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An approach to establishing the age of carbonate rock over Alcock Rise, the Andaman Sea through foraminiferal proxy

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The first-ever carbonate sample recovered from the southern part of Alcock Rise from NE-SW trending ridge top within the water depth of 258m was studied in detail. The rock is a bioclastic limestone mainly made up of planktic and benthic foraminifera, pteropods, bryozoans mat, gastropods, algal mat, and lithic fragments. The clasts are embedded in a calcareous mud matrix. Bioclasts have been picked and identified based on phylogenetic taxonomic description mainly based on surface morphological structure. Twenty-eight species of planktic foraminifera belonging to nine genera have been identified in which the most dominant genus are *Globigerina, Globigerinoides, Globorotaloides, Beella, Neogloboquadrina, Globorotalia, Catapsydrax, Globigerinita,* and *Globigerinella*. Some of the species represent intermediate interphase morphogroup forms between *Globigerina ciperonensis-Globorotalia quinqueloba* and *Globorotalia (Fohsella) Kugleri* to *Globorotalia (Fohsella) peripheroronda*. The foraminiferal assemblage of the sample comprises planktic forams of early to middle Miocene affinity along with a few late Miocene affinities. The above foraminiferal assemblage points towards a very slow carbonate precipitation rate in the area since the formation of the Alcock Rise in the Early Miocene.

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INTRODUCTION

The Andaman Sea is part of backarc extensional basin tectonics that resulted due to the subduction of the Indian plate below the overriding Australian plates (McCaffery, 1992; Curray, 2005 and Cochran, 2010). This tectonic setup has resulted in different morphotectonic elements in different periods such as an accretionary prism, forearc basin, volcanic-arc, and backarc. Systematically, these features have been documented (Rodolfo, 1969; Rao *et al.,* 1996; Raju *et al.,* 2004; Curray, 2005; Morley and Alvey, 2015; Tripathi *et al.,* 2016). Stratigraphy of the Andaman Islands has been well studied by Oldham (1885); Srinivasan, (1977); Srinivasan and Sharma (1973); Azmi and Srinivasan, (1974); Pal *et al. (*2003); Ray (1982) and Koley *et al.* (2015). However, lithological information and biostratigraphic record of the tectonically active marine domain of the Andaman Sea is meager and only a few deep drill cores of 700m (NGHP-01-0A), International Ocean Discovery Program (IODP) were studied in detail using calcareous nannofossils and planktic foraminifera (Flores *et al.,* 2014). Curray (2005) and Raju (2005) tried to establish the age of the seamounts through various proxies such as Ar-Ar dating and paleomagnetic data. Though geological information of the ridges and seamounts is not well documented and origin is still controversial. Researchers have a difference in opinion regarding its origin and tectonics of the Alcock Rise. Rodolfo (1969), Raju (2005), and Curray (2005) pointed out that the part of Alcock Rise is comprised of basaltic rocks. On the other hand, Morley and Alvey (2015) concluded that the volcanic dredged samples from the Alcock Rise were extruded onto the older crust and do not represent the part of the oceanic crust formation. Moreover, the occurrence of limestone rock over the southern part of Alcock Rise was also reported by Tripathi and Banerjee (2016). Amongst such ambiguity regarding the origin and formation of Alcock Rise, in the present work, the authors got an opportunity to establish the age of the carbonate rock formation over the ridges through time by planktic foraminiferal study.

MORPHOTECTONICS OF THE STUDY AREA

Presently, Alcock Rise is bounded by the active strike-slip transform faults in the east and right-lateral West Andaman transform faults and Sumatra, Seulimeum faults in the southwest (Fig.1, Curray, 2005; Cochran, 2010). Most of the fault systems were found to be older than the formation of these Rises (Curray, 2005). Whilst, the formation of the

Alcock Rise is traced back to 23-15 Ma and then onward, it experienced a series of faulting and rifting in association with the movement of the Indian plates (Curray, 2005). During Mid- Miocene, the conjoined Alcock Rise and Invisible bank got separated from Sewell and in a later stage, the conjoined Alcock and Sewell Rises started rifting away from the edge of continental crust (Curray, 2005). Soon after, a phase of rift has taken place between the Alcock and Sewell rise and resulted in a deep basin complex at about 4 Ma, which is continuing in the NE-SW direction (Fig. 1; Raju, 2005; Curray, 2005). Due to the overall nature of transtension, a series of NE-SW normal faults was also formed over Alcock Rise and those aligned parallel with the major ridge system present over Alcock Rise (Tripathi *et. al*, 2019). The trend of these ridges varies between N55°E to N72°E and general slope varies from 1.09° to 2.48°and height varies from 167 m to 1178 m. Moreover, its basal width and water depth vary from 3243 m to 14259 m and 55 m to 2000 m (Shah *et al.,* 2015).

MATERIALS AND METHODS

Sample for the present study was collected through Vibro corer from the southern part of the Alcock Rise (at location 12° 1.5413'N; 94° 38.9020'E; Fig. 1) from the NE-SW ridge top within the water depth of 258 m. In the laboratory, the collected Vibro corer sample was split and one portion was crushed to millimeter size, and the other half was used for thin sections preparation. A crushed sample (mm size) was added with mild hydrogen peroxide and kept overnight and further boiled in water with washing soda for about 30 minutes. The mixture was allowed to cool and later washed under the jet of water through a set of three sieves of 80, 120, and 230 mesh size. The entire fraction recovered from the different sieve fractions was examined under the stereo zoom microscope and each species were picked and grouped in the microfaunal tray. Subsequently, representative specimens were mounted on aluminium stubs with the help of double-sided carbon tape and scanned under scanning electron microscope for their detailed taxonomy in Palaeontology Division, CHQ, GSI, Kolkata. A thin section of the rock sample was studied for detailed petrography at Petrology Division, ER, GSI, Kolkata. Based on the petrography study, a few relevant points were selected for the detailed Electron Micro Probe Analyzer (EPMA) study at Central physical laboratory, CHQ, GSI, Kolkata.

RESULTS AND DISCUSSION

Collected rock fragments have fresh broken surfaces and are composed of calcareous shells of both micro and smaller fossils. In the hand specimen, rock pieces are yellowish-grey to grey and it seems that grains are embedded in the calcareous mud (Fig. 2).

Petrographic study

A petrographic study reveals that grains are bounded by the calcareous mud matrix. According to Dunham classification, this rock can be grouped under the wackestone to packstone category (Fig. 2). Along with the biogenic clasts, several mineral grains mainly apatite, magnetite, hematite, pyroxene, and mica were also observed. The proportion of bioclasts represented by planktic and benthic foraminifera, algal mat, micro-gastropods, and pteropods is greater than that of the mineral grain clasts. The Wall of the foraminifera seems to be unaltered and intact within the calcareous matrix. EPMA study reveals that the matrix is mainly comprised of CaO (48% to 59%) and P_2O_5 (0.02 to 0.5%) along with a minor amount of other major oxides. Where Na_2O content is around 1.28% followed by FeO content around 0.2%. However, the concentration of SiO_2 (0.02%), MgO (0.16%), MnO (0.01%), and K_2O (0.2%) are present in considerably low amount. Petrographic study along with EPMA analysis suggest that the microorganisms were deposited first, followed by filling of lime mud in the interstitial spaces as a matrix. This association suggests that the wave energy was inadequate to winnow the lime mud matrix from the grains.

SYSTEMATICS

As mentioned above, the sample is fresh and depicts in-situ in nature dominantly made up of bioclasts (Fig. 2). Planktic foraminifera constitutes more than 50% of the clasts and the rest is represented by benthic foraminifers, pteropods, bivalves, and interspersed mineral grains. All the tests of planktic foraminifera extracted from the sample were thoroughly studied and identified based on morphology and surface structure based on the phylogenetic taxonomic description provided by Blow (1969); Bolli and Saunders (1989); Kennett and Srinivasan 1983; Chaisson and Leckie, 1993; Spezzaferri, 1994; Pearson and Chaisson, 1997 and Nathan and Leckie 2003. Accordingly planktic zonation was made following the tropical zonation classification of Blow 1969 (as described in Kennett and Srinivasan 1983). Nearly, twenty-eight species from nine genera have been identified and are represented by the foraminiferal species *i.e., Globigerinoides triloba* Reuss, *Globigerinoides subquadratus* Bronnimann, *Gs. diminutus* Bolli, *G. ruber, Gs. altiapertura* Bolli, *Gs. bolli, Globorotalia (Globorotalia) tumida tumida*, *Gr. nana* Bolli. *Globorotalia (Jenkinsella) bella, Globorotalia* cf**.** *Gr. (F.) kugleri* Bolli, *Globorotalia (Tenuitella) munda, Globigerinella praesiphonifera* Blow, *Globigerinella obesa* Bolli, *Globorotaloides hexagona* (Natland), *Globigerina bulliodes, Globigerina (Globigerina) quinqueloba* Natland, *Globigerina (Zeaglobigerina) connecta,* Jenkins, *Globigerina (Globigerina) falconensis,* Blow, *triloba, Globigerina (Globigerina) praebulloides* Blow, *Globigerina woodi,* Jenkins, 1960, *Globigerina (Zg.) brazieri, Globigerina* (*Zeaglobigerina*) *decoraperta* Takayangi *Neogloboquadrina continuosa, Catapsydrax parvulus* Bolli, Loeblich, Tappan, *Catapsydrax unicavas* Bolli, Loeblich, Tappan, *Catapsydrax dissimilis,*

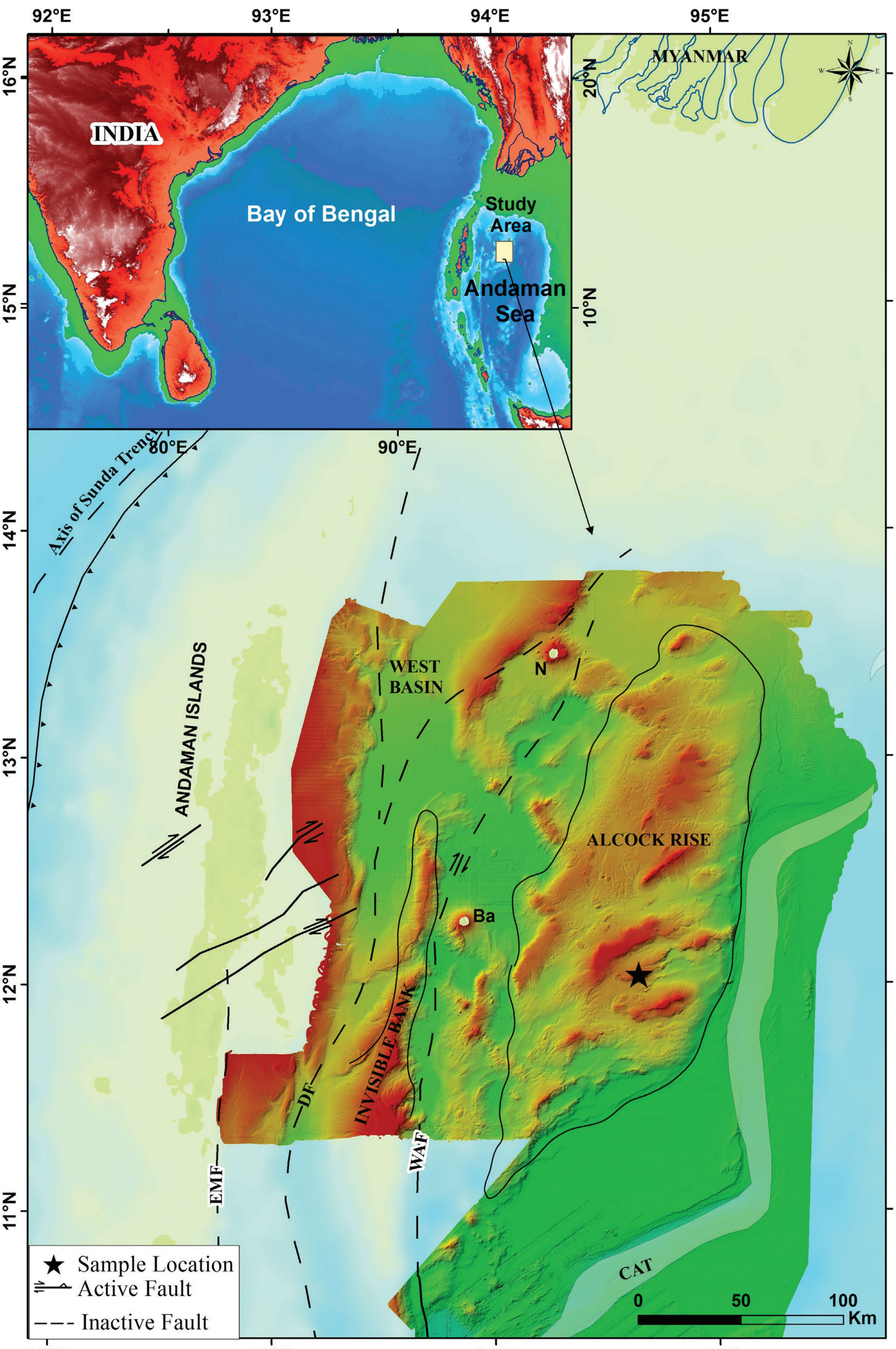


Fig. 1. Multibeam map superimposed on a bathymetric map with major tectonic feature showing sample location. Where, N= Narcondam Island, Ba= Barren Island, CAT=Central Andaman Trough, WAF= West Andaman Fault, EMF= Eastern Margin Fault, DF= Diligent Fault.

