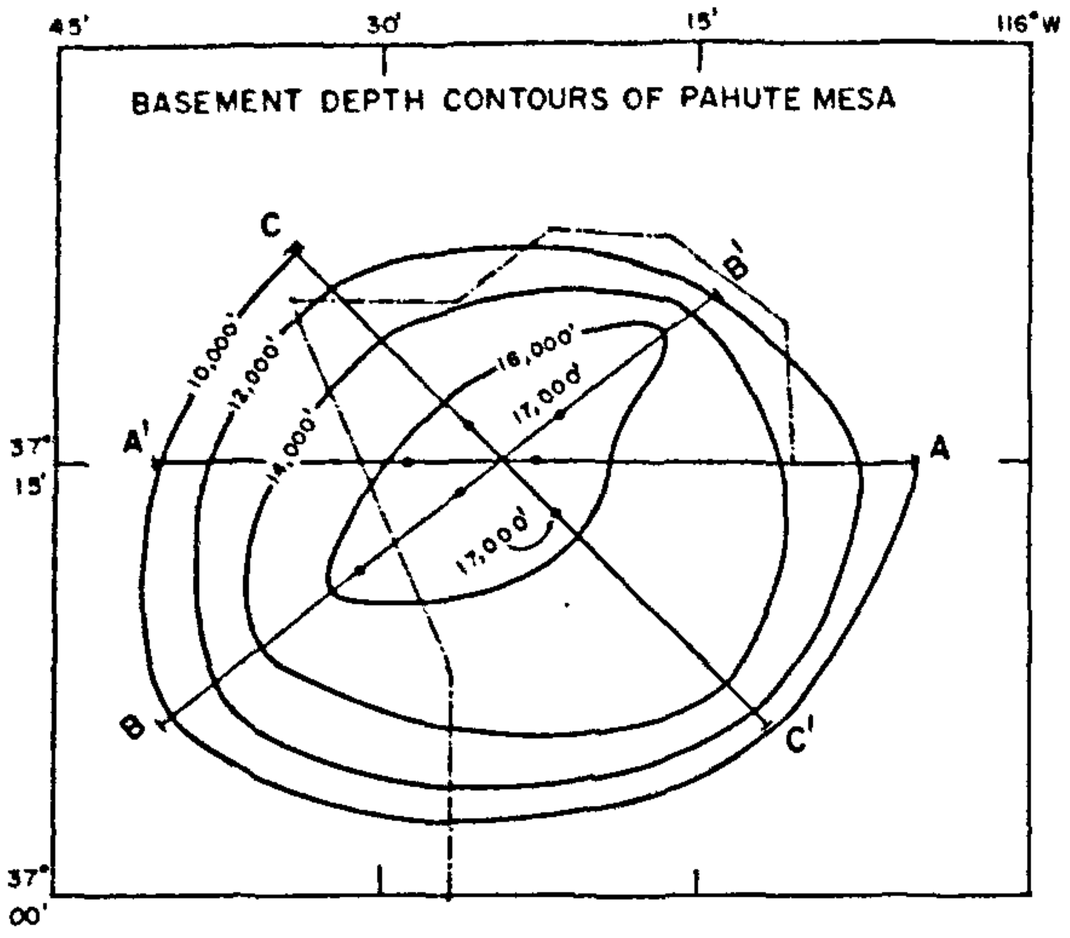

Figure 6. Basement configuration of the Silent Canyon. Profiles AA′, BB′ and CC′ are interpreted. Filled circles show depths of 17,000 ft. Contour interval is 2000 ft. The Nevada test site is shown by the dotted and dashed line.

The new approach, based on finite element concept to derive the regional and residual gravity anomalies, has some unique features. In the present example, just eight gravity values have been used to compute the regional component. The effects of the shallower features inside the survey space do not enter into the regional computations. The FEA regional automatically takes care of isostatic effects, i.e. the isostatic compensation due to the high topography at Pahute Mesa, therefore, is implicitly incorporated into FEA regional. The results of the new approach are not only the residual map and the more acceptable basement configuration, but a method with several new features for future gravity interpretation.

