Proc Indian Natn Sci Acad **82** No. 3 July Spl Issue 2016 pp. 675-683

DOI: 10.16943/ptinsa/2016/48476

Review Article

Marine Geology and Coastal Surveys for Seabed Mapping and Mineral Resource Evaluation in India – An Overview

SUDESH KUMAR WADHAWAN*
Former Director General, Geological Survey of India, Kolkata, India

(Received on 12 May 2016; Accepted on 12 June 2016)

Off-shore geoscientific studies and systematic mapping of the seafloor, both in Exclusive Economic Zone (EEZ) and Territorial Waters (TW) along east and west coasts in India, started with the acquisition of research vessels R. V. Samudra Manthan in 1983 and two coastal vessels in 1984. Since then Marine and Coastal Survey Division in Geological Survey of India has been acquiring geoscientific data on the sea bed sediments, seabed morphology, mineral resources, geochemistry and geophysical parameters. The three vessels have collected thousands of surface and subsurface samples from the Indian and international waters during their past over 30 years of service to the nation. As the seabed mapping/ reconnaissance had been completed for EEZ (23,05,143 km^2) during the first phase of marine geological mapping and exploration by GSI, the compilation and synthesis of this enormous wealth of geoscientific data is now attempted[63 maps from EEZ and 143 maps from TW]. The second phase of detailed marine geological exploration has been launched as 'National High Resolution Seabed Mapping and Resource Evaluation within EEZ of India and Beyond' during the flagging off of the newly acquired all-weather modern research vessel RV Samudra Ratnakar flagged off on 23rd December, 2013 from the Port of Mangalore. Operational strategies such as marine surveys through progressively closer intervals, systematic ocean bottom probing and sampling, prognostication of natural resources based on conventional methods, conceptual modeling, etc.; are finalized for a focused approach for targeting and prioritizing offshore mineral resources within EEZ of India. Placer heavy mineral resources up to a depth of 1-1.5m thickness from the sea floor on the middle shelf have been identified in an area of 764 sq km with a proven reserve of 108 million tons. On the basis of the delineated OGP (~2,40,000 km^2) for the present, Focused Offshore Mineral Exploration (FOME) Cruises are planned to be taken up for Rare Earth Elements & Yttrium (REY), Seafloor Massive Sulphides (SMS), phosphorites, lime mud, gas hydrates, carbonate sand etc; onboard R.V. Samudra Ratnakar.

Keywords: Marine Geology; Coastal Surveys; Seabed Mapping; Obvious Geological Potential Areas; Off-shore Mineral Resources; Research Vessel *Samudra Ratnakar*

Introduction

The Indian subcontinent is surrounded by three seas and one ocean viz., Arabian Sea in the west, Bay of Bengal (BoB) and Andaman Sea in the east and Indian Ocean in the south. India has a coastline of around 7500 km and is characterized by both passive and active type of margins. The Exclusive Economic Zone (EEZ) of India has an area of 2.02 million sq km within a limit of 200 Nautical Miles (NM) from the coastline (Fig. 1), which is likely to be extended up to 350 NM (Under Article 76 of the III UNCLOS the outer limit of the continental shelf). This extension would add an additional area of 1.07 million sq km to the existing EEZ. Geological Survey of India (GSI), the prime survey organization of the Government of India (GoI) is actively involved in the systematic multidisciplinary marine surveys from 1984 onwards, after the acquisition of its own deep sea and coastal survey vessels in 1983-84. Since then it has mounted over 700 cruises on board its deep sea research vessel "R. V. Samudra Manthan" and twin coastal survey vessels "R. V. Samudra Kaustubh" and "R. V. Samudra Saudhikama" within the Indian EEZ, Territorial Waters (TW) and adjoining International waters. Although GSI had started working on marine related problems as early as 1871 after its inception in 1851, the marine