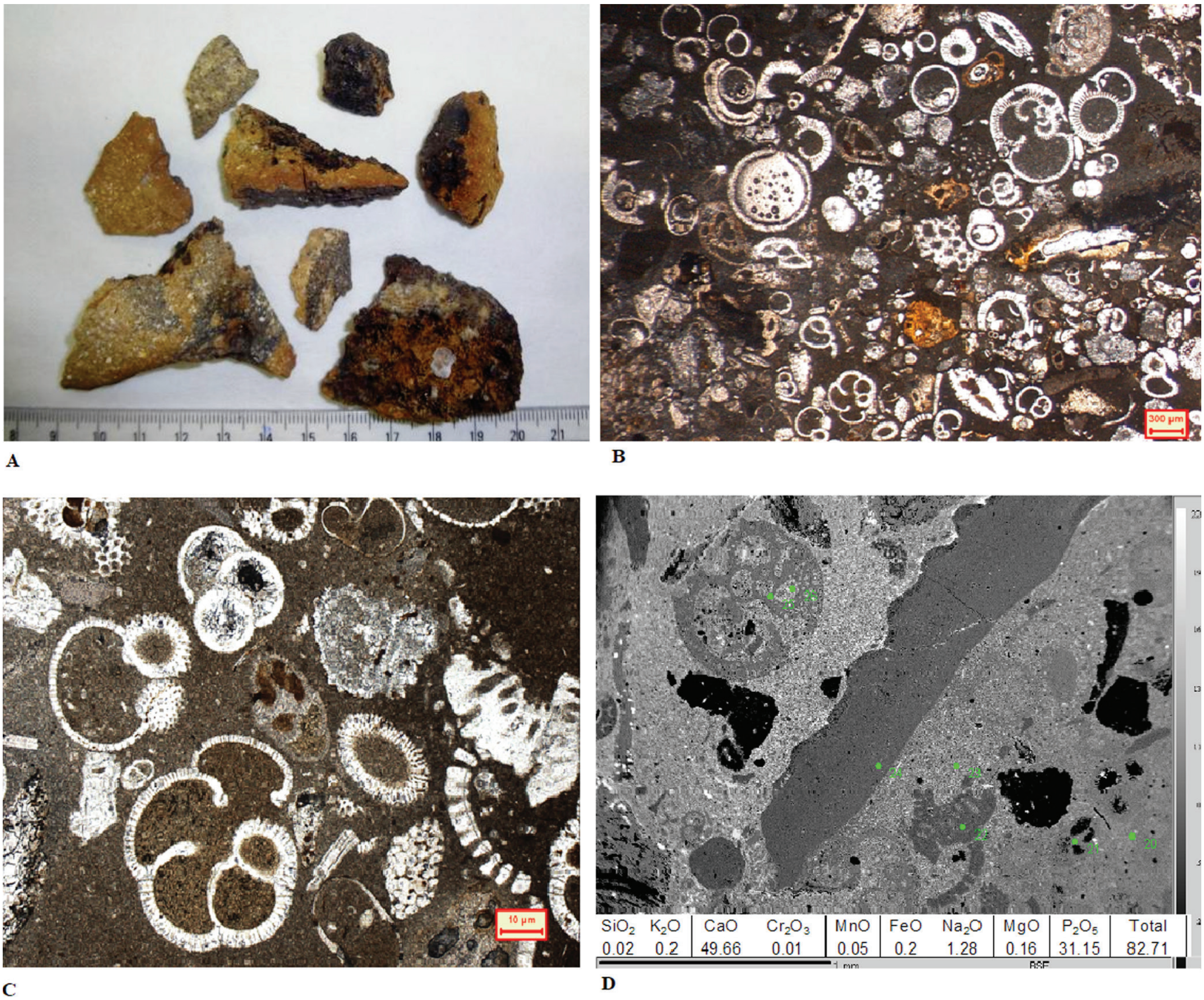


Fig. 2. A) photograph of a rock sample collected from Alcock Rise, Andaman Sea; B) Thin section showing Packstone- Wackestone nature. Planktic foraminifera, benthic foraminifera, coral, Bryozoans are embedded within the calcareous mud matrix; C) Thin section of Wackstone. Interspaces of the Planktic foraminifera, benthic foraminifera, coral, Bryozoans are embedded within the calcareous mud matrix; D) BSE image of the thin section along with the analytical result. Bright white points represent the grains of Apatite.

Globigerinita glutinata (Egger), and *Beela praedigitata* (Parker). The taxonomic details of the identified foraminifera are as follows.

Order: Globorotaliida
Family: Globorotaliidae
Genus: *Globorotalia* Cushman, 1927
Subgenus: *Globorotalia* Bandy, 1972

Globorotalia tumida tumida (Brady)
(Plate-I, Figs. 1-3)

Pulvinulina menardii var. tumida, Brady, 1877, p. 535.

Globorotalia tumida (Brady), Banner and Blow, 1960, p.26, pi. 5, fig. 1.

Globorotalia tumida tumida (Brady), Kennett & Srinivasan, 1983, p.159, pl. 38, figs. 1-3.

Test trochospiral, biconvex, slightly convex umblical side, axial periphery acute with heavy keel. Umbilical sutures radial, depressed; surface densely perforate with pores of uniform sizes; aperture intermarginal, extraumblical-umbilical, a low arch covered by a plate-like lip. Here, specimens show some dissolution.

Stratigraphic Distribution: Late Miocene to Recent.

Subgenus: *Jenkinsella* Kennett and Srinivasan 1983

Globorotalia (Jenkinsella) bella Jenkins
(Plate-I, Figs. 4-6; Plate-IX, Fig. 7)

Globorotalia bella Jenkins 1967, N.Z. Jour. Geol. and Geophys.10(4), p.1069, figs.3,1-6

Globorotalia (Jenkinsella) bella Jenkins, Kennett and Srinivasan, 1983, p. 174, pl. 42, fig.1-1.

Globorotalia bella, Nathan and Leckie 2003. P-28.

Test low trochospiral, lobate equatorial periphery, axial periphery rounded, chambers subspherical to ovate, five in final whorl increasing uniformly in size as added, radial and depressed sutures on both umbilical and spiral side, surface uniformly perforated, with smooth circular pores, small narrow interiomarginal extra umbilicus aperture with narrow lip.

Stratigraphic Distribution: Early Miocene to Pleistocene.

Subgenus: *Tenuitella* Fleisher, 1974

Globorotalia (Tenuitella) munda (Jenkins)
(Plate-III, Figs. 1-4)

Turborotalia munda Jenkins, 1966, p. 1121, pl. 14, figs.126-133, pl. 13, fig. 152-156 (fide Ellis &Messina, 1942-2010).

Globorotalia (Tenuitella) munda, Kennett & Srinivasan, 1983, p. 162, pl. 39, figs. 5-7.

Tennuitella munda Jenkins, 1966, Li, 1987, p. 310, pl. 2, fig. 13

Tenuitella munda (Jenkins, 1966), Beldean *et.al.*, 2012, p. 182, pl. 2, fig. 2

Test very small, low trochospiral, equatorial periphery quadrilobate, axial periphery rounded, chambers spherical to subspherical, four to four and a half in final whorl, increasing rapidly in size as added; spiral sutures curved and depressed, umbilical sutures radial. Surface smooth with fine pustules; umbilical narrow; aperture low arc interiomarginal with a thin lip.

Stratigraphic Distribution: Early Oligocene to lower part Early Miocene.

Subgenus: *Fohsella* Bandy, 1972

Globorotalia cf. *Gr. (F.) kugleri*
(Plate-II, Figs. 9-12)

Globorotalia kugleri Bolli, 1957, p. 118, pl. 28, figs. 5 a-b.

Globorotalia (Fohsella) kugleri Bolli, Kennett, and Srinivasan, 1983 p. 94, Pl.21, figs.1, 3-5.

Test low trochospiral, equatorial periphery slightly lobate, axial periphery rounded to sub-angular, chambers spherical to ovate, six in the final whorl; suture on spiral side curved and depressed, on umbilical side radial, distinctly depressed; umbilical narrow aperture interiomarginal. Surface pores; chamber arrangement and aperture development indicates that it is an intermediate form between *Gr. (F.) kugleri* to *Gr. (F.) peripheroronda.*

Stratigraphic Distribution: Late Oligocene to Early Miocene.

Subgenus: *Globoconella* Bandy, 1975

Globorotalia cf. *Globorotalia nana* Boli,
(Plate-III, Figs. 9-12)

Globorotalia opima nana Bolli, 1957, p. 118, pl. 28, fig. 3a-c.

Globorotalia nana (Bolli), Kennett and Srinivasan, 1983, p. 106, pl. 24, figs. 3-5.

Paragloborotalia nana Bolli, Nathan and Leckie 2003. P-28.

Test small, very low trochospiral, tightly coiled, equatorial periphery quadrilobate, axial periphery rounded; chambers four to four half in the final whorl, increasing rapidly in size as added; suture on both spiral and umbilical sides radial and depressed; surface distinctly cancellate with sub hexagonal pits; umbilicus narrow; aperture interiomarginal. This species seems in transitional form between *Globorotalia (Globoconella) opima nana* Boli and *Globorotalia (Globoconella) incognita* by developing a high arc aperture.

Stratigraphic Distribution: Early Miocene.

Genus: *Neogloboquadrina* BANDY, FERICHS and Vincent, 1967

Neogloboquadrina continuosa, Blow
(Plate-I, Figs. 7-9)

Globorotalia opima Bolli subsp. *continuosa* Blow, 1959, p. 218, pl. 19, fig. 125a–c.

Neogloboquadrina continuosa (Blow), Kennett and Srinivasan, 1983, p. 192, pl. 47, figs. 3-5.

Neogloboquadrina continuosa (Blow), Nathan and Leckie 2003. P-26.

Test low trochospiral with equatorial periphery lobulate and axial rounded periphery, subspherical to ovate chambers, four in the final whorl, increasing rapidly in size; suture depressed and radial on both umbilical and spiral side; surface pitted; umbilicus narrow, deep; interiomarginal to the extra umbilicus, low arch aperture bordered by a distinct rim.

Stratigraphic Distribution: Early Miocene to Middle Miocene.

Genus: *Globigerinella* Cushman, 1927

Globigerinella praesiphonifera Blow
(Plate-II, Figs. 1-4)

Hastigerina (H.) siphonifera praesiphonifera BLOW, 1969, P- 408, pl. 54, figs. 7-9.

Globigerinella praesiphonifera (BLOW), Kennett and Srinivasan, 1983, p-238, pl. 60, figs.1-3.

Globigerinella praesiphonifera. Nathan and Leckie 2003. P-15.

Test low trochospiral, equatorial periphery lobulate; axial periphery broadly rounded; chambers inflated, subglobular to ovate, five in final whorl continuously and slowly increasing in size as added, suture curved, radial and depressed; umbilical narrow and deep; aperture interiomarginal and extraumbilicus without rim, the last chamber is larger and oval. Slightly evolving stage towards *Ge. aequilateralis* but overall surface morphology is more resemble to *Globigerinella praesiphonifera.*

Stratigraphic Distribution: Early Miocene to Middle Miocene.

Genus: *Globigerinella obesa*, Bolli
(Plate-II, Figs. 5-8)

Globorotalia obesa Bolli, 1957, p. 119, pl. 29, figs.2-3.

Globorotalia obesa Bolli, 1957, Bolli & Saunders, p. 204, fig. 44.

Globigerinella obesa (Bolli, 1957), Kennett & Srinivasan, p. 234, pl. 59, figs. 2-5.

Globigerinella obesa **(**Bolli), Nathan and Leckie 2003. P-15.

