6. Santharam, G. and Balasubramanian, M., *Indian J. Agric. Sci.*, 1980, **50**, 726–727.
7. Ramakrishnan, N., Chaudhari, S., Kumar, S., Rao, R. S. N. and Sathyanarayan, S. V. V., *Tobacco Res.*, 1981, **7**, 129–134.
8. Santharam, G., Regupathy, A., Easwaramoorthy, S. and Jayaraj, S., *Indian J. Agric. Sci.*, 1978, **48**, 676–678.
9. Chaudhari, S. and Ramakrishnan, N., *Indian J. Entomol.*, 1980, **42**, 592–596.
10. Jayaraj, S., Santharam, G., Narayanan, K., Soundararajan, K. and Balagurunathan, R., *Andhra Agric. J.*, 1980, **27**, 26–29.
11. Senthil Kumar, C. M. and Rabindra, R. J., *J. Biol. Control*, 2003, **17**, 57–61.
12. Ignoffo, C. M. and Shapiro, M., *J. Econ. Entomol.*, 1978, **71**, 186–188.
13. Smits, P. H. and Vlak, J. M., *Ann. Appl. Biol.*, 1988, **112**, 249–257.
14. Shapiro, M. and Bell, R. A., *Ann. Entomol. Soc. Am.*, 1981, **74**, 27–28.
15. Evans, H. and Shapiro, M., Viruses. In *Manual of Techniques in Insect Pathology*, Academic Press, London, 1997, pp. 17–53.
16. Panse, V. G. and Sukhatme, P. V. E., *Statistical Methods for Agricultural Workers*, Indian Council of Agricultural Research, New Delhi, 1985, p. 381.
17. Duncan, O. D., *Am. J. Sociol.*, 1966, **72**, 1–16.
18. Shapiro, M., *In vivo* mass production of insect viruses for use as pesticides. In *Microbial and Viral Pesticides* (ed. Kurstak, E.), Marcel Dekker, New York, 1982, pp. 463–492.
19. Kalia, V., Chaudhari, S. and Gujar, G. T., *Phytoparasitica*, 2001, **29**, 1–6.
20. Van Beek, N. A. M., Flore, P. H., Wood, H. A. and Hughes, P. R., *J. Invertebr. Pathol.*, 1990, **55**, 85–92.
21. Flipsen, H., Pathogenesis induced by (recombinant) baculoviruses in insects. Ph D thesis, University of Wageningen, Holland, 1995.
22. O'Reilly, D. R. and Miller, L. K., *Science*, 1989, **245**, 1110–1112.
23. Hernández-Crespo, P., Sait, S. M., Hails, R. S. and Cory, J. S., *Appl. Environ. Microbiol.*, 2001, **67**, 1140–1146.
24. Gryzwacz, D., Mc Kinley, D. J., Jones, K. A. and Moawad, G., *J. Invertebr. Pathol.*, 1997, **69**, 151–156.
25. McKinley, D. J., Moawad, G., Jones, K. A., Grzywacz, D. and Turner, C. R., In *Pest Managaement in Cotton* (eds Green, M. B., Lyon, D. J. de B.), Ellis Horwood, Chichester, UK, 1989, pp. 93–100.
26. Cherry, A. J., Parnell, M. A., Grzywacz, D. and Jones, K. A., *J. Invertebr. Pathol.*, 1997, **70**, 50–58.

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Record of rhodoliths from Aramda Reef Member (Late Pleistocene to Holocene) of Chaya Formation, Dwarka–Okha area, Gujarat and their paleoenvironmental significance

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Rhodoliths are defined as 'certain more or less nodular forms of nongeniculate coralline algae with a nucleus and a number of concentric thallus layers around them'. In the present study we have recorded rhodoliths from Units II, III and IV of Aramda Reef Member (Late Pleistocene to Holocene) of Chaya Formation, Dwarka–Okha area, Gujarat. Unit II rhodoliths are multispecific, discoidal, columnar concentric type and multispecific, ellipsoidal, branching class III and class IV type. Unit III rhodoliths are multispecific, ellipsoidal, laminar, concentric type and multispecific, spheroidal, laminar boxwork type. Unit IV rhodoliths are multispecific, spheroidal, laminar, concentric type and multispecific ellipsoidal, laminar, concentric type and multispecific, spheroidal, branching class IV type. The thin-section study of rhodoliths reveals the presence of nongeniculate algal genera such as *Lithoporella, Lithothamnion, Lithophyllum*, *Porolithon* and *Sporolithon* and geniculate coralline alga *Amphiroa.* The rhodoliths and other algal assemblages point to high energy conditions with turbulence during the deposition of Units II and IV and low to moderate energy conditions during the deposition of Unit III of Aramda Reef Member.

