



# Geochemical and mineralogical analysis of stone anchors from west coast of India: provenance study using thin sections, XRF and SEM-EDS

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## ABSTRACT

Stone anchors have been recovered along the Indian coast as a part of the maritime archaeological studies at the National Institute of Oceanography (NIO), Goa. Study of stone anchors provides clues to understand the ancient maritime trade contacts of India with other countries. These anchors resemble those found in the Mediterranean Sea, Persian Gulf and Red Sea Coast. Underwater explorations at Bet Dwarka, Dwarka, Goa, Visawada and Somnath have yielded stone anchors of widely varying shapes, sizes and weights ranging between 16 and 410 kg. Sixteen (10 Indo-Arabian, 4 Ringstone and 2 Single hole type) of the total of 269 stone anchors have been studied to determine provenance of rock through petrographic analysis using thin section studies, X-ray Fluorescence (XRF), and Scanning Electron Microscope – Energy Dispersive Spectrometer (SEM-EDS).

Our results suggest that these anchors were made from various rock types, such as granodiorite, dolerite, varieties of basalt, schist, calcareous sandstone, limestone and sandstone. The coastal tract of western India has exposures of all these rock types of igneous and sedimentary rock suites while ultramafic rocks occur inland along the Gujarat and Rajasthan border. It is inferred that these stone anchors have been sourced from rock formations from Gujarat, Goa, Karnataka and Maharashtra regions for use in maritime trading activities of the ancient and medieval periods.

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## 1. Introduction

Maritime archaeologists are actively involved in mapping the ancient maritime trade routes to understand the evolution of civilisation, trade and cultural relationships among different countries. In order to achieve this, underwater explorations and excavations are conducted to locate shipwrecks, remains of ports, anchorages and anchors. During explorations, artefacts that survive decomposition, such as amphorae, semi-precious artefacts, metal objects, ceramics, stone and iron anchors, glasses, etc. are generally found. The recovery of stone anchors validates the assumption that ships had anchored or sailed in the area in maritime past. Information on shape, size, weight and other characteristics of stone anchors found both underwater and on land will help to relate them to other finds.

Numerous stone anchors of different shapes and types have been reported during onshore and offshore explorations around the world, notably from Arabian Gulf, Egypt, Israel, Greece, India, China, Korea, Japan, Sri Lanka, Black Sea, Mediterranean Sea, South China Sea and Red Sea (Agius, 2005; Athiyaman and Jayakumar,

2004; Frost, 1970, 1985, 1989, 1996; Gaur et al., 2007; Kapitan, 1994; Moll, 1927; Nibbi, 1993; Nouhuys, 1951; Raban, 2000; Tripathi et al., 1998, 2003; Tripathi, 2009; Souter, 1998; Upham, 1983; Wachsmann, 1998).

Since the initiation of maritime archaeological research in 1983 in Indian waters by the National Institute of Oceanography (NIO), Goa, (<http://www.nio.org>) to locate submerged habitational and port sites and shipwrecks and several types of stone anchors have been recovered during both onshore and underwater explorations off Bet Dwarka, Aramda, Dwarka, Miyani, Visawada, Somnath, Mithi Virdi, Vijaydurg, Sindhudurg, Goa, Kannur, Minicoy, Manapad and Chilika Lake (Table 1 & Fig. 1).

In order to ascertain the provenance of stone anchors, it is essential to understand the rock types of stone anchors as well the exposures of rocks along the coastline. The paper discusses results of studies of mineralogy, petrology and geochemical analyses of 16 stone anchors recovered from west coast of India to infer the provenance of rocks.

### 1.1. Geology of the west coast of India (WCI)

The west coast of India is a near straight coastline of ~2000 km length between 8° and 24° N with exposures of

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**Table 1**  
Various types of stone anchors observed along the Indian coast (North–South).

Find Sites	Composite Anchors	Indo-Arabian Anchors	Ring stone Anchors	Single hole Anchors	Total
West Coast					
Bet Dwarka, Gujarat	13	7	1	—	21
Aramda, Gujarat	2	1	—	—	3
Dwarka, Gujarat	35	63	24	1	123
Miyani, Gujarat	2	6	4	—	12
Visawada, Gujarat	10	2	1	1	14
Somnath, Gujarat	6	2	35	—	43
Mithi Virdi, Gujarat	—	4	—	—	4
Vijaydurg, Maharashtra	1	23	—	—	24
Sindhudurg, Maharashtra	3	5	—	—	8
Baga, Goa	—	1	—	—	1
Sunchi Reef, Goa	—	1	1	—	2
Grandelsland, Goa	—	2	—	—	2
Kannur, Kerala	—	1	—	—	1
Minicoy, Lakshadweep Is.	—	1	—	—	1
East Coast					
Chilika Lake, Orissa	4	—	—	1	5
Manapad, Tamil Nadu	—	—	—	5	5

various rock types ranging from Archaean granites/schists to recent alluvium. Various rock sequences of Indian sub-continent have been well mapped in detail (Krishnan, 1968; Pascoe, 1959; Wadia, 1975). The exposures to the north of the Gulf of Kachchh include recent sedimentary deposits Tertiary to Jurassic rock sequences, mostly sedimentary rocks with fossils (Merh, 1995). Along the northern WCI, (Maharashtra and Gujarat) Deccan Trap basalts, miliolite limestones and fossiliferous limestones of Quaternary age and fossiliferous sedimentary rocks of Tertiary sequence are exposed. In the central WCI, (particularly Goa) laterite cliffs are present with a few locations having metamorphosed sequence of metagreywacke and quartzites (Gokul et al., 1985; Purushothaman et al., 2009) while Deccan Trap basalts line the coast with alkaline complexes at few locations (Deshpande, 1998). The southern WCI (Kerala and Karnataka) has rock suites of granites, schists, granitic and gneissic complexes with localised exposures of Pleistocene sequence (Soman, 2002) (Fig. 4).