*Author for Correspondence: E-mail: wadhawansk.leo@gmail.com

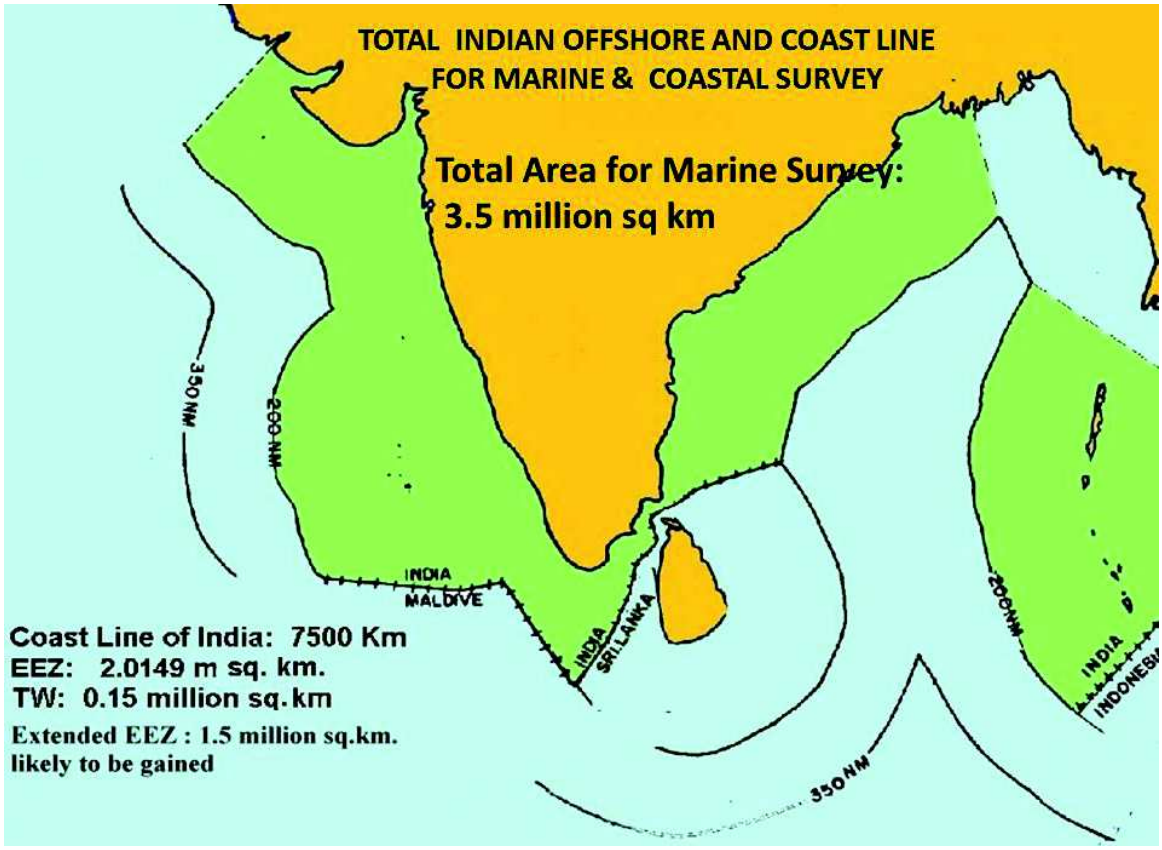

Fig. 1: Schematic Map showing EEZ and TW Boundary of India

survey in Geological Survey of India got a fillip after GSI's participation in the International Indian Ocean Expedition. A separate Marine Geology Unit with quite a good number of Geoscientists was set up in 1965 at Kolkata, the HQ of GSI. Today renamed as Coastal & Marine Survey Division, it has a combined strength of over 120 dedicated geologists, geophysicists and geochemists and operates from four major operational offices, two each on the east coast (Kolkata and Vishakhapatnam) and west coast (Mangalore and Kochi) of India.

Geological Survey of India began the systematic mapping of the seafloor with the acquisition of research vessels R. V. Samudra Manthan in 1983 and two coastal vessels in 1984. Since then Marine and Coastal Survey Division (erstwhile Marine Wing) has been acquiring geoscientific data on the sea bed sediments, seabed morphology, mineral resources, geochemistry and geophysical parameters. Reconnaissance Survey of the seabed falling in the Exclusive Economic Zone (EEZ) of India has been covered in 40 km x 20 km grid by R.V. Samudra Manthan that enriched GSI's database with the geoscientific information on the nature of seabed surface sediment distribution, bathymetry, magnetic properties and economic mineral potential zones.