CORALLINE algae have been known as the most important agents in the building of carbonate sequences since the early Palaeozoic[1]. Many studies have shown that coralline algae are reliable palaeoenvironmental indicators[2–6]. The calcified skeletal tissue enables coralline algae to construct algal reefs[4,7,8] and rhodoliths[5,9]. Rhodoliths are defined as 'certain more or less nodular forms of unattached nongeniculate coralline algae which have developed around a nucleus and which usually consist of a number of concentric thallus layers'[10]. Rhodoliths containing monospecific and multispecific nongeniculate coralline algae have been described from several parts of world like Norway[11], France[12], Bermuda[9,13], Ireland[14], Malta[15–17], Florida[18], Italy[19] and Australia[20]. From India, Rao *et al.*[21] have documented carbonate nodules containing foraminifera and coralline algae from Late Quaternary deposits along the shelf break between Goa and Cape Comorin and discussed their significance in environment and sea-level changes. In the present

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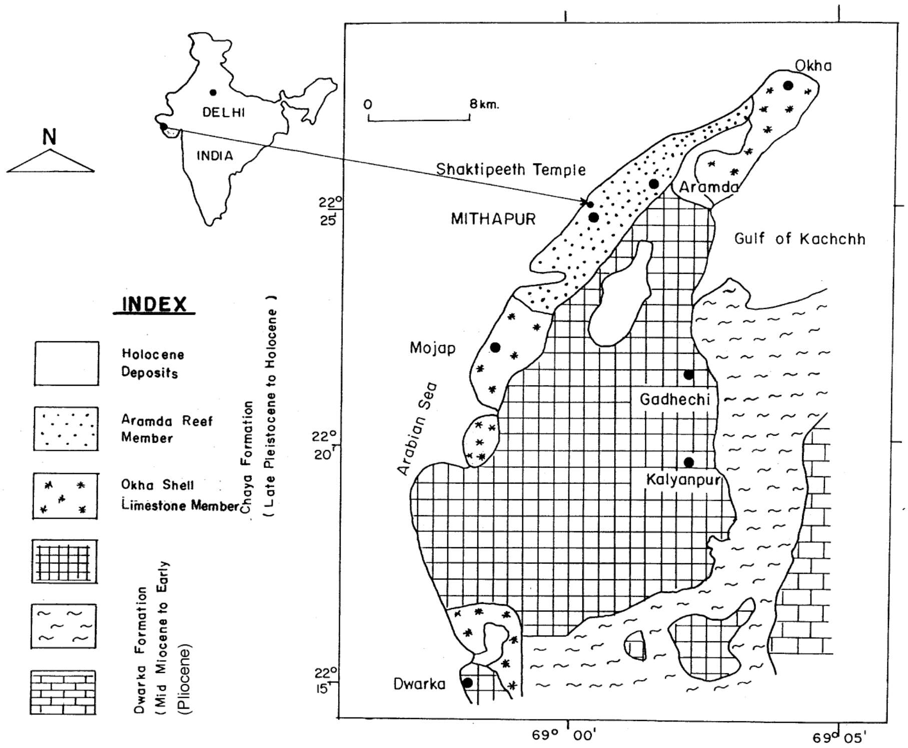

Figure 1. Geological map of study area[22].

Table 1. Lithostratigraphic succession of Chaya Formation, Dwarka–Okha area (after Bhatt[22])

Stratigraphic unit		Lithology	Age
Holocene deposits		Beach and dune sands, tidal clays and alluvium	Holocene
........Unconformity........			
Chaya Formation	Aramda Reef Member (4 m)	Coral Reef Limestone	Late Pleistocene–Holocene
	Okha Shell Limestone Member (10 m)	Off-white coloured bioclastic limestone and conglomerate	Middle – Late Pleistocene
........Unconformity........			
Dwarka Formation		Bioclastic limestones, variegated clays and shales	Middle Miocene – Pliocene

communication rhodoliths from Aramda Reef Member (Late Pleistocene to Holocene), Chaya Formation, Dwarka–Okha area, Gujarat (Figure 1) are described morphologically and interpreted for their palaeoenvironmental significance.