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Coralline algae from the Kakana Formation (Middle Pliocene) of Car Nicobar Island, India and their implications in biostratigraphy, palaeoenvironment and palaeobathymetry

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Coralline algae are reported here for the first time from the Kakana Formation (Middle Pliocene) of the Car Nicobar Island. The algal assemblage is represented by 10 species of crustose and articulated coralline red algae belonging to 7 genera, viz. *Lithothamnion*, *Mesophyllum*, *Lithophyllum*, *Porolithon*, *Amphiroa*, *Corallina* and *Arthrocardia*. Biostratigraphical, palaeoenvironmental and palaeobathymetrical implications of this assemblage are also highlighted.

THE first record of fossil algae from the Andaman and Nicobar Islands in Bay of Bengal was by Gee[1]. This included *Lithothamnion nummuliticum* and *L. suganum* from the Middle Andaman and fragments of *Lithothamnion* from the foraminiferal limestone of Hut Bay, Little Andaman and Wilson Island (Ritchie's Archipelago). All these occurrences were reported from the post-Eocene sediments. Narayana Rao[2] reported *Amphiroa oceanica* and *Corallina andamanica* from the Lepidocyclina Limestone of the Long Island, Middle Andaman and assigned a Late Oligocene or Early Miocene age to this limestone bed. Chatterjee and Gururaja[3] published an illustrated account of the coralline algae from the Andaman Islands which were described as *Lithothamnion andamanensis*, *Lithoporella melobesoides* and *Distichoplax biseriales* from the Palaeocene sediments of Cheria Tapu, South Andaman and *Lithothamnion wilsonensis*, *Lithophyllum* aff. *L. prelichenoides*, *Lithothamnion* sp., *Corallina raoi* and *Jania* sp. from the Early Miocene sediments of Wilson Island (Ritchie's Archipelago). Besides, *Amphiroa* sp. was also recorded by them from the Early Miocene sediments of the Little Andaman Island[3]. However, Lemoine[4] and Lemoine[5] questioned the validity of *Distichoplax* as an alga. They showed analogies between chitinous parts of the living and fossil Pterobranchia belonging to *Rhabdopleura* and suggested exclusion of *Distichoplax* from the algal group. Badve and Nayak[6] and Ghosh *et al.*[7] also agree with the above contention. Gururaja[8] reported *Neosolenopora* from the Miocene sediments of Hut Bay,

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Little Andaman Island. Badve and Kundal[9–13] carried out detailed studies on fossil algae from Palaeocene to Oligocene sediments of Baratang Island, South Andaman. These algal floras are composed of *Rivularia andamanica*, *Baratangia densituba*, *Ethelia indica*, *Peyssonelia baratangensis*, *Permocalculus* sp. cf. *P. irreanae*, *Halimeda chiplonkarii*, *H. agharkarii*, *Broeckella baratangensis*, *Dissocladella deserta*, *Neomeris plagnensis*, *Trinocladus indicus*, *Parachaetetes asvapatii*, *P. flexuosa*, *Parachaetetes* sp. A, *Pycnoporidium mukherjeei*, *P. parvatum*, *Pycnoporidium* sp. A, *Solenopora* sp. cf. *S. sahnii*, *Sporolithon chamorrosum*, *S. oulianovii*, *Sporolithon* sp. cf. *S. saipanense*, *Sporolithon* spp. A and B, *Lithothamnion aggregatum*, *L. andrusovii*, *L. flexuosa*, *L. geei*, *Lithothamnion* sp. aff. *L. nannosporum*, *L. wallisium*, *Lithothamnion* spp. A and B and *Distichoplax biserialis*. As mentioned earlier, the validity of *Distichoplax* as an alga is questionable.

The present study has been carried out on fossil algae from the limestone belonging to the Kakana Formation of the Car Nicobar Island. Car Nicobar is the northernmost island of the Nicobar group of islands and is situated between 09°07′ and 09°13′45″ north latitudes and 92°43′ and 92°50′ east longitudes (Figure 1). The Car Nicobar Island is largely flat with low relief. Principal rock types are mudstone and limestone only. Lithostratigraphy and biostratigraphy of the Car Nicobar Island have been studied by several workers[1,14–30].

