NEWS AND NOTES

A Comprehension on Coral Atolls of the Remote Lakshadweep, Arabian Sea, Indian Ocean –

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The Lakshadweep are least studied coral atoll group situated in the northern part of the Laccadive-Chagos ridge at a distance of 200-300 km from the west coast of India. The ridge is a continuation of the Aravalli Mountains and the islands are the remnants of submerged mountain cliffs. They lie between latitude 8^0-14^0N and longitude 71^0-74^0E. The islands cover an area of only 32 km^2 and Kavaratti is the capital of the Lakshadweep group of islands. The atolls have formed on the Lakshadweep-Chagos ridge. There are 11 major islands and lagoons (Kavaratti, Kalpeni, Agatti, Chetlat, Bitra, Kiltan, Kadmat, Amini, Bangaram, Suheli, Minicoy), 4 submerged reefs (Baliapani, Cheriapani, Perumalpar, Androth) and 5 banks (Bassas de Pedro, Sessostris, Coradivh, Aminipitti, Elikalpeni). The term is generally interpreted as hundred thousand isles (Laksha – one hundred thousand; Dweep-island). The present article on Coral Atolls of Lakshadweep very briefly covers important aspects on geology of Lakshadweep. In view of this, the effort will be a source of information about a comprehensive picture on the present status of the atolls on various aspects The islands have a lagoon area of 4,200 km^2, Territorial waters of 20,000 km^2 and 4,00,000 km^2 of Exclusive Economic Zone.

Previous Work

The earliest information on these islands dates back to 19th Century when Agassiz (1903), Gardinar (1903) and Sewell (1935) visited these islands. Geological Survey of India carried out detailed sampling in the lagoons and offshore areas to assess the potentiality of calcareous sands for industrial use (Siddiquie and Mallik, 1973). An area of 380 sq.km was covered and 2490 samples were collected with 1190 line km echo sounding. Surveys indicated 288 m. tones of calcareous sands in the lagoons up to a depth of 1m. Various aspects of the coral reefs and exploration work in Lakshdweep and the economic aspects has also been discussed by Mallik (2008). The DSDP borehole 219 on the ridge has brought out the sedimentation and tectonic history at the site (Whitmarsh et al. 1974). Coral reefs of the world has been compiled by Shepard and Wells (1988) and there is lot of information on the Lakshadweep in the Indian Ocean Volume. Important studies on coral reefs of India has been presented by IUCN (2012). Review of fauna of Lakshadweep is available (GSI publication 1991; Pillai, 2010; Mukundan, 1979). The science and Technology Department has set up a cell at Kavaratti for keeping a track of scientific investigations. CESS, Trivandrum is also engaged with few projects on various geological aspects of the islands.

General Setting of the Atolls, Islands Lagoons and Reefs

An atoll is a ring-shaped coral island in the open sea. It forms when coral builds up on a submerged bank or on the rim of the crater of a sunken volcano. The atoll surrounds a body of water called a lagoon. One or more channels connect the lagoon to the open sea.

Growth of coral will require clear shallow water with a particular temperature. Corals are formed by tiny lime secreting animal growing in millions in different shapes like branching trees, large domes, small irregular crusts, or tiny organ pipes. According to Menard (1986) plate tectonics is the key to understand the creation, distribution and history of the islands. Other important features which play a major role are changes in sea level.

Islands in most of the atolls are situated on eastern leeward side of the reef. Lagoon side beach is sandy. The eastern part of the island has steep storm bouldery beach and formed by storms from east. Beaches are the important ecosystem of the islands. The beach consists of unvegetated part of the shoreline formed of loose material usually made up of dead coral boulders, shingles, gravel that extends from the upper berm to the low water line. Beaches are the focal point for coastal recreation and tourism in the islands. They are also the first line of defense against storms and erosion. Birds, reptiles and other animals nest and breed on the berm and open beaches.