Bhatt[22] lithostratigraphically classified the Neogene–Quaternary carbonate deposits of Dwarka–Okha area, of Gujarat as Gaj Formation, Dwarka Formation and Chaya Formation. He subdivided the Chaya Formation of Pleistocene–Holocene age into the Lower Okha Shell Limestone Member and Upper Aramda Reef Member (Table 1). The Okha Shell Limestone Member (Middle to Late Pleistocene) represents bioclastic shore deposits[23], whereas the Aramda Reef Member (Late Pleistocene–Holocene) represents dead coral reef[22]. The radiocarbon dates of corals, gastropods and foraminifers ages from Aramda Reef Member, Chaya Formation[24] are 41.2 and 18.3 Ka BP. Pandey *et al.*[25] re-examined the Aramda Reef Member for faunal assemblage, sequence stratigraphy and depositional environment. On the basis of biotic community associated in Aramda Reef Member, they proposed that this could be divisible into the Lower and the Upper sequences. Further, the Lower sequence is subdivided into Unit I and Unit II and the Upper into Unit III and Unit IV (Figure 2). Pandey *et al.*[25] have noted the presence of coralline algae in all

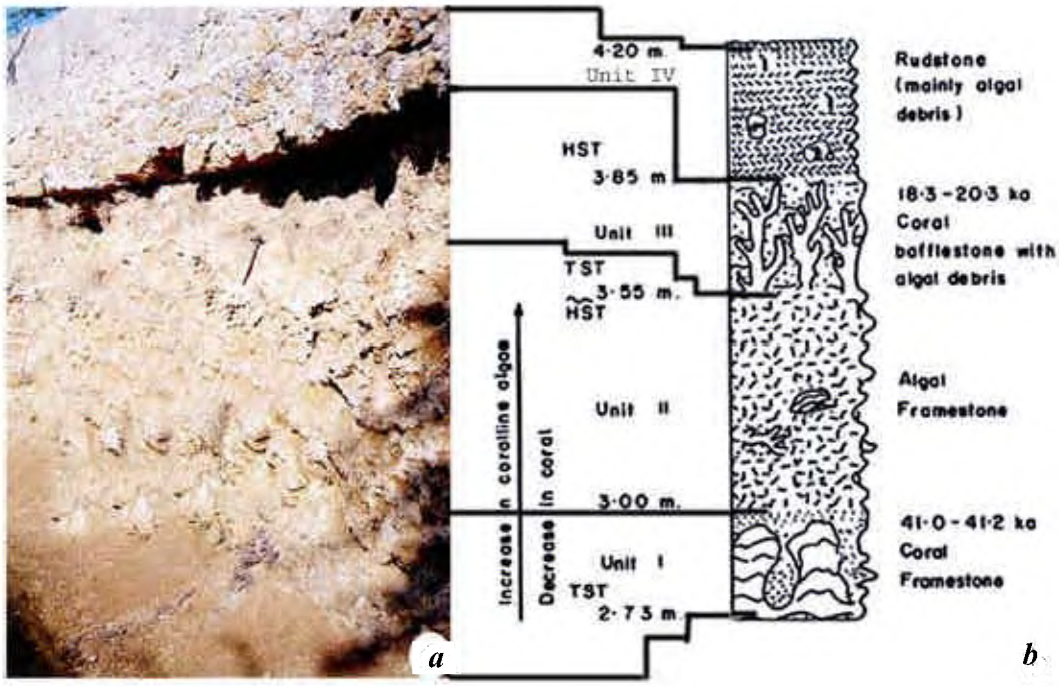

Figure 2. Field photograph and lithosection of study area[24].