According to Chandra and Saxena[30], three lithostratigraphic units (formations) are developed in the Car Nicobar Island. In ascending order, these are Sawai Bay Formation (Srinivasan and Azmi[27]), Kakana Formation (Chandra and Saxena[30]) and Malacca Limestone Formation (Srinivasan and Sharma[23]). The Sawai Bay Formation consists of light grey to bluish grey, moderately hard, calcareous mudstone. The Kakana Formation, conformably overlying the Sawai Bay Formation, is made up of yellow, arenaceous limestone and chalky limestone occasionally containing molluscan shell fragments. The Kakana Formation is unconformably overlain by the Malacca Limestone Formation, which contains white, hard, compact, semicrystalline limestone with abundant larger foraminifers.

Samples for the present algal study were collected from the type section of the Kakana Formation which is located at about 1 km north-east of Kakana village (lat. 9°07′N, long. 92°48′E) in the south-eastern part of the Car Nicobar Island (Figures 1 and 2). This section is exposed on a hill slope on the right side and on a cliff on the left side of Malacca–Kakana Road near the 38 km stone. The section exposes both Sawai Bay and Kakana formations. Locations of the samples, which yielded coralline red algae, are shown in Figure 3 (CN 1, CN 2 and CN 5).

Seven genera and ten species of both crustose and articulated corallines represent the algal flora recovered from the yellowish, hard, arenaceous limestone of the Kakana Formation. The taxa belonging to crustose corallines (Subfamily – Melobesioideae) are *Lithothamnion aucklandicum* Foslie (Figure 4 *d*), *Mesophyllum savornini* Lemoine (Figure 4 *i*), *M. iraquense* Johnson (Figure 4 *j*), *Lithophyllum kotschyanum* (Unger) Foslie (Figure 4 *a*) and *Porolithon marshallense* Taylor (Figure 4 *b*). The articulated corallines (Subfamily-Corallinoideae) are rep-

