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NEOGENE/QUATERNARY BOUNDARY IN INDIAN BASINS*

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ABSTRACT

The Neogene/Quaternary boundary in many parts of the Indian subcontinent has so far been defined principally on non-marine data, barring the studies in Andaman Islands. A correlation between the Lower Pleistocene type area in Italy and equivalent marine sediments on the Western and Eastern continental shelves and the coastal sediments have been attempted for the first time in this paper based on the changes associated with the appearance of *Globorotalia truncatulinoides*.

The criterion of climatic deterioration marking the base of Mediterranean Quaternary are tenable neither in the fresh-water nor marine shelf sediments of India although widespread occurrence of *Operculina ammonoides* and *Nummulites venosus* appearing with *Globorotalia truncatulinoides* proves quite helpful for a practical correlation of Quaternary base on the Indian Shelf. This level marks the onset of Pleistocene transgression on the shelves after a hiatus in the Early Pleistocene. In the fresh-water Siwalik mammalian chronology, this is a level of non-event.

In India, a strong boundary-event equally recognizable in the marine and fresh-water sediments, lies close to Gaus/Matuyama Chron boundary, i.e. around 2.4 Ma. It triggers a major regression or a strong fall of sea level on the shelf and an activation of volcanism in the Himalayan belt associated with first entry of migrant *Equus* in the Siwalik sediments. It is a more suitable datum for N/Q boundary in India in contrast to the faunistically ill-defined Olduvai subchron boundary in the Mediterranean.

INTRODUCTION

A definition of the Neogene/Quaternary boundary in different Indian basins has been attempted by different authors (Niyogi, 1979; Prasad, 1979; Rajaguru, 1979; Rao *et al.*, 1979; Verma, 1979; Sastry, 1979; Sastri *et al.*, 1981; Rao, 1988; Srinivasan, 1979, 1981). A precise demarcation of this boundary on micro-biostratigraphic criteria has so far been obtained only in Andaman islands (Srinivasan, 1979, 1988) where a modest break at this level is inferable. Very lately Rao (1988) has tied up bio-and magnetochronologic levels in the Siwalik Series for accurate definition of the boundary, although magnestostratigraphic studies on the N/Q boundary in the Siwalik have been persued for quite some time (Yokoyama, 1981; Tandon *et al.*, 1984; Rao *et al.*, 1988).

A large amount of subsurface data collected by ONGC, however, has not been considered in the above studies. This paper deals with the data generated from sub-crops, including the continental shelves and both the coasts of the Indian Peninsula. This paper also aims at correlating important tectonic and environmental changes in the outcropping and subsurface Late Tertiary-Quaternary beds in major parts of the country so that regionally important geological isochronous events are established.

In the surface and subsurface Cenozoic sequences of India worked out by the Oil & Natural Gas Commission (India), the Neogene/Quaternary boundary falls within well defined marine strata only in some of the offshore wells. In most of the coastal wells, in the Cambay Basin of Gujarat, and in a large tract of Northern India, between Punjab and Tripura the well-columns at the Neogene/Quaternary boundary pass through nonmarine strata without any diagnostic faunal change.

The subsurface correlation tools enable a viable correlation between the geological events around the marine Neogene/Quaternary boundary in the far offshore areas of the Indian shelf and the coastal areas. This correlation also reflects gross geological events of this subcontinent that provide, in turn, useful criteria to extend the better defined Neogene/Quaternary boundary of the marine sediments to the freshwater bone-bearing strata of the Siwalik Hills in the Himalayas.

The key areas covered in this paper, for the purpose of the Neogene/Quaternary boundary correlations, include the Western Indian Shelf, the Eastern Indian Shelf and the Siwalik belt of Himalayas (Fig. 1). The other areas, including Indo-Gangetic plains and Brahmputra Valley have not been included here principally because of negligible faunal control in the subsurface sections.

* The views expressed in the paper are of the authors only and not necessarily of the ONGC.

