiful architecturally. These Buddhist caves are situated near the Uparkot Fort[27].

The miliolite limestone was shipped to Mumbai, Kolkata, Chennai, Karachi and even to Myanmar as it was highly valued by sculptors and architects. The facade of the Public Works Department Office in Mumbai was constructed in 1870 using miliolite limestone. Many public buildings in Mumbai, including the Victoria Terminus, Bombay High Court, Crawford Market and Knesset Eliyahoo Synagogue have been built using miliolite limestone[28] (Figure 4).

Miliolite limestone is also used for industrial purposes (cement, chemical, soda ash industries).

Miliolite limestone is also found along the southern Arabian Sea and Persian Gulf coast (Figure 5). It belongs to three formations: the aeolian Ghayathi Formation, the continental Aradah Formation and the marine Fuwayrit Formation. The Fuwayrit Formation was deposited during the last interglacial[29]. At Dhofar (southwestern Sultanate of Oman) on the shore of the Arabian Sea, miliolite limestone is used in the manufacture of cement. Several types of limestone have been traditionally used for building mosques, houses and sheds in the Fuwairit archaeological site in NE Qatar. They include limestone of Dammam Formation (middle Eocene) and oolitic limestone. At Jebel, Fuwairit oolites are found as fossil dunes[30]. In Bermuda, the equivalent of miliolite limestone of India, Pakistan, Arabian Sea and the Persian coast is aeolianite (Figure 6). This is a testament to dune activity during Pleistocene–Holocene.

Out of 22 sites that have been designated as GHSR, five are limestone sites[31], three belong to the Jurassic, and one each to the Cretaceous and Miocene. For example:

(1) Portland Stone of the Jurassic in Dorset, England.
(2) Podpeč Limestone of the Lower Jurassic, in southern and southwestern Slovenia[32].
(3) Lioz limestone of the Cretaceous, in Portugal and outcrops in Lisbon and neighbouring countries[33].
(4) Lower Coralline limestone of the Miocene in the Maltese Islands.
(5) Bath Stone an oolitic limestone of the Jurassic from Somerset, England.

Thus the miliolite limestone is suitable to be declared as a GHSR.


**Figure 5.** Distribution of miliolite limestone along the Persian Gulf and Arabian Sea coast from Dofar to Farur (after Evans[35]).

**Figure 6.** Beach and dune deposits of Pleistocene–Holocene of Bermuda. In the foreground are the ancient beach deposits formed when the sea level was higher than at present. In the background are the dune deposits (aeolianites formed) when the sea level fell (after Rowe[36]).


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# The Diyodar meteorite fall in India

A meteorite fall was witnessed by the villagers of Rantila and Ravel, Diyodar taluka, Banaskantha district, Gujarat, India, at around 19:30 h (IST) on 17 August 2022. Here we discuss the circumstances of the fall and provide a brief description of the meteorite in hand specimen and a few preliminary examinations.

The meteorite fall was observed in two nearby villages, i.e. Rantila and Ravel, about 10 km apart. Figure 1 shows the location of the fall areas. The meteorite was observed to fall at Rantila village (24°14′26″N; 71°46′45″E) in a soft, clayey agricultural land. One of the villagers mentioned that he did not witness any trail, but a thunderous sound was heard, like the passing of a jet plane. During the fall, a large piece of the meteorite hit a neem tree branch and broke into several fragments due to the impact. The tree branch also broke into several large pieces (Figure 2). Several fragments of the meteorite were found scattered in the field (Figure 2). The villagers collected the large pieces immediately after the fall. The mass of the largest piece was around 200 g and about 12 cm × 6 cm × 4 cm in size (Figure 3). The large pieces of the meteorite were handed over to the local Tehsildar (Mamlatdar) office of Diyodar taluka. The next day after the meteorite fall, both the villages witnessed heavy rainfall and the strewn field was almost submerged in water. A few smaller pieces of the meteorite were recovered beneath the soil cover after the flood-like situation improved and the farmland became relatively dry. At Ravel village (24°09′55″N; 71°42′45″E), a fragment fell close to a villager while she was cleaning her porch (Figure 2). A loud sound was heard by her and many residents of the village. The fragment had damaged the floor tiles of the porch, creating a small crater (~14 cm diameter and ~4–5 cm deep) (Figure 2). According to the villagers, the meteorite fragments yielded a strong, pungent smell similar to the sulphur gas.

A group of Physical Research Laboratory (PRL), Ahmedabad scientists visited the fall areas and collected two large fragments (about 200 and 20 g) from the Tehsildar office at Diyodar on 23 August 2022 (Figure 3). They also did a thorough search in the vicinity of the fall sites to look for more meteorite fragments. After interviewing several eyewitnesses and plotting the fall locations on a map, the trajectory of the meteorite was predicted from the southwest to the northeast direction (Figure 1). This direction of impact and the spread indicate that there could be more fragments in between and away from these villages along the trajectory of the meteorite.

The hand specimen of the meteorite fragments appeared as fragmental/regolith breccia and were similar in both locations, suggesting that they were likely part of a single meteorite mass before breaking during its passage through the Earth's atmosphere, perhaps at low height in a low-angle trajectory. The fragments were fragile, and the inner material was brittle. A light brown fusion crust (apparent thickness ~0.5 mm) has been partly preserved over small areas in both fragments (Figure 3), which indicates that the fragments are part of a larger meteorite chunk. The sample was a stony achondrite breccia with predominantly white pyroxene grains of various sizes and shapes. Large pyroxene grains (up to 2.0 cm) occurred as bright white translucent crystals with two perfect sets of prismatic cleavages (Figure 3). The pyroxenes appeared to be predominantly enstatitic in the hand specimen.

The main fragment of the collected meteorite was examined for the presence of