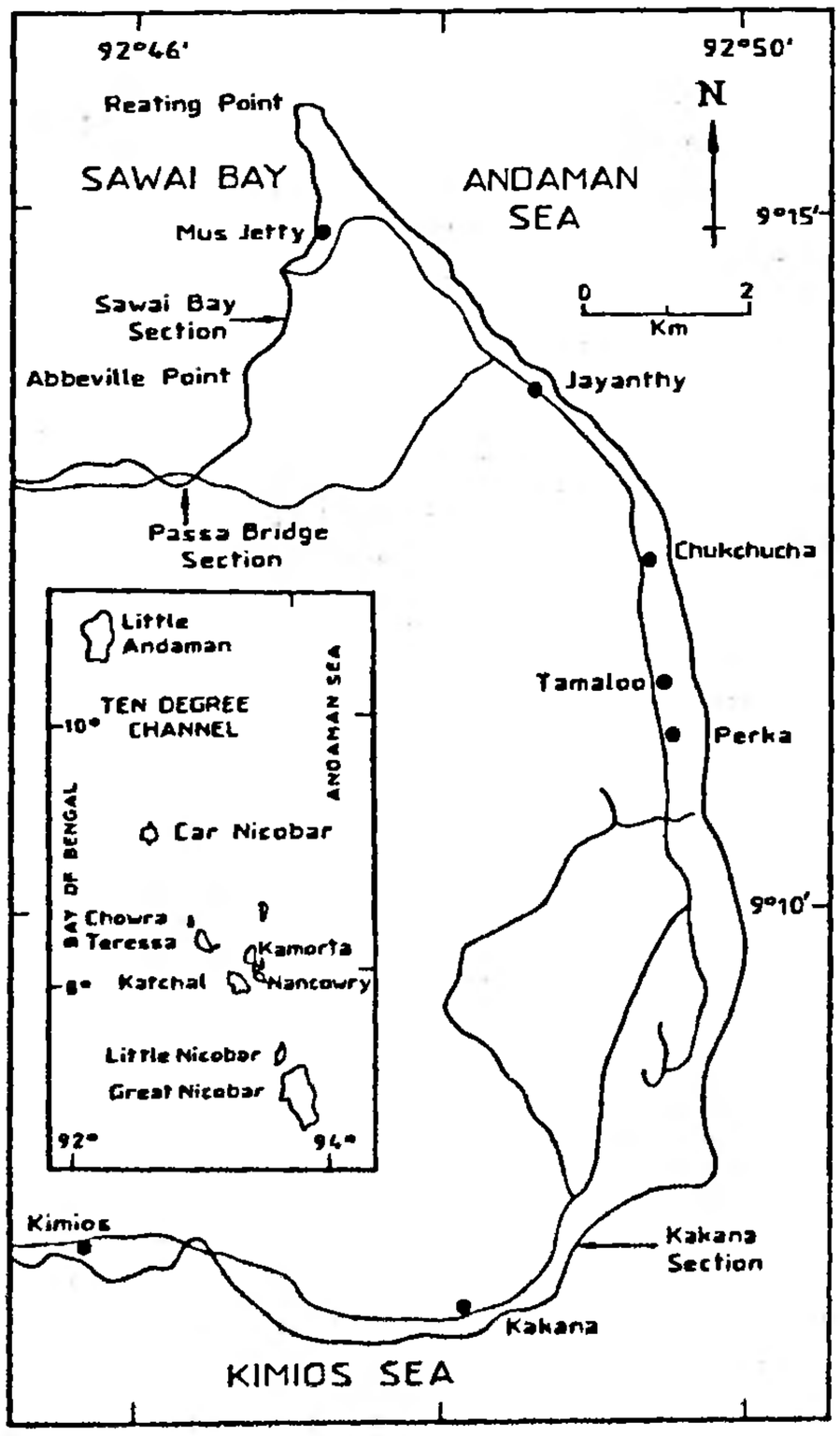

Figure 1. Location of the Kakana Section in Car Nicobar Island.

Figure 2. Kakana Formation (limestone) exposed in the type section.

resented by 5 species belonging to 3 genera. These are *Amphiroa fragilissima* (Linnaeus) Lamouroux (Figure 4 *g*), *A. prefragilissima* Lemoine (Figure 4 *f*), *A. medians* Johnson (Figure 4 *e*), *Corallina eniwetokensis* Johnson (Figure 4 *c*) and *Arthrocardia* sp. (Figure 4 *h*). Slides and negatives of the figured specimens are stored in the repository of the Birbal Sahni Institute of Palaeobotany, Lucknow.

The earliest representatives of coralline red algae appeared during Jurassic Period[31]. According to Johnson[32], majority of the algal genera remained the same from Eocene to Recent. The taxa recorded here from the Kakana Formation were known chiefly from the Miocene, Pliocene or Pleistocene sediments[33,34]. Most of the Pliocene and Pleistocene species recorded here are still living. These are *Lithothamnion aucklandicum* and *Lithophyllum kotschyanum*. The algal assemblage of the Car Nicobar Island is dominated by the Miocene taxa, viz. *Mesophyllum savornini*, *M. iraquense*, *Amphiroa fragilissima*, *A. prefragilissima*, *A. medians*, *Corallina eniwetokensis* and *Arthrocardia* sp. Of these, *Amphiroa prefragilissima* was recorded[35] also from the Alifan Limestone (Pliocene), Guam and *Arthrocardia* sp. was reported[31] also from the Eocene sediments of Guam. In the present assemblage, one taxon, namely *Porolithon marshallense* is exclusively Recent. The present day

