TEXTULARIID AND MILIOLID FORAMINIFERA FROM A 50-CM CORE SEGMENT FROM THE ARABIAN SEA

[1]Nimmy, P. M., [1*]Rajeshwara Rao, N., [1]Nandita Nandan, T., [2]Neelavannan, K. and [2]Hussain, S. M.
[1]Department of Applied Geology and [2]Department of Geology
University of Madras, Guindy Campus, Chennai 600 025, India

Abstract: The Arabian Sea is one of the most productive regions of the world ocean and hence has been the focus of attention of micropaleontologists from all over the world. A 5.4-m gravity core was retrieved onboard the *CRV Sagar Kanya* from off Goa, Arabian Sea, and its uppermost 50 cm examined for foraminifers. The systematic paleontology of textulariid and miliolid foraminifera from this core segment is presented with relevant remarks and comments on their ecology and distribution.

Keywords: Foraminifera; Taxonomy; Textulariids; Miliolids; Ecology; Arabian Sea.

Introduction: The seasonal reversal of the winds caused by the alternate heating and cooling of the Tibet Plateau controls the circulation in the Arabian Sea. It has, therefore, been extensively studied with respect to diverse aspects of both benthic and planktic foraminifers. Between June and September (summer), offshore Ekman transport and intense upwelling along the Oman and Somalia margins (Shi *et al.*, 2000) are caused by the strong south-westerly winds that blow across the Arabian Sea. This upwelling process brings cold, nutrient-rich waters from a few hundred meters depth to the surface and considerably increases the biological productivity in the euphotic zone, making the Arabian Sea one of the most productive regions of the world ocean (Qasim, 1977).

Previous studies: Perhaps the first study on Recent foraminifers from the Arabian Sea was by Chapman (1895), who reported 274 species from the *Investigator* collections made off the Laccadives. Later, a monograph of foraminifers from the Arabian Sea was published by Hofker (1930). Cushman's (1936) report on the occurrence of *Elphidium indicum* from the shore sands of Bombay Harbour was the earliest on foraminifers recovered from beach sands. Stubbings (1939) recorded about 300 species and varieties from the sediments collected by the John Murray expeditions off the Arabian Sea.

Kurian (1951) reported the occurrence of *Operculina granulosa* from coastal Travancore. Later, he (1953) recorded 22 species from the bottom sediments off the Travancore coast, within the 15 fathom (about 30 m) line. Chaudhury and Biswas (1954) reported 12 species of perforate foraminifers from the Juhu Beach sands, Bombay (present-day Mumbai). A couple of years later, Bhatia (1956) identified and recorded 46 foraminiferal taxa from the Chowpathy and Juhu beaches, near Bombay, and from the shore sands near Bhogat in Saurashtra. Sethulekshmi Amma (1958) reported 114 foraminiferal species from off the Travancore coast and its backwaters. Rocha and Ubaldo (1964a) studied and recorded 52 species of foraminifers, 22 of which were already known, from the dune and beach sands of Diu, Gogola and Simbor, Gujarat coast, and suggested weak terrigenous sedimentation based on the absence of agglutinated forms. They also (1964b) recorded 24 taxa from the Jampore and Baga areas of Goa.

A few years later, Antony (1968) studied the shelf water foraminifers off the Kerala coast and presented the bathymetric distribution of a few common species, out of the 164 taxa identified from the surface sediments. Kameswara Rao (1970a, b, 1971a) identified and illustrated 84 species belonging to 34 genera from the Gulf of Cambay. He (1970c) also reported a rare species, *Triloculina echinata* d'Orbigny, from the north-eastern part of the Arabian Sea. Subsequently, he (1971b) studied eight coretop samples from the same region and recorded 92 foraminiferal taxa belonging to 40 genera. During the same year, Seibold (1971) studied samples from the Cochin backwaters and provided sections and stereoscan microphotographs which revealed that only one species, *Rotalia beccarii* var. *sobrina* was a 'true' *Ammonia*.

A preliminary report on the transport of foraminifers into the Cochin backwaters was presented by Seibold (1972). Venkatachalapathy and Shareef (1972) reported pyritization in certain foraminifera from Recent sediments of Mangalore area. Guptha (1973a) published a preliminary report on the foraminiferal assemblages from the lagoon sediments of Kavaratti Atoll in the Laccadives, in which he identified 20 species of benthic foraminifera. Setty (1974) recorded 32 species of benthic foraminifera, including *Hyalinea balthica* from the shelf sediments of the Kerala Coast, along with a brief account of the important characters of each species. The following year, Antony (1975) recorded the occurrence of living *Ammonia beccarii* in the sediments of Kayamkulam Lake. This was followed by observations on the seasonal occurrence of *Rotalia beccarii* (Linne) in the Vembanad Estuary by Antony and Kurian (1975). Seibold (1975) reported 69 benthic foraminiferal species, including one new species, from the lagoon and coast of Cochin. The morphology, distribution pattern and wall structure of *A. beccarii* were discussed by Venkatachalapathy and Shareef (1975).

Bhatia and Kumar (1976) reported 35 benthic taxa from the inner shelf area around Anjediv Island, off Binge. Jain and Bhatia (1978) recorded 37 species of foraminifera, including one new species of *Pararotalia*, from the Mandvi area of Kutch. The Calangute Beach sands were examined for foraminifera by Bhalla and Nigam (1979) who reported 36 species and compared the fauna with eastern beaches. According to Setty *et al.* (1979), some foraminiferal genera such as *Ammonia*, *Elphidium*, *Trochammina*, *Bulimina*, *Bolivina*, *Nonion*, *Nonionella* and *Florilus* were dominant in the inner neritic zone (0 to 55 m water depth) off the central west coast of India; they presented their graphical distribution patterns. Antony (1980) recorded 17 species of living, intertidal foraminifera from the sandy beaches of the south-west coast of India.