Table 2. Classification of rhodoliths (after Bosence[5])

Monospecific	Spheroidal	Laminar	Concentric (Con) or Boxwork
	Ellipsoidal	Branching	Classes I, II, III, IV
Multispecific	Discoidal	Columnar	

For example multispecific, spheroidal, laminar, concentric type rhodolith or (M,S, L, Con); Monospecific ellipsoidal branching class III type rhodolith or (Mono, E, B, Class III).

four units and illustrated a solitary alga *Lithothamnion*, which in fact is a fragment of coralline alga from Unit II. Kundal and Dharashivkar[26–28] have documented a rich assemblage of benthic nongeniculate and geniculate coralline algae from Dwarka Formation and Chaya Formation of Dwarka–Okha area, Jamnagar district, Gujarat. The studied rhodolith samples are collected from the Aramda Reef Member of Chaya Formation exposed in a shallow dug well of large diameter located near the Shaktipeeth Temple, 1.75 km NW of Mithapur village, Dwarka–Okha area (Figure 1).

Bosense[5,6] made significant contributions on rhodoliths and classified them into two major groups as monospecific and multispecific types, and based on morphology and structure into spheroidal, ellipsoidal and discoidal types. These are subdivisible into laminar, branching and columnar forms. Depending on growth habits laminar forms can be either concentric or boxwork type and branching forms, depending on intensity and complexity of branching, could be further separated into branching class I, II, III and IV type (Table 2).

Unit I, whose base is not seen, is 30 cm thick and mostly comprises branching and massive corals like *Acropora, Favia* and coralline algae[25]. However, we have not identified coralline algae from this unit. Unit II is about 60 cm thick and comprises coralline algae. It has been designated as algal framestone by Pandey *et al.*[25]. Detailed examination indicated the presence of multispecific, discoidal, columnar (Figure 3 *a*) type rhodolith and multispecific, ellipsoidal, branching class III (Figure 3 *g*) and class IV (Figure 3 *d*) type rhodoliths. Class III and Class IV branching rhodoliths are differentiated on the basis of complexity and type of branching. In Class III type (Figure 3 *g*), the branches are less intermingled compared to Class IV type (Figure 3 *d*) rhodoliths. The thin section examination of rhodoliths revealed the presence of geniculate and nongeniculate coralline algae. *Amphiroa* (Figure 4 *i*) represents geniculate coralline and *Lithothamnion* (Figure 4 *a*) represents nongeniculate coralline. Apart from coralline algae, Unit II has a rich and diversified ostracod assemblage and a few reworked corals[25].

Unit II–Unit III contact can be separated by the appearance of massive corals like *Favia speciosa*, *Porites*, *Leptastrea tranversa* and other branching corals. It is also more appropriate to state here that the rhodoliths are also totally different and are more useful in defining the Unit II and Unit III contact. Unit III is 30 cm thick and consists of coral bafflestone[25]. Rhodolith samples collected from Unit III are multispecific, ellipsoidal, laminar, concentric type (Figure 3 *c*) and multispecific, spheroidal, laminar boxwork type (Figure 3 *h*). This unit is dominantly made up of rhodoliths. The thin section examination indicated the presence of nongeniculate coralline algae which are represented by algal genera distributed between Lithophylloides and Sporolithoides. The Lithophylloides comprise *Lithophyllum* (Figure 4 *e* and *f*) and *Porolithon* (Figure 4 *b*), and Sporolithoids is marked by *Sporolithon* (Figure 4 *d*). The *Porolithon* is predominant over *Lithophyllum*. Benthic foraminifers and ostracodes are also associated with them. This unit is also comprised of reworked fossils such as bivalves, gastropods, crabs and shell fragments.

