resulted in either underestimation or overestimation of SOC stock for a farm scale. This is because most of the previous studies on SOC stock assessment were based on mean SOC content for a region or for a specific soil type, and the methods of SOC estimation were different in most cases. Consideration of spatial variation may result in accurate estimation of SOC stock of a farm and will also lead to a surface map of SOC stock, which may be an essential requirement for adoption of site-specific carbon sequestration strategies.

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Petrographic studies on a newly discovered Indo-Arabian stone anchor from the Gulf of Kachchh, Gujarat: implications for source area

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Finding of stone anchors in the onshore and offshore regions of India points to maritime contacts with neighbouring countries. This communication reports a new Indo-Arabian type stone anchor recovered from a depth of 53 m off the coast of Gulf of Kachchh, Gujarat, India. The anchor stone is composed of sharp angular quartz and feldspar grains floating in a ferruginous matrix with point contacts between them as seen under a microscope. SEM–EDS studies showed few and isolated zircon and apatite grains as accessory mineral phases. The rock is identified as epiclastic sandstone derived from pyroclastic source rocks. A similar rock has been reported from the Habo Formation exposed near Jhikadi village, Kachchh, Gujarat.

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Keywords: Maritime archaeology, petrography, stone anchors, source rocks.

IN recent years, a great deal of new evidence related to maritime archaeology has come from onshore, intertidal and offshore surveys. Among the finds, ancient stone anchors serve to understand maritime contacts of India with other parts of the world. In India, the earliest evidence of stone anchors belonging to the Harappan period (2500–1900 BC), consisting of simple stone anchors, was found in the land excavations at Lothal and Kuntasi[1,2]. These stone anchors differ in size and shape from the anchors recovered during the maritime archaeological explorations along the Indian coast. In recent years, archaeological excavation at Kadakkarapalli in Kerala unearthed an iron-fastened boat along with a stone anchor dated between 13th and 15th century AD (ref. 3). Maritime archaeological exploration in India has brought out a variety of stone anchors from Gujarat, Maharashtra, Goa, Kerala and Lakshadweep on the west coast, and Tamil Nadu and Odisha along the east coast. The localities where stone anchors have been found are shown in Figure 1. In India, so far 269 stone anchor finds have been catalogued. They have been documented for their physical characters and dimensions[4–12]. On the basis of their shapes, they have been classified into Indo-Arabian, ring stone, single hole and composite types.

Numerous stone anchors of distinct types have been recovered from the Black Sea, Indian Ocean, Mediterranean Sea, Persian Gulf, Red Sea and South China Sea coast. They have all been largely studied only for their typology and the context. Studies leading to identification of source rocks used for stone anchors and understanding their origin have not been carried out. Frost[13] for the first time initiated a petrographic study of thin sections to identify the provenance and origin of the rocks used for stone anchors. Considering the large number of stone anchors found throughout the world, such studies were rare prior to 2002. Evrin *et al.*[14] carried out X-ray diffraction (XRD) and thin-section studies on anchor stones recovered from a shipwreck in Uluburun, Anatolian coast, Turkey, and also on stone anchor specimens displayed at the Museum of Underwater Archaeology at Bodrum, Turkey. In India, composite, ringstone and single-hole-type stone anchors collected off the coast of Dwarka in Gujarat were analysed by XRD[15]. In recent years, 16 stone anchors consisting of Indo-Arabian, ring stone and single-hole types discovered from Goa and Gujarat waters have been studied to determine their provenance. The study included petrography, X-ray fluorescence analysis and scanning electron microscopic energy dispersive spectrometry (SEM–EDS)[16].

In this communication, we report an Indo-Arabian type of stone anchor discovered off the Gulf of Kachchh, Gujarat and describe its petrographic and mineralogical composition following the same methodology as adopted by Tripati *et al.*[16]. We also discuss the context and significance of this new stone anchor find for the maritime history of the region.