Bhalla and Raghav (1980) identified 25 foraminiferal taxa from the Malabar Coast and suggested that salinity was the chief governing factor. Setty and Nigam (1980a) studied the distribution of 72 dead and 32 living benthic foraminiferal species within the neritic regime of the Dabhol-Vengurla region and suggested the existence of a microenvironment; they (1980b) also observed eccentricity and twinning in *Virgulinella pertusa* (Reuss). The relationship between organic carbon and foraminiferal assemblages in the sediment samples of the western Indian continental shelf was studied by Setty and Nigam (1982); their study revealed that *Ammobaculites agglutinans* (d'Orbigny) and *Ammonia* spp. exhibited a positive relationship with organic carbon. On the other hand, *Quinqueloculina* spp., *Spiroloculina* spp., *Triloculina* spp., *Florilus-Nonion* and *Nonionella* spp. showed an inverse relationship.

Setty *et al.* (1984) recorded 44 benthic foraminiferal species from the Miramar-Caranzalem intertidal shoreline. Srivastava *et al.* (1984) reported 26 species of benthic foraminifera from the beach sands near Veraval, Saurashtra Coast, and concluded the assemblage to be typical of warm waters. Nigam (1984), while observing the response of living benthic foraminifera in a high tidal environment, Gulf of Khambat, recorded 60 species of which 16 were living taxa. Bhalla and Lal (1985) presented a preliminary note on Recent foraminifera from the Okhla Beach sands, Gujarat, in which they identified 18 taxa and compared the fauna with those from other western beaches.

The lagoonal sediments of Agatti, Kavaratti, Suhelipar and Minicoy atolls of the Laccadives were examined for foraminifera by Kameswara Rao *et al.* (1987); they identified 107 species and observed that the fauna was dominated by calcareous forms. The rare occurrences of arenaceous forms were attributed to the coarse nature of the sediments. Srivastava *et al.* (1985) observed that the foraminiferal assemblages from Kavaratti Island were dominated by hyaline forms with subsidiary porcelaneous and agglutinated taxa. Bhalla and Gaur (1986; 1987) made a detailed and systematic study of 29 Recent foraminifera from the Colva Beach sands, Goa. Shareef and Venkatachalapathy (1988) recorded 40 foraminiferal taxa from Bhatkal Island, and 41 species from Devgad Island shore sands. The reciprocity between coiling direction and dimorphic reproduction in benthic foraminifera was demonstrated by Nigam and Khare (1992).

A 26.5-m core collected from the outer shelf area off Bombay at 75 m water depth was studied by Nigam *et al.* (1992). They found ooids and shallow-water benthic foraminifera throughout the core and inferred that the sea level had transgressed considerably prior to 10,000 years B.P. By comparing with global events, they also deciphered that the sea level was at 101.5 m below the present-day level ~14,500 years B.P. In order to understand the paleoenvironmental setting of the nearshore area of the central west coast of India, Gujar and Guptha (1993) analyzed three vibro cores for sedimentological, mineralogical and foraminiferal aspects. They opined that the early Holocene was dry and arid, while the mid-Holocene was moist and humid, as reflected by the abundances of *Florilus scapha* and *Ammonia beccarii* in the dry and humid phases, respectively.

Surface sediment samples in a water depth range of 15 to 1,750 m off the west coast of India indicated the presence of abundant relict foraminiferal specimens encrusted with the sessile cirripedes, *Tetraclita squamosa*, at depths between 60 and 90 m (Nigam *et al.*, 1993). Dominance of the relict foraminiferal assemblage by reefal species, *Amphistegina* and *Nummulites*, oolite-rich sediment and ^{14}C date of ~9,000 to 11,000 years B.P. were considered reliable indicators of paleosea-levels. Khare (1994) reported the occurrence of *Pavonina flabelliformis* for the first time from shallower depths, off Karwar, and updated its lower water depth limit to 33 m as opposed to greater depth records in previous studies. The effects of river discharge on morphogroups of 148 benthic foraminiferal species were studied by Nigam and Khare (1994) from the Karwar area. Khare (1995) recorded eight benthic foraminiferal taxa, from off Karwar, for the first time from the Arabian Sea.

Variations in the mean proloculus size (MPS) of the benthic foraminifer, *Rotalidium annectens*, were studied by Nigam and Khare (1995) from a core collected off Karwar at a water depth of 20 m. Comparison with downcore variations in the MPS with 100-year rainfall data (5-year average) revealed a direct correlation between the two, implying that their correspondence was of high potential in the reconstruction of paleo-precipitational history. Benthic foraminifera from 45 surface sediment samples (20 to 86 m water depth) off Mangalore were classified by Khare *et al.* (1995) into two morpho-groups: angular-asymmterical and rounded-symmetrical. They observed the former to be abundant in relatively deeper waters, while the latter dominated the nearshore regions, and suggested that rounded-symmetrical forms favour high turbulence associated with enhanced fresh water riverine discharge in shallow regions.

A 1.15-m long core, collected from 20 m water depth off Karwar on the western continental shelf of India was studied by Nigam *et al.* (1995) to reconstruct the paleomonsoonal precipitational history during the recent past with fine time resolution by exploiting foraminifera as proxy. Their attempts to establish correlation between inferred paleomonsoonal precipitation with known climatic cycles affecting the earth's climate suggested a possible link with the Gleissberg solar cycle of ~80 ± 10 years. Kameswara Rao (1996) recorded 60 foraminiferal species belonging to 38 genera and 23 families from grab sediment samples of the Cochin backwaters. They observed that *Ammonia beccarii* was the most dominant and successful form in a wide range of salinity fluctuating between 3.27 and 35.96‰.