Lagoons are shallow water bodies parallel to the island coastline. They are often highly productive and habitat for variety of plants and aquatic animals, serve as nurseries for fishes and also sites for harbour, aquaculture, industry, recreation and tourism. The islands in the eastern side have lagoons which vary in size and are the habitat for a variety of plants and aquatic animals. The smaller lagoons are virtually filled with sediments. The larger lagoons are comparatively deep with depth of about 10 to 16 m. At low tide the reef is exposed and during high tide it is submerged.

Geomorphology: There are various types of atolls which vary in shape from circular, sub-circular to elliptical. Some enclose lagoons, some are with islands, some are without islands, and some are partially drowned. Reef usually varies in width from 200-400m. in different islands. Wave cut platform extends from the reef margin to a distance of 50-100m towards the sea and the depth falls steeply within a short distance. A number of well defined submerged terraces exist on the sea ward side of the reef at 7-12m, 15m, 21-36m (prominent) and 43-47m depths. The first break usually represents a wave cut platform and the deeper terraces (>12 m) appear to have been formed during periods of lowered sea level. Generally the topography of the lagoon towards the island margin is considerably even but it is rugged due to outcropping corals at the reef margin. A number of surge channels oriented in NW-SE to NE-SW direction are also present in the outer reef.. The sets of storm beaches are almost at the same level and progressively

younger towards shore and beach on these parts of the island. They have grown by about 10 m to 200 m in 1000 years The radiocarbon data (Siddiquie,1980) of the corals from the storm beaches range from modern to 2975±100 B.P. and indicates clustering between 3000 to 2000 B.P. Recent studies also indicate that the shore line of many islands has been receding which has been a matter of great concern to administrator (Prakash et al., 2014).

Biodiversity: There is a wide variety of forms in the lagoons, islands, reefs and adjacent areas .Among vertibrates cattles and poultary birds are common. House mice *Mus ratus* is seen everywhere. About 24 km north of Kavaratti, Pitti island is situated consisting of reef and sand bank and is known as bird island. Two types are common Tharahasi (*Sterna fuscate*) Karifetu (*Anousstolidus pitelus*). Among reptiles common are wall lizard (*Pallis Geeko* sp.) and coral snakes. In the sea, green turtles and leathery turtles are common. Imporant molluscan form include Cyprea tigris, cyprea talpa and cyprea maculifera.Among bivalves Tridacna fossa are seen in the crevices which exhibits coloured mantles (Department of Science and Technology, Section I, Title 1& 2, 1983).

- The coral community is most dominant and occurs in colonies as well as in single individual species. Different types of growth forms such as branching, robust, massive, platy, foliated or flowerlike are quite common. The reef areas are the living places of various communities of corals belonging to different families of *Acroporidae*, *Poritidae*, *Pocilloporidae, Favidae, Fungiidae, Mussidae* etc.
- Besides a large number of speices of *Gastropods, Bivalves, Echinoids, Foraminifers, Ostracods and Bryozoans* are also present.
- *Halimeda* is the most important constituent of the lagoon sands and played most important role in building up the reef.

About 105 species of hard corals, 86 species of macrophytes, 10 species of anomurean crabs, 81 species of brachyulam crabs, 155 species of gastropods, 24 species of bivalves.13 species of asteroids, 6 species of ophiroids, 23 species of holothurians, 15 species of echinoids, 6-3 species of fishes and 4 species of turtles are recorded from Lakshadweep (Raheem, 2012). There is plenty of scope to study the varied fauna in the lagoons and reef areas.

Nonliving Resources: Survey in the lagoons and shallow offshore areas indicated that the estimated reserves of these sands in the lagoons down to 1-m depth are 288 million tons. The sands have a low amount of silica, alumina and Fe_2O_3. They are suitable for a number of industries like cement, chemical, glass and paper. However, the geomorphic situation on the coral islands are delicate and precautions have to be taken while mining these sands. The present calcareous sands occur on the lagoon floor and will be easier to mine. We can expect a quick return from these deposits without disturbing the delicate balance. If limited quantity of sands are removed, there will not be appreciable change in the rate of production or derivation. Slight changes will be automatically adjusted. The most important sediment-forming site is the reef area and it should not be disturbed as far as possible. The lagoon is the most important accumulation site and the lagoon will have the tendency to fill up automatically if the sands are taken out. However, a close environmental monitoring should be done.