Test low trochospiral, equatorial periphery lobulate; axial periphery broadly rounded; chambers spherical, inflated, four to four and one half rapidly increasing chambers in the final whorl, sutures radial, depressed; perforation is not visible due to cementing; umbilical wide, deep aperture a low to medium

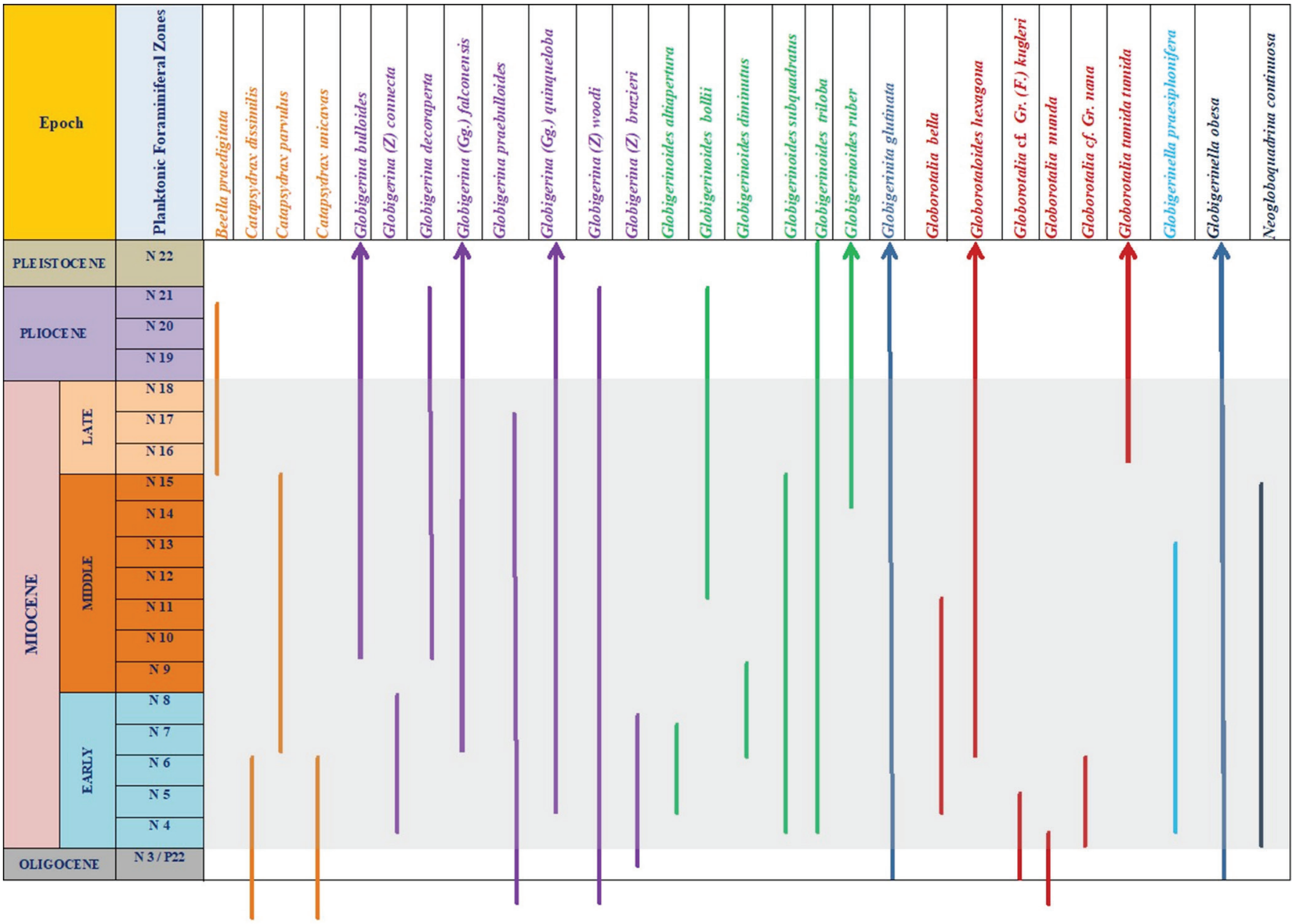


Fig. 3. Planktonic foraminiferal assemblage range age of the carbonate rock, Alcock Rise, Andaman Sea.

arch without lip, interiomarginal, umbilical extraumbilical.

Stratigraphic Distribution: Late Oligocene to Recent.

Genus: *Globorotaloides* Bolli, 1957

Globorotaloides hexagona (Natland)
(Plate-III, Figs. 5-8)

Globigerina hexagona Natland, 1938, p. 149, pl. 7, figs. 1, a-c.

Globorotaloides hexagona (Natland), Kennett and Srinivasan, 1983, p.216, pl. 54, figs.1, 3-5.

Globorotaloides hexagona (Natland), Nathan and Leckie 2003. P-15.

Test very low trochospiral, spiral side almost flat; equitorial periphery lobate, axial periphery broadly rounded; chambers spherical, five in final whorl, increasing rapidly in size as added; sutures on both spiral and umbilical sides slightly curved to nearly radial and depressed. Aperture very low arc inertiomarginal.

Stratigraphic Distribution: Early Miocene to Recent.

Genus: *Globigerina* d'Orbigny, 1826
Subgenus: *Globigerina*

Globigerina (Globigerina) bulloides (d'Orbigny)
(Plate-IV, Figs. 1-4 and Plate-VIII, Fig. 7)

Globigerina bulloides d'Orbigny, 1826, p. 3, pl. 1, figs. 1-4.

Globigerina (*Globigerina*) *bulloides* (d'Orbigny), Kennett and Srinivasan, 1983, p.36, pl. 6, figs. 4-6.

Globigerina bulloides d'Orbigny, Nathan and Leckie 2003. P-14

Test low trochospiral, usually four chambers in final whorl; chamber spherical to sub- spherical, increasing regularly in size as add; suture depressed; surface uniformly and densely perforate with cylindrical pores; Aperture interiomarginal, Aperture umbilical with high symmetrical arch.

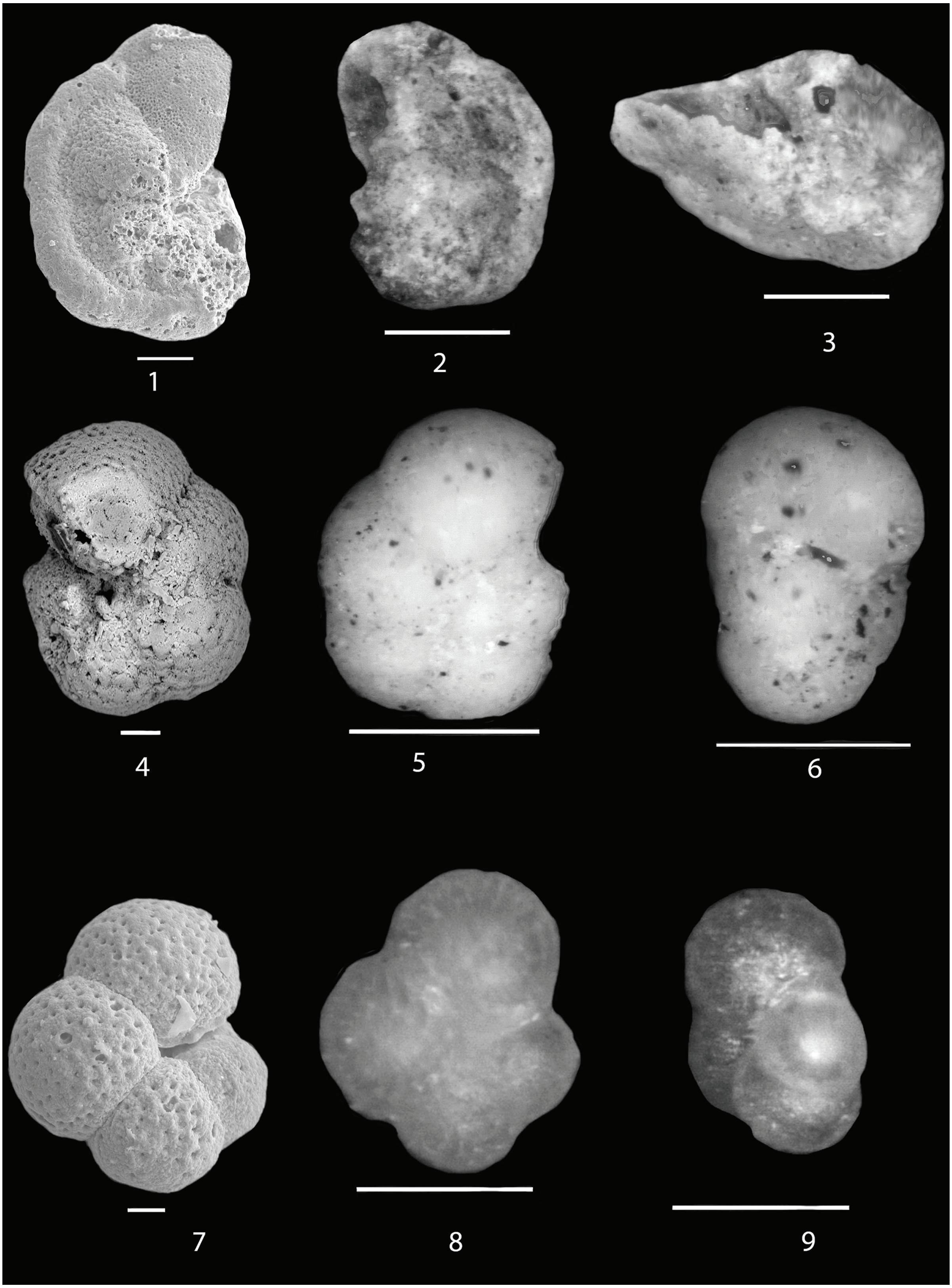
Stratigraphic Distribution: Early Middle Miocene to Recent.

Genus: *Globigerina (Globigerina) quinqueloba* Natland
(Plate-IV, Figs. 5-7)

Globigerina quinqueloba Natland; (pl. P-1, figs. 11, 12; pl. P-3, fig. 24; pl. P-6, fig.24). *Globigerina (Globigerina) quinqueloba* Natland, Kennett and Srinivasan, 1983, p. 32, pl. 75, figs. 4-6.

Globigerina quinqueloba, Li et. al. 2003, p-20, pl. P1, p.48 fig.11 and 12.

Plate I



EXPLANATION OF PLATE I

1-3. *Globorotalia tumida tumida* (100µm); 4-6. *Globorotalia (J.) bella* (20µm); 7-9. *Neogloboquadrina continuosa* (20µm).

Test small, slightly compressed, trochospiral, five chambers in the final whorl, rapidly increasing in size as added; chambers inflated, subglobular; final chamber distinctly raised with pore pits; sutures radial and depressed; aperture elongate silt but here flap is broken. It is descendent of *Gg. (Gg.) ciperoensis* during the early Miocene. Individual flap-like extension of the final chamber fused on one or earlier chambers. Based on the ultrastructure this specimen resembles the phase in between *Gg. (Gg.) ciperoensis* and *Gg. (Gg.) quinqueloba.*

Stratigraphic Distribution: Early Miocene to Recent.

Genus: *Globigerina (Globigerina) falconensis,* Blow
(Plate-VI, Figs.1-4)

Globigerina falconensis, Blow, 1959, p. 177, pl. 9, figs. 40a-c; Bolli and Saunders,1985, p. 303, figs. 5.2, 4.

Globigerina (*Globigerina*) *falconensis* (Blow), Kennett and Srinivasan, 1983, p. 40, pl. 7, figs. 1-3.

Globigerina falconensis Blow, Nathan and Leckie 2003. P-14

Test low trochospiral, slightly compressed, with four chambers in the final whorl; chambers spherical, increasing slowly in size as added; the last chamber typically smaller as visible from the outline of the broken part, sutures on both sides radial, depressed, surface with small, regularly distributed pores. Umbilicus is small but deep, partly covered by the final chamber. Aperture umbilical.

Stratigraphic Distribution: Early Miocene to Recent.

Genus: *Globigerina (Globigerina) praebulloides* Blow
(Plate-VIII, Figs. 5, 6, 10, 11 and Plate-IX, Figs. 1, 8)

Globigerina praebulloides Blow, 1959, p. 180, pl. 8, fig. 47, pl. 9, fig. 48 (fide Ellis & Messina, 1942-2010).

Globigerina praebulloides Blow, 1959, p. 180, pl. 8, fig. 47a-c; pl. 9, fig. 48.

Globigerina praebulloides Blow, 1959, Cicha *et al.,* 1998, p. 220, pl. 34, figs. 13-16.

Globigerina (Globigerina) praebulloides (Blow), Kennett and Srinivasan, 1983, p. 38, pl. 6, figs. 1-3.

Globigerina praebulloides Blow, Nathan and Leckie 2003. P-14.

Test medium, trochospiral, equatorial periphery elongate with four rapidly enlarging chambers in the final whorl; sutures on the both side radial to slightly curved; umbilical small; aperture umbilical low to moderate asymmetrical arch.

Stratigraphic Distribution: Late Eocene to Middle Miocene.

Subgenus: *Zeaglobigerina* Kennet and Srinivasan

Genus: *Globigerina (Zeaglobigerina) connecta,* Jenkins
(Plate-V, Figs. 1-3, Plate-VIII, Fig. 12, Plate-IX, Figs. 10-11)

Globigerina (Zeaglobigerina) connecta, Kennett and Srinivasan, 1983, p. 44, pl. 8, figs. 1-3. *Globoturborotalita connecta* (Jenkins), Li et al. 2003, pl. P1, fig. 15, p.48.

Test small, medium compact, low trochospiral, equatorial periphery trilobate, initial whorl indistinct, chambers subovate; the three chambers of the final whorl increasing in size as added and tending to overlap upon the earlier chambers; sutures radial, gently depressed, aperture a low arch with faint rim.

Stratigraphic Distribution: Early Miocene.

Genus*: Globigerinoides cf. Gs. triloba*
(Plate-VIII, Fig. 4)

Globigerina triloba Reuss, 1850, p. 374, pl. 447, fig. 11a-c.

Globigerinoides triloba (Reuss), Kennett and Srinivasan, 1983, p. 62, pl. 10, fig. 4; pl. 13, figs. 1-3.

Globigerinoides trilobus (Reuss), Bolli and Saunders, 1985, p. 196, fig. 20.15.

Globigerinoides triloba (Reuss), Nathan and Leckie 2003. P-17

Test small, compact, low trochospiral, equatorial periphery trilobate, initial whorl indistinct, chambers subovate; the three chambers of the final chamber tending to overlap upon the earlier chambers; sutures radial, gently depressed, aperture a low arch with a faint rim. Ultrastructure is between *Gs. triloba* to *G. connecta*.

Stratigraphic Distribution: Early Miocene.