Kameswara Rao and Balasubramanian (1996) identified 78 foraminiferal species from the Cochin Estuary and observed that the abundance and total populations were poor during the south-west monsoon season; they attributed this to reduced salinity due to increased freshwater influx through river water. Chaturvedi *et al.* (2000) studied surface sediment samples from the Kharo Creek, Kachch, Gujarat, and identified 44 benthic foraminiferal species. They observed that the foraminiferal distribution was mainly controlled by organic carbon, suspended load, substrate nature and tidal influences. The foraminifera from beach sands along the Saurashtra Coast, north-west India, were examined by Kameswara Rao and Srinath (2002), who identified 107 species. Their study showed that *Ammonia beccarii* (Linné) variant was the dominant and most widely distributed species of the coast. They also discussed the relationship between the abundance of foraminifers and median grain size of the sediment substrate.

Assemblages of living deep-sea benthic foraminifera, their densities, vertical distribution pattern, and diversity, were investigated in the inter-monsoon period after the northeast monsoon in the Arabian Sea in spring 1997 (Heinz and Hemleben, 2003). They observed foraminiferal numbers to show a distinct gradient from north to south, with a maximum of 623 foraminifera in 50 cm^3 at the northern site. Most stations showed a typical vertical distribution with a maximum in the first centimeter and decreasing numbers with increasing sediment depths.

Analysis of benthic foraminiferal contents in 128 surface sediment samples off Goa revealed the abundance of species belonging to the genera *Bolivina*, *Cassidulina*, *Lernella*, *Uvigerina* and *Eponides* in a water depth range of 150 to 1,500 m, a zone considered to be the oxygen minima zone (OMZ) in the Arabian Sea (Mazumder *et al.*, 2003). Foraminiferal studies on a shallow water sediment core off Karwar, central west coast of India, by Khare and Nigam (2006) revealed significant changes in the monsoonal precipitation during the last around 720 years. Their results hinted at some possibility of a linkage between monsoonal precipitation and solar variability during this period.

Nigam and Chaturvedi (2006) examined 134 subsurface sediment samples from three cores collected along the coast of Kachchh, off Gujarat, and 151 foraminiferal species. Q-mode cluster analysis on foraminiferal data for each core and radiocarbon dating at ten different downcore depths revealed an inverted sequence, with fine-grained sediments and small foraminifers sandwiched between normal detrital sediments at water depths of 10–20 m. They hypothesized that the erosion and transportation of fine-grained sediments from deeper water, and their deposition in shallower water against the rule of gravity, are the result of storm/tsunami influence.

Bhalla *et al.* (2007) reviewed the published literature on foraminiferal investigations on nearshore, shallow-water regions up to a depth of 50 m along the west coast of India, including the Laccadive Archipelago. Their review showed that most of the studies had been focused on taxonomical and/or ecological aspects, although other application-oriented studies had also been initiated. The response of rectilinear bi- and triserial benthic foraminifera (RBF) to oxygen-depleted conditions in the Arabian Sea was studied by Nigam *et al.* (2007), who observed that the intermediate depth zone of increased abundance of RBFs coincided with the prominent intermediate water OMZ of the Arabian Sea. They proposed that the increased abundance of RBFs could be used as an indicator of oxygen-depleted conditions in the Arabian Sea.

Saraswati (2007) recorded 11 genera of symbiont-bearing benthic foraminifera from the lagoonal waters of the Laccadives, and opined that the assemblage was comparable with any other high diversity reef assemblages of the Indian and Pacific oceans. He also speculated that the species diversity could be even higher if a detailed study of the fore-reef areas could be carried out. Based on granulometric and foraminiferal studies on a 2-m-long, shallow-water sediment core, representing the last 2,500 years, collected from the tropical Arabian Sea from the inner shelf (22 m water depth) off Karwar, near the mouth of the Kali River, Khare *et al.* (2008) inferred a considerable decrease in the intensity of monsoons approximately around 2,000 years B.P., which was followed by an increase in the intensity of the precipitation around 1,000 years B. P.

Intertidal foraminifera in the Narmada and Tapti macro-tidal estuaries of the Gulf of Cambay were studied by Ghosh *et al.* (2009), who observed that foraminifers were widely distributed in the sand flats, mud flats and marshes at the mouths of the estuaries; the overall foraminiferal assemblage was, however, low in diversity. In their study on the sediment samples of Ashtamudi Estuary, Kerala, Nagendra *et al.* (2011) identified 29 foraminiferal species belonging to 17 genera and attributed the low diversity and low frequency of foraminifers in the eastern, western and southern parts of the estuary to inhospitable microniches possibly caused by coir husk retting activities. Estuarine foraminifera from the Gulf of Cambay were studied by Ghosh (2012), who observed a low diversity, epifaunal to infaunal foraminiferal assemblage widely distributed in the sand flats, mud flats and marshes along the coastal tracts of the gulf. Interestingly, he recorded the presence of a triserial planktic foraminifer, *Gallitellia vivans*, an indicator of stressed and upwelling areas, in the estuaries.