Ground water Resources: Ground water is the most critical natural resource of the islands. The only source of portable water in the islands is rain, which seeps down the porous coral, sandy soil and floats as lens above the saline water base. This water is drawn through wells. With consumption, the lens keeps on shrinking till it gets recharged by next rains. The sustainable yield of ground water in the islands is not sufficient to meet the demand. A fresh water desalination plant has also been installed in Kavaratti to meet the local needs and the industries. Cases of excess extraction from the fragile lenses by pumping and resultant salinization is harmful. Detailed resistivity sounding coupled with well inventory helped to map the base level of Fresh Ground Water. Verma et al. (2004) have suggested a dual aquifer model for these coral atolls.

Living Resources: Lakshadweep has immense potential for marine fisheries. The fishery resources are mainly characterized by a rich and diversified fish fauna of tuna and allied species tipora. Coconut grows in plenty. The islanders are supplying coconuts to the main land. Lot of handicrafts are manufactured from coconut shells, oil is also extracted from coconuts in some islands. The coir and copra industries of these islands are famous.

Lakshsadweep Development Corporation Ltd. (LDCL) is producing value added products from fish and coconut abundantly available in the island through its canning factories at Minicoy and packing units at Kadmat, Androth and Kalpeni.

Sediments, their source and transport: Sediment distribution in these atolls is related to the sources, morphology, and transporting agencies. The sediments in the lagoons consist of various types of sands and gravel size pieces resulted due to breaking of reefs. Outcropping corals break the pattern of distribution of the sediments in the lagoons. Large areas are covered with seaweeds. Boring by the Harbour Engineering Department in the Kavaratti shows that the sands extend beyond 10m depths. Besides coral, halimeda, shells of gastropods, foraminifera, ostracods and bryozoans are present. The sediments show a bimodal to polymodal character. Halimeda is the most important constituent of the lagoon sands in addition to corals. A substantial amount of the sediments in the reef front is lost in the deep sea because of morphology, waves and currents. The inner reef flat has thicker sediment cover, parts of which are transported to the lagoon.

The corals are derived from the reef edge which is the principal area of production of sediment. It is largely “rocky” in character Coral heads in the lagoons are sparse and little coral debris can be added during transport. Halimeda live in the finer mud, particularly and have high aragonite content. Sediment generated within edge zones is carried by wave action over the reef and into the

lagoon area. Wave refraction will tend to transport it "onshore" irrespective of wind direction although there will be an alongshore component. The islands on the eastern margins of the atolls lie within the wave shadows of both the main wind directions and this is probably the reason for their formation in these positions. External currents are not relevant here. Thus, the sediment arrives in suspension and having once settled moves infrequently.

Mineralogy: Beach rocks contain mainly aragonite and traces of calcite with some doubtful kaolinite. The lagoon sample contains calcite and aragonite as major constituent. The samples from the reef areas contain major calcite aragonite. The major source of aragonite is from corals, halimeda and mollusks. The lagoon sediments essentially consisting of halimeda and coral are mainly responsible for aragonite portions and the foraminifers contribute to the calcite portion. Diagenetic alteration causes changes in mineralogical composition (Mallik, 1979).

