



SPECIES OF *AMPHIROA* LAMOUREUX (CORALLINACEAE, RHODOPHYTA) FROM THE CHAYA FORMATION (QUATERNARY) OF THE DWARKA AREA, GUJARAT AND THEIR SIGNIFICANCE

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ABSTRACT

The present paper records four species of *Amphiroa* from the Quaternary sediments of the Chaya Formation exposed near Dwarka, Jamnagar district, Gujarat. These species have earlier been known from the Mio-Pliocene of the study area. Comparison with the modern species of the *Amphiroa* shows that the two species, e.g. *Amphiroa fragilissima* and *A. foliacea*, also occur as living species near the Dwarka coast. The fossil form, *Amphiroa ephedraea*, is known to occur in the Indian Ocean. *Amphiroa anchiverricosa* is close to a modern living form, *A. cryptarthrodia* and appears to be conspecific with the latter.

Stratigraphically speaking, *A. foliacea* is known from the Pliocene of the Dwarka-Okha area, whereas *A. anchiverricosa* is distributed in the Miocene-Pliocene in the study area as well as other parts of the country; however, they are recorded for the first time from the Chaya Formation. *Amphiroa ephedraea*, commonly known to occur as a Miocene to Holocene species of the study area, is also first time recorded from the Armada Reef Member of the Chaya Formation.

Keywords: *Amphiroa*, Chaya Formation, Quaternary, Dwarka, Gujarat.

INTRODUCTION

The studies on fossil coralline algae in different parts of the world have been carried out by several workers. Their works are published mostly in geological journals which are usually not seen by the biologists. Hence, there are two schools of thought on coralline algae; one examines the fossil forms, while the other observes the extant plants. Unfortunately, there has been a communication gap between them. Most of the work on fossil algae is concerned with describing plants that grew in different areas in the geological past; a little work has been done on the material that perfectly shows the structures required to assign plants to genera and species. This communication gap is reflected in the classification system involving fossils and extant plants; it has created doubt about the generic concepts followed by both the groups of scientists. It is, therefore, felt that the placement of fossil taxa in extant genera must be examined carefully.

In recent years, the botanical characters of living coralline algae have been used because of their preservation even in the fossil specimens and possibility of their comparison with the modern living species. This type of study helps in correct identification of fossil specimens up to generic/specific level and also allows to establish correlation between them. This correlation is helpful in understanding their evolutionary relationships and palaeogeographical distribution.

The present paper deals with a comparative study of fossil and living species of the genus *Amphiroa* and their correlation on the basis of vegetative thallus and anatomical characters. It may help correlate the fossil species with their specific living species. In this context, it may be mentioned that Basso *et al.* (1997, 1998) had earlier established conspecificity of some fossil species with the living ones in the coralline algae. Conspecificity of fossil and living species and their autoecology is of great importance in palaeoecological studies.

The genus *Amphiroa* belongs to the subfamily Lithophylloideae of the Corallinaceae. It is a common tropical and subtropical genus of articulated corallines that live in coral

reefs around the world. This genus consists of upright axes composed of alternating uncalcified genicula and calcified intergenicula, characterized by the anatomy of the branching fronds, which are made up of groups of filaments derived from the meristematic tissues. The apical meristems and intercalary meristems produce both the medulla and epithallium, whereas the lateral meristem produces the cortex (Dolan, 2001). The medullary filaments are organized in tiers, each tier consisting of a transverse row of parallel cells of a particular cell length. The arrangement of tiers has been used in distinguishing genera of articulated corallines.

The presence of alternating long and short cells in the medulla of *Amphiroa* was first reported by Zanardini (1871) and later illustrated by Kützing (cited in Dolan, 2001). The species of this genus have a regular dichotomous branching pattern with conceptacles borne in a single swollen chamber at the apices of the intergenicula. The species are distinguished from one another by the taxonomic features such as frond height, intergenicular width, intergenicular shape in section, the number of long and short cells in the genicula and plant habit in the living form. The number and length of medullary tiers have been used as infrageneric taxonomic criteria in *Amphiroa* (Norris and Johansen, 1981). Recently, Dolan (2001) studied four Bermudian species of *Amphiroa* using medullary unit pattern of intergenicula and genicula useful in the discrimination of species. In the present study, the taxonomic criteria of Dolan (i.e. medullary unit pattern of intergenicula) have been followed because in fossil forms only anatomical features of the medullary unit pattern of intergenicula are preserved.