Depletion of terrestrial mineral resources, has forced us to turn our attention to the vast potential of mineral resources within the offshore areas of our country. Marine and Coastal Survey Division (M&CSD) of Geological Survey of India has carried out more than 700 cruises within the EEZ of India since 1983 (deep sea vessel)/1984 (coastal launches) using three Research Vessels: RV Samudra Manthan, RV Samudra Shaudhikama and RV Samudra Kaustubh to generate baseline marine-geoscientific data. Seabed mapping carried out so far lead to exploration for economic heavy minerals (HM) in the Territorial Waters (TW) of India which has resulted in delineation of huge deposits of economic worth. Similarly, estimation of construction grade sand in five blocks off Kerala (Dinesh, 2014) has been completed by M&CSD. Further, vast resources of high grade calcium carbonate clay (Lime Mud) located along the

outer continental shelf and continental slope off Gujarat and Maharashtra are evaluated in detail. As the seabed mapping/reconnaissance had been completed for EEZ (23,05,143 km^2) during the first phase of marine geological mapping and exploration by GSI, the compilation and synthesis of this enormous wealth of geoscientific data is now attempted. The second phase of detailed marine geological exploration has been launched as 'National High Resolution Seabed Mapping and Resource Evaluation within EEZ of India and Beyond' during the flagging off of the newly acquired all-weather modern research vessel RV Samudra Ratnakar on 23rd December, 2013 from the Port of Mangalore. Operational strategies such as marine surveys through progressively closer intervals, systematic ocean bottom probing and sampling, prognostication of natural resources based on conventional methods, modern technology based advanced R&D, conceptual modeling, etc; are finalized for a focused approach for targeting and prioritizing offshore mineral resources within EEZ of India.

Marine Survey's Major Achievements

Seabed Survey and Mapping

Reconnaissance survey in the Exclusive Economic Zone: 19,81,478 sq. km. out of 20,14,500 sq. km. has been covered on board three vessels R V Samudra Manthan, R V Saudhikama and R V Kaustubh through over 700 cruises from 1983 to 2014. By virtue of these surveys based on 40 km x 20 km grid sampling and laboratory analyses, regional reconnaissance level geoscientific information on the nature of surface seabed sediments, bathymetry, total magnetic field of the earth, potential areas of mineral occurrences, geochemistry of seabed sediment, and history of palaeo-strand lines, geotechnical properties, etc. have been collected. The out puts are represented in the