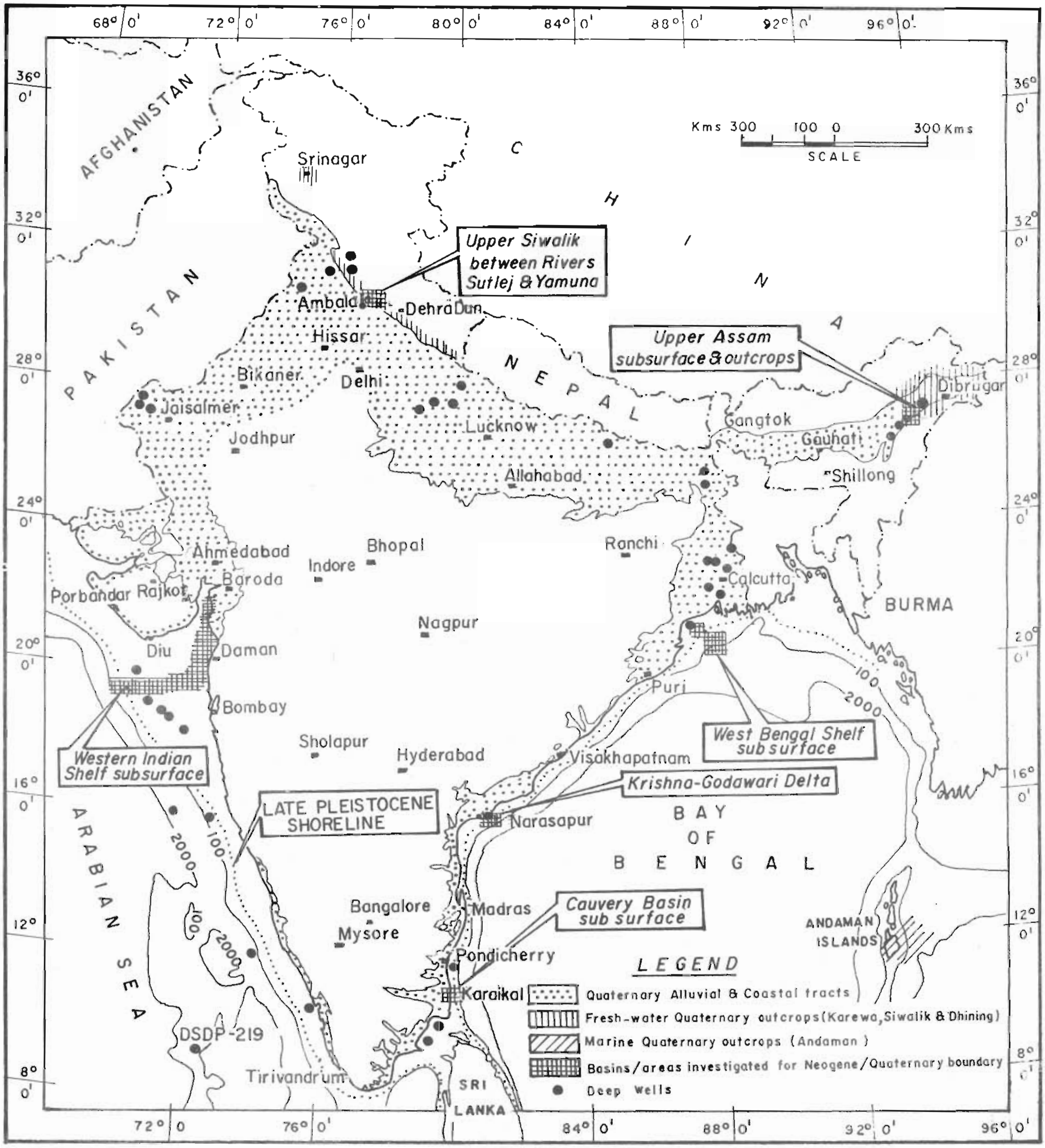

Fig. 1. Quaternary Sedimentaries of India

The faunal identification and taxonomy of this paper have been carried out by J. Pandey and the interpretation of the data as presented here, have been jointly carried out by S. Ramanathan and J. Pandey.