In this paper, the changed taxonomic criterion of *Amphiroa* given by Bailey (1999) has resulted in the revised system of classification for Lithophylloideae subfamily. Bailey (1999) has emended the diagnosis of Lithophylloideae and revised the classification of this subfamily; he (1999) transferred this genus to non-geniculate coralline algal group on the basis of 18S rRNA gene sequencing and indicated its relationship with

Titanoderma of subfamily Lithophylloideae. In the present study, we have placed *Amphiroa* in subfamily Lithophylloideae of non-geniculate coralline algae. As a result, this subfamily now includes both non-geniculate and geniculate corallines in which cells of the contiguous filaments are normally joined only by secondary pit-connections; cell fusions are very rare or absent; genicula present or absent, and when present, is composed of one or more tiers of uncalcified cells, nonmeristematic, often corticated (Bailey, 1999).

The study area is interesting as it provides an example where both fossils and living representatives of the coralline algae are found in close proximity. The Chaya Formation of Dwarka (Fig. 1) provides an opportunity to study the fossil species of the *Amphiroa* in association with their living representatives.

The Neogene-Quaternary sediments of the Dwarka area have been subdivided (in ascending order) into the Gaj, Dwarka, Miliolite, Chaya, Katpur and Mahuva formations. Pandey *et al.* (2007) gave a detailed stratigraphic account of the Chaya Formation. Accordingly, the Chaya Formation is subdivided into the Okha Shell Limestone Member, the Aramda Reef Member and the Porbandar Calcarene Member (Table 1). Species of *Amphiroa* are distributed in all the three members of the Chaya Formation in the Dwarka area (Fig. 2). The rock samples were collected from the Okha Shell Limestone (Sheorajpur village), the Aramda Reef Member (Mojap Coast) and the Porbandar Calcarene Member (Makhanpur quarry) and for comparison the living forms were collected from the Dwarka Coast (Fig.1).