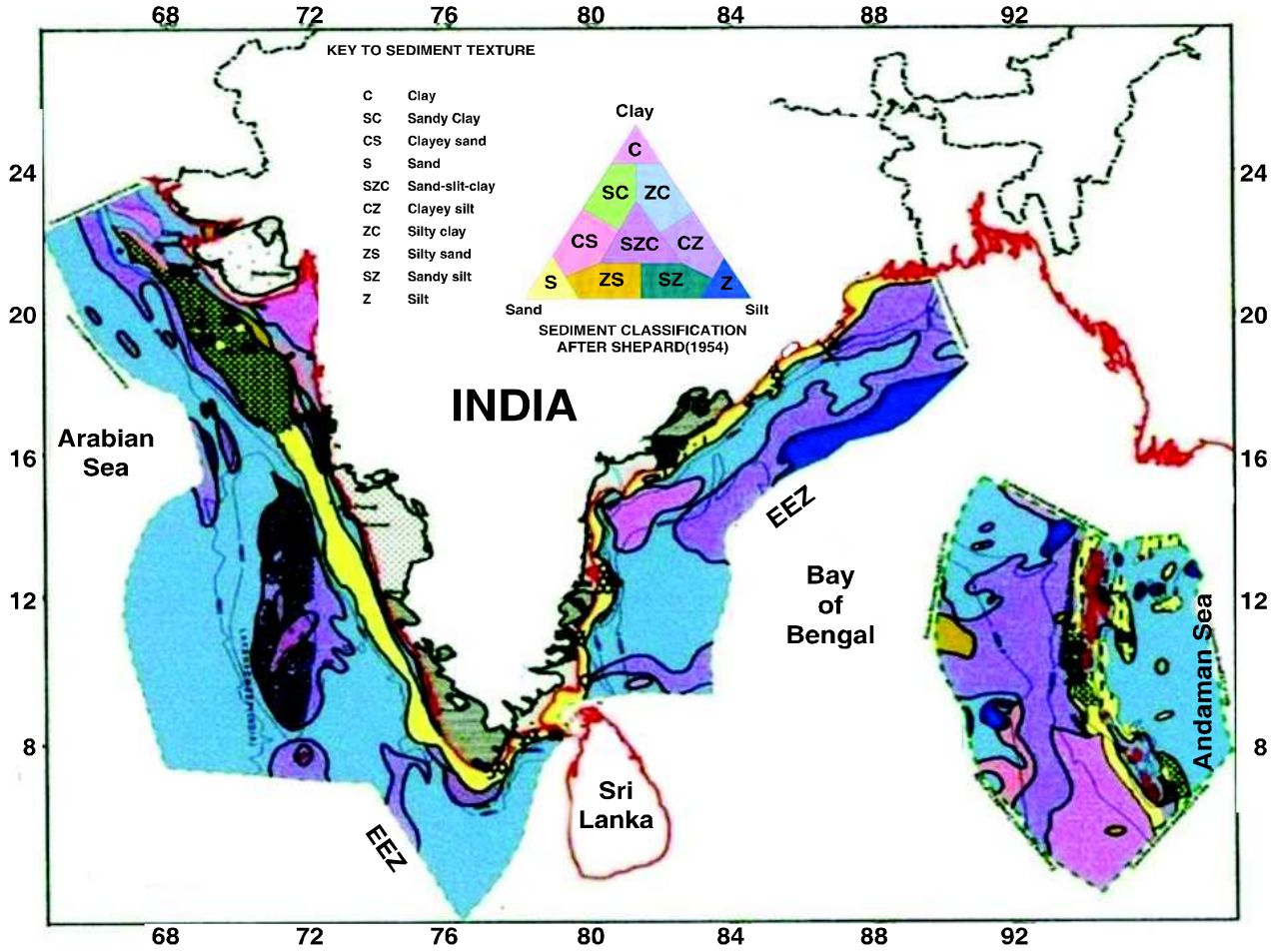

Fig. 2: Regional Seabed Map of Sediment Types in Indian Off-shore Territory

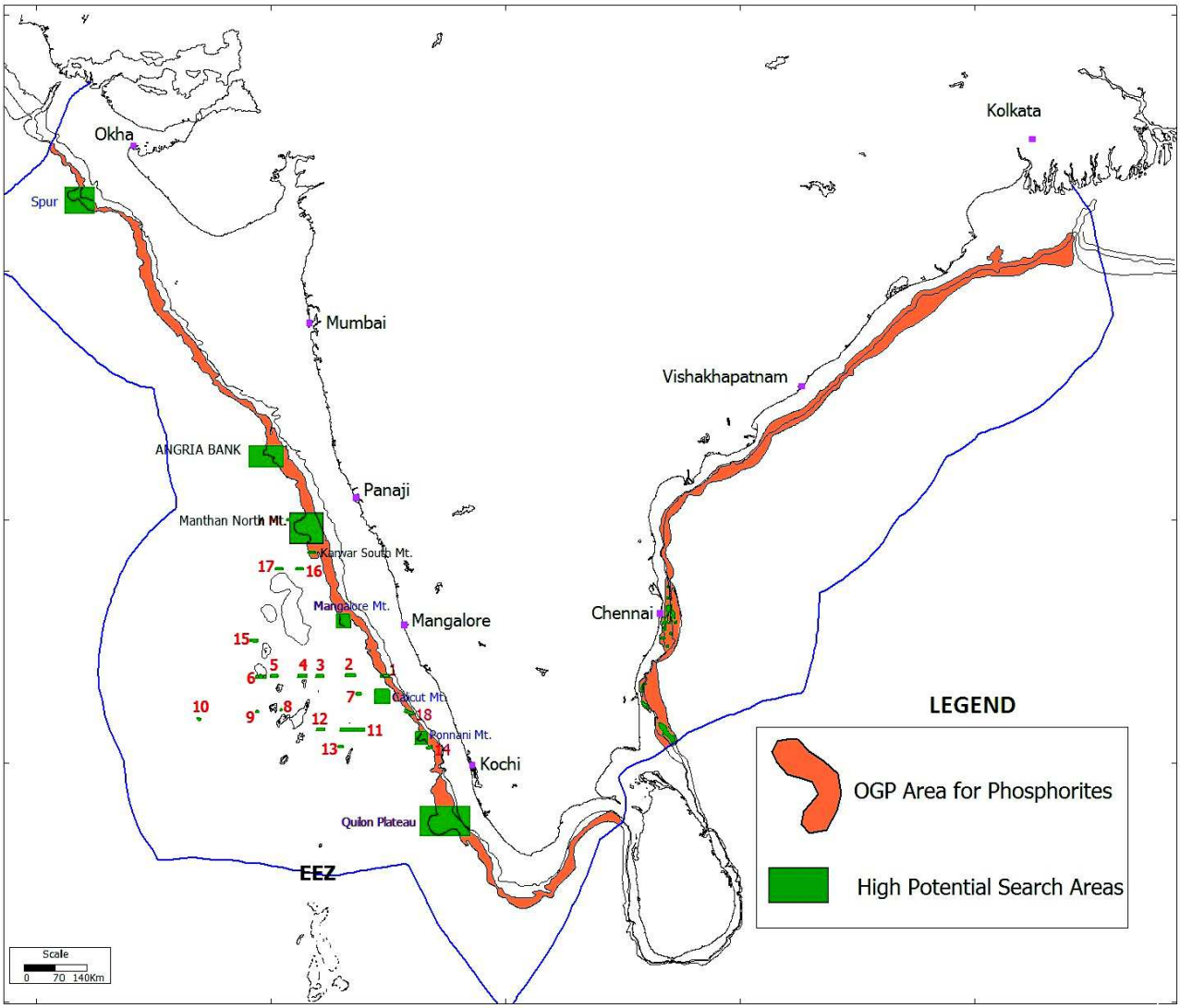

Fig. 3: Placer heavy mineral deposit occurrences along Indian coast

form of seabed maps [a total of 63 maps covering EEZ and 143 maps covering TW respectively] have been compiled (Fig. 2) and generated several progress reports and peer-reviewed publications (GSI Annual Report, 2014).

Up to March 2015, GSI has completed seabed mapping of 1,32,585 sq km out of 1,50,000 sq km in 5 km x 2 km grid within Territorial Waters and 18,54,534 sq km out of 18,64,900 sq km in the EEZ beyond Territorial Waters on reconnaissance scale. The total EEZ coverage including TW is 19,87,119 sq km out of a total EEZ area of 20,14,900 sq km. (GoI, Ministry of Mines Annual Report for 2015-16).

Surveys in the near shore zones (0m-10m isobaths) were carried out using hired small mechanical boats. The main purpose of the marine and coastal survey is not only to discover the undersea treasure of Economic Minerals but also to unravel the evolutionary history of formation of seabed morphology and its continuous transformation under the influence of various dynamic processes still operative on different scales in different parts of the globe.

Offshore Mineral Exploration

The detailed exploration cruises have generated a wealth of parametric and thematic data on the mineral occurrences including marine sand, silt and clays. Investigations on placer mineral resources,

construction sand, lime mud, Phosphate-bearing sediments both on the east coast and west coast of India, have been taken up. Placer mineral resources up to a depth of 1-1.5m thickness from the sea floor on the middle shelf have been identified in an area of 764 sq km with a proven reserve of 108 million tons (Fig. 3). Out of this potential area, 46 blocks have been notified in the Gazette of India for further exploration and exploitation by interested entrepreneurs. Ministry of Mines, Government of India, vide its order dated 3rd August 2015 constituted a committee for preparation of rules under section 12 of Offshore Areas Mineral (Development