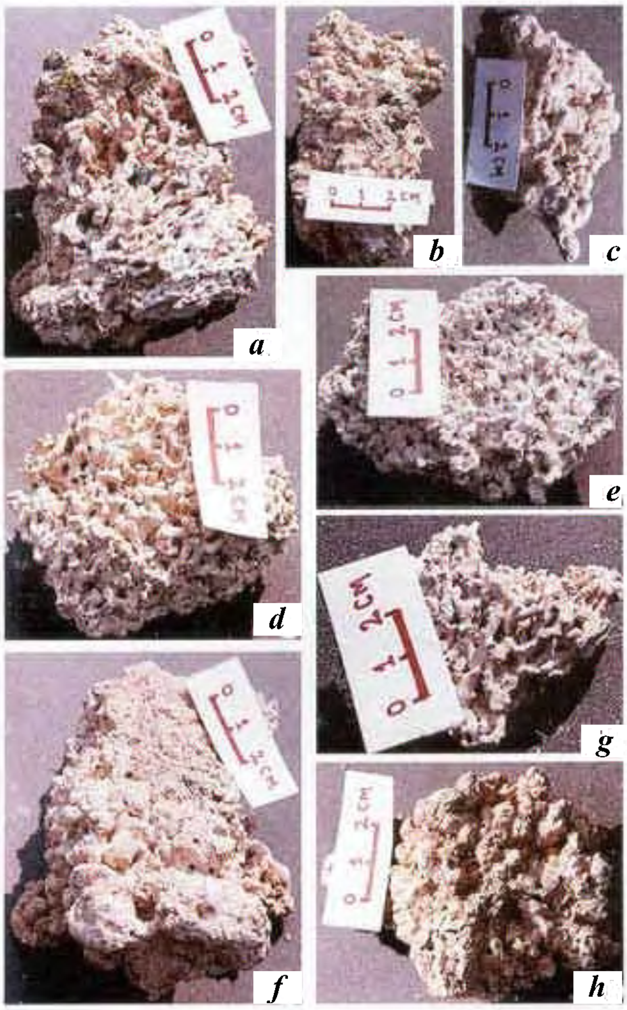

Figure 3. Different morphological classes of rhodoliths. ***a***, Rhodolith showing two different habits (A). Multispecific, discoidal, columnar concentric type and (B) multispecific, ellipsoidal, branching class IV from Unit II. Specimen No. PGTDG/SCA/RHO/48. ***b***, Rhodolith showing multispecific, spheroidal, laminar concentric type from Unit IV. Specimen no. PGTDG/SCA/RHO/53. ***c***, Rhodolith showing multispecific, ellipsoidal, laminar concentric type from Unit III. Specimen no. PGTDG/SCA/RHO/51. ***d***, Rhodolith showing multispecific, ellipsoidal, branching class IV type from Unit II. Specimen no. PGTDG/SCA/RHO/49. ***e***, Rhodolith showing multispecific, spheroidal, branching class IV type from Unit IV. Specimen no. PGTDG/SCA/RHO/54. ***f***, Rhodolith showing multispecific ellipsoidal, laminar, concentric type from Unit IV. Specimen no. PGTDG/SCA/RHO/55. ***g***, Rhodolith showing multispecific ellipsoidal, branching, class III type from Unit II. Specimen no. PGTDG/SCA/RHO/50. ***h***, Rhodolith showing multispecific, spheroidal, laminar boxwork type from Unit III. Specimen no. PGTDG/SCA/RHO/52.

Unit III is conformably succeeded by Unit IV, which comprises rhodoliths that can be identified as multispecific, spheroidal, laminar, concentric type (Figure 3 *f*) and multispecific ellipsoidal, lamilar, concentric type (Figure 3 *b*) and multispecific, spheroidal, branching class IV type (Figure 3 *e*). These are morphologically different classes of rhodoliths and can be easily demarcated on the transition from Unit III to Unit IV. These rhodoliths mainly comprise of melobesioidean and mastophoroidean coralline algae. The melobesioidean are represented by nongeniculate coralline algal genera *Lithothamnion* (Figure 4 *c*), *Lithophyllum* (Figure 4 *f*) and *Porolithon* (Figure 4 *g*), whereas *Amphiroa* (Figure 4 *h* and *i*) marks the geniculate corallines. Mastophoroideae is represented by the *Lithoporella* (Figure 4 *g*). The other associated fossil groups are gastropods, ostracodes, foraminifers and shell fragments. Almost all the faunal fragments are reworked and derived from underlying units[25]. Thus, the thin section study of rhodoliths from Dwarka–Okha area reveals that the rhodoliths have ubiquitous presence of nongeniculate algal genera such as *Lithoporella*, *Lithothamnion*, *Lithophyllum*, *Porolithon* and *Sporolithon* and geniculate coralline alga like *Amphiroa.*