Genus*: Globigerina* (*Zeaglobigerina*) *decoraperta,* Takayangi and Saito
(Plate-VIII, Fig. 1**)**

Globoturborotalita decoraperta (Takayanagi and Saito), Hofker, 1976, pp. 47-53.

Globigerina decoraperta (Takayanagi and Saito), Kennett and Srinivasan, 1983, p.48, pl. 9, figs. 4-6.

Globoturborotalita decoraperta (Takayanagi and Saito), Nathan and Leckie 2003. P-25.

Test compact, low to medium-high trochospiral, equatorial periphery lobulate, chambers spherical to subspherical, four in the final whorl, increasing uniformly in size added; sutures on spiral and umbilical side almost radial and depressed; umbilicus wide and deep; aperture interiomarginal, umbilical, largely semicircular, bordered by a rim.

Stratigraphic Distribution: Early middle Miocene-Late Pliocene.

Genus*: Globigerina* (*Zeaglobigerina*) *woodi,* Jenkins, 1960
(Plate-VIII, Fig. 8)

Globigerina woodi Jenkins, 1960, p. 352, pl. 2, figs. 2a-c.

Globigerina (Zeaglobigerina) woodi (Jenkins), Kennett and Srinivasan*,* 1983, p. 43, pl. 7, figs. 4-6.

Globoturborotalita woodi (Jenkins), Nathan and Leckie 2003. P-26.

Test medium, low trochospiral, equatorial periphery quadrilobate, chambers spherical to subspherical, increasing uniformly in size as added, four in the final whorl; sutures radial depressed on both side curved of umbilical and spiral; aperture intriomarginal umbilical high arch. Surface coarsely pitted with subhexagonal pits.

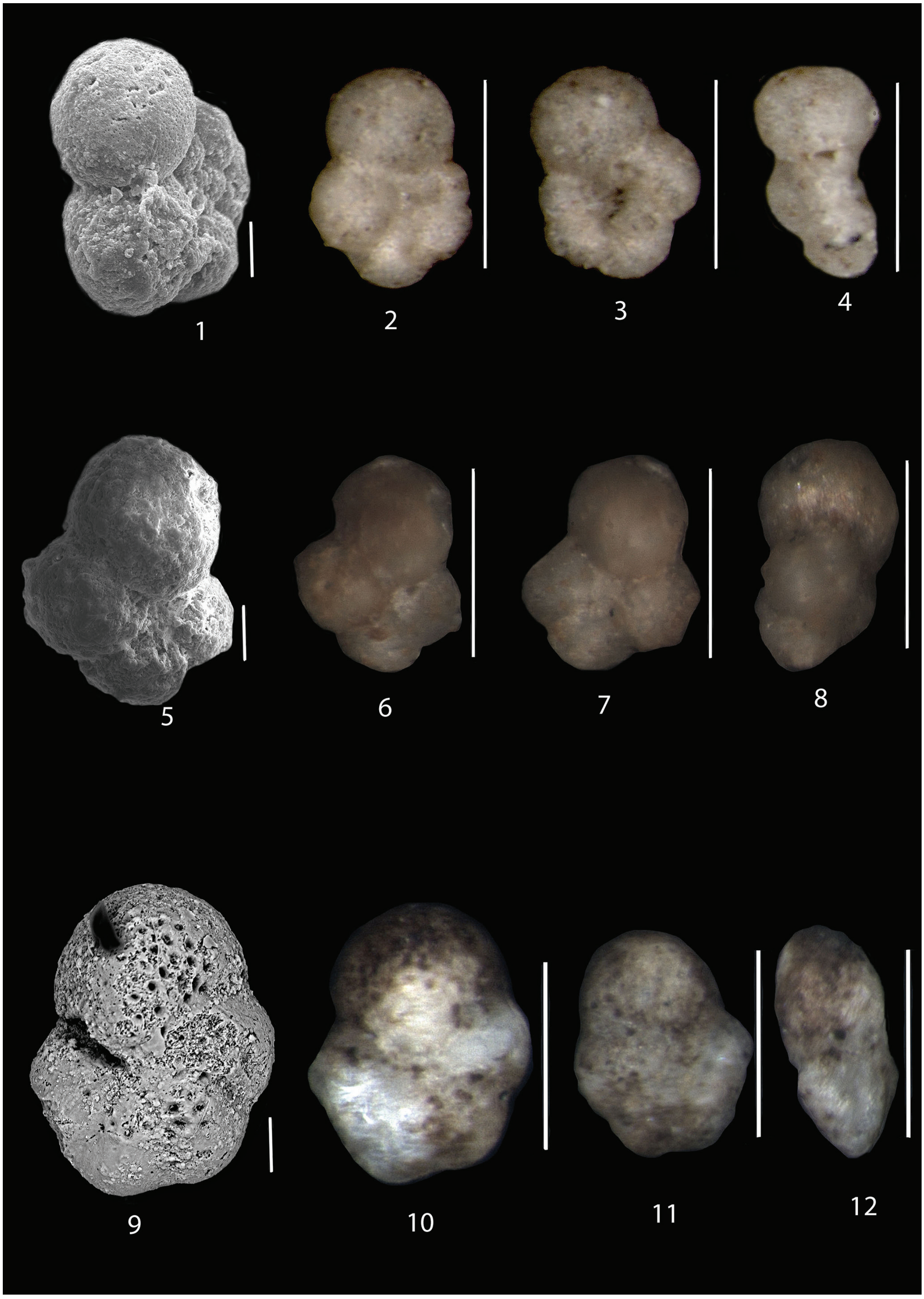
Stratigraphic Distribution: Late Oligocene to late Pliocene.

Genus*: Globigerina* (*Zeaglobigerina*) *brazieri*,
(Plate-IX, Fig. 5)

Globoturborotalita brazieri (Jenkins); Jenkins, 1985, as *Globigerina brazieri*, p. 274, fig. 6.20. (Li et. al. 2003, p-22).

Globigerina brazieri Jenkins, 1966, p.1098, fig.6, nos.43-51.

Plate II



EXPLANATION OF PLATE II

1-4. *Globigerinella praesiphonifera* (30µm); 5-8. *Globigerinella obesa* (30µm); 9-12. *Globorotalia (Fohsella)* cf. *Gr. (F.) kugleri* (20µm).

Globigerina (Zeaglobigerina) brazieri, Kennett and Srinivasan*,* 1983, p. 43, pl. 7, figs. 7-9.

Test subquadrate, low trochospiral, chambers sphericals to subsphericals, increases in size as added, three chambers in the final whorl; sutures radial to slightly curved and depressed on both sides; surface distinctly cancellate; the pores occupy well-developed pore pits separated by interpore ridges. Umbilical open, deep; aperture a very high arch with a thick rim, umbilical in position.

Stratigraphic Distribution: Latest Oligocene to Early Miocene.

Genus: *Globogerinoides* Cushman, 1927

Globigerinoides triloba Reuss
(Plate-IV, Figs. 8-11; Plate-VIII, Fig. 9)

Globigerina triloba Reuss, 1850, p. 374, pl. 447, fig. 11a-c.

Globigerinoides triloba (Reuss) Kennett and Srinivasan, 1983, p. 62, pl. 10, fig. 4; pl. 13, figs. 1-3.

Globigerinoides trilobus (Reuss) Bolli and Saunders, 1985, p. 196, fig. 20.15.

Globigerinoides triloba (Reuss), Nathan and Leckie 2003. P-17.

Test trochospiral, chambers spherical, three in the final whorl increasing rapidly in size as added; sutures on both sides gently curved and depressed, supplementary sutures in the spiral side in form of an irregular slit. Surface distinctly cancellate the pores located in well-developed pore pit separated by interpore ridges.

Stratigraphic Distribution: Early Miocene to Pleistocene.

Genus*: Globigerinoides cf. Globigerinoides subquadratus* Bronnimann
(Plate-VI, Figs. 5-8, Plate-IX, Fig. 4)

Globigerinoides subquadratus Brönnimann, 1954, p. 680, pl. 1, fig. 8a-c.

Globigerinoides subquadratus Brönnimann, 1954, Kennett and Srinivasan, 1983, p. 74, pl. 16, figs. 1-3.

Globigerinoides subquadratus Brönnimann, 1954, Chaisson and Leckie, 1993, p.159, pl. 2, fig. 12.

Globigerinoides subquadratus Brönnimann, Nathan and Leckie 2003. P-17.

Test subquadrate, trochospiral, chamber spherical to subspherical, three in the last whorl, increasing moderately in size as added; suture on the spiral side slightly curved, depressed, on umbilical side radial and depressed; surface distinctly perforate, spine visible on the interpore ridges; primary aperture interiomarginal, umbilical with a high arch bordered by rim; two prominent supplementary apertures over sutures of earlier chambers. Ultrastructure of this specimen resembling *Globigerina (Zeaglobigerina) brazieri* indicates its lineage from *G. (Z.) brazieri*.

Stratigraphic Distribution: Early Miocene to Middle Miocene.

Genus*: Globigerinoides cf. G. ruber* (d'Orbigny)
(Plate-VI, Figs. 9-12)

Globigerina rubra d'Orbigny, 1839, p. 82, pl. 4, figs. 12-14.

Globigerinoides ruber (d'Orbigny) Kennett and Srinivasan, 1983, p. 78, pl. 10, fig. 6; pl. 17, figs. 1-3.

Globigerinoides ruber (d'Orbigny), Nathan and Leckie 2003. P-17

Test Medium, low to high trochospire with three subspherical chambers in the final whorl, increasing moderately in size; sutures radial, distinctly depressed; surface coarsely perforate; umbilical narrow, primary aperture interiomarginal, umbilical with a wide arch opening bordered by a rim, with two supplementary sutural apertures situated opposite sutures of earlier chambers. This form is intermediate between *Globigerinoides subquadratus* and *G. ruber*. The overall architecture resembles *G. ruber* but the ultrastructure of this specimen is close to *Gs. subquadratus.*

Stratigraphic Distribution: Late Middle Miocene to recent.

Genus: Globigerinoides ruber (d'Orbigny)
(Plate-IX, Fig. 3)

Globigerina rubra d'Orbigny, 1839, p. 82, pl. 4, figs. 12-14.

Globigerinoides ruber (d'Orbigny), Kennett and Srinivasan, 1983, p. 78, pl. 10, fig. 6; pl. 17, figs. 1-3.

Globigerinoides ruber (d'Orbigny), Nathan and Leckie 2003. P-17

Test Medium, low trochospire with subspherical chambers and slightly small flat chamber in the final whorl, sutures radiate, distinctly depressed; umbilicus narrow, primary aperture interiomarginal, umbilical with a wide-arched opening bordered by a rim, with two supplementary sutural apertures situated opposite sutures of earlier chambers. It is a morpho- form of *Globigerinoides ruber.*

Stratigraphic Distribution: Late Middle Miocene Zone to Recent.

Genus*: Globigerinoides diminutus* BOLLI
(Plate-VII, Figs. 4-6)

Globigerinoides diminutus Bolli, 1957, p.114, pl.25, figs.11a-c.

Globigerinoides diminutus Bolli, Bolli, Saunders and Perch-Nielsen, 1989 p.194, figs.20.3: 7,9,12.

Globigerinoides diminutus BOLLI, Kennett and Srinivasan, 1983, p. 74, pl. 16, fig. 4-6.

Test small, trochospiral, equatorial periphery subquadrate, chambers spherical and become laterally compressed; three chambers in the final whorl, suture on both spiral and umbilical side; umbilicus small and almost circular; supplementary sutural aperture.

Stratigraphic Distribution: Late early to Early middle Miocene.