During the seismic surveys off the coast of Gulf of Kachchh (22°35.211′N and 68°52.602′E) in October 2007, on-board *RV Sonne*, a team from the National Institute of Oceanography (NIO), Goa, retrieved a stone anchor while recovering an ocean bottom seismometer. The stone anchor was recovered from a depth of 53 m at a distance of 54 km off Mandvi and 23 km off Okha (Figure 2).

The stone anchor is of Indo-Arabian type (Figure 3). The rock has been trimmed neatly and chisel marks are visible on the surface as well as in the holes. The upper hole has circular cross-section and lower holes are square. The lower holes are of different sizes. The base of the anchor stone is uneven. It has a maximum length of 165 cm (Figure 4). Taking the density of the rock as 2323 kg/m^3, its estimated weight is ~ 300 kg. While the anchor was being retrieved, it fell from the dredger and broke into two pieces along a fracture plane that developed 70 cm below the upper circular hole. Barnacle and shell growth have been observed on the surface and in the holes. Edges of the holes are sharp, indicating minimal wear and tear, suggesting that the stone anchor had been sparsely used.

A chip of the stone anchor was taken for petrographic studies. The rock is composed dominantly of quartz and feldspar grains floating in a brown to black ferruginous matrix. The mineral grains are sharp, angular and show only point contacts (Figure 5 *a*). The rock shows bedding

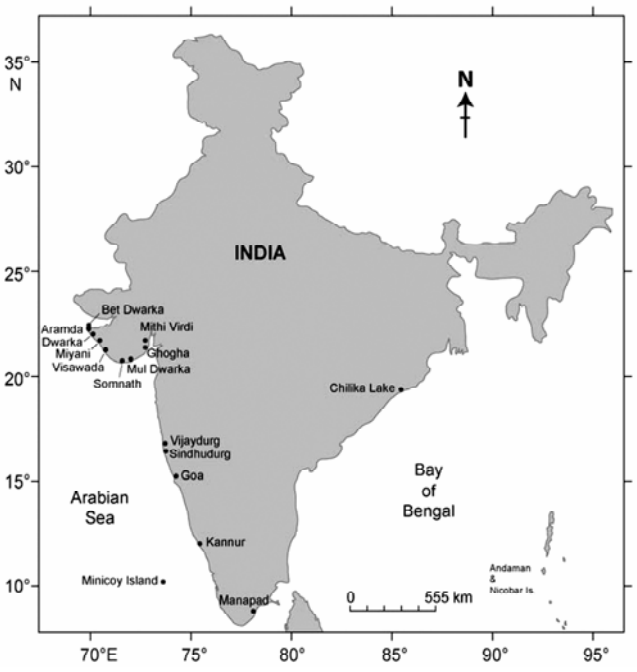

Figure 1. Locations of sites where stone anchors have been found in India.

lamination defined by clayey layers (Figure 5 *b*). The quartz and feldspar grains vary in size in a narrow range between 50 and 100 μm. The opaque mineral is magnetite. SEM–EDS study shows apatite and zircon as accessory minerals, in addition to quartz, feldspar and magnetite, which are the main minerals (Figure 6). Textural features and mineralogical composition indicate that the rock may be an epiclastic sandstone, which formed from sandy sediment that had witnessed short-distance transport from a possible pyroclastic source area. The chemical composition of the rock determined by X-ray fluorescence method is SiO_2 52.36, TiO_2 0.27, Fe_2O_3 3.95, MnO 0.25, MgO 8.39, CaO 11.17, Na_2O 1.23, K_2O 1.8 and P_2O_5 0.16. An alkali mafic to intermediate composition is evident.

Arabs and Persians sailed the Indian Ocean and used the type of anchors under study since the 9th century. Indo-Arabian-type stone anchors have been reported from the western Indian Ocean countries, namely East Africa,

Figure 2. Map showing the location of the anchor site off the Gulf of Kachchh, Gujarat, west coast of India.