Coralline algae occupy a large depth range, i.e. 0–270 m in the ocean bottom[29] and usually occur from low tide level down to a depth of 25–30 m[30]. Bosense[31] summarized the relationship between coralline algae and turbulence of water. He showed that coralline algae which live in high energy conditions have thick crust and radial branching and those that thrive in moderate to low energy conditions have delicate framework with branching and concentric layers. Rhodoliths are absent in Unit I. Unit II is characterized by the presence of multispecific, discoidal, columnar, rhodolith and multispecific, ellipsoidal, branching Class III and Class IV type with coralline algae like the nongeniculate *Lithothamnion*, *Porolithon* and geniculate alga *Amphiroa*. This suggests high energy conditions with high turbulence. Unit III has rhodoliths having multispecific, ellipsoidal, laminar, concentric type and multispecific, spheroidal, laminar boxwork type, consisting of nongeniculate coralline algae which are distributed between Lithophylloides and Sporolithoides, indicative of low to moderate energy conditions. During Unit IV there was a recurrence of conditions similar to Unit II, i.e. high energy conditions with high turbulence as the rhodoliths are morphologically multispecific, spheroidal, laminar, concentric type and multispecific

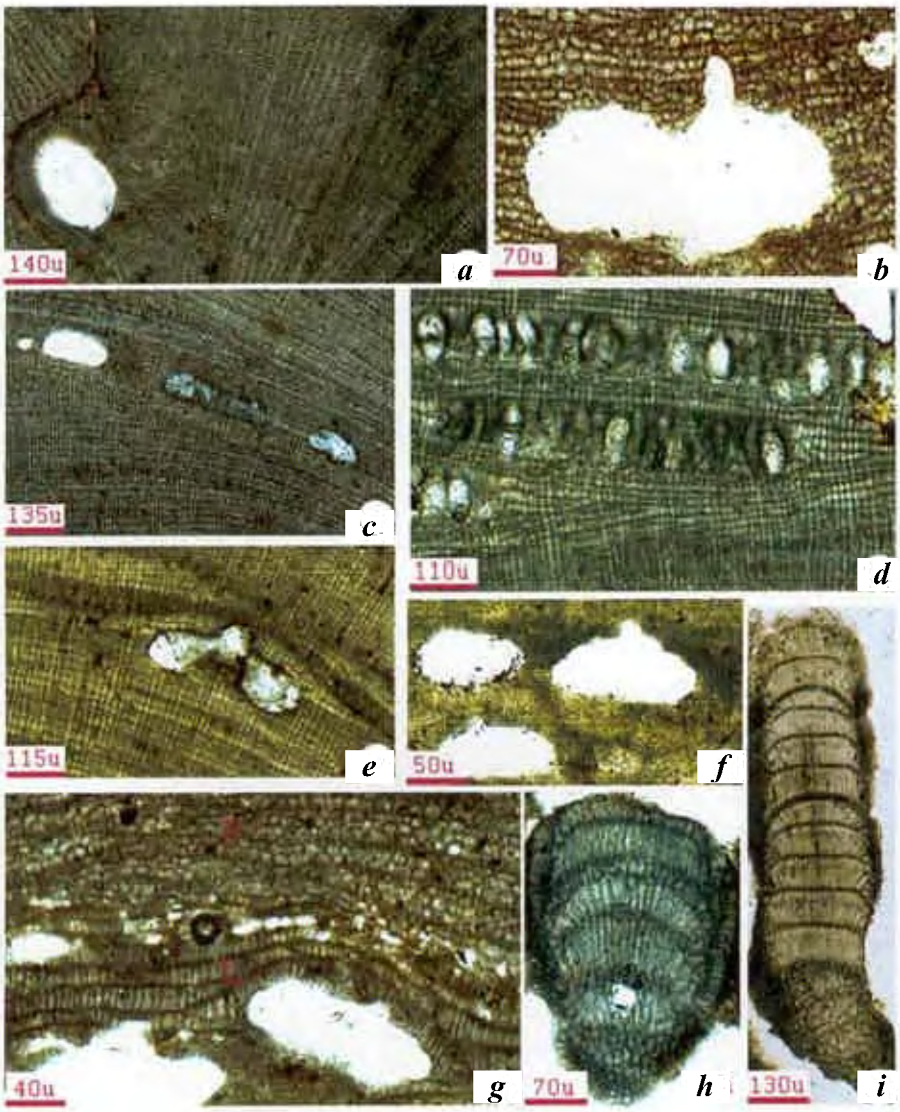

Figure 4. ***a***, *Lithothamnion* sp. from Unit II. Specimen no. PGTDG/MF/SCA/384. ***b***, *Porolithon* sp. from Unit III. Specimen no. PGTDG/MF/SCA/386. ***c***, *Lithothamnion* sp. from Unit IV. Specimen no. PGTDG/MF/SCA/390. ***d***, *Sporolithon* sp. from Unit III. Specimen no. PGTDG/MF/SCA/387. ***e***, *Lithophyllum* sp. from Unit III. Specimen no. PGTDG/MF/SCA/388. ***f***, *Lithophyllum* sp. from