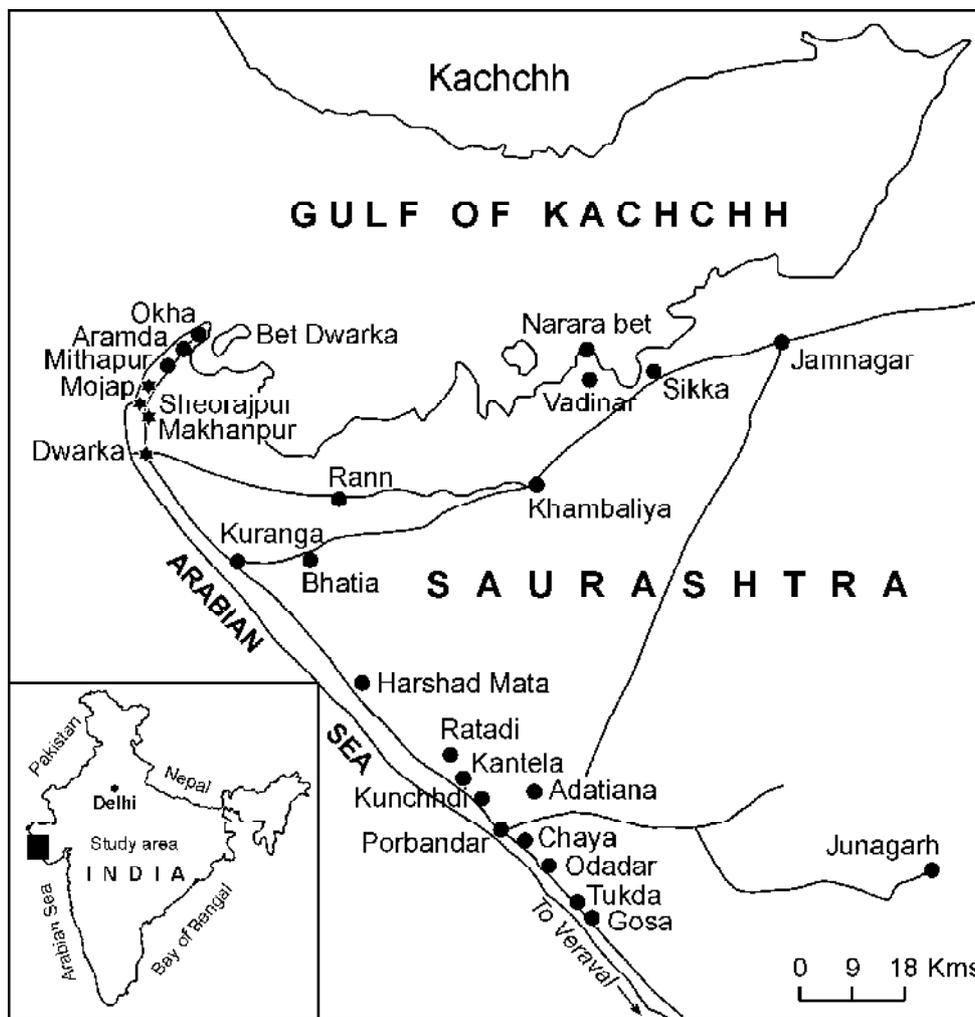


Fig. 1. Location map of the study area (*) (Pandey *et al.*, 2007).

EXPLANATION OF PLATE I

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| <p>1-5. <i>Amphiroa fragilissima</i>
 1. Living specimen of <i>Amphiroa fragilissima</i> showing genicula and intergenicula.
 2. Decalcified genicula (G) and intergenicula (I) shows long and short cells (indicated by arrows) of the living specimen.
 3, 5. Fossil specimens show long and short cells in intergenicular region.
 4. A Fossil specimen show branching pattern.</p> | <p>6. Living specimen of <i>Amphiroa. foliacea</i> showing genicula and intergenicula.
 7. Decalcified intergenicula shows long and short cells (indicated by arrows) of living the specimen.
 8-9. Fossil specimens show long and short cells in intergenicular region.
 10. Fossil specimen of <i>Amphiroa ephedraea</i> shows long and short cells in intergenicular region.
 11. Fossil specimen of <i>Amphiroa anchiverricosa</i> shows long and short cells in intergenicular region.</p> |
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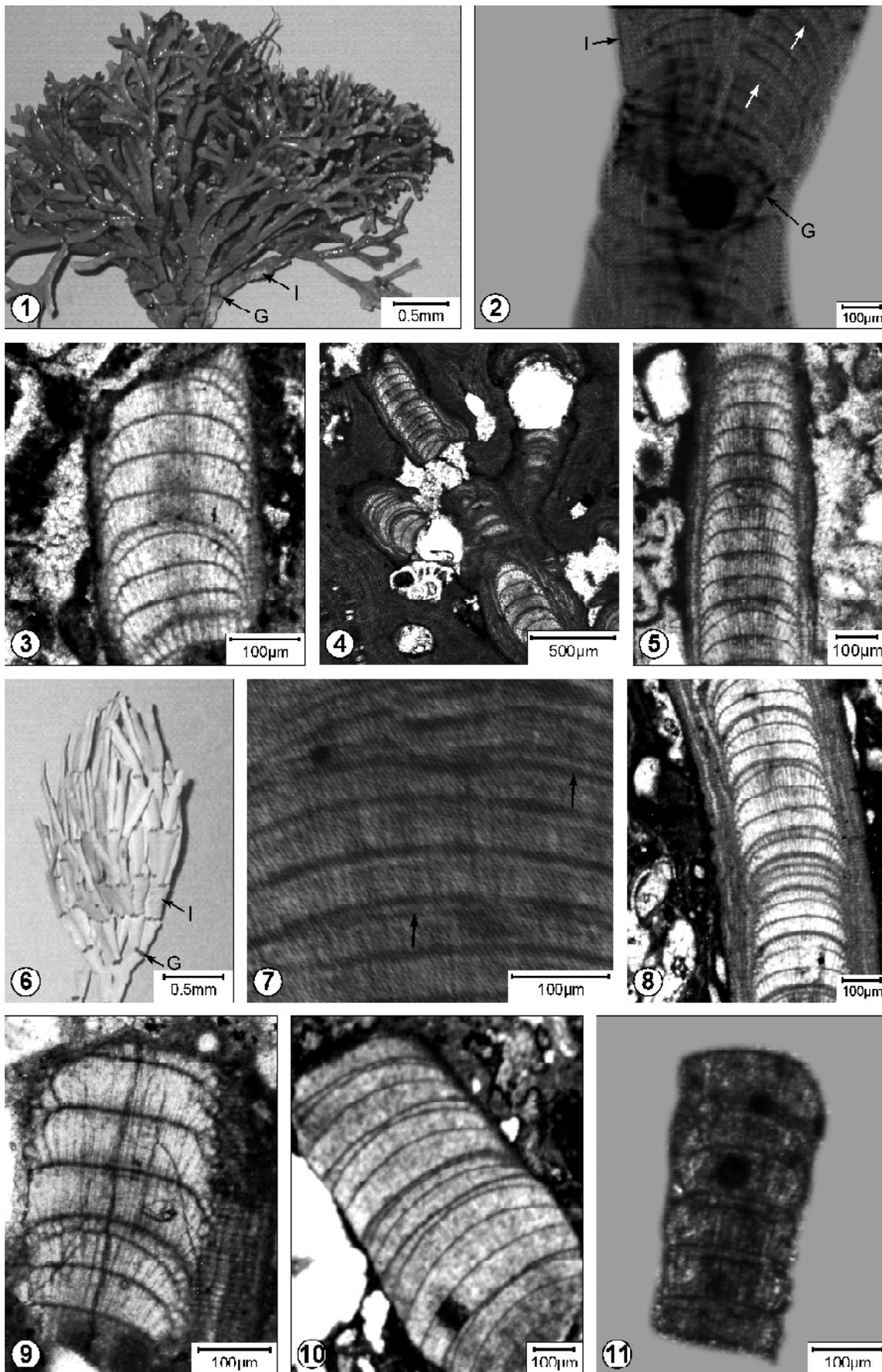