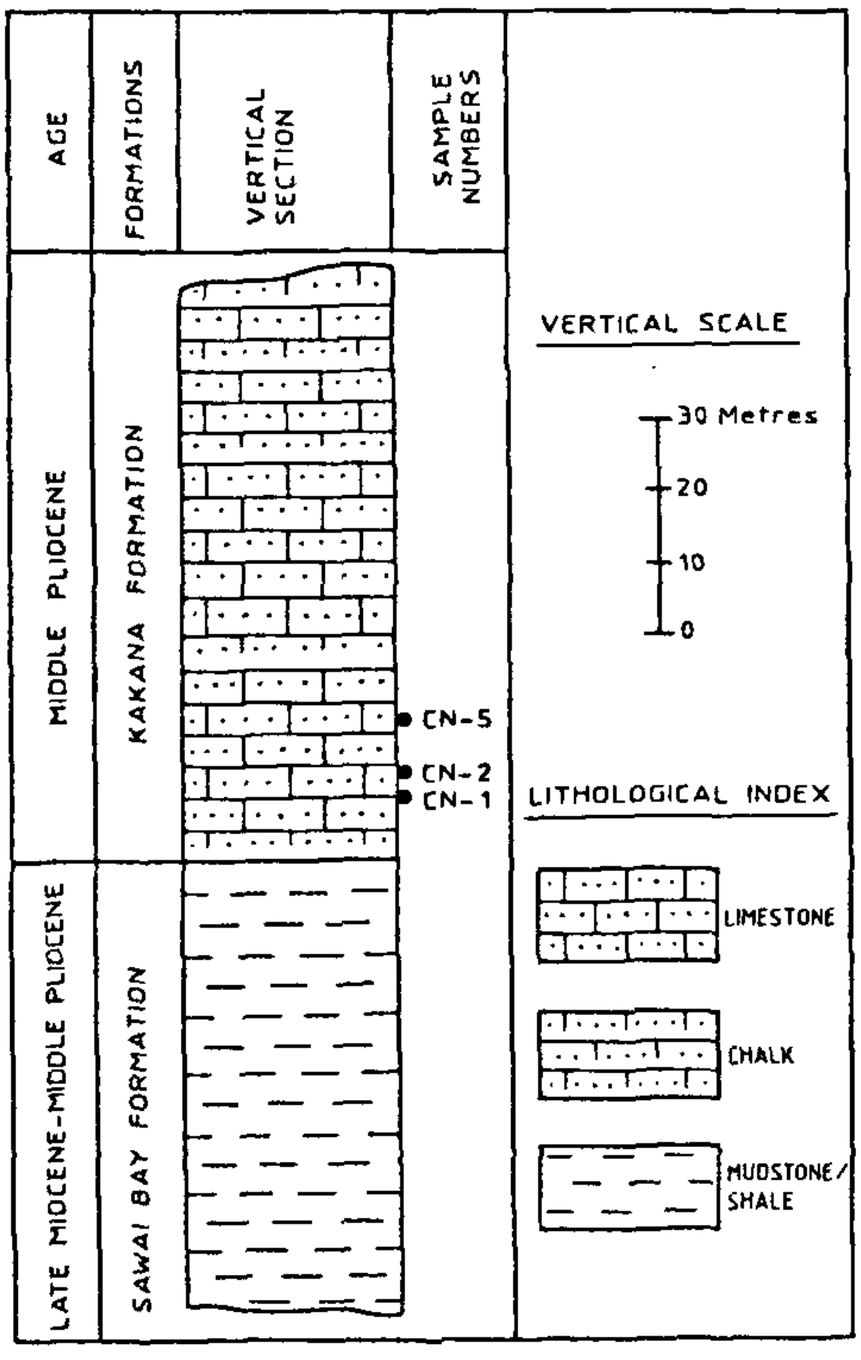

Figure 3. Litholog of the Kakana Section showing location of the productive samples (CN 1, CN 2 and CN 5).

Porolithon occurs abundantly in the Indian and Pacific Oceans on and around the reefs[34,36]. It has a restricted geological range from Pliocene to Recent with abundant development during Middle Pleistocene[34]. *Lithothamnion* and *Lithophyllum* recovered in the present assemblage range from Late Jurassic to Recent. *Mesophyllum* and *Corallina* recorded in the present assemblage have not been reported so far in rocks older than Palaeocene. However, articulated coralline genera *Amphiroa* and *Arthrocardia* represented in the algal assemblage of Kakana Formation are known to occur since Middle Cretaceous and continue in the Pliocene/Pleistocene[31].