Petrography: Beach rock consist of moderately well sorted calcarenite composed of reef detritus of corals, coralline algae shells of gastropod, foraminifera, bivalves, bryozoans etc. Coralline algae occur very frequently in the old reef rocks. Portions of algae often show micritisation and give a porous appearance. Recrystallization sometimes completely obliterates the cell walls. Fragments of intraclasts are present in some of these samples. In thin section corals show a feathery appearance and differential extraction of material results in a number of pore spaces depending on growth habits. Beach rocks at places show little or no cement indicating immaturity (Mallik, 1979). The spaces between the grains are generally filled up with micritic matrix showing slightly brownish colour. Some void spaces have been filled up by sparry calcite. Fluorescent microscopic studies indicated boundaries of aragonite and calcite clearly. The aragonite shows brighter fluorescents. Presence of bright white yellow specks with much brighter fluorescent may be indicative of presence of bitumen like material or resinous body showing effect of bacteria. Shells of foraminifers showing bright outer rims of higher fluorescence within the coralline algae may be indicative of development of similar type of material. These features are interesting for petroleum geologists as the coral reef areas are analogous to ancient reefs where valuable oil pools have been discovered.

Human Impact, anthropogenic induced hazards and Remedial Measures: The growth of the coral has been seriously hampered in these islands when boat channels are dredged or portions removed for mining or construction purposes. High population densities in some of the islands create more problems. Over exploitation, over fishing or pollutants released by ship oil etc. damage the reefs. Fishing using dynamite fish poisons or intoxicants is widespread. These can be extremely damaging, destroying the reef. Intensive recreational use by diving, boat anchoring and tourist generated pollution affects the coastal strips of many of the islands. A variety of fish and reef invertebrates have been heavily overexploited where they are important to local people and are in demand by tourist. The ornamental coral trade in Philippines has led to significant localized reef damage. Ornamental shells are heavily exploited. All these factors results in destruction of the reefs rapidly. Scientists should be involved in preparation of detailed spatial plan of islands. Dwelling units including some of the infrastructural facilities can be mapped first using GPS. The conservation and preservation zones are the key components and should be mapped separately. The Centre for Earth Science Studies in Trivandrum considered the limited land area, fragile environment, limited resources and major environmental constraints faced by the islands and developed an integrated Island Management Plan for the Lakshadweep islands in accordance with the guide lines of the Island Protection zone Notification 2011 of the Ministry of Environment and Forest. Upgrading physical and social infrastructure in the island is an important issue. The emergency cyclone shelters can be built in elevated area having double story building. The existing provisions can be upgraded in terms of land built space and facilities. Solid waste disposal /management problems should be solved. Electricity generation through solar panels and wind mills can be very effective in these remote islands.

Effect of Sea level changes and Origin: The Lakshadweep group of atolls is situated in the Lakshadweep Ridge and the history of these islands is related to the history of the ridge. The ridge is oriented N-S and extends for about 2200 km between 10^0 S – 12^0 N The Laccadive-Chagos ridge system was considered as a zone of transition between oceanic crust in the west and continental crust in the east due to block faulting along the west coast of India. There is a considerable debate on the tectonic implication of Lakshadweep-Maldive-Chagos ridge and its relation to Indian mainland, Sedimentary records obtained through DSDP Site 219 north of Maldive indicate that these islands have been affected by vertical movements since Miocenec with periods of subsidence and uplift. The subsidence is to the tune of 2000m (Whitmarsh et al, 1974).The Lakshadweep islands have been considered to be a volcanic island with coral atolls, According to Naini and Talwani (1982) the island chain along with Laxmi ridge in its northward continuation is of continental origin, Rhyolite tuffs have also been noted in site 219, which indicates continental affinity. There are various theories of origin of the Lakshadweep ridge. Whitmarsh et al. (1974) suggested a hot spot origin connected with the motion of the Indian Plate over a fixed spot. DSDP SITE-219 was drilled at a water depth of 1766m on Lakshadweep ridge penetrated 411m and a sequence of upper paleocene to recent was recovered. The sea bed began to sink to about 2000m in early Eocene times. The studies of the fauna also suggested that the ridge was connected to eastern shelf during late Paleocene and the western shelf extended as far as Lakshadweep ridge. Sedimentation history suggests that the site was once close to Indian landmass or perhaps a part of the main landmass. However, there is still a controversy about the origin of this ridge, and further geophysical studies are required to solve this problem.