Analysis of foraminiferal content in 103 surface sediment samples collected from the water depth range of 15-3,300 m along the Vijaydurg-Karwar stretch of the central west coast of India by Mazumder *et al.* (2012) revealed the occurrence of a relict benthic foraminiferal assemblage at 50 to 135 m water depth. Based on the occurrence of the genera *Amphistegina*, *Operculina* and *Alveolinella*, they inferred the presence of coral reef at this depth during early Holocene. This inference was vindicated by the presence of barnacle fouling on relict foraminifers at 60 to 90 m water depth. Bharti and Singh (2013) reported *Bulimina arabiensis*, a new species of benthic foraminifera from the Arabian Sea, and opined that its morphological characteristics suggest its preference for infaunal microhabitat and low bottom water oxygen. They stated that its downcore abundance pattern is suggestive of controls by both paleoproductivity and bottom oxygen conditions. Mazumder and Nigam (2014) analyzed foraminiferal contents in 52 surface sediment samples collected from the region off Goa, central west coast of India from water depths of 15–3,300 m. Their study focused on the individual distribution of four rectilinear foraminiferal genera, namely *Fursenkoina*, *Bolivina*, *Bulimina* and *Uvigerina* in the OMZ and recorded their bathymetric preferences within this zone. Rose-Bengal-stained foraminiferal assemblages (>150 µm) were analyzed along a five-station bathymetric transect across the core and the lower part of the oxygen minimum zone (OMZ) on the Indian margin of the Arabian Sea (Caulle *et al.*, 2014; 2015). They observed that similar species were found at sites with comparable bottom-water oxygen concentrations but with very different surface water productivity, suggesting that, within the strongly developed Arabian Sea OMZ, bottom water oxygen concentration, and not the organic flux to the sea floor, is the main factor controlling the species composition of the foraminiferal communities.

Methodology: A 5.4-m long core was retrieved onboard the *CRV Sagar Kanya* off Goa, Arabian Sea, at a water depth of 517 m (Fig. 1). The core was sub-sampled at 2-cm intervals and 25 sub-samples comprising the uppermost 50 cm were selected for the present study. Each of the 25 sub-samples was subjected to deflocculation (made to stand overnight) using distilled water. The sub-samples were then wet-sieved through ASTM 230 mesh (opening = 63 µm) to remove the mud content (silt + clay). The sub-samples were then oven-dried at 50° C. It was observed that the residue had very little sediment (sand content) and was almost entirely comprised of several foraminiferal tests, few ostracod carapaces, diatoms and radiolarians. There was, therefore, no need for grain size-based fractionation of the sub-samples. The dried sub-samples were examined under a stereo zoom binocular microscope (NOVEX-Holland), and all the foraminiferal tests were hand-picked using a soft-bristled 0.00 brush.

The hand-picked foraminiferal tests from each sub-sample were transferred to 24-chambered micro-paleontological slides and mounted over a thin layer of gum tragacanth according to the family, genus and species, wherever possible. The different genera and species were identified; type specimens of each species were selected and transferred to single, double or four-round punch microfaunal slides with cover slips. For identifying the hypotypes at the generic level, Loeblich and Tappan's (1988) classification was used. Individual species were identified with the help of various atlases, monographs and research publications available in the personal collections of Prof. Rajeshwara Rao.

The hypotypes selected were mounted on aluminium stubs of 2.5-cm diameter and were sputter-coated with gold for 60 to 120 seconds (Cressington Sputter Coater-108 Auto). The stubs were then placed in the vacuum chamber of the SEM (HITACHI–3400M) and the specimens of selected species were photographed at the desired magnification in the Center for Advanced Studies in Botany, University of Madras, Chennai (Plate 1). All the hypotypes were duly indexed with numbers and placed in the repository of the Department of Applied Geology, University of Madras, Chennai 600 025 (NNT-AG-001 through 013).

Systematic Paleontology: In the following pages, the systematic paleontology of 13 benthic foraminiferal species is presented. Five are arenaceous, agglutinated taxa of the suborder Textulariina, while the remaining 8 are calcareous, imperforate, porcelaneous forms belonging to the suborder Miliolina.

Order FORAMINIFERIDA Eichwald, 1830

Suborder TEXTULARIINA Delage and Hérouard, 1896
Superfamily SPIROPLECTAMMINACEA Cushman, 1927
Family SPIROPLECTAMMINIDAE Cushman, 1927
Subfamily SPIROPLECTAMMININAE Cushman, 1927
Genus SPIROPLECTAMMINA Cushman, 1927
Spiroplectammina taiwanica Chang, 1956
Pl. 1; Fig. 1

Original citation: *Spiroplectammina taiwanica* CHANG, 1956, p. 67, pl. 1, figs. 1–11.

Remarks: This species was reported by Langer (1993) as *Spiroplectinella taiwanica* Chang. He classified phytal species into four morpho-types and categorized this species under 'D' implying that the species is permanently motile and epiphytal.

Repository: NNT–AG–001

Genus SPIROPLECTINELLA Kisel'man, 1972
Spiroplectinella wrightii (Silvestri, 1903)
Pl. 1; Figs. 2, 3

Original citation: *Spiroplecta wrightii* SILVESTRI, 1903, p. 59, text-figs. 1–6.

Remarks: *Spiroplectinella wrighti* can be distinguished from *Textularia sagittula* by its more flattened tests. This infaunal (Corliss, 1991) species has been recorded by Di Bella (2010) to be rare in Plio-Pleistocene foraminiferal assemblages of the Monte Mario site in Rome, Italy. According to Spezzaferri *et al.* (2014), *S. wrightii* is present in the coral rubble, sediment clogged coral and mud facies along the Norwegian margin and generally in the off-mound and dead coral facies in the Porcupine/Rockall region.

Repository: NNT–AG–002

Superfamily TEXTULARIACEA Ehrenberg, 1838
Family TEXTULARIIDAE Ehrenberg, 1838
Subfamily TEXTULARIINAE Ehrenberg, 1838
Genus TEXTULARIA Defrance, 1824
Textularia porrecta (Brady, 1884)
Pl. 1; Figs. 4, 5

Original citation: *Textularia agglutinans* D'ORBIGNY var. *porrecta* BRADY, 1884, v. 9, p. 364, pl. 43, figs. 4a, b.