CORRELATION CONTROL FOR BOUNDARY IDENTIFICATION

Nikiforova (1978) emphasised that the Neogene/-Quaternary boundary should be based on the changes in the marine fauna and that the marine Calabrian formation of Italy be taken as the lowest limit of the Pleistocene.

In the type area (Le Castella section of the Calabrian formation) the following observations have been made (cf. Selli, 1967; Haq *et al.*, 1977; Nikiforova, 1978):

i) The Neogene/Quaternary boundary is taken at the disappearance level *Globigerinoides extremus* (top of the Olduvai Normal, 1.6 Ma or million years before present).

ii) The boundary marked by the appearance of *Globorotalia truncatulinoides* (N22 base, base of Olduvai Normal, 1.8 Ma) is two metres below the *G. extremus* disappearance level.

In later studies, Vrica section has been noted as more suitable for defining the base of the Calabrian Stage (Selli, 1971; Nakagawa, 1981). Here the boundary was initially tied up with Reunion Subchron at 2.02 Ma (Harland *et al.*, 1982). However, as Berggren *et al.* (1985) suggest, even the Vrica N/Q boundary is at 1.6 Ma.

Extending the above observations to the Indian

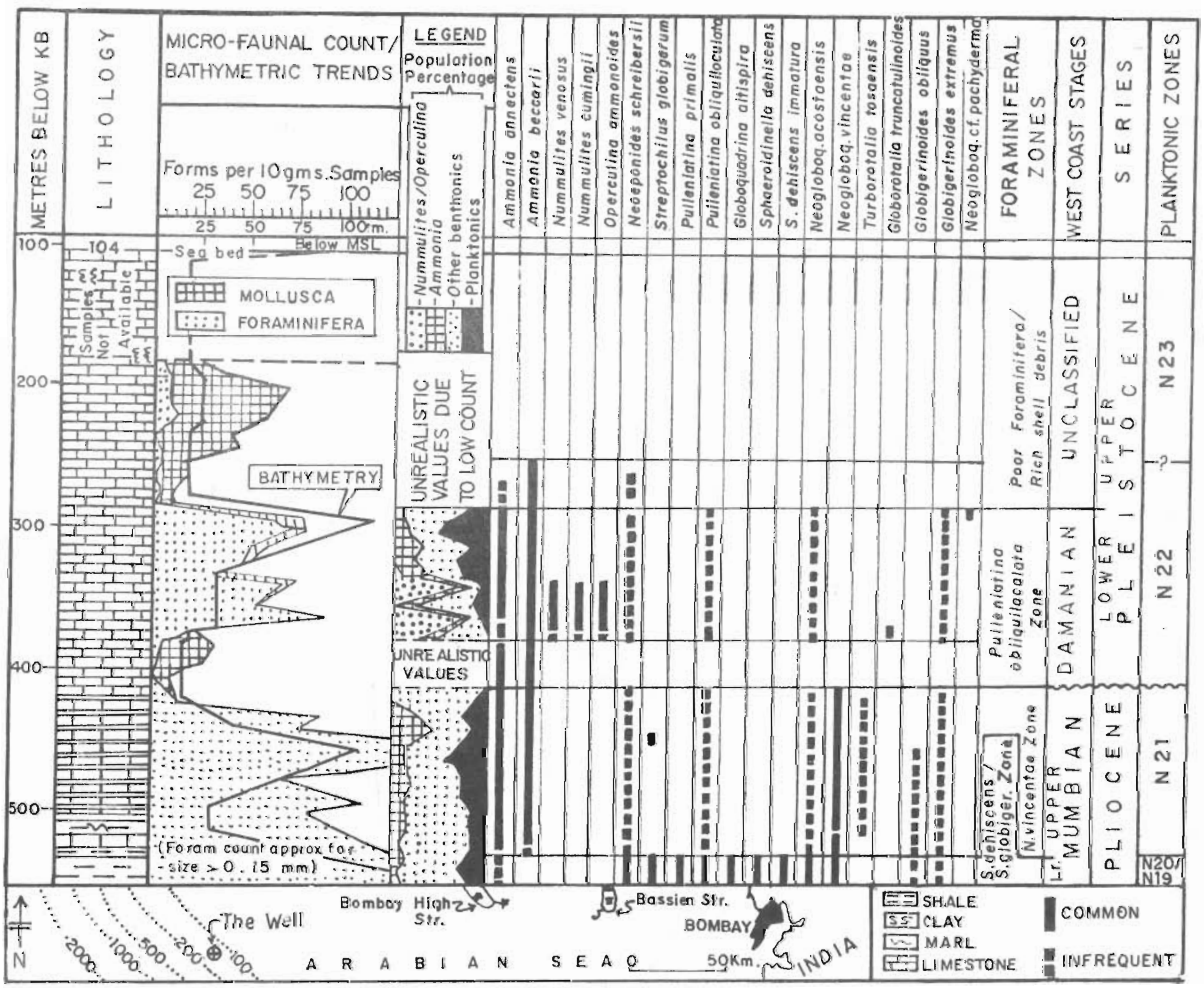

Fig. 2. The late Pliocene-Pleistocene zonation in the offshore well SM-1

Ocean, the Deep Sea Drilling Project site DSDP-219, situated about 450 kilometers off the Kerala Coast (Fig. 1), may be taken as the reference well for correlation between the type area in Italy and the subcrops of the Indian Ocean. The following observations from this well are relevant:

i) Fleisher (1974) has recorded both *G. truncatulinoides* and *G. extremus* from this well. However, the sedimentary thickness between the appearance level of *G. truncatulinoides* and disappearance of *G. extremus* is 13.5 metres (cf. core positions vide Whitmarsh *et al.*, 1974) in contrast to 2 metres of sediments only in the type area.

ii) Assuming uniform rate of sedimentation and the age of *G. truncatulinoides* as 1.8 Ma, the *G. extremus* exit datum will correspond to 1 Ma. This contrasts with 1.6 Ma for the same datum in the type area.