Table 1: Lithostratigraphy of the Chaya Formation of Saurashtra (Pandey *et al.*, 2007).

Stratigraphic unit			Lithology	Age
Group	Formation	Member		
Porbandar Group	Chaya Formation	Porbandar Calcarenite Member	Semiconsolidated to consolidated calcarenite with megafossils (pack to grainstone/rudstone)	Late Pleistocene to Late Holocene
		Aramda Reef Member	Coral-algal reef, coral bafflestone and algal rudstone with micro and mega-fossils	
		Okha Shell Limestone Member	Cross-bedded pack to rudstone, bioturbated shell limestone with mega-fossils	

The Okha Shell Limestone, well exposed near Sheorajpur village and Mozap coasts, consists of cross-bedded, bioturbated packstones. The Aramda Reef Member, well exposed in vicinity of the Mozap and Mithapur coasts, is a reefal unit mainly consisting of coral-algal skeletal material. It directly overlies the Okha Shell Limestone. The Porbandar Calcarenite Member is exposed in Makhanpur. It is a calcarenite facies represented by packstones-grainstones/rudstones and contains megafossils such as gastropods, echinoderm spines, etc.

The work on fossil species of *Amphiroa* from Dwarka and the adjoining areas has been carried out by Kundal and his coworkers. Kundal and Dharashivkar (2003) reported eight species of *Amphiroa* from the Pliocene sediments of the Dwarka-Okha area. Kundal and Dharashivkar (2005) reported

an unidentified species of *Amphiroa* (i.e. *Amphiroa* sp.) from the Aramda Reef Member (Chaya Formation) of the Dwarka-Okha area. Kundal and Mude (2010) reported seven species of *Amphiroa* from the Porbandar Calcarenite Member of the Chaya Formation, Adatiana Member of the Miliolite Formation and the Dwarka Formation of the Porbandar areas.

SYSTEMATIC DESCRIPTION

Division **Rhodophyta** Wettstein, 1901

Class **Florideophyceae** Cronquist, 1960

Subclass **Corallinophycidae** Le Gall and Saunders, 2007

Order **Corallinales** Silva and Johansen, 1986

Family **Corallinaceae** Lamouroux, 1812

Subfamily **Lithophylloideae** (Setchell) Bailey, 1999

Genus ***Amphiroa*** Lamouroux, 1812

Amphiroa fragilissima (Linnaeus) Lamouroux
(Pl. I, figs. 1-5)

Amphiroa fragilissima Lamouroux: Johnson and Ferris, 1950, p.19. - Khalifa, 1984, p. 194. - Kundal and Dharashivkar, 2003, p.253. - Kundal and Mude, 2010, p.42.