Figure 3. Stone anchor recovered off the Gulf of Kachchh, Gujarat.

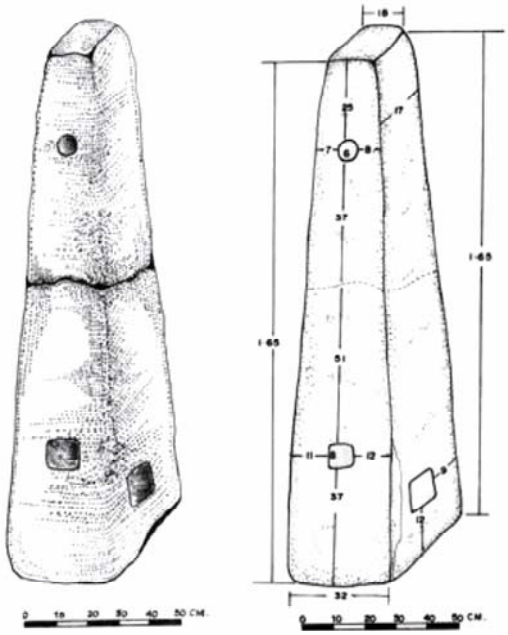

Figure 4. Indo-Arabian stone anchor recovered off the Gulf of Kachchh, with detailed measurements.

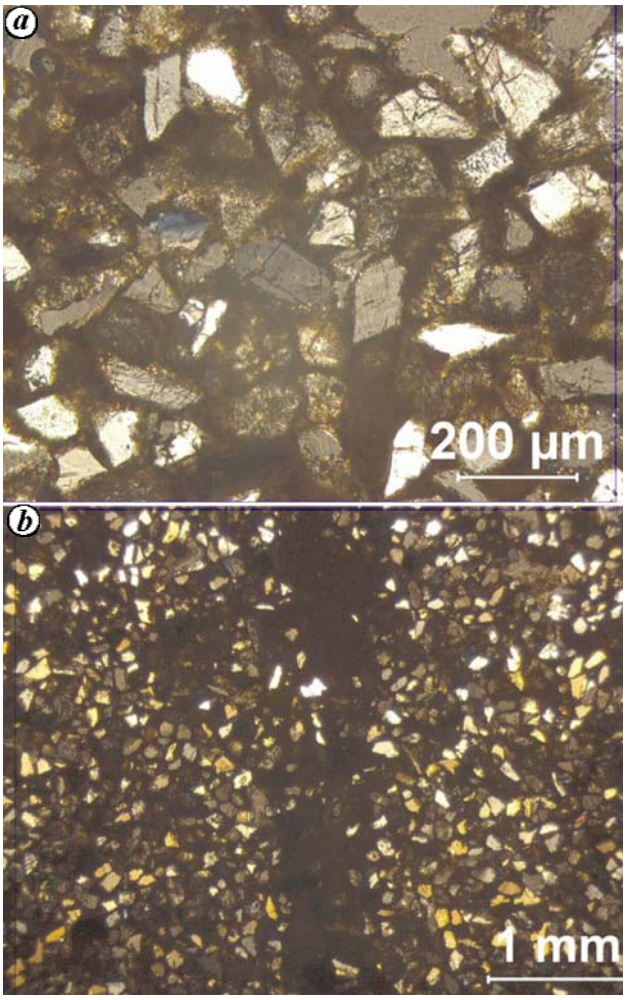

Figure 5. Photomicrographs of the stone anchor.