Remarks: The types for this species came from the Torres Strait at a depth of 283 m, and were described originally by Brady (1884) from specimens found on the coral reefs of the South Pacific Ocean. Heron-Allen and Earland (1922, p. 119) considered *T. porrecta* to be a link between *T. agglutinans* and *T. sagittula* occurring in the New Zealand region and remarked, "These N.Z. specimens appear to link up two widely differentiated species, *T. sagittula* and *T. agglutinans*. In their compressed cuneiform outline, spiroplectine initial chambers, and fistulosity, they closely indicate a relationship to *T. sagittula*, Defrance, whereas the inflated later chambers and the oval, or nearly circular, cross-section of the later plan are characteristic of *T. agglutinans*". Brady (1884) and several other New Zealand workers (Topping, 1973; Adams, 1979; Wells, 1985) used *T. porrecta* to refer only to those specimens with rounded chambers throughout. According to Szarek (2001), this cosmopolitan species with calcareous cement has a bathymetric range of upper to middle bathyal on the Sunda Shelf; it is present on the continental shelf of the Gulf of Mexico (Sen Gupta *et al.*, 2009). Goineau *et al.* (2012) stated that the additional input of riverine organic matter after a major flood event can be beneficial for taxa such as *Textularia porrecta*, which are "visibly able to thrive in environments submitted to a noticeable riverine influence".

Repository: NNT–AG–003

Textularia sagittula d'Orbigny, 1839
Pl. 1; Figs. 6, 7

Original citation: *Textularia sagittula* D'ORBIGNY, 1839, p. 138, pl. 1, figs. 19–21.

Remarks: In their studies on the foraminifers from the Mediterranean Sea, Cimerman and Langer (1991) remarked, "As *Textularia sagittula* is both initially planispiral and perforate by minute parapores (see also Le Calvez, 1974, pp. 82–84), it must be placed in *Spiroplectinella* Kisel'man (compare Hottinger *et al.*, 1990 and Bender, 1989)". Recently, however, this species has been reverted to the genus *Textularia* and, accordingly, the forms from the core examined have been assigned to *Textularia*. According to Biswas (1976), *T. sagittula* (=*Spiroplectinella sagittula*) has a bathymetric range of 120 to 200 m on the Sunda Shelf, Indonesian Archipelago. As it is an indicator of well oxygenated bottom waters and low concentrations of organic carbon in the sediment, *T. sagittula* is one of the species used in the computation of the benthic foraminiferal oxygen index (BFOI). Hohenegger *et al.* (1993) recorded a patchy distribution of *T. sagittula* in the surface sediments of the shallow sub-tidal Gulf of Trieste, northern Adriatic Sea. They also stated that this species seemed to actively burrow in anoxic sediment. Schönfeld (2002), however, opined that this species is epibenthic and is capable of using elevated microhabitats. According to Buosi *et al.* (2012), *T. sagittula* is one of the most abundant benthic foraminifera in the surface sediments of the current-dominated Strait of Bonifacio, Mediterranean Sea, and its distribution is closely linked with bathymetry. Mazumder *et al.* (2012) recorded this species as an important constituent (maximum abundance of 28.13%) of the relict assemblage present in a water depth range of 50 to 135 m off the Vijaydurg-Karwar sector of the central west coast of India. *Textularia sagittula* was observed by Suresh Gandhi *et al.* (2016) to be rare on the shallow inner shelf off Colachel, south-east coast of India.

Repository: NNT–AG–004

Textularia truncata Höglund, 1947

Original citation: *Textularia truncata* HÖGLUND, 1947, pp. 175, 176, pl. 12, figs. 8, 9, text-figs. 147–149.

Remarks: Höglund reported this species from the Gullmar, Fijord and the Skaggerak. It is common in the Tasman Sea, around New Zealand, Mediterranean Sea and Norwegian Sea. *Textularia truncata* possesses calcareous cement (Murray and Alve, 2000; Murray, 2003). According to Murray (2006), the inner and middle temperate shelf areas extending from the Skagerrak to Portugal, including the Adriatic, are affected by tidal currents and periodically by storm waves. The distribution of key species reflects these different energy conditions. High-energy areas have coarse sediment which may include gravel-grade material that provides a substrate for attachment of foraminifera and also for hydroids, bryozoa, etc., to which foraminifera may attach. Typical assemblages of these environments are dominated by *Textularia sagittula*, *T. truncata* and several others. Debenay (2012) gave a bathymetric range of 10 to 200 m off New Caledonia in the south-western Pacific Ocean.

Repository: NNT–AG–005

Suborder MILIOLINA Delage and Hérouard, 1896

Superfamily MILIOLACEA Ehrenberg, 1839

Family SPIROLOCULINIDAE Wiesner, 1920

Genus SPIROLOCULINA d'Orbigny, 1826

Spiroloculina communis Cushman and Todd, 1944

Pl. 1; Figs. 8, 9

Original citation: *Spiroloculina communis* CUSHMAN and TODD, 1944, pp. 63, 64, pl. 9, figs. 4, 5, 7 and 8.