and Regulation) Act 2002 with terms of reference to prepare scientific parameters to be prescribed for carrying out detailed exploration activities, details on work schedule and to notify guidelines of United Nations Framework Classification, UNFC, for assessment of Reserves and Resources of Offshore Areas as per Mineral Concession Rules, 2006.

1. **Compilation of Seabed Maps:** Publication of Seabed Maps of both TW and EEZ: 63 maps covering EEZ and 143 maps covering TW have been compiled and are in the process of being published. These geoscientific maps and archived samples can be made available to researchers and stake-holders as per the guidelines provided in the Data Sharing and Accessibility Policy of GSI and GoI 2014a.

2. **Sponsored Projects:** Marine and Coastal Survey Division of GSI carried out 45 sponsored projects between 1991 to 2011 for various organizations like ONGC, BARC, NPOL, Indian Navy, DOD, SAC, and various State Port Trusts from which it has earned considerable revenue for the Govt. of India exchequer.

3. **Procurement of a state-of-the-art Deep Sea Research Vessel:** GSI acquired R.V. Samudra Ratnakar and flagged off on 23rd December, 2013 on its maiden marine survey from Mangalore Port, is a unique ocean going research vessel in the world built at Hyundai Heavy Industries, S. Korea (Figs. 4A & 4B). It is equipped with state-of-the-art modern instruments equipped with advanced geological, geophysical and oceanographic survey capabilities. The second phase of detailed offshore surveys is aimed at high resolution mapping (10 km interval grid pattern) of the EEZ of India with seismic, magnetic, gravity and deep piston coring. In the initial years, priority sector for the vessel would be the Obvious Geologic Potential Areas in the offshore (OGP-Offshore) that has been identified and delineated based on the reconnaissance surveys (Fig. 5). Further detailed surveys in the OGP-Offshore sectors will be done with Sub-bottom profiler, Multi-beam echo-sounder (MBES), Synthetic Aperture Mapping Sonar, Remotely Operated Vehicle, Heat Flow Measuring System, etc. for detailed mapping and mineral resource evaluation.