Based on foraminiferal data, Kakana Formation has been dated[23,30] as of Middle Pliocene age. It has been observed that this algal assemblage is dominated by Miocene forms. Accordingly, it is concluded that the Miocene taxa of coralline red algae continued to grow in the Middle Pliocene times. Occurrence of *Porolithon* in the present assemblage is significant as the genus appeared during the Pliocene and did not occur abundantly before the Pleistocene.

Present day coralline red algae are exclusively marine and cosmopolitan in distribution. Their distribution is controlled by temperature, depth, salinity, substrate and energy[31]. Crustose coralline forms namely *Mesophyllum* and *Lithothamnion* are primarily cold water genera, but they are also known to occur in lower latitude (warm water) regions in deep water environment. However, *Porolithon* is restricted to tropical and subtropical waters. Articulated coralline genus *Corallina* is generally cosmopolitan[31]. In tropical waters, the present day *Corallina* occurs in association with *Amphiroa*. Both crustose and articulated corallines grow principally in normal, marine, saline water. Members of Corallinaceae are considered to be important Cenozoic reef builders in tropical and subtropical realms, both as frame-building organisms and as sediment producers[31]. Present day reef front or algal ridge (high-energy) locations are typified by thick crusts, which are closely superposed. According to Bosence[37], branches and columns are thick and perithallial tissue from neighbouring branches may fuse to further strengthen the framework. Coralline genera *Lithophyllum* and *Porolithon*[37] occurring in the present algal assemblage commonly form such frameworks. Reef frameworks from medium energy reefs and build-ups are formed by leafy crusts, which may leave the substrate and overgrow neighbouring the crusts[37]. The algal flora of the Kakana Formation are represented by some genera, viz. *Mesophyllum*, *Lithophyllum* and *Lithothamnion* which usually form such leafy and branching frameworks. The foregoing discussion indicates that the coralline algae of the present assemblage existed in moderate to slightly high-energy conditions in tropical waters of normal marine salinities.

Adey[38] provided an established depth/abundance chart for coralline algae from the Caribbean and Pacific Oceans. According to Bosence[37], the present day crustose