Remarks: This species was originally described by Cushman and Todd (1944), with its types coming from off the San Andreas Island, Philippines, at a depth of 91 m. Hatta and Ujiie (1992) recorded and illustrated this species from the coral seas between Ishigaki and Iriomote Islands, Southern Ryukyu Island Arc, north-western Pacific Ocean and remarked, "This species shows broad variation in test outline from roundly ovate to rather elongate, in test periphery from concave to slightly convex, and in suture-elevation; these characters are most prominent in its variety, *incisa*. In a single species population, however, these variable morphologies gradually change. As illustrated here (pl. 5, fig. 4c), the aperture is furnished by a T-shaped tooth on the inner margin and another same-shaped tooth on the opposite margin, sometimes, agreeing with the original description of the species". We have observed the presence of two diametrically opposite teeth in our specimens of *S. communis*, but not in all. According to Sen Gupta *et al.* (2009), *Spiroloculina communis* is a cosmopolitan species with a very wide bathymetric range in the Gulf of Mexico (8 to 370 m), occurring in the south-eastern and south-western parts of the gulf. This epifaunal species has been classified as an oxic indicator and its presence indicates oxygen levels >2 ml/L (Kaminski, 2012).

Repository: NNT–AG–006

Family HAUERINIDAE Schwager, 1876

Subfamily SIPHONAPERTINAE Saidova, 1975

Genus AMMOMASSILINA Cushman, 1933

Ammomassilina alveoliniformis (Millett, 1898)

Original citation: *Massilina alveoliniformis* MILLETT, 1898, p. 609, pl. 13, figs. 5–7.

Remarks: The types for this species came from the Malay Archipelago (Millett, 1898). Henriques (1993) studied the distribution of foraminifera in surface sediments off the central west coast of India and recorded *Ammomassilina alveoliniformis* to be rare (<1%). *Ammomassilina alveoliniformis* was found to occur in the reef lagoonal system of Moorea Island (Le Calvez and Salvat, 1980); it was also recorded, albeit rarely, in the hemipelagic mud beside hydrothermal vents at a depth of 2,430 m in the north-east Pacific (Jonasson *et al.*, 1995). According to Szarek (2001), it has a bathymetric range of inner shelf to upper bathyal on the Sunda Shelf. *Ammomassilina alveoliniformis* has a bathymetric range of 19 to 22 m in the south-eastern part of the Gulf of Mexico (Sen Gupta *et al.*, 2009); it has been recorded from the Caribbean, Pacific and Indian oceans.

Repository: NNT–AG–007

Subfamily HAUERININAE Schwager, 1876

Genus QUINQUELOCULINA d'Orbigny, 1826

Quinqueloculina polygona d'Orbigny, 1839

Pl. 1; Figs. 10–12

Original citation: *Quinqueloculina polygona* D'ORBIGNY, 1839, p. 198, pl. 12, figs. 21–23.

Remarks: The types for this species came from Cuba and Jamaica (d'Orbigny, 1839). The large size, laterally compressed chambers that are rectangular in cross-section, minutely pitted nature of the wall, and the squarely truncate periphery are characteristic features of this species. *Quinqueloculina polygona* is a stenohaline species and has low resistance to low concentrations of oxygen (Todd and Brönnimann, 1957; Boltovskoy, 1965). It differs from *Siphonaperta hallocki* Förderer and Langer, 2016 in its smooth and shiny surface, the pronounced carinae and the less inflated chambers. *Quinqueloculina polygona* is a common component of an assemblage that is characteristic of samples with mud content >30% that are associated with the South Bahia coral reefs in Brazil (Araújo and Machado, 2008). According to Sen Gupta *et al.* (2009), *Q. polygona*, a cosmopolitan species, has a bathymetric range of 0 to 324 m and is present in the entire Gulf of Mexico.

Repository: NNT–AG–008

Subfamily MILIOLINELLINAE Vella, 1957

Genus PYRGO Defrance, 1824

Pyrgo laevis Defrance, 1824

Pl. 1; Fig. 13

Original citation: *Pyrgo laevis* DEFRANCE, 1824, v. 32, p. 273, pl. 88, fig. 2.

Remarks: The types for this species came from the Pliocene Caloosahatchee marl, Caloosahatchee River, Fla in Italy (Defrance, 1824). Hofker (1978) recorded *Pyrgo laevis* only at one station in the Gulf of Bone, in the eastern part of the Indonesian Archipelago, at a water depth of 1,374 m. According to Henriques (1993), this rare species (<1%) occurs only at a few stations in the surface sediments off the central west coast (Vengurla-Mangalore) of India in the depth range of 44 to 332 m. This species is quite rare in the core segment studied. *Pyrgo laevis* was also observed to be rare on the inner shelf off Karikkattukuppam, south of Chennai (Rajeshwara Rao, 1998). From the available data, it seems that *P. laevis* has a wide bathymetric range, from the inner shelf to lower bathyal depths.

Repository: NNT–AG–009

Pyrgo oblonga abdosulcatus Rajeshwara Rao, 1998

Original citation: *Pyrgo oblonga* (D'ORBIGNY) var. *abdosulcatus* RAJESHWARA RAO, 1998, pp. 102, 103, pl. 18, figs. 4, 5.

Remarks: Quite a few specimens were obtained in the core segment studied which exhibited the features of *Pyrgo oblonga* (d'Orbigny) consistently. An additional feature is the characteristic sulcus at the aboral end and, therefore, forms that possess the sulcus were placed under the new subspecies erected by Rajeshwara Rao (1998) based on specimens obtained from the inner shelf, off Karikkattukuppam, at water depths ranging from 45 to 55 m.

Repository: NNT–AG–010

Subfamily SIGMOILINITINAE Luczkowska, 1974

Genus SPIROSIGMOILINA Parr, 1942

Spirosigmoilina tenuis (Cžjžek, 1848)

Pl. 1; Fig. 14

Original citation: *Quinqueloculina tenuis* CŽJŽEK, 1848, p. 149, pl. 13, figs. 31–34.