Description: Plant geniculate, branched to fragments. Thallus about 3.2 mm long and up to 0.55 mm broad, medullary filaments showing alternation of rows of long and short cells with following formula 4L, 1S to 8L, 1S. Long cells 40-60 µm in length and 6-8 µm in width, short cells 10-15 µm long and 6-8 µm broad, peripheral filaments about 20 µm to 0.15 mm in diameter and cells 4-6 µm in length and 5-7 µm in width.

Remarks: The present specimen is identified as *Amphiroa fragilissima* on the basis of its characteristic feature of alternation of 4-8 long cells with a single row of short cells in thallus as suggested by Johnson and Ferris, 1950. The fossil species is comparable with the living species in its characteristic medullary unit pattern of intergenicula. Living specimens from the Dwarka coast of this species are extremely fragile as indicated by the name. It is a heavily calcified seaweed which is very brittle and breaks easily into small pieces. It is a pink plant, up to 3.0 cm long, consisting of upright axes of alternating uncalcified genicula and calcified intergenicula, branches mainly dichotomous, originating from intergenicula (Pl. I, fig.1). Decalcified intergenicula of the living specimen also shows 4 long cells in alternation with a single row of short cells in thallus (Pl. I, fig. 2). Comparative study of both the fossil and living specimens indicates that it is similar to the extant species of the Dwarka coast. Johnson and Ferris (1950) reported it from the Miocene of Lau, Fiji; Khalifa (1984) recorded it from the Pliocene of Red Sea, Egypt; Kundal and Dharashivkar (2003) described it from the Pliocene of Dwarka-

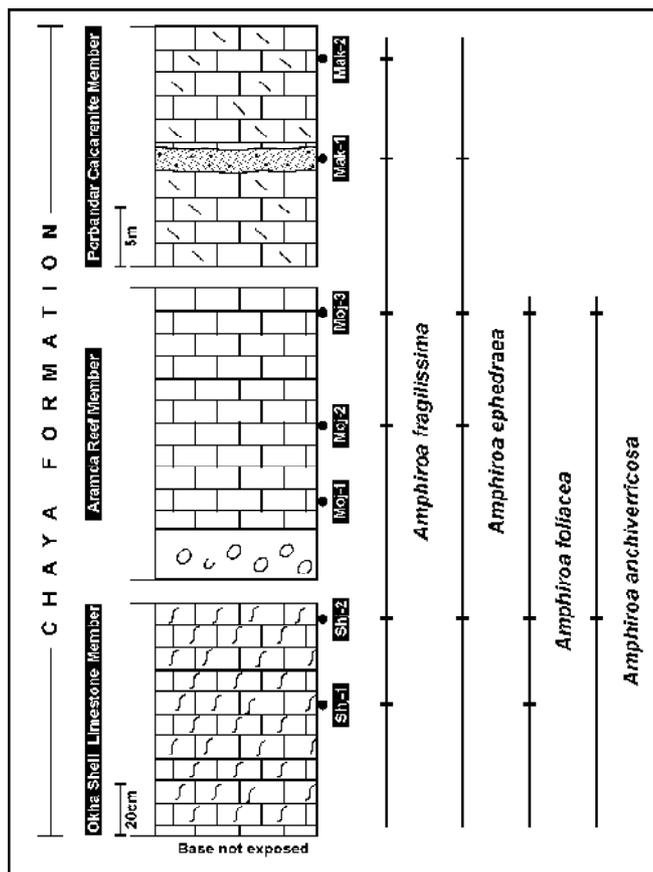


Fig. 2. Litho column of the Dwarka area of the Chaya Formation.

Okha, India and Kundal and Mude (2010) reported it from the Pleistocene to Holocene of the Chaya Formation, India.

Slide No.: OSL-3; MT-3, M-5, M-7, M-9, M-35; PCM-2.

Locality : Sheorajpur village, Mojab Coast, Makhanpur quarry, Dwarka Coast.