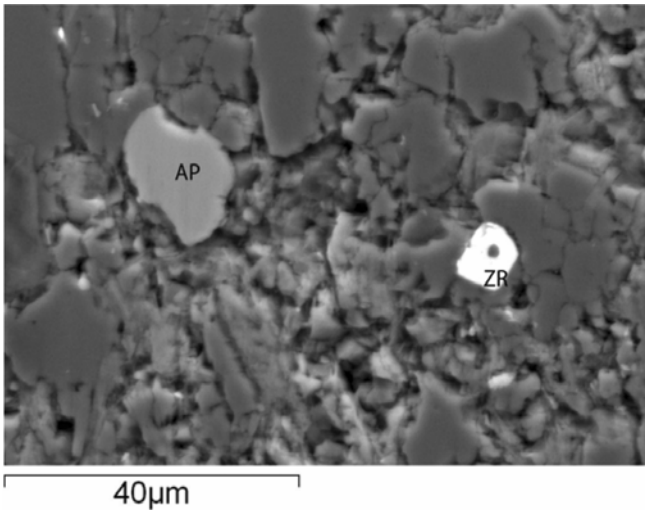

Figure 6. SEM photograph showing apatite (AP) and zircon (ZR) grains in the sandstone, dull grey mineral grains are quartz.

India, Persian Gulf countries and Sri Lanka, suggesting close maritime contacts and trade relations among these countries. The ports in the Gulf of Kachchh have contributed significantly to maritime trade since ancient times, and such trade was extensive between Gujarat and the Arab world even during the medieval period. A number of Indo-Arabian stone anchors in addition to other types have been reported from the southern coast of the Gulf of Kachchh, namely from Bet Dwarka, Dwarka, Ghogha, Miyani, Somnath, Visawada, Mithi Virdi and other sites along the Indian coast. No anchors have been reported so far from the northern coast of the Gulf of Kachchh. Further, the stone anchors reported from Gujarat or elsewhere in India are primarily from ports and harbour sites, sheltered bays and shipwreck sites. The anchor reported in this study has been found in none of the above described contexts. Very little is known about the finding of stone anchors in waters deeper than 20 m along the Indian coast. Recovery of a stone anchor from deeper water is a unique find where the seabed is thickly sedimented especially like the Gulf of Kachchh. This is the first stone anchor that has been found in the northern part of the Gulf of Kachchh at a depth greater than 50 m.

The ancient text *Milindapanho* (1st and 2nd century BC) mentions that stone anchors fasten the ships even in the mighty sea and in the expanse of waters agitated by the crowding of the ever-varying waves[17]. In ancient Indian literature, there is mention of throwing away of heavy cargo, stone anchors, etc. for the safety of the ship during storms and cyclones. It is also possible that stone anchors could have fallen accidentally during the sailing of a ship or during a shipwreck. No shipwreck debris has been recovered along with the stone anchor while retrieving the ocean bottom seismometer. On this basis, while shipwreck can be ruled out, it is difficult to choose between the other alternatives.

Figure 5 shows that the quartz and feldspar grains in the stone anchor are sharp, and angular and are set in a ferruginous matrix. The sharp angularity of the mineral grains is akin to what is observed in volcani-clastic rocks that have witnessed only short-distance transportation from eruptive centres. The detrital grains are seen floating in the matrix with only point contacts, indicating that the detritus did not undergo much post-depositional compaction under load. Lithification is largely due to cementation by the ferruginous matrix. No megascopic and microscopic fossils have been observed in the anchor stone. Although the texture of the rock with detrital grains floating in a ferruginous matrix is similar to that described from Jhikdi sandstone in the Habo dome of Kachchh[18], the unfossiliferous nature of the anchor sandstone distinguishes it from the Jhikdi sandstone, which is fossiliferous[19]. Kshirsagar *et al.*[20] have documented pyroclastic volcanic rocks from Kachchh. Further comparative studies of epiclastic rocks from these areas are required to verify whether the stone anchor reported in this study could have been made from one of these rocks. An earlier study showed[16] that stone anchors recovered from Indian waters are made of rocks found along the Indian coast. As there are no associated finds along with the stone anchor in the present study, it is difficult to determine the exact age. However, on the basis of comparative analysis, similar type of Indo-Arabian-type of stone anchors have been dated between 9th and 17th century AD in the Indian waters.

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