R. V. Samudra Ratnakar-Deep Sea state-of-the-art Survey & Research Vessel

A

B

Fig. 4: A: Recently acquired new all weather modern Ocean Going Research Vessel Samudra Ratnakar on its maiden cruise and B: New all weather modern Research Vessel Samudra Ratnakar at Mangalore Port, India

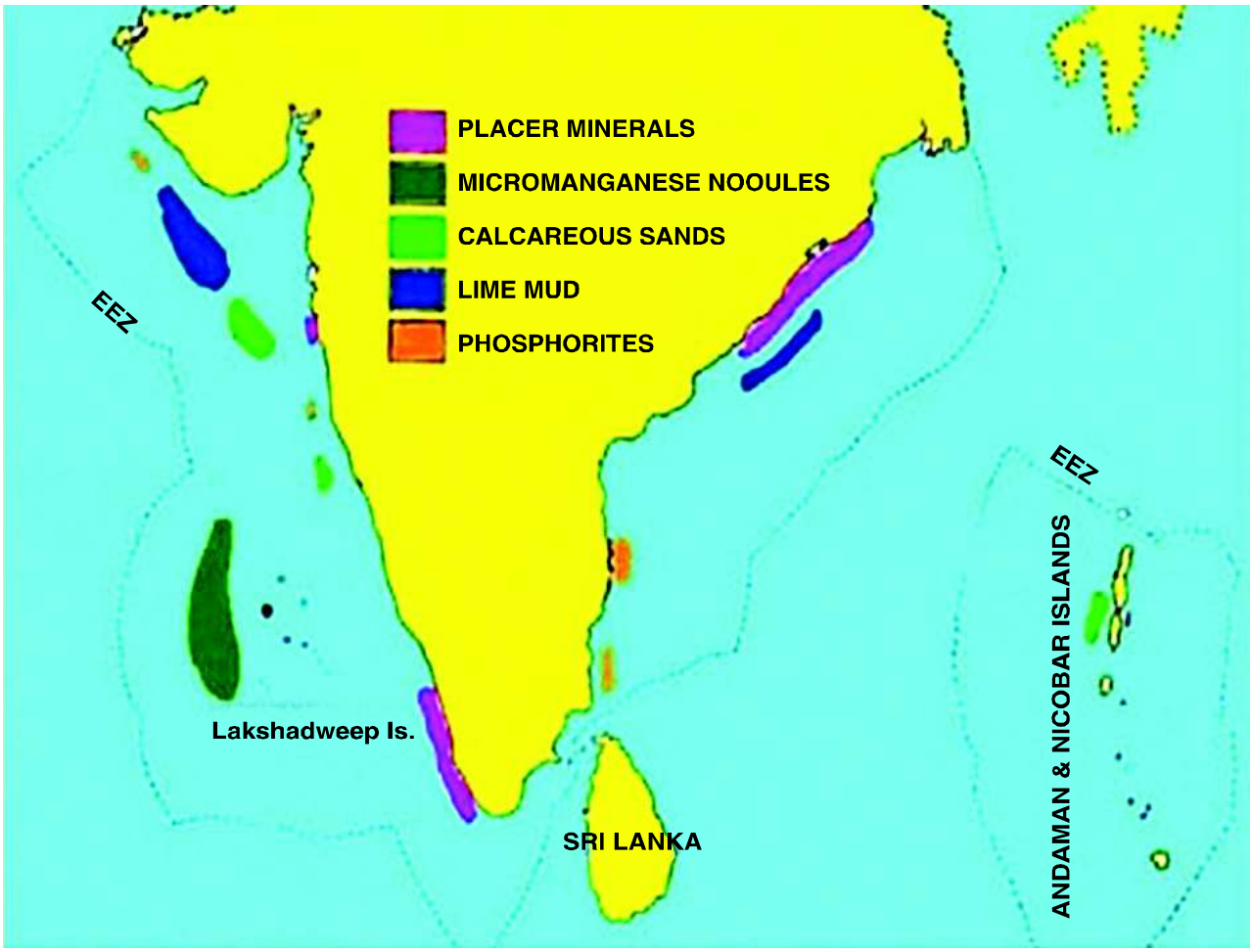

Fig. 5: Off-shore Mineral rich tracts constitute Obvious Geological Potential areas for detailed exploration and scientific exploitation

4. **Creation of a Centralized Onshore Data Center:** Creation of a centralized onshore data center is envisaged for the geophysical, geological and geochemical data with processing centers having dedicated teams of experts at all the operational offices for handling the huge amount data to be acquired through second phase of systematic mapping of the sea bed through MBES, ADAP, SAS, Deep Seismic, Gravity and Magnetic surveys on board R V Ratnakar.