Genus*: Globigerinoides cf. G. ruber*
(Plate-VII, Figs. 7-9)

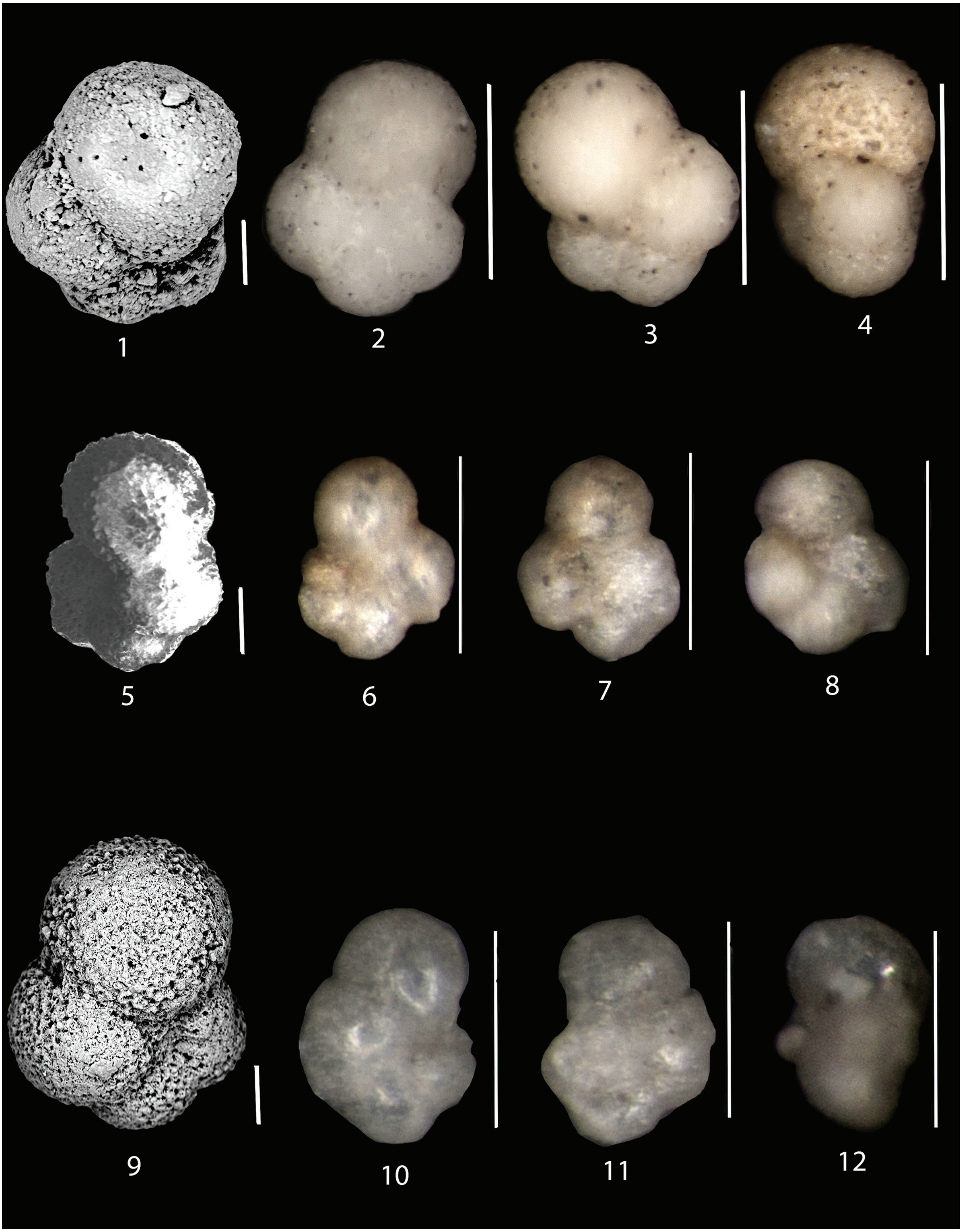
Globigerina rubra d'Orbigny, 1839, p. 82, pl. 4, figs. 12-14.

Globigerinoides ruber (d'Orbigny), Kennett and Srinivasan, 1983, p. 78, pl. 10, fig.6; pl. 17, figs. 1-3.

Globigerinoides ruber (d'Orbigny), Nathan and Leckie 2003. P-17

Test subquadrate, trochospiral, chamber spherical to subspherical, three in the last whorl, increasing moderately in size as added; suture on the spiral side slightly curved, depressed, on umbilical side radial and depressed; surface distinctly perforate, spine visible on the interpore ridges;

Plate III



EXPLANATION OF PLATE III

1-4. *Globorotalia (Tenuitella) munda* (20µm); 5-8. *Globorotaloides hexagona* (30µm); 9-12. *Globorotalia nana* (20µm).

primary aperture interiomarginal, umbilical with a high arch bordered by rim; two prominent supplementary apertures over sutures of earlier chambers. The ultra-structure of this species is between evolving stage from *Gs. subquadratus* to *G. ruber.*

Stratigraphic Distribution: Late Middle Miocene to recent.

Genus*: Globigerinoides bollii* BLOW
(Plate-8, Fig. 2)

Globigerinoides bollii BLOW, 1959, p.189. pl.10, figs. 65 a-c.

Globigerinoides bollii BLOW*,* Kennett & Srinivasan, 1983, p. 70, pl. 15, figs. 4-6.

Globigerinoides bollii BLOW, Bollii and Saunders, 1985, fig.20.8, p.192

Globigerinoides bollii BLOW, Spezzaferri, 1994:36, pl. 15, figs. 1a-c

Test small trochospire, chambers spherical to ovate, four in the final whorl; distinct radial sutures on both umbilical and spiral sides, depressed, surface coarsely pitted; primary aperture a arch shaped interiomarginal, umbilical, one small supplementary aperture at the suture junction between the ultimate and penultimate chambers.

Stratigraphic Distribution: Middle Miocene to Late Pliocene.

Genus: *Globigerinoides altiapertura* Bolli
(Plate-IX, Figs. 2, 12-13)

Globigerinoides triloba altiapertura Bolli, 1957, p. 113, pl. 25, fig. 7a-c.

Globigerinoides altiapertura (Bolli), Kennett and Srinivasan, 1983, p. 54, pl. 10, fig.1; pl. 11, figs. 4-6.

Globigerinoides altiapertura (Bolli), Chaisson and Leckie, 1993, p. 157, pl. 2, figs. 9-11.

Globigerinoides altiapertura Bolli, Nathan and Leckie 2003. P-16.

Test low trochospiral, chambers spherical, increasing rapidly in size as added; three in the umbilical aspect and three and a half in spiral aspect, sutures on both sides depressed and slightly curved; surface with large pores and small spine bases on the pore ridge, hispid on the final chamber. The primary aperture is interiomarginal, umbilical, a high, distinct arch bordered by a rim. One supplementary sutural aperture opposite the primary aperture on the last few chambers.

Stratigraphic Distribution: Early Miocene.

Genus: *Globigerinita* Bronnimann, 1951

Globigerinita glutinata (Egger)
(Plate-VII, Figs. 1-3)

Globigerina glutinata Egger, 1893, p. 371, pl. 13, figs. 19-21.

Globigerinita glutinata (Egger), Kennett and Srinivasan, 1983, p. 224, pl. 56, figs. 1, 3-5.

Globigerinita glutinata (Egger), Nathan and Leckie 2003. P-15.

Test small, low to medium trochospiral, equatorial periphery lobulate, chambers spherical to subhglobular, four in the final whorl, increasing rapidly in size; sutures depressed; surface smooth with irregularly distributed fine perforation largely covered by small, subconical crystallites; primary aperture covered by an irregular bulla expanding along the earliest sutures with numerous infralaminal supplementary aperture bordered by tiny arched of tubulose opening.

Stratigraphic Distribution: Late Oligocene to recent.

Genus: *Catapsydrax* Bolli, Loeblich, and Tappan, 1957

Catapsydrax parvulus Bolli, Loeblich, Tappan
(Plate-V, Figs. 4-6)

Catapsydrax parvulus Bolli, Loeblich, and Tappan, 1957, p. 36, pl. 7, figs. 10a-c.

Catapsydrax parvulus Bolli, Loeblich, and Tappan, Kennett and Srinivasan, 1983, p. 26, pl. 2, figs. 7-9.

Catapsydrax parvulus Bolli, Loeblich, and Tappan, Nathan and Leckie 2003. P-15.

Test small, subglobular, low trochospiral, chambers ovate, increasing rapidly in size as added, usually four in the final whorl; sutures gently depressed, surface distinctly cancellate with polygonal ridges surrounding pore pits; primary aperture interiomarginal, umbilical and covered by an arched bulla with a single infralaminal accessory aperture at one side.

Stratigraphic Distribution: Early Miocene to Middle Miocene.

Genus: *Catapsydrax unicavas* Bolli, Loeblich, Tappan
(Plate-V, Figs. 7-9, Plate-IX, Fig. 9)

Catapsydrax unicavus Bolli, Loeblich, and Tappan, 1957, p. 37, pl. 7, figs. 9a-c.

Catapsydrax unicavus Bolli, Loeblich, and Tappan, Kennett and Srinivasan, 1983, p. 26, pl. 3, figs. 1-3.

Catapsydrax unicavus Bolli, Loeblich, and Tappan, Nathan and Leckie 2003. P-13

Test low trochospiral, chambers subglobular, four in the final whorl; sutures distinct, depressed and sightly curved. Surface distinctly cancellate; umbilicus covered by a bulla, which is attached on three sides, with a single infralaminal aperture on the fourth side.

Stratigraphic Distribution: Early Eocene to Late Miocene.

Catapsydrax dissimilis (Cushman and Bermudez)
(Plate-IX, Figs. 14-16)

Globigerina dissimilis Cushman and Bermúdez, 1937, p. 25, pl. 3, figs. 4-6.

Catapsydrax unicavas Bolli, Loeblich and Tappan, 1957, p. 37. pl. 7, figs. 9a-c.

Globigerinita dissimilis ciperoensis Blow and Banner,1962. p. 107. pl. 14. figs. a-c.

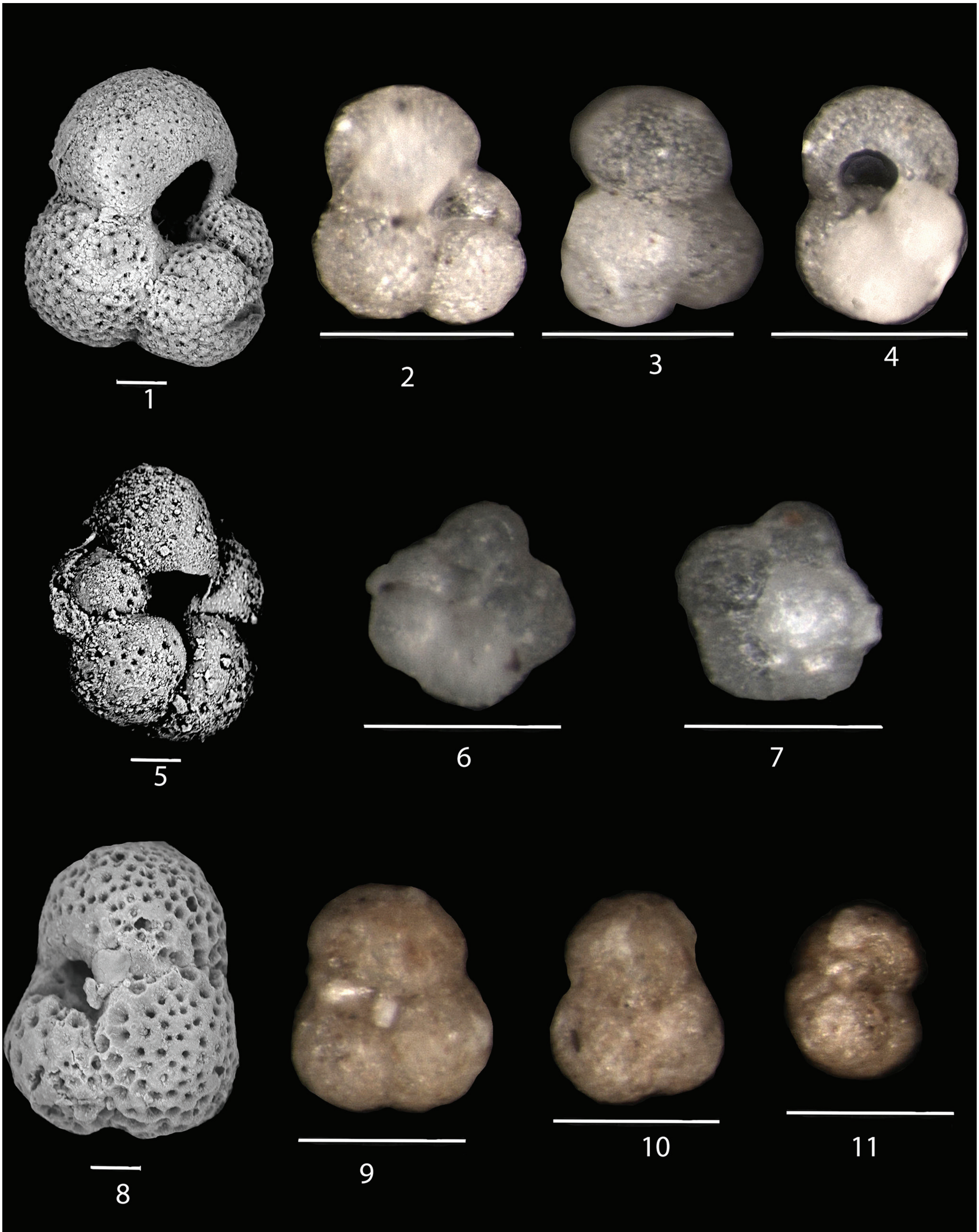
Catapsydrax dissimilis (Cushman and Bermudez)- Kennett and Srinivasan, p.22, pl.2, Figs.1, 3-8.

Catapsydrax dissimilis (Cushman and Bermúdez), Nathan and Leckie 2003. P-13.

Test of medium size, compact, four chambers in the final whorl, sutures depressed, radial, surface distinctly cancellate. Aperture covered by single umbilical bulla with one or more infralaminal apertures.

Stratigraphic Distribution: Late Eocene to Early Miocene.

Plate IV



EXPLANATION OF PLATE IV

1-4. *Globigerina bulloides* (20µm); 5-7. *Globigerina (Globigerina) quinqueloba* (20µm); 8-11) *Globigerinoides triloba* (20µm).

Genus: *Beella* Banner and Blow, 1960

Beella praedigitata (Parker),
(Plate-VIII, Fig. 3, Plate-IX, Fig. 6)

Globigerina praedigitata Parker, 1967, p. 151, pl. 19, figs. 5-8.

Beella praedigitata (Parker), Kennett and Srinivasan, 1983, p. 232, pl. 58, figs. 2-5.

Beella praedigitata (Parker), Nathan and Leckie 2003. P-13.