Remarks: Todd and Brönnimann (1957) recorded this species from the eastern Gulf of Paria, Trinidad, as *Sigmoilina tenuis*. It is a typically deep-water species. Some confusion exists about the generic name. Jones (1994) regards *Sigmoilinita* Seiglie, 1965 as a junior synonym of *Spirosigmoilina* Parr, 1942 and refers *Sigmoilinita tenuis* (Cžjžek), the type species, to *Spirosigmoilina tenuis*. Both genera have initial chambers added in a sigmoiline series, and the later whorls are planispiral (Sen Gupta *et al.*, 2009). Hayward (1981) studied benthic foraminiferal associations with macrofauna (bivalves, polychaetes etc) in the Tutukaka Harbor, New Zealand, and observed *Spirosigmoilina tenuis* to be associated with fine sandy and muddy substrates at shallow depths ranging between 0.8 and 11 m. Szarek (2001) studied the biodiversity and biogeography of recent benthic foraminiferal assemblages on the Sunda Shelf and stated that this species occurs in the entire bathymetric range. According to Sen Gupta *et al.* (2009), who recorded this species as *Sigmoilinita tenuis* (Cžjžek), it is a cosmopolitan species occurring throughout the Gulf of Mexico in a very wide water depth range of 1 to 3,237 m. This species resembles *Quinqueloculina microcostata* Natland, in having ovate chambers but differs in having sigmoid coiled chambers (Obaje and Okosun, 2013).

Repository: NNT–AG–011

Spirosigmoilina pusilla (Earland, 1934)

Pl. 1; Fig. 15

Original citation: *Spiroloculina pusilla* EARLAND 1934, p. 47, pl. 1, figs. 3, 4.

Remarks: The figures illustrated by Brady (Barker, 1960) are of a specimen recovered from the sediment dredged at Challenger Station 332, in the South Atlantic Ocean, at a depth of 2,200 fathoms (~4,023 m). *Spirophthalmidium pusillum* was referred by Brady (1884) to *Spiroloculina tenuis* (Cžjžek), while Earland (1934, p. 47) referred it to *S. pusilla* nov. Later, Cushman and Todd (1944, p. 76) transferred it to *Spirophthalmidium* Cushman, 1927. Szarek (2001) studied the biodiversity and biogeography of recent benthic foraminiferal assemblages on the Sunda Shelf and stated that *Spirosigmoilina pusilla* has a water depth range of inner shelf to upper bathyal. According to Hayward *et al.* (2010), this species has a bathymetric distribution of lower bathyal-mid abyssal (1,000 to 4,000 m), off New Zealand.

Repository: NNT–AG–012

Subfamily SIGMOILOPSINAE Vella, 1957

Genus SIGMOILOPSIS Finlay, 1947

Sigmoilopsis schlumbergeri (Silvestri, 1904)

Original citation: *Sigmoilina schlumbergeri* SILVESTRI, 1904, v. 22, p. 267, pl. 7, figs. 12–14; p. 481, text-fig. 6; p. 482, text-fig. 7.

Remarks: This species was referred by Brady (1884) to *Planispirina celata* (Costa), and by Silvestri (1904, p. 267) to *Sigmoilopsis schlumbergeri*. Finlay (1947, p. 270) erected the genus *Sigmoilopsis* with *S. schlumbergeri* (Silvestri) as the genotype. Hayward *et al.* (2001) studied the depth distribution of Recent deep-sea benthic foraminifera east of New Zealand and gave a water depth range of 750–2,700 m for this species.

Repository: NNT–AG–013

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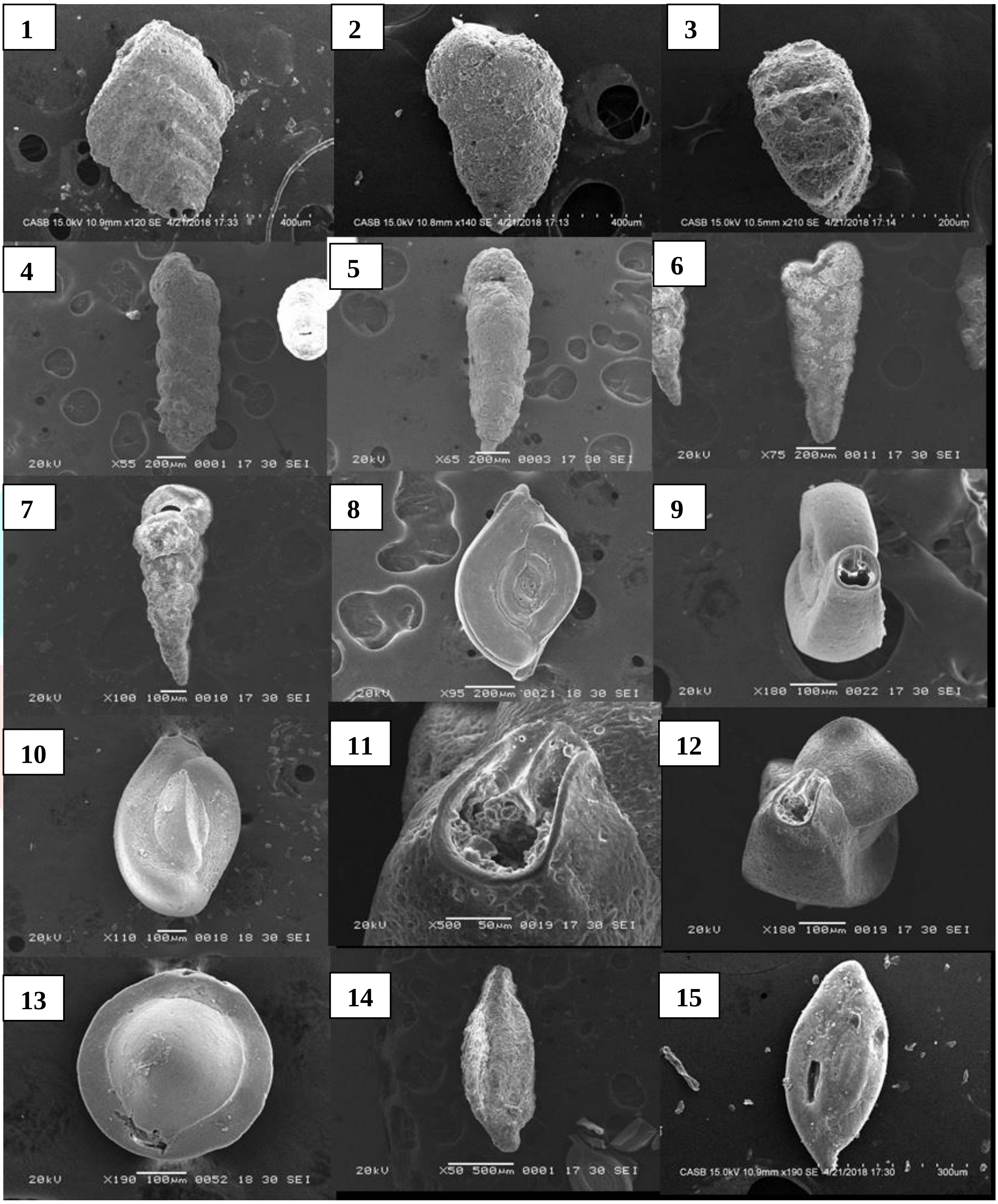
PLATE 1