Unit III. Specimen no. PGTDG/MF/SCA/389. ***g***, Contact between *Porolithon* sp. and *Lithoprella* sp. from Unit IV. P, *Porolithon* sp. and L, *Lithoporella* sp. Specimen no. PGTDG/MF/SCA/391. ***h***, *Amphiroa* sp. from Unit IV. Specimen no. PGTDG/MF/SCA/392. ***i***, *Amphiroa* sp. from Unit II. Specimen no. PGTDG/MF/SCA/385.

ellipsoidal, laminar, concentric type and multispecific, spheroidal, branching Class IV type and are comprised of nongeniculate corallines demarcated by *Lithoporella*, *Lithothamnion*, *Lithophyllum* and *Porolithon*, whereas *Amphiroa* marks the geniculate corallines. Based on nature of sediments and different faunal assemblages, Pandey *et al.*[25] deduced that Unit I and Unit II were deposited in lagoonal reefs and Unit III and Unit IV were deposited in nearshore to lagoonal beach environment. Thus the palaeoenvironmental conditions deduced based on rhodoliths from Units II to IV broadly corroborate those surmised by us based on rhodoliths.

1. Wray, J. L., *Calcareous Algae. Development in Paleontology and Stratigraphy*, Elsevier, Amsterdam, 1977, vol. 4, p. 185.
2. Adey, W. H. and Macintyre, I. G., Crustose coralline algae: A re-evaluation in Geological Sciences. *Geol. Soc. Am. Bull.*, 1973, **84**, 883–904.
3. Adey, W. H., Crustose coralline algae as microenvironmental indicators in the Tertiary. In *Historical Biogeography, Plate Tectonics and the Changing Environment* (eds Gray, J. and Boucot, A. J.), Oregon State University Press, 1976, p. 459.
4. Bosence, D. W. J., Coralline algae reef framework. *J. Geol. Soc. London*, 1983, **140**, 365–376.
5. Bosence, D. W. J., Description and classification of rhodoliths. In *Coated Grains* (ed. Peryt, T.), Springer Verlag, 1983, pp. 217–224.