5. **Core Library and Archived Samples:** All the samples collected during the off-shore cruises have been meticulously archived at GSI Mangalore and Vizag offices. The archival of samples is systematic and each sample has been assigned unique ID number which helps quick retrieval of samples. A detailed documentation of all the seabed surface samples collected from the offshore region of west coast of India has been compiled into a publication "Handbook on Archived surface samples off west coast of India" and released during the 53rd CGPB meeting of Ministry of Mines/ GSI held at New Delhi on 2nd February, 2014.

   Further, it is imperative to building larger dry and air conditioned (temperature controlled) core libraries and marine sample repositories at all the four operational offices in view of the huge amount of sediment cores to be generated by 30m long piston corer on board the R.V. Ratnakar and the proposed new Geotechnical vessel.

6. **Marine Data Management System**: There is need to develop a robust Marine Data

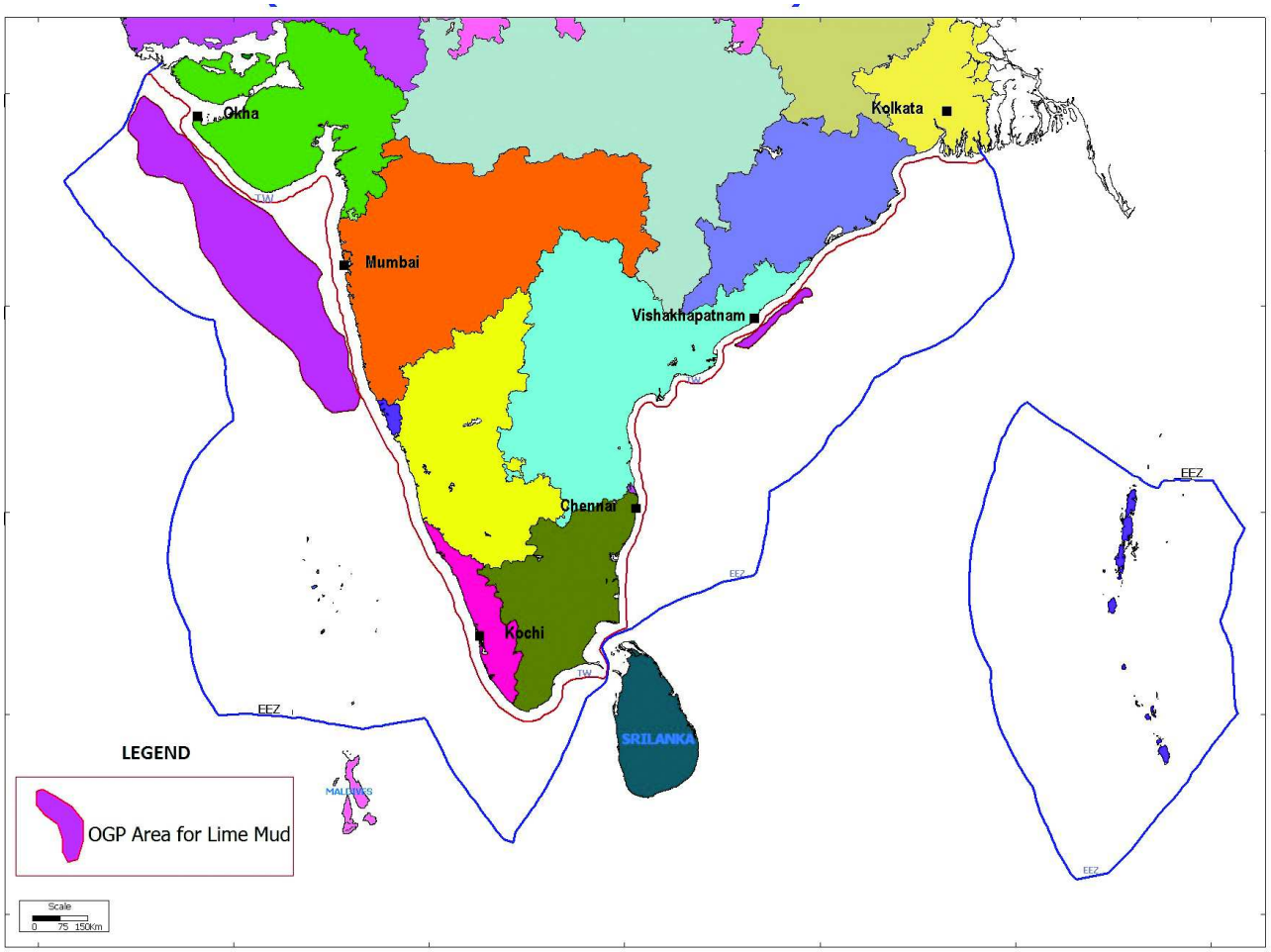

Fig. 6: Lime-mud resource occurrences delineated in Obvious Geological Potential areas off Gujarat Coast by GSI

Management System and to create a user-friendly Resource Database for integration and synthesis of all the data generated through various cruises in a standard format for easy access, retrieval and further processing/ up-gradation.

Obvious Geological Potential Areas for Offshore Minerals

In order to meet the ever growing demand for mineral resources, the delineation of Obvious Geological Potential Areas for offshore minerals in EEZ of India (Fig. 5) was considered imperative for strategizing future course of detailed marine geological studies and prioritising the concerted action plans for R.V. Samudra Ratnakar (Wadhawan *et al*. 2013). On the basis of the delineated OGP (~2,40,000 km^2) for the present, Focused Offshore Mineral Exploration (FOME) Cruises are planned to be taken up for Rare Earth Elements & Yttrium (REY), Seafloor Massive Sulphides (SMS), phosphorites, lime mud, gas hydrates, carbonate sand etc; onboard R.V. Samudra Ratnakar.