Explanation for Plate 1

1: *Spiroplectammina taiwanica*, side view, x120; **2**. *Spiroplectinella wrightii*, side view, x140; **3**. *S. wrightii*, apertural view, x210; **4**. *Textularia porrecta*, side view, x55; **5**. *T. porrecta*, apertural view, x65; **6**. *Textularia sagittula*, side view, x75; **7**. *T. sagittula*, peripheral-apertural view, x100; **8**. *Spiroloculina communis*, side view, x95; **9**. *S. communis*, apertural view, x100; **10**. *Quinqueloculina polygona*, side view, x110; **11**. *Q. polygona*, magnified apertural view, x500; **12**. *Q. polygona*, apertural view, x100; **13**. *Pyrgo laevis*, side view, x190; **14**. *Spirosigmoilina tenuis*, peripheral view, x50; **15**. *Spirosigmoilina pusilla*, side view (inverted), x190.

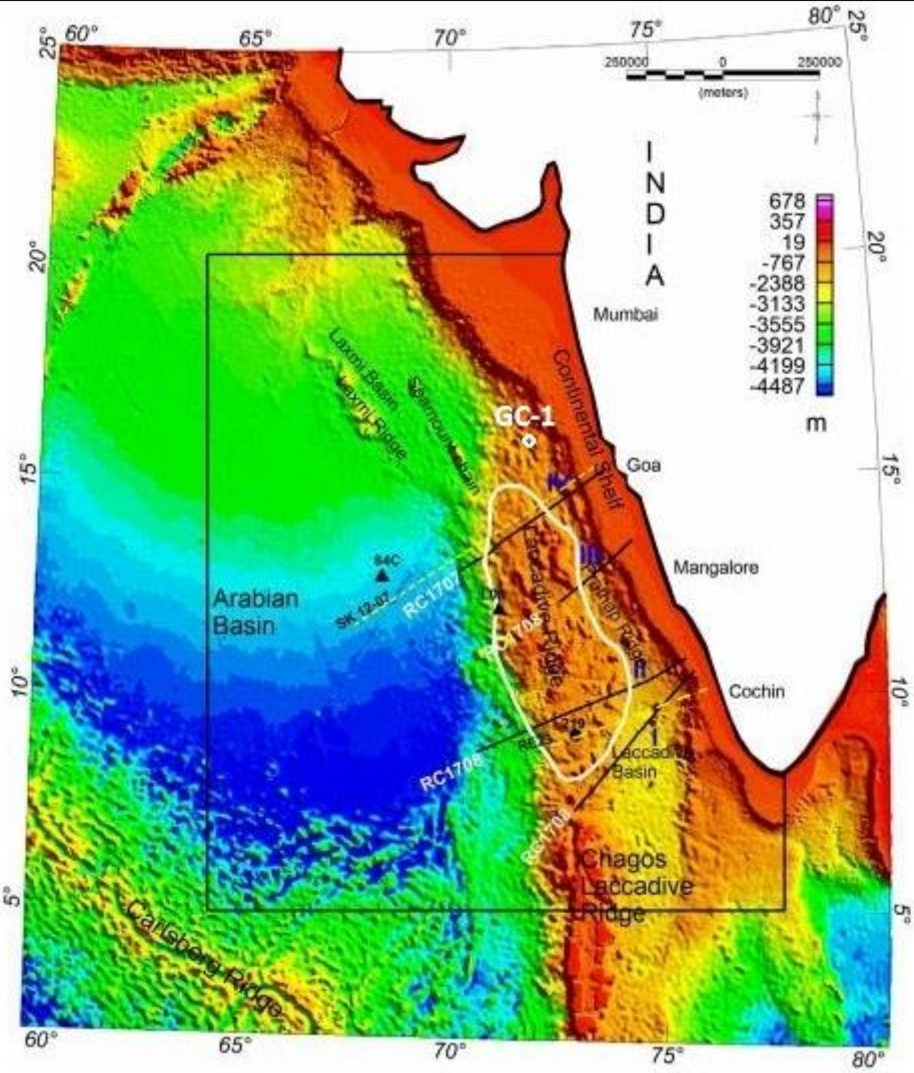


Figure 1. Map of the study area showing the core location (GC-1). *Source:* Nair *et al*. (2013)