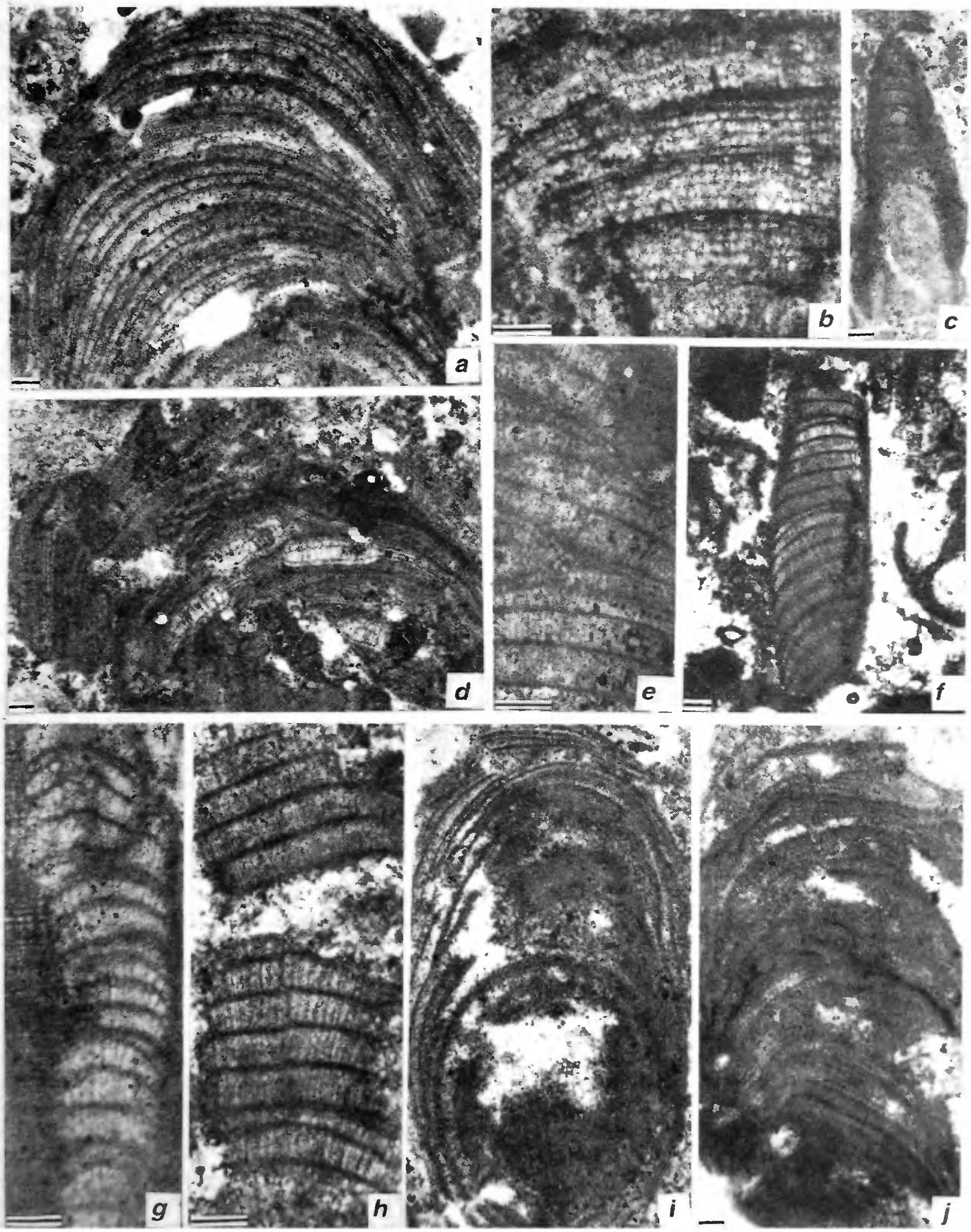

Figure 4. Coralline algae in thin sections (scale = 0.1 mm). *a*, *Lithophyllum kotschyanum* (Unger) Foslie × 40, BSIP Slide No. 12068 (Loc. No. 1902, CN 1); *b*, *Porolithon marshallense* Taylor × 100, BSIP Slide No. 12069 (Loc. No. 1902, CN 1); *c*, *Corallina eniwetokensis* Johnson × 40, BSIP Slide No. 12070 (Loc. No. 1902, CN 2); *d*, *Lithothamnion aucklandicum* Foslie × 40, BSIP Slide No. 12071 (Loc. No. 1902, CN 5); *e*, *Amphiroa medians* Johnson × 100, BSIP Slide No. 12071 (Loc. No. 1902, CN 5); *f*, *Amphiroa prefragilissima* Lemoine × 40, BSIP Slide No. 12068 (Loc. No. 1902, CN 1); *g*, *Amphiroa fragilissima* (Linnaeus) Lamouroux × 100, BSIP Slide No. 12072 (Loc. No. 1902, CN 2); *h*, *Arthrocardia* sp. × 100, BSIP Slide No. 12070 (Loc. No. 1902, CN 2); *i*, *Mesophyllum savornini* Lemoine × 40, BSIP Slide No. 12072 (Loc. No. 1902, CN 2); and *j*, *Mesophyllum iraquense* Johnson × 40, BSIP Slide No. 12072 (Loc. No. 1902, CN 2).

genera exist since Miocene. Hence, the bathymetric ranges should be applicable to the Neogene sediments. As per the bathymetric chart of Bosence, *Porolithon* and *Lithophyllum* usually thrive in intertidal water of approximately 20 m depth and *Lithophyllum*, *Mesophyllum* and *Lithothamnion* can grow in the depth range of 40 to 60 m. However, depth/abundance data of other genera (viz. *Amphiroa*, *Corallina* and *Arthrocardia*) represented in the present assemblage are not available. It may therefore be inferred that the algal forms possibly thrived at a water depth from 20 to 60 m.

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