Three domains within the EEZ of India viz; West Coast, East Coast, Andaman Region are demarcated based on their distinct morphotectonic and sedimentological characteristics. The EEZ off East Coast is sediment dominant due to the huge terrigenous input by the major rivers draining into the basins whereas the EEZ off West Coast is sparsely covered by terrigenous sediments (Subramanyam and Chand, 2006). In contrast to this, the volcanic seamounts/ridges within the EEZ off Andaman are either thinly covered or completely devoid of sediments. Data on salinity, temperature, pH, carbonate content and micropalaeontology pertaining to this region suggest an induced acidic environment by intermittent submarine volcanism. This is the major

causative factor that inhibits the preservation of carbonate over the seamounts/ridges. Such seamounts/ridges facilitate the growth of Fe-Mn crust that hosts the rare earth metals. This makes the volcanic seamounts/ridges of Andaman Region a highly potential zone for REY (Curray, 2005). Based on the reported occurrences of phosphorites along the Western Continental Margin of India (WCMI), huge phosphorite deposits are envisaged. The sporadic occurrences of phosphorites are also reported from the outer shelf/upper slope off Tamil Nadu coast. The Indian National Gas Hydrate Program (NGHP) identified the presence of gas hydrates in the Krishna-Godavari, Mahanadi and Andaman Basins (Timothy *et al*., 2008). Hence, the formation and sustenance of mineral deposits within these three domains are distinct from one another.

Rare Earth Elements and Yttrium (REY)

REY have innumerable applications in the fields of health, industry, energy, space technology etc. The future clean green technology is entirely based on REY. Though India has got an approximate reserve of 12 Metric Million Tons (MMT) of monazite which is one of the primary ores of Light Rare Earth Elements (LREE), the presence of radioactive thorium (Th) and involvement of several steps in the extraction of the metals poses a serious challenge. The offshore REY is relatively enriched in deep sea mud (metalliferous sediments, zeolitic clay and pelagic red clay), near-shore carbonaceous clay with high metal content and cobalt-rich Fe–Mn crusts and nodules deposited on the volcanic seamounts/ridges and in the abyssal plains respectively (German *et al*., 1990; Byrne and Kim, 1990, GSI, 2014). Furthermore, extraction of REY is environmentally safe and sustainable due to the absence of radioactive thorium in the host sediments of marine origin.

Acknowledgements

Author is grateful to Sh. M Hariprasad, S Raghav and A C Dinesh, Marine Geoscientists of GSI for their help in collection of figures, advice and support from Professor A K Singhvi and Dhiraj M Banerjee were encouraging.

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