## 1.2. Maritime activities of the WCI

The people of the Indus civilisation were the first mariners in India who began the maritime trade along the west coast of India. Contacts of the Indus civilisation with Egypt, Mesopotamia and Persian Gulf countries have been documented since the third millennium BC (Rao, 1991). During the Christian era, maritime trade contacts of India with Roman, Greek and Southeast Asian countries flourished (Mookerji, 1912; Mukerjee, 1956; Warmington, 1974). Recent archaeological finds from the WCI and the *Periplus Maris Erythraei* (60–100 AD) (Casson, 1989) and Ptolemy's Geography (150 AD) (McCrindle, 1985) provide information on India's maritime trade contacts in regions of the Mediterranean Sea, Persian Gulf and Red Sea (Sidebotham et al., 2001–2002; Tomber, 2008). These evidences show that Arab, Roman and other mariners frequently visited the ports of India during this period. Arabs were great seafarers before the birth of Islam (Sridharan, 1982) and had trade contacts with the west coast of India. During the 8th century AD maritime trade between India and Arab grew. Since then great number of Arab mariners came to India as traders. By the end of the 12th century, with the decline of the Chola kingdom, the Arabs

gained control over the east coast of India. Hourani (1995) suggested that Arab traders used heavy anchors onboard their ships and Indo-Arabian type of stone anchors were an important feature of the Arab ships. Similar types of Indo-Arabian anchors have been reported from Siraf port, Iran on the northern shore of the Persian Gulf (Whitehouse, 1970), east African and Red Sea coast (Chittick, 1980; Raban, 1990), in conjunction with other findings, dated between 8th and 14th centuries. Along with Indo-Arabian type of stone anchors, ringstone anchors have also been found in the Persian Gulf (Vosmer, 1999). Some of the anchors recovered in the waters of west coast of India may also belong to the above period, and some are dated to the later period as Arab traders were active along the Indian coast during this period.

## 1.3. Types of anchors in the WCI

Studies on stone anchors offer new evidences on the maritime activities of a country; hence Frost (1973) suggested that stone anchors are the potsherds of maritime archaeology. Anchors are mostly found along the ancient trade routes, particularly in sheltered bays, ports and harbour sites and within shipwrecks.

In India, the evolution of stone anchors has been traced during onshore and underwater archaeological explorations. In land excavations at Lothal and Kuntasi (Rao, 1979; Dhavalikar et al., 1996) unearthed the simplest type of stone anchors along with other finds belonging to the Harappan period (2500–1900 BC) but these stone anchors differ in shape and size from the anchors found in maritime archaeological explorations.

Earliest stone anchors had only one hole for tying the rope without flukes and were termed as dead weight anchors due to their weight. These anchors are even used now in country crafts by the mariners in shallow and back waters. Later on stone anchors were sculpted with two or three holes and were termed as composite anchors made of triangular or prismatic shaped stone blocks. In these anchors the apex hole meant for cable whereas wooden flukes were provided in lower holes. Composite anchors continued from the Bronze Age to the Early Historic and Historic period. Subsequently, mariners invented Indo-Arabian stone anchors, which were different in shape and size from composite stone anchors. These anchors were developed when the size and carrying capacity of ships increased and were highly useful in the regions with corals and rocky seabed. The other type of anchors, called ringstone (mushroom type) anchors, came into use simultaneously. In all these anchors wooden flukes were introduced. Even Ludovico di Varthema (AD 1470–1510), the Italian traveller mentions that in Kerala coast anchors made of marble were used, which were eight *palmi* long and two *plami* every other way (Jones, 1863; Mookerji, 1912). Historically, the stone anchors gave way to lead stock anchors and further to iron anchors. Although the Europeans introduced iron anchors in India during the 16th–17th centuries (Qaisar, 1982), the finding of various types of stone anchors in Indian waters suggests that they were in use as recently as the 20th century.

About 269 stone anchors pertaining to composite, Indo-Arabian, ringstone and single hole types have been observed in Indian waters and their physical characteristics and dimensions are catalogued and documented. Some of the stone anchors have been recovered from Bet Dwarka, Dwarka, Goa, Somnath and Visawada waters (Gaur et al., 2002, 2005; Gaur and Tripathi, 2006; Rao, 1999; Tripathi, 2002; Tripathi et al., 2003; Sundaresh et al., 1999, 2002), whereas anchors of other sites are *in situ*. Total 16 stone anchors of various size and shape and constituting different rock types from Bet Dwarka, Dwarka, Goa, Somnath and Visawada waters in the west coast of India have been selected for the present study (Table 2 & Fig. 2).

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