Test low to medium trochospiral, equatorial periphery strongly lobulate; chamber inflated initially spherical, later becoming ovate, four to five rapidly increasing chambers in the final whorl; sutures distinct, depressed; smooth with circular to subcircular pores and discrete tubrcles representing spine bases. Aperture interiomargnal, umbilical, a semicircular arch bordered by a pronounced lip.

Stratigraphic Distribution: Late Miocene to late Pliocene.

Interpretation of palaeontological data

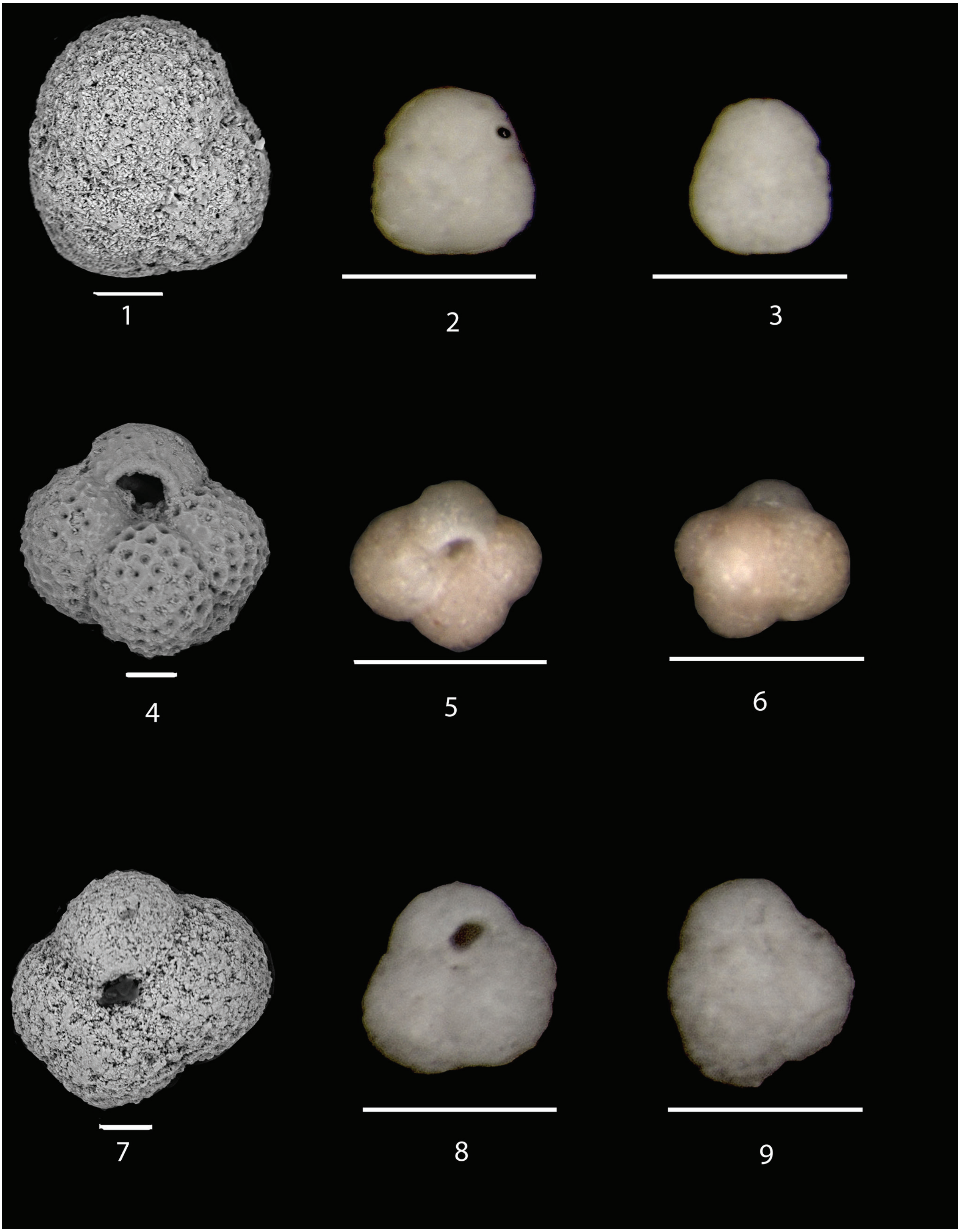
The bioclastic limestone sample has yielded planktic foraminiferal assemblage with several distinct morpho-species. However, several forms of intermediate stages were also recorded. Forms intermediate between *Globorotalia (F) kugleri* Bolli and *G. (F) peripheroronda* and intermediate forms between *Globorotalia nana* Bolli and *G. (G) incognita* were demarcated based on slightly high arc aperture developed during Early Miocene. The intermediate form between *Globigerinella praesiphonifera* and *G. aequilateralis* Blow is also present in the material. *Globorotalia munda* represent zone N-4A of the Early Miocene (Blow 1969). The basal foraminiferal zone of the Miocene epoch is represented by *Globorotalia kugleri* Zone of Stainforth *et al.* (1975). In a broad sense, *Globorotalia kugleri* represent the level near the Oligocene-Miocene boundary (Zone N-4B) on either side of the Atlantic and in the Pacific Region (Stainforth *et al.,* 1975). Whereas, *G. (F.) peripheroronda* has a restricted range from N4-B to N-10 of Early Miocene to Middle Miocene (Stainforth *et al.,* 1975). Based on the study of the South Pacific DSDP, *G. (F.) kugleri* considered to be the direct ancestor of *G. (F.) peripheroronda* (Srinivasan and Kennett, 1981a; Kennet and Srinivasan, 1983) which supports the view of Fleisher (1974) and Stainforth *et al.,* (1975). The intermediate form present in the material indicates that the *Globorotalia (Fohsella) kugleri* are evolved towards *G. (F.) peripheroronda* (Fig. 3) marked the boundary of Zone N-4B (Blow 1969; Stainforth *et al.,* 1975). *Globorotalia (Globoconella) nana* has an established range of Oligocene to Early Miocene and *Globorotalia (Globoconella) incognita* is restricted well with in the Early Miocene (Blow 1969). The intermediate form in the present material between *Globorotalia (Globoconella) nana* and *Globorotalia (Globoconella) incognita* indicate Early Miocene affinity. *Catapsydrax dissimilis* and *Catapsydrax unicavas* are recorded up to the zone N-6 (Fig-3). (Blow 1969; Stainforth *et al.,* 1975; Bolli and Sanders, 1989). Similarly, *Globigerinoides altiapertura* is restricted between Zone N-5 to N-7 (Fig-3 Blow, 1969) of Early Miocene (*Catapsydrax stainforthi* Zone of Stainforth *et al.* 1995, Fig-3). *Globigerina* (*Zeaglobigerina*) *decoraperta* and *Globigerinoides bolli* generally belongs in the *Globorotalia fohsi foshi* zone (N-12, Berggren and Van Couvering, 1974). *Globigerinella praesiphonifera* Blow is generally recorded from the Early to Middle Miocene (N4B-N13, Blow, 1969). Several forms present in the material such as *Globogerina praesiphonifera, Neogloboquadrina, Globorotaloides hexagona* and *Globigerina bulloides* range from Early Miocene to Middle Miocene. *Globigerina (Globigerina) quinqueloba* represent zone N-4 and N-5 (Blow, 1969) with evolve ultra structure towards *Gg. Ciperonensis.* Whereas, *Globigerinoides triloba* possess ultrastructure in-between *Gs. altiapertura* to *Gs. triloba* but more resembles to *Gs. triloba*. *Globigerinoides subquadratus* ultrasructure is resembled towards *Gg. (Zg.) brazieri*, but in terms of chamber arrangement and apertural opening more towards the *Gs. subquadratus*. Another evolved stage was noticed in the *Gs. subquadratus*, showing ultrastructure in between *Gs. ruber* and *Gs. subquadratus.*

Several forms of the present study *viz.,* are *Globigerina (Globigerina) quinqueloba, Globigerina (Zeaglobigerina) woodi, Globigerina (Zeaglobigerina) obesa, Globigerinoides triloba* are long ranging and some are found even in recent time. *Gs. subquadratus* are recorded from Early Miocene to Middle Miocene (up to N-14) and *Gs. ruber* on the other hand appears in the Middle Miocene and continues up to Recent. Similarly, *Globigerina (Zeaglobigerina) decorperta* are recorded from Middle Miocene to Late Pliocene (N-9 to N-21 of Blow, 1969). The presence of *Beella praedigitata* represents Late Miocene to Late Pliocene epoch of deposition over Alcock Rise. Foraminiferal assemblages in the sample represent taxa of mixed affinity. Based on the presence of different taxa of planktic foraminifera and tropical Neogene zonations of Blow 1969, the sample may be assigned an age of Early Miocene to Late Miocene.

Palaeoecology and depositional environment

Detailed petrography and textural analysis of the rock sample suggest that bioclasts are floating within mud matrix and their interstitial spaces are also filled with similar material. This association suggests that the entire process took place under low to moderate energy conditions in relatively shallow water which allowed carbonate mud to precipitate as a matrix within the pore spaces. This is also supported by the presence of the pteropods mainly a variety of *Heliconoides inflata, Heliconoides Limacina, Limacina valvatina*, *Limacina trochiformis, Limacina inflata* along with the other most dominating benthic foraminifera assemblages like *Cibicidoides dohmi, Cibicidoides eocaenus,* and *Cassudulina* sp. A variety of pteropods reveal that the entire deposition was taken place above the Aragonite Compensation Depth (ACD). Along with the pteropods, coralline algae (*Lithoporella* sp.,) were also observed. This variety of coralline algae is mostly found in shallow water and supports low energy conditions (Bosense, 1991; Kundal, 2010). EPMA analysis of lithic fragments depicts the presence of pyroxene; magnetite and apatite within the matrix which might have derived from the nearby source. However, if the above ecological condition correlated with the origin of the entire seamount then it was formed simultaneously with the formation of the ridge (Alcock Rise) during the Early Miocene period (Curray 2005). According to Curray 2005,

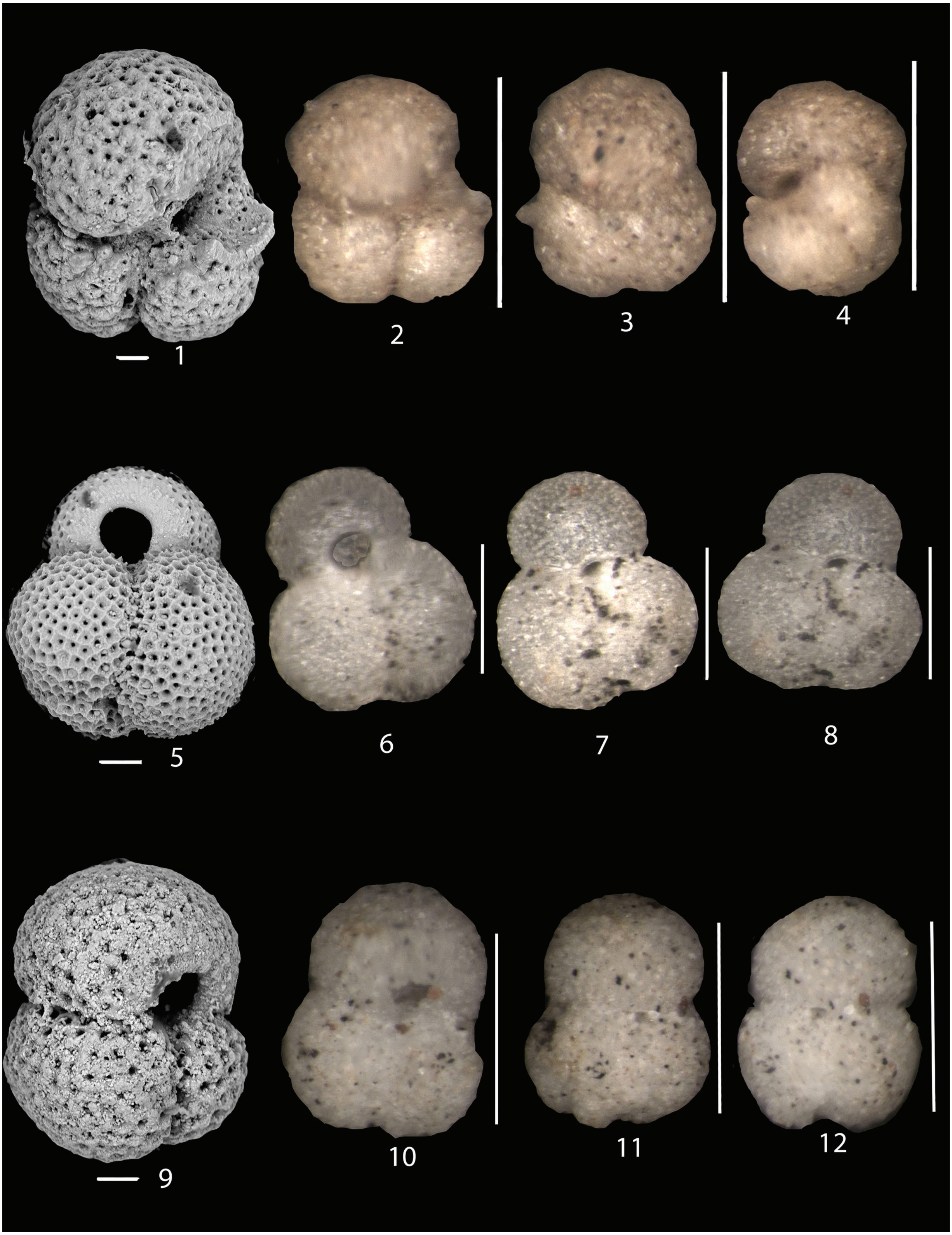
Plate V



EXPLANATION OF PLATE V

1-3. *Globigerina (Zeaglobigerina) connecta* (30µm); 4-6. *Catapsydrax parvulus* (20µm); 7-9. *Catapsydrax unicavas* (20µm).