6. Bosense, D. W. J., The occurrence and ecology of recent rhodoliths. A review. In *Coated Grains* (ed. Peryt, T.), Springer Verlag, Berlin, 1983, pp. 225–242.
7. Ginsburg, R. N. and Schroeder, J., Growth and submarine fossilization of algal–cup reefs, Bermuda. *J. Sedimentol.*, 1973, **20**, 275–314.
8. Bosence, D. W. J., Construction of two coralline algal reefs, St. Croix, Caribbean. *Paleontology,* 1984, **27**, 549–574.
9. Bosellini, A. and Ginsburg, R. N., Form and internal structure of recent algal nodules (Rhodolites) from Bermuda. *J. Geol.*, 1970, **79**, 660–682.
10. Woelkerling, W. J., *The Coralline Red Algae: An Analysis of Genera and Subfamilies of Nongeniculate Corallinaceae*, British Museum (Natural History), London and Oxford University Press, Oxford, 1988, p. 268.
11. Foslie, M. H., The Norwegian forms of *Lithothamnion*. *Dan K Norske Vidensk Seleske Skr*., 1894, **2**, 1–201.
12. Lemoine, P., Repartition et mode de vie du maerl (*Lithothamnium calcareum*) aux environs de Concarneau (finistere). *Ann. Inst. Oceanogr.*, *Monaco*, 1910, **1**, 1–28.
13. Gebelein, C. D., Distribution, morphology and accretion rate of Recent subtidal algal stromatolites, Bermuda. *J. Sediment. Petrol.*, 1969, **39**, 49–69.
14. Bosence, D. W. J., Ecological studies on two unattached coralline algae from western Ireland. *Paleontology*, 1976, **19**, 365–395.
15. Bosence, D. W. J. and Pedley, H. M., Palaeoecology of a Miocene coralline algal bioherm, Malta. *Bull. Cent. Rech. Explor-Prod. Elf-Aquitaine*, 1979, **3**, 463–470.
16. Bosence, D. W. J. and Pedley, H. M., Sedimentology and palaeoecology of a Miocene coralline algal bioherm from the Maltese Island. *Palaeogeogr. Palaeoclimatol. Palaeoecol.*, 1982, **38**, 9–43.
17. Bosence, D. W. J., Coralline algae from the Miocene of Malta. *Paleontology*, 1983, **26**, 147–173.
18. Bosence, D. W. J., The morphology and ecology of mound-building coralline alga (*Neogoniolithon strictum*) from the Florida keys. *Paleontology*, 1985, **28**, 189–206.
19. Basso, D., Deep rhodolith distribution in the Pontian Islands, Italy: A model for the paleoecology of a temperate sea. *Palaeogeogr. Palaeoclimatol. Palaeoecol.*, 1992, **137**, 173–187
20. Lund, M., Davis, P. J. and Braga, J. C., Coralline algal nodules off Fraser Islands, Eastern Australia. *Facies*, 2000, **42**, 25–34.
21. Rao, V. P., Montaggioni, L., Vora, K. H., Almeida, F., Rao, K. M. and Rajagopalan, G., Significance of relic carbonate deposits along the Central and Southwestern margin of India for Late Quaternary environmental and sea level changes. *Sediment. Geol.*, 2003, **159**, 95–111.
22. Bhatt, N., Lithostratigraphy of Neogene–Quaternary deposits of Dwarka–Okha area, Gujarat. *J. Geol. Soc. India*, 2000, **55**, 139–148.
23. Bhatt, N. and Patel, M. P., Bioclastic shore deposits: Indicators of Late Quaternary high sea in Saurashtra, Western India. *J. Geol. Soc. India*, 1998, **52**, 537–542.
24. Mathur, U. B. and Pandey, D. K., Radiocarbon dates of corals, gastropods and foraminifers from Saurashtra peninsula, Gujarat and their implications for sea level studies. *J. Geol. Soc. India*, 2002, **60**, 303–308.
25. Pandey, D. K., Mathur, U. B., Rakesh Singh and Tej Bahdur, Late Pleistocene Coral-Algal sediments of Chaya Formation of Mithapur area, Jamnagar, Gujarat. *J. Geol. Soc. India*, 2003, **61**, 195–201.
26. Kundal, P. and Dharashivkar, A. P., Geniculate coralline alga, *Amphiroa* from Lower Pliocene of Dwarka–Okha area, Gujarat, India. In *Recent Developments in Micropaleontology and Stratigraphy* (ed. Kundal, P.), Gond. Geol. Mag., Spl. Pub. 6, 2003, pp. 245–259.
27. Kundal, P. and Dharashivkar, A. P., *Lithothamnion* Philippi and *Mesophyllum* Lemoine from Lower Pliocene to Late Pleistocene of Dwarka–Okha Area, Jamnagar District, Gujarat, India. In VIII ISFA, Granada, Spain, 2003, p. 35.
28. Kundal, P. and Dharashivkar, A. P., *Sporolithon* Heydrich, a non-geniculate coralline alga from Lower Pliocene to Late Pleistocene of Dwarka- Okha area, Gujarat, India and its stratigraphic, paleobiogeographic and paleoenvironmental implications. In IXI ICMS on Recent Developments in Indian Ocean Paleoceanography and Paleoclimate (ed. Sinha, D. K.), 2003, p. 75.
29. Littler, M. M., Littler, D. S., Blair, S. M. and Norris, J. N., Deep-water plant communities from an uncharted seamount of San Salvador Island, Bahamas: distribution, abundance and primary productivity. *Deep-Sea Res.*, 1986, **33**, 881-892.
30. Johnson, J. H., Coralline algae: Mineralization, taxonomy and paleoecology. *Limestone Building Algae and Algal Limestones*, Colorado School of Mines, Colorado, 1961, pp. 1–297.
31. Bosence, D. W. J., *Calcareous Algae and Stromatolites* (ed. Riding, R.), Springer Verlag, Berlin, 1991, pp. 98–113.

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