iii) Similarly in the well SM-1 (Fig. 1) located about 300 kilometers west off the Bombay coast on the continental shelf, both the characteristic horizons are present with about 40 metres of sediments intervening. This would again ascribe a much younger age for disappearance level of *G. extremus* (Pl. 5, figs. 2, 3; Pl. 6, fig. 1) when compared to its equivalent in the Italian type section.

Therefore, the appearance of *Globorotalia truncatulinoides* (Pl. 8, fig. 4), though extremely rare, can be taken as a more reliable datum for demarcating the Neogene/Quaternary boundary in the Indian Region. On the shelf, however, the solitary record of this species, is not associated with its ancestor *Turborotalia tosaensis* characterizing the lower N22. The species and associated *Nummulities cumingi* are therefore in the upper N22 (Fig. 2).

QUATERNARY SUCCESSION OF WESTERN INDIAN SHELF

WELL SM-1

The outermost well drilled on the Western Indian shelf is SM-1. In this well, with sea bottom situated 104 m below the Kelly bush, the Late Pliocene-Pleistocene sediments are about 400 metres thick (Fig. 2) and are amenable to a good foraminiferal zonation with ample planktonic control (Fig. 2). On the west coast, the Pliocene base has been defined by the first appearance of *Globorotalia tumida* (N18 base; Pandey, 1982). The first appearance of *Sphaeroidinella dehiscens*, marking the base of the succeeding zone N19 of the Pliocene, is also commonly recorded in many wells of the Western Indian Shelf like DCS-1 and SM-1. Further up in the sequence, there are three significant levels of micro-faunal change intimately related to the regional ecological fluctuations on the shelf. In SM-1, these changes include (cf. Fig. 2):

a) Rapid disappearance or rarefiction of *Streptochilus globigerum, Sphaeroidinella dehiscens immatura* assemblage at 530 m in a regression, quickly followed by *Ammonia beccarii*, (and rare *A. papillosus*) and *Turbororalia tosaensis* assemblage in a renewed transgression. This faunal change approximately corresponds to N19/N20 boundary coinciding with the Gilbert/-Gauss Polarity boundary at 3. Ma.