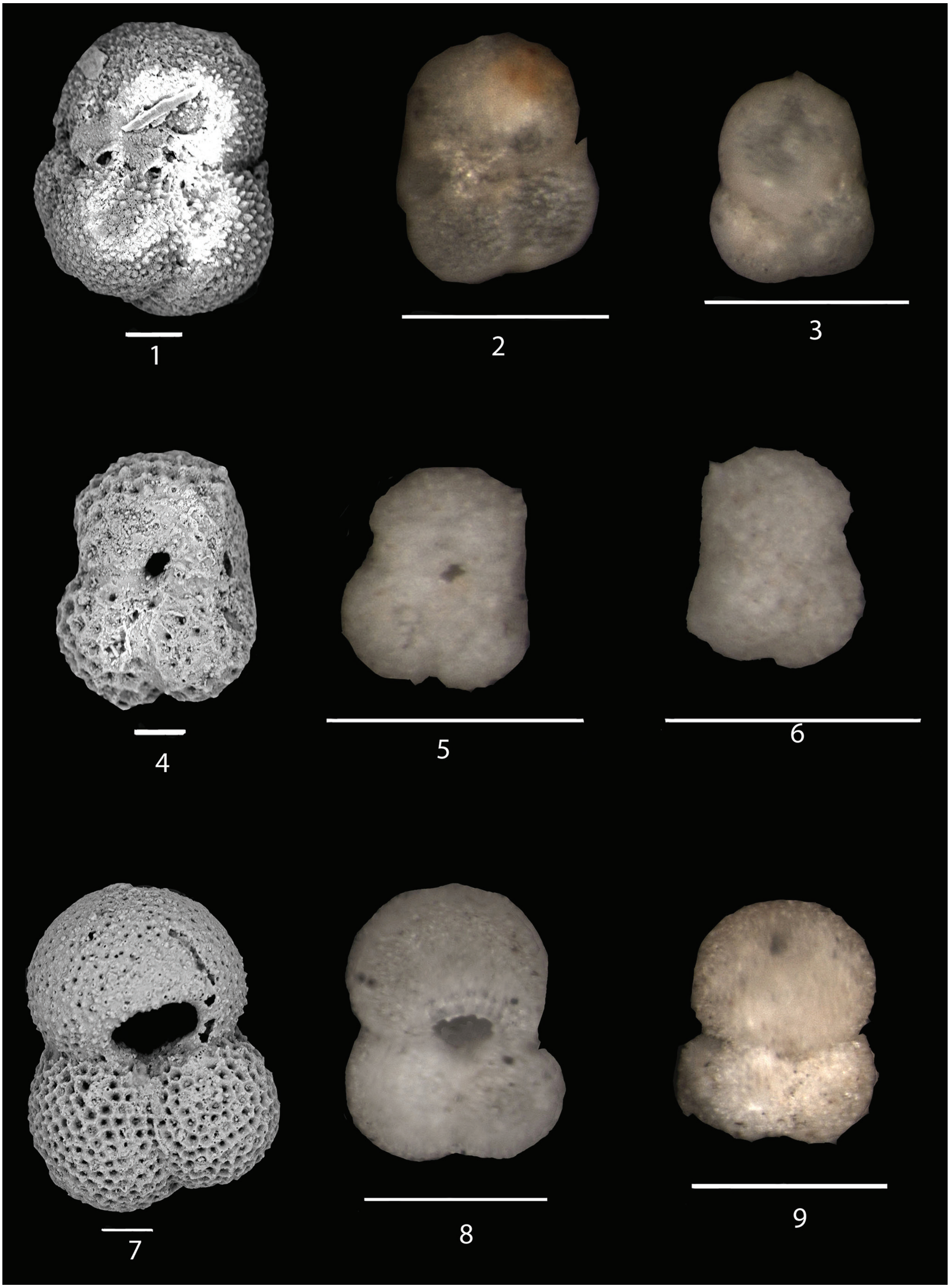
Plate VI



EXPLANATION OF PLATE VI

1-4. *Globigerina (Globigerina) falconensis* (20µm) (final chamber broken); 5-8. *Globigerinoides cf. Globigerinoides subquadratus* (20µm); 9-12. *Globigerinoides cf. Gs. ruber* (20µm).

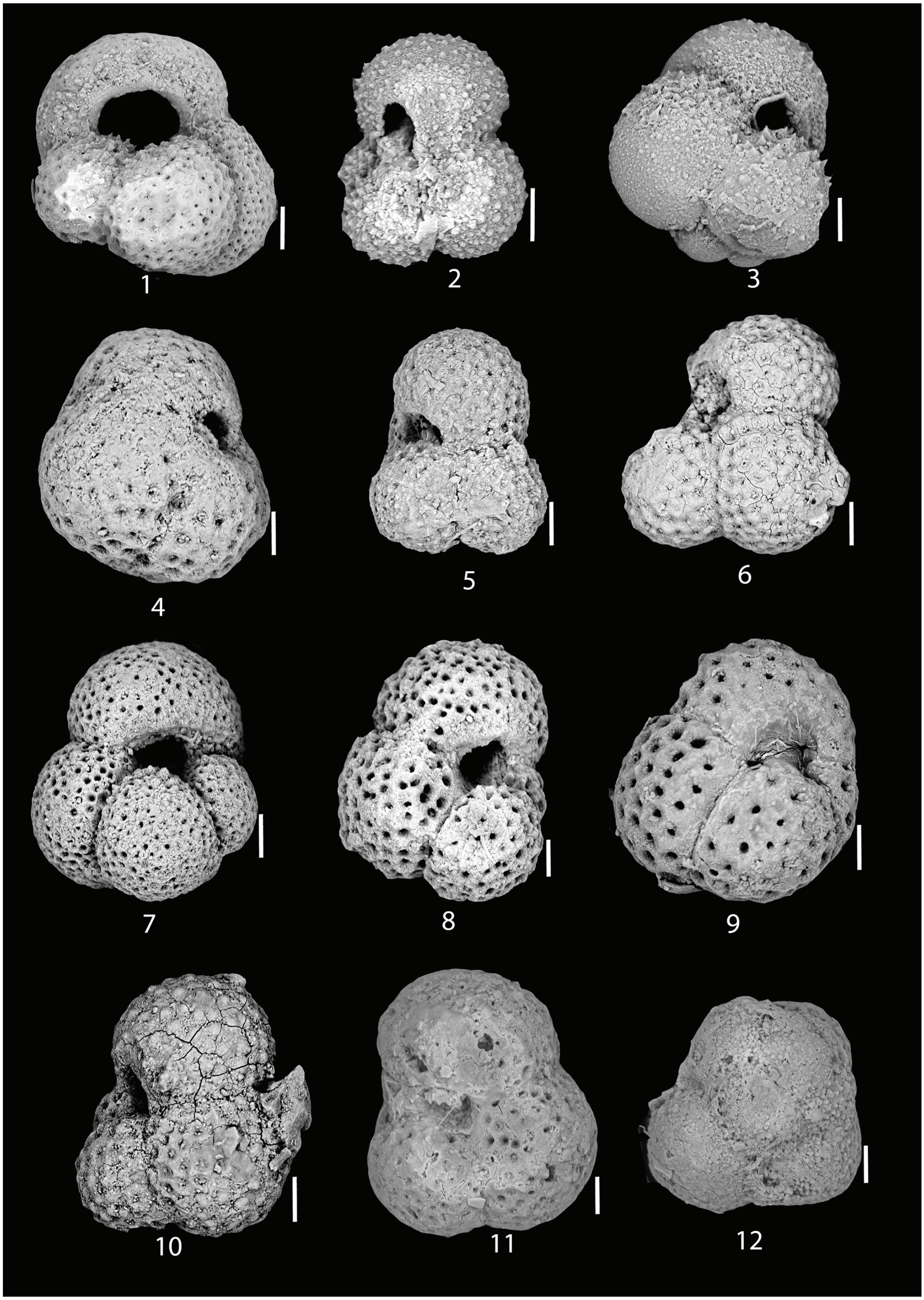
Plate VII



EXPLANATION OF PLATE VII

1-3. *Globigerinita glutinata* (20µm); 4-6. *Globigerinoides diminutus* (20µm); 7-9. *Globigerinoides cf. Gs. ruber* (20µm).

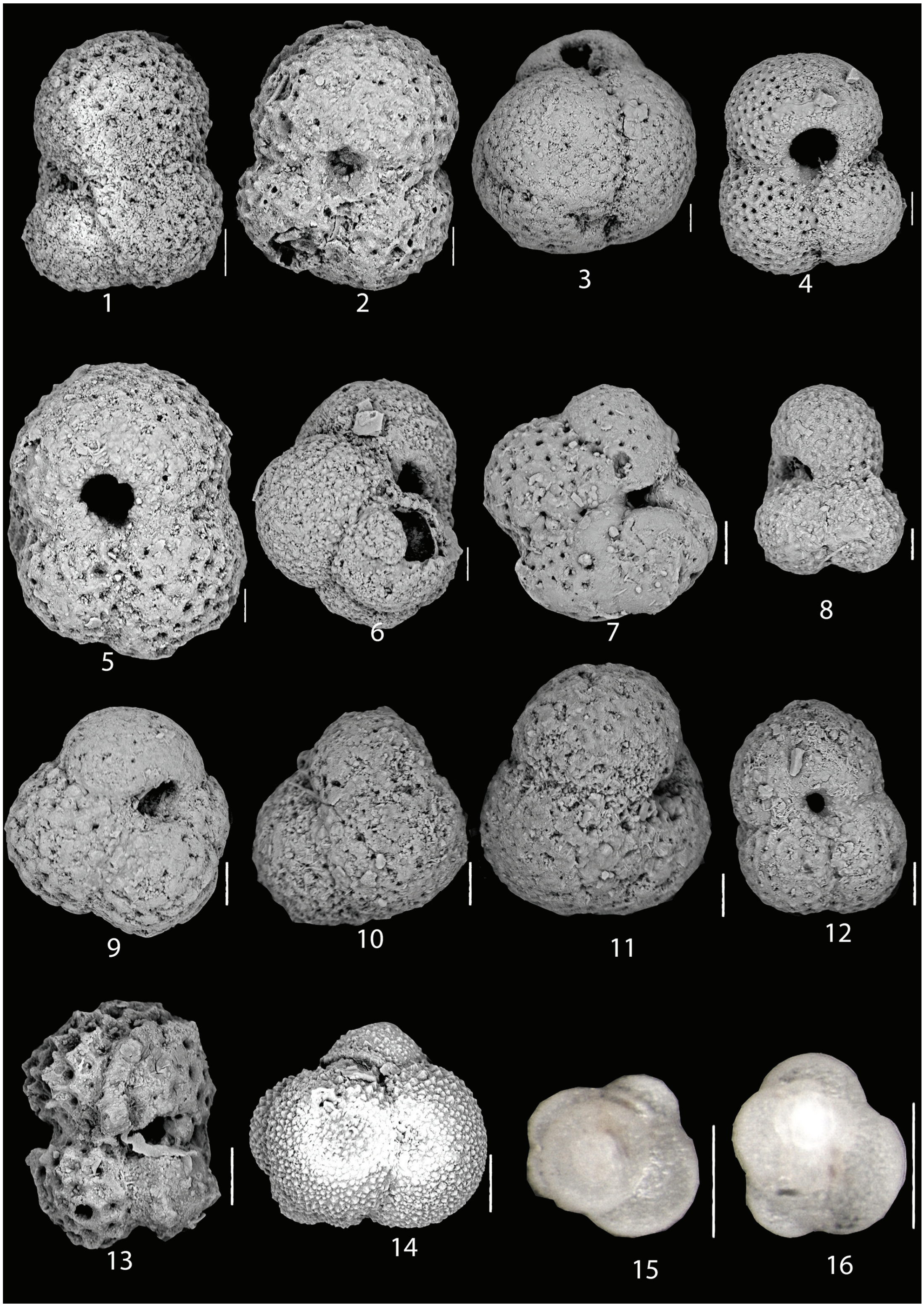
Plate VIII



EXPLANATION OF PLATE VIII

1. *Globigerina (Zeaglobigerina) decoraperta* (20µm); 2. *Globigerinoides bollii* (20µm); 3. *Beella praedigitata* (30µm); 4. *Globigerinoides cf. Gs. triloba* (20µm); 5-6. *Globigerina (Globigerina) praebulloides* (20µm); 7. *Globigerinoides bulloides* (30µm); 8. *Globigerina woodi* (20µm); 9. *Globigerinoides triloba* (20µm); 10-11. *Globigerina praebulloides* (20µm); 12. *Globigerina connecta* (20µm).