Horizon : Okha shell Limestone, Aramda Reef and Porbandar Calcarenite Members of the Chaya Formation.

Amphiroa foliacea Lamouroux
(Pl. I, figs. 6-9)

Amphiroa foliacea Lamouroux: Kundal and Dharashivkar, 2003, p. 229.

Description: Plant geniculate, branched to fragmented. Thallus about 1.2 mm long and up to 0.35 mm broad, medullary filaments showing alternating rows of long and short cells with following formula (3L, 1S). Long cells 60-80 µm in length and 10-14 µm in width, short cells 25-30 µm long and 8-10 µm broad, peripheral filaments about 60-70 µm in diameter and cells 8-10 µm in length and 14-16 µm in width.

Remarks: The present specimen is identified as *Amphiroa foliacea* on the basis of its characteristic alternation of rows of long and short cell in the thallus as described by Kundal and Dharashivkar (2003). Kundal and Dharashivkar recorded this species from the Pliocene of the Dwarka Formation of the Dwarka and Okha area. Living specimens of this species are characterized by more or less erect, sometimes bushy, branching dichotomous, occasionally irregular plant (Pl. I, fig.6). Decalcified intergenicular region shows 3 long cells alternating with a single row of short cells in the thallus (Pl. I, fig. 7). Comparative study of both the fossil and living specimens indicates that the fossil species is similar to the extant species of the Dwarka coast on the basis of its characteristic medullary unit pattern of intergenicula.

Slide No.: OSL-4; MT-5.

Locality : Sheorajpur village, Mojab Coast.

Horizon : Okha shell Limestone and Aramda Reef Members of the Chaya Formation.

Amphiroa ephedraea (Lamarck) Decaisne 1842
(Pl. I, fig. 10)

Amphiroa ephedraea (Lamarck) Decaisne 1842, p. 124. - Kundal and Mude, 2010, p.40.

Description: Plant geniculate, fragments. Thallus about 650-700 µm long and up to 420 µm broad, medullary filaments showing alternation of rows of long and short cells with following formula 3L, 1S; 2L, 1S. Long cells 60-70 µm in length and 8-12 µm in width, short cells 14-20 µm long and 8-12 µm broad; peripheral filaments not preserved.

Remarks: The present specimens are assigned to *Amphiroa ephedraea* on the basis of its characteristic alternation of long and short cell rows in the thallus. The shape and size of cells of the medullary region has also been considered for its identification. Kundal and Mude (2010) reported this species from the Miocene to Holocene of Gujarat, India. As a living species, it occurs in the Indian Ocean. In the present study, we have not recorded any living specimens of this species from the Dwarka coast. However, it is comparable with a living species, *Amphiroa ephedraea* of Johansen (1981, p. 67-69, fig. 10D) on the basis of its characteristic medullary unit pattern of intergenicula. The comparative study supports that *Amphiroa ephedraea* is an extant species of the genus *Amphiroa*.

Slide No.: OSL-2; MT-7; PCM-1

Locality : Sheorajpur village, Mojab Coast, Makhanpur quarry.

Horizon : Okha shell Limestone, Aramda Reef and Porbandar Calcarenite Members of the Chaya Formation.

Amphiroa anchiverricosa Johnson and Ferris, 1950
(Pl. I, fig. 11)

Amphiroa anchiverricosa Johnson and Ferris, 1950, p.19. - Kundal and Mude, 2010, p.40. - Kundal *et al.*, 2011, p. 188.

Description: Plant geniculate, fragments. Thallus about 400-450 µm long and up to 250 µm broad, medullary filaments showing alternation of rows of long and short cells with a following formula 1L, 1S. Long cells 80-120 µm in length and 10-15 µm in width, short cells 15-25 µm long and 8-10 µm broad, peripheral filaments not preserved.