b) Termination of *Turborotalia vincentae* (Pl. 4, figs. 1-5) - *T. tosaensis* (Pl. 8, figs. 1-3) assemblage at 425 m in a severe short lived regression bringing about 75 m shallowing of the sea in the site SM-1 and, as evident from faunal composition and establishment of a shallow molluscan community in this area after near elimination of foraminiferal fauna. In a renewed transgression after this event *Nummulites venosus* and *Operculina ornata, O. ammonoides* assemblage appears at 360-65 m and *G. truncatulinoides* (solitary) at 340-45 m.

c) The appearance of *G. truncatulinoides* (1.9 Ma) is followed upwards upto 0.6 Ma by *G. tosaensis* assemblage (Berggren *et al.*, 1985). The appearance of *G. truncatulinoides* without *G. tosaensis* on the west coast is tentatively taken to mark the horizon of 0.6 Ma and tied at best with the base of Brunhes Normal. *G. extremus* exit, is referred as still younger. Based on the uniform sedimentation rates, the regression acme at 405 m in the well (Fig. 2) corresponds to 1.2 Ma approx. The new transgression of the shelf begins around 1.2 Ma with first entry of *Operculina ammonoides* fauna — assemblage.

d) The hiatus between the Late Pliocene zone (N21) and the first appearance of the Pleistocene assemblage, in view of the above considerations is around 1 Ma in the deepest part of continental shelf explored so far in view of the above observations. There is no continuity of the sediments to define the N/Q boundary in the shelf sediments upto a depth of about 100 m of sea bottom. The hiatus seen in the well SM-1 is correlatable in Andaman because in both places the *G. tosaensis* assemblage is followed by *G. truncatulinoides* without or marginal co-occurrence of the two species (Srinivasan, 1981).

e) Termination of *G. extremus* assemblage is just after the first entry of *Neogloboquadrina pachyderma* (Pl. 3, figs. 1) around 300 metres depth of the well. A prolonged shallowing follows thereafter wherein foraminifera recede and molluscan assemblage dominates. This level, as already noted, corresponds to 1 Ma level in the well DSDP well-219. Here the datum may be up in the Brunhes Normal Ca.0.5 Ma. In the succeeding sequence, till the highest studied sample, about 78 m below the sea bed, foraminiferal fauna is too poor to reveal any change between zones N22 and N23 and comprises mainly *Ammonia* spp. and some other benthonic forms.

OTHER WELLS ON THE SHELF AND WEST COAST

The correlation of the zonal boundaries of SM-1 can be extended to other wells on the Western Indian Shelf like DCS-1 and Tarapur-1 by the help of overlapping faunal criteria (Fig. 3). It may be observed that the Late Pliocene top in these two wells is more clearly marked by a regressive event and disappearance of the Neogene taxa corresponding to the post-*T. tosaensis* regression of SM-1. In none of the easterly wells appearance of *Globorotalia truncatulinoides* and associated faunas of SM-1 show a typical development.

Further, correlation between the offshore wells and the wells in Gujarat is handicapped due to the paucity of key taxa in the coastal wells. Nevertheless, considering the gross paleo-ecological cycles in the Cambay basin this correlation has been continued from Hazira-1 through Aliabet-1 and Dhadhar-1 to Cambay-1 (Fig. 3, inset 1). However, the fact remains that there is no faunal control to establish the Neogene/Quaternary boundary in the wells in Gujarat.

THE EASTERN INDIAN SHELF

On the Eastern Indian Shelf, offshore wells are still fewer barring in the offshore of Krishna-Godavari basin. The available data from most of them is inadequate for the Neogene/Quaternary boundary demarcation in the clastic dominated sequence, although presence of *G. truncatulinoides* is known from the Krishna-Godavari Offshore. For the present analysis, the well BB-A-1 of the West Bengal Offshore has been taken as reference for the Eastern Indian Shelf, although similar data is also recorded from the well SNE-1. The well has been studied by Mohan *et al.* (1976) and their palaeontological data provide the basis for the zonation and correlation of the well section (Fig. 4). The zones and zonal boundaries established in this well have also been correlated to the coastal wells of Karaikal-1 and Narsapur-1 in a later discussion.