Plate IX



EXPLANATION OF PLATE IX

1. *Globigerina (Globigerina) praebulloides* (20µm); 2. *Globigerinoides altiapertura* (20µm); 3. *Globigerinoides ruber* (30µm); 4. *Globigerinoides subquadratus* (20µm); 5. *Globigerina brazieri* (20µm); 6. *Beella praedigitata* (20µm); 7. *Globorotalia bella* (20µm); 8. *Globigerina (Globigerina) praebulloides* (20µm); 9. *Catapsydrax unicavus* (20µm); 10 & 11. *Globigerina connecta* (20µm); 12-13. *Globigerinoides altiapertura* (20µm); 14-16. *Catapsydrax dissimilis* (20µm).

the origin of the Alcock Rise was around 23-15 Ma by the Oceanic filled basalt, and then onward it experienced a series of faulting and rifting. Hawkins (mentioned in Curray 2005) described the rocks as 'moderately fractionated tholeiitic basalts' and calculated ages of around 19.8±0.7 and 20.5±1.0 Ma based on K-Ar dating. But Morley and Aveny (2015) disagreed with the above statement; according to them, the basaltic rock had extruded onto an older continental remnant. The biostratigraphy age of the collected rock piece, matches with the age model given by the Curray, 2005. The appearance of *Catapsydrax dissimilis* in the sample marked the M2 zone of Berggren *et al.,* 1995 and *Catapsydrax dissimilis* zone of Stainforth *et al.,* 1975 reveals the formation age of the rock is Early Miocene. The presence of *Gs. triloba*, *Gs. subquadratus, Gs. altiapertura* made their appearance in the early Miocene (M2 zone of Berggren *et al.,* 1995). *Gs. altiapertura* is a short range from restricted within Early Miocene (*Catapsydrax stainforthi* Zone of Stainforth *et al.,* 1975). *Globorotalia tumida tumida* (Brady) also recovered in the sample marked the age Late Miocene to Recent. So, the presence of *cf. Globorotalia (F.) Kugleri*, *Catapsydrax dissimilis,* and *Beella praedigitata* in the sample depict the age of the formation of this rock between Early Miocene to Late Miocene. The Early Miocene carbonate build-up record over Alcock Rise matches very well with the record of Morley (2017). According to him, during the Early Miocene localized shallow-water depositional features such as small carbonate build-ups and pinnacles over the Mergui Ridge area were also witnessed. So, the above finding substantiates that during the Early Miocene, shallow marine localized carbonate platform buildup was recorded throughout the backarc basin of the Andaman Sea. Hence, the first record of carbonate rocks over the Alcock Rise can resolve the existing age-related controversies and provides the biostratigraphic age of the samples as Early Miocene which also matches with the age model given by the Curray 2005. Detailed analysis about the origin, age, and tectonics of the region can only be resolved after the deep drilling in this area.

CONCLUSIONS

Detailed analysis and above discussion suggest that the studied carbonate rock was formed by a very slow rate of deposition at shallow depths in association with intermittent magmatic activity. Biostratigraphic evidence and evolution of intermediate planktic foraminifera in the samples indicate that the *Globorotalia (Fohsella) kugleri* evolved towards *G. (F.) peripheroronda* and has an established age range of Oligocene to Early Miocene. *Catapsydrax dissimilis* and *Catapsydrax unicavas* are also establishing the age of the Early Miocene. Moreover, the presence of *Beella praedigitata* also represents the Late Miocene depositional phase over Alcock Rise. Long-range mixed foraminiferal assemblage points towards a very slow rate of carbonate precipitation in the area since the formation of the Alcock Rise. Based on the zone N-4 and N-5 foraminiferal assemblages the age of the carbonate material could be around 20.5 Ma. Therefore, the origin of the carbonate material age matches with the age data provided by Curray 2005. However, the limited rock sample for the present study is not enough to solve the controversies involved within origin and tectonics. Thus, solving the depositional history of the Alcock Rise will only be possible by deep drilling in this area.

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REFERENCE

Azmi, J. R. and Srinivasan, M. S., 1974. Late Miocene-Pliocene Planktonic foraminifera of Guitar Island, Andaman Sea. Proc VI, *Indian Colloquium Stratigraphy and Micropaleontology*: 55-58.

Berggren, W. A. and J. A. Van Couvering, 1974. The Late Neogene: biostratigraphy, geochronology, and paleoclimatology of the last 15 million years in marine and continental sequences. Palaeogeography, Palaeoclimatology, Palaeobiology, 16(l-2): p. 1-126.

Berggren, W.A., Kent, D.V., Swisher, C.C., and Aubry, M.P., 19 95. A Revised Cenozoic Geochronology and Chronostratigraphy; 10.2110/pec.95.04.0129.

Berggren, W. A., Hilgen, F. J., Langereis, C. G., Kent, D. V., Obradovich, J. D., Raffi, I., Raymo, M. E. and Shackleton, N. J., 1995a. Late Neogene chronology: new perspectives in high-resolution stratigraphy. Geological Society of America Bulletin, 107: 1272-1287.

Blow, W.H. 1969. Late middle Eocene to Recent planktonic foraminiferal biostratigraphy. In: Bronnimann, P. and Renz, H.H. (Editors), Proceedings of the First International Conference on Planktonic Microfossils, Geneva, 1967, Leiden, Netherlands, pp. 380-381.

Bolli, H.M. and Saunders, J.B. 1985. Oligocene to Holocene low latitude planktonic foraminifera. In: Bolli, H.M., Saunders, J.B. & Perch-Nielsen, *K. (*eds*.),* Plankton Stratigraphy, Cambridge University Press*,* 155-262.

Bolli, H. M. and Saunders, J. B. 1989. Oligocene to Holocene Low latitude planktic foraminifera, In Bolli, Saunders & Perch-Neilsen (eds.) *Plankton stratigraphy*, 1:156-263.

Bosence, D. W. J. 1991. Coralline Algae Mineralisation, Taxonomy, and Paleoecology, pp. 99-113. In: Riding, R. (ed.), Calcareous Algae and Stromatolites, Springer-Verlag, New York, 571.

Chaisson, W.P., Leckie, R M. 1993. Neogene planktonic foraminifera of ODP Site 130-806. PANGAEA, https://doi.org/10.1594/PANGAEA.779905.

Cochran, J. R. 2010. Morphology and tectonics of the Andaman Forearc, northeastern Indian Ocean, Geophysical Journal International. 182(2):631–651, doi:10.1111/j.1365-246X.2010.04663.X.

Curray, J.R. 2005. Tectonics and history of Andaman sea region. Journal of Asian Earth Science, 25: 187–232.

Flores J.A., Johnson J.E., Mejía-Molina A.E., Alvarez M.C., Sierro F.J., Singh S.D., Mahanti S, Giosan L, 2014. Sedimentation rates from calcareous nannofossil and planktonic foraminifera biostratigraphy in the Andaman Sea, northern Bay of Bengal, and the eastern Arabian Sea. Marine and Petroleum Geology*,* 58: 425-437.

Fleisher, R. L. 1974. Cenozoic planktonic foraminifera and biostratigraphy, Arabian Sea Deep Sea Drilling Project Leg 23A. In Whitmarsh, R. B., Weser, O. E., Ross, D. A., *et al.,* Initial Reports of the Deep Sea

Drilling Project, v. 23: Washington (U. S. Government Printing Office), pp.1001- 1072.

Jenkins, D.G. 1960. Planktonic foraminifera from the Lakes Entrance oil shaft, Victoria, Australia. Micropaleontology,6: 345-371.

Jenkins, D.G. 1971. New Zealand Cenozoic Planktonic Foraminifera. New Zealand Geological Survey, Paleontological Bulletin, 42: 1-278.

Kennett, J. P. and Srinivasan, M. S. 1983. Neogene Planktonic Foraminifera, A Phylogenetic Atlas. New York: Hutchinson Ross Publishing, pp. 1-265.

Koley, T., Anju, C. S., Parhi, S. and Das, S. 2015. Report of foraminifera in the Andaman Flysch Group of rocks in South Andaman and its implication. Indian Journal of Geoscience, 70(2): 161-168.

Kundal, P. 2010. Biostratigraphic, paleobiogeographic and Paleoenvironmental Significance of Calcareous Algae. In: Kundal, P. and Humane, S.K. (Eds), Special issue on "Applied Micropaleontology", Gondwana Geological Magazine, 25 (1): 125-132.

McCaffrey, R. 1992. Oblique plate convergence, slip vectors, and fore-arc deformation, Journal of Geophysical Research, 97: 8905–8915, doi:10.1029/92JB00483.

Morley, C. K. 2017. Cenozoic rifting, passive margin development and strike-slip faulting in the Andamans sea: a discussion of established v. new tectonic model. Geological Society London Memoirs, 47: 27-50.

Morley, C. K. and Alvey, A. 2015. Is spreading prolonged, episodic or incipient in the Andaman Sea? Evidence from deepwater sedimentation. Journal of Asian Earth Science, 98: 446-456.

Nathan, S. A. and Leckie, R. M. 2003. Miocene planktonic foraminiferal biostratigraphy of Sites 1143 and 1146, ODP Leg 184, South China Sea. *In* Prell, W.L., Wang, P., Blum, P., Rea, D.K., and Clemens, S.C. (Eds.), Proc. ODP, Sci. Results, 184, 1-43

Oldham, R. D. 1885. Notes on the Geology of the Andaman Islands. Record Geological Survey of India, 18(3): 135-145.

Pal, T., Chakraborty, P. P., Dutta Gupta, T., Singh, C. D. 2003. Geodynamic evolution of an outer arc-fore arc in convergent margin of active Burma–Java subduction complex, a document from Andaman Islands, Bay of Bengal. Geological Magazine, 140: 289–307.

Pearson P. N. and Chaisson W. P. 1997. Late Paleocene to Middle Miocene planktonic foraminifer biostratigraphy of the Ceara Rise N.J. Shackleton, W.B. Curry, C. Richter, T.J. Bralower (Eds.), Proceedings of the Ocean Drilling Program: Scientific Results, 154, Ocean Drilling Program, College Station, Texas (1997),: 33-68

Raju, K.A. Kamesh, 2005. Three-phase tectonic evolution of the Andaman backarc basin. Current Science, 89(11): 1933-1937.

Raju, K.A. Kamesh, Ramprasad, T., Rao, P.S., Rao, B.R., and Varghese, J. 2004. New insights into the tectonic evolution of the Andaman Basin, northeast Indian Ocean. Earth Planet Science Letter, 221: 145–162.

Rao, P.S., Kamesh Raju, K.A., Ramprasad, T., Nath, B.N., Rao, B.R., Rao. Ch.M. and Nair, R. R. 1996. Evidence for hydrothermal activity in the Andaman Backarc Basin. Current Science, 70: 379-385.

Ray, K. K. 1982. A review of the geology of Andaman and Nicobar Islands. Memoirs Geological Survey of India, 41(2):110-125.

Rodolfo, K. S. 1969. Bathymetry and marine geology of the Andaman basin and tectonic implications for SE Asia. Geological Society of America Bulletin, 80: 1203–1230.

Shah, B. M., Nagendran, G., Vijaya Durga, N., Chakravarthi, D., Das, F. S., Mishra, R. K., Anupam Bara, Lukram Ingocha Meetei, Samgna, S., Durga Prasad, P., Titir Mukherjee, S. V. Gowtamaraju, M., Vasu, P., Danish Anwar, Reshma, A., Sandeep Routroy, Jha, A. K., Sanjay Kumar Verma, Ashalatha, C. P., V. Kailash Lahudas, Ramesh, P. J., 2015. Multichannel bathymetric mapping of a part of Central Andaman Trough and study of evolutionary history and possible locales of submarine hydrothermal mineralisation in the basin and surrounding area, (Cruise SR-002, FS 2013-2014), Geological Survey of India Report.

Spezzaferri, S. 1994. Planktonic foraminiferal biostratigraphy of the Oligocene and lower Miocene in the oceanic record. An overview. Palaeontographica Italiana, 81: 1-187.

Srinivasan, M. S. and Kennett J. P. 1981a. A review of Neogene planktonic foraminiferal biostratigraphy: applications in the equatorial and South Pacific: The Deep-Sea Drilling Project; A Decade of Progress; Spec Publ. Society of Economic Paleontologists and Mineralogists, 32: 395–432.

Srinivasan, M. S. and Kennett J. P. 1981. Neogene planktonic foraminiferal biostratigraphy and evolution: Equatorial to subantarctic, South Pacific, Marine Micropaleontology, 6: 499-533.

Srinivasan, M. S. 1977. Standard planktonic foraminiferal zones of the Andaman- Nicobar Late Cenozoic. In Recent Researches in Geology, 3. Hindustan Publishing Corporation, Delhi, pp.23-39.

Srinivasan, M. S. and Sharma, V. 1973. Stratigraphy and microfauna of Car Nicobar Island, Bay of Bengal. Geological Society of India, 14(1):11.

Stainforth, R. M., Lamb, J. L., Luterbacher, H., Beard, J. H., and Jeffords, R. M. 1975. Cenozoic planktonic foraminiferal zonation and characteristics of index forms. University of Kansas paleontological contributions, 62:1-425.

Tripathi S. K., Sathikumar R, Kaustubhakumari, J. B., Guha P. D, and Meitei S. I. 2019. Genesis and Morphotectonic Characterization of Crescent-Shaped feature from Alcock Rise, Andaman Sea. Bulletin of the Marine Geology, 34(2): 89 -114.

Tripathi, S. K. and Banerjee, K. 2016. First record of Limestone rock over Alcock Rise, Andaman Sea. www. gsi.gov.in, November, 1-5.