Remarks: The present specimens are assigned to *Amphiroa anchiverricosa* on the basis of their characteristic regular alternation of rows of long and short cells in the thallus (i.e. one row of long cells followed by one row of short cells) as suggested by Johnson and Ferris (1950). Johnson and Ferris (1950) have emphatically suggested its affinity with a living species, *A. verrucosa* Kützing of the Pacific. They reported this species from the Miocene of Fiji. Kundal and Mude (2010) reported this species from the Dwarka Formation (Miocene) and Kundal and Dharashivkar (2003) described it from the Pliocene of Gujarat, India. Our observations both on the fossil and living specimens support its affinity with *A. verrucosa* Kützing on the basis of its similarity in medullary unit pattern of intergenicula (Rosas-Alquicira *et al.* 2010, figs. 21-22). According to Rosas-Alquicira *et al.* (2010), *A. cryptarthrodia* Zanardini is considered to be conspecific with *A. verrucosa* Kützing. Hence, *Amphiroa anchiverricosa*, the fossil species, is also regarded as conspecific with *A. cryptarthrodia* Zanardini.

Slide No.: OSL-4; MT-33

Locality : Sheorajpur village, Mojab Coast, Dwarka Coast

Horizon : Okha shell Limestone and Aramda Reef Members of the Chaya Formation

DISCUSSION

The present paper records four species of genus *Amphiroa* from the Quaternary sediments of the Chaya Formation of the Dwarka area. The genus *Amphiroa* is morphologically as well as anatomically distinctive and is distinguished from other geniculate coralline forms simply by its alternation of long and short cell rows in the thallus. Internal anatomy of *Amphiroa* is characterized by two distinct regions, i.e. medullary (central) and cortical (peripheral) regions. The medullary filaments are organized in tiers. The size and arrangement of tiers constitutes the characteristic medullary unit pattern of particular species of *Amphiroa* (Dolan, 2001). This medullary unit consists of one short-celled tier and one to more long-celled tiers per unit that make up the intergenicula and genicula of thallus. The tier height and number of medullary unit patterns in the intergenicula are potentially useful for delimiting the fossil species of *Amphiroa*, while other characters such as thickness of peripheral filaments, nature of conceptacles and morphology (such as branching pattern) are less significant because they are rarely preserved in fossil forms.

The four fossil species described in this paper seem to be

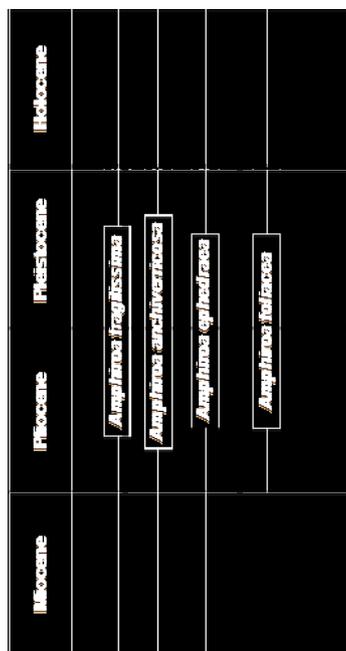


Fig. 3: Biostratigraphic ranges of *Amphiroa* species of the Dwarka area.

the extant species of the genus *Amphiroa* treated in the recent literature (Johansen, 1981). While the three fossil species of *Amphiroa*, i.e. *Amphiroa fragilissima*, *A. foliacea* and *A. ephedraea* are identified as extant species, the fourth (*A. anchiverrucosa*) is comparable with a living species, *A. cryptarthrodia* Zanardini on the basis of the anatomical characters such as long cell tier alternating with short cell tier in the intergenicula and shape and size of the intergenicula which suggest its conspecificity with the living form.

In view of their long stratigraphic ranges, the biostratigraphic use of the present *Amphiroa* species is limited. In the present case, *Amphiroa fragilissima*, *A. ephedraea* and *A. anchiverrucosa* are known to range from the Miocene to the Recent, whereas *A. foliacea* is known from the Pliocene to Recent (Fig. 3).

Species of *Amphiroa* are common in the intertidal and shallow subtidal zones in the tropical and subtropical areas of the world. They grow in a variety of habitats but usually require some degree of wave action. Ecological data indicate that *Amphiroa* generally lives in waters less than 30m deep (Cloud, 1952) but is common at depths between 20 and 25 m (Johnson, 1957). All the recorded species, i.e. *A. fragilissima*, *A. ephedraea*, *A. foliacea* and *A. anchiverrucosa* (= *A. cryptarthrodia*) are known to grow in shallow and deep waters in the sheltered and shaded sites; sometimes found on rocky pools in the exposed areas.

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