The corals started growing in the ridge depending on the hydrological and bathymetric character of the area. Fringing reefs formed in the western part as the waves supplying food were

coming from the west. Active reef growth continued in the west to form arcuate shapes. The various terraces noted represent the various stages in the growth of the atolls. These could be either due to strands in the rise of the sea level or by neo tectonic activity. The two depth ranges 22-27 m and 10-16 m perhaps formed important strands. Sea level at this depth would have been around 10,000 to 7000 yr B.P. Perhaps the corals comprised at these level and the rims of the atolls were formed. The eastern reef on many atolls is narrower limiting the capacity of carbonate production. Sediments generated are deposited in the reef front and subsequently in the lagoon. A large volume of sediment is generated from the reef that is gradually deposited in the lagoon. Most of the sediments generated are lost through the gaps in the reefs. Very large amount of sediment is generated in the atolls. Sands and boulders piled up on the leeward side to form islands. Different coral communities thrived in these environments and various processes continued to act on the reef system giving rise to present configuration.

Suggestions and Recommendations

From the various observations it may be inferred that little sediment is generated within the lagoon. The sands originate and are transported irrespective of their final resting place. We do not have a correct idea about the rate of sediment production. Large scale dredging operations may affect the floral and faunal systems within and peripheral to lagoon. Any significant lowering of lagoon floors will be expected to have the effect of increasing wave amplitude on downwind shores. This will result in erosion, Dredging activity will undoubtedly draw much larger volumes of sediment into suspension than normal. Certainly any channel will be a site of concentrated water flow during ebb tides. A new channel will probably promote active erosion in its head ward area at the lowest stage of the falling tide.

Disposal of calcareous sands in the open ocean by various industrial departments should be stopped immediately and the sand should be put to use or for reclaiming areas of the island. Dredging of sand for industrial purpose should not have harmful effect if limited quantities are removed from the lagoon. Islands with high population should not allow tourism to be expanded rapidly. Overexploitation of fish by local people should be avoided. There should be control on ornamental coral trade since all these factors results in destruction of the reefs rapidly.

Human induced damage to corals reefs can be avoided by careful control. Sewage outfalls can be placed below the level of coral growth, thermal effluent can be discharged in deep water. There are new methods of dispersing oil and alternative methods may be applied to the local area available for construction.

Upgrading physical and social infrastructure in the island is an important issue. Some physical infrastructure required in the islands are primary health care facilities, high schools, primary schools, nursery schools etc. The emergency cyclone shelters can be built in elevated area having double story building. The existing provisions can be upgraded in terms of land built space and facilities. Parks, playground can be upgraded Potable water supply is generally short in most of the islands. Desalination plants fill up the gaps in Kavaratti, Agatti and Minicoy .Facility should be installed in all islands. For sewage disposal two pit flush septic tanks are in place. Solid waste disposal /management pose problem and alternative to sea dumping needs must be explored. Electricity is generated through solar panels and wind mills can act as alternative source. Coastal zone management and planning is particularly important. Reef management has to be considered in the context of the entire coastal zone.

Inspite of the fact that lot of work has been done on different aspects of the reef it is still believed that the reefs are very fragile and vulnerable to human activity. The resources of the Lakshadweep atolls are enormous and it may be relevant to decide to what extent this fragile ecosystem can be used to gain maximum profit without causing any damage to the delicate balance... In Lakshadweep the lagoon is the most important sediment accumulating site. A large volume of sediment is being generated from the reef and deposited in the lagoon. So, if a limited amount of sand is taken out there is no danger at all. However, a close environmental monitoring should be done. Once the system of exploitation is established in such an environment it can be widely used in other areas also. There is still plenty of scope to work on a number of different aspects on the Lakshadweep group of atoll.

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