Zones proposed for the well BB-A-1 (Fig. 4) closely correspond to the zones in the well SM-1 (Fig. 2). It is evident from the following table 1.

TABLE 1
Late Pliocene - Pleistocene correlation levels in BB-A-1 and SM-1.

Levels in BB-A-1	Levels in SM-1	Standard Planktonic Zone Levels
5. *Asterorrotalia pulchella* and *Ammonia annectens* Zonal boundary	Top of *Pulleniatina obliquiloculata* Zone	Within N22
4. *Ammonia papillosus* and *A. pulchella* Zonal boundary	*Neogloboquadrina vincentae* and *P. obliquiloculata* Zonal boundary	Upper part of N21
3. *Brizalina simpsoni* and *A. papillosus* Zonal boundary	Within *N. vincentae* Zone (at well depth 520 m)	N1 9/20 and N21 boundary
2. *Pseudoeponides japonica/Pulleniatina obliquiloculata* and *B. simpsoni* Zonal boundary	*Sphaeroidinella dehiscens/Streptochilus globigerum* and *N. vincentae* Zonal boundary	Upper part of N19/20
1. *Lenticulina thalmanni* and *P. Japonica/P. obliquiloculata* Zonal boundary		? N18/N19 boundary or older

From the above correlation between the Eastern and the Western Indian shelves and Himalayan tectonic scenario, it is evident that the N19/20 and N21 boundary is marked by a major geological event as already noted by Pandey (1982). On both the shelves, a reappearance of *Ammonia papillosus* is seen at this level. This species disappears from the Indian Shelf, at the Early/Middle Miocene boundary but reappears in the Late Pliocene (Pandey, ibid).

Other important observations emerging out of the comparison between the Western and Eastern shelves are:

i) In the studied well of the Eastern shelf, planktonic control is poor. The first appearance of *Asterorotalia pulchella* in the BB-A-1 is closely associated with first introduction of *Nummulites* approximately in the same geological level as the Western Indian Shelf (SM-1).
ii) Introduction of *Nummulites venosus*, slightly antedating the appearance of *G. truncatulinoides* in SM-1, has been taken to extend the Neogene/Quaternary boundary on the Eastern Indian Shelf where clastics dominate and establishment of hiatus at N/Q boundary is hard to establish. Association of *Nummulites venosus* with *A. pulchella* in BB-A-1 and other areas of Mahanadi-Meghalaya shelf is taken to mark the Neogene/Quaternary boundary on this part of the Eastern Indian Shelf.
iii) There is a better scope of studying N/Q boundary in offshore areas of Krishna-Godavari basins due to occurrence of *G. truncatulinoides*. This will be attempted some time in future.

In the coastal tract adjoining Bay of Bengal, the Pleistocene sediments are extremely thin even in the near-shore wells of Narsapur-1 and Karaikal-1 and the column is no more than 20 to 25 m thick (Fig. 4). In Narsapur-1 a good correlation is observed from the offshore well BB-A-1 on the basis of locally observed occurrence of *Asterorotalia pulchella*. In this correlation the Quaternary base is seen at 21 m and followed by sudden sandiness of the sequence and regression at 15 m.

The correlation between Karaikal-1 and Narsapur-1 is very slender since nothing more than a few molluscs occur in the upper fifty metres of Karaikal-1. Possibly a band of shells (20-25 m below KB) connotes Lower Pleistocene transgression and its base may be correlated with the Pleistocene base in Narsapur-1 (Fig. 4). More studies, however, are needed in the Cauvery basin to demarcate the Neogene/Quaternary boundary on the marine fauna.

CORRELATION WITH HIMALAYAS

Although there is no direct correlation between the marine fauna of the Western Indian Shelf and the Pleistocene mammalian fauna of the Upper Siwalik of Pinjore type area (Fig. 5), a correlation is suggested between these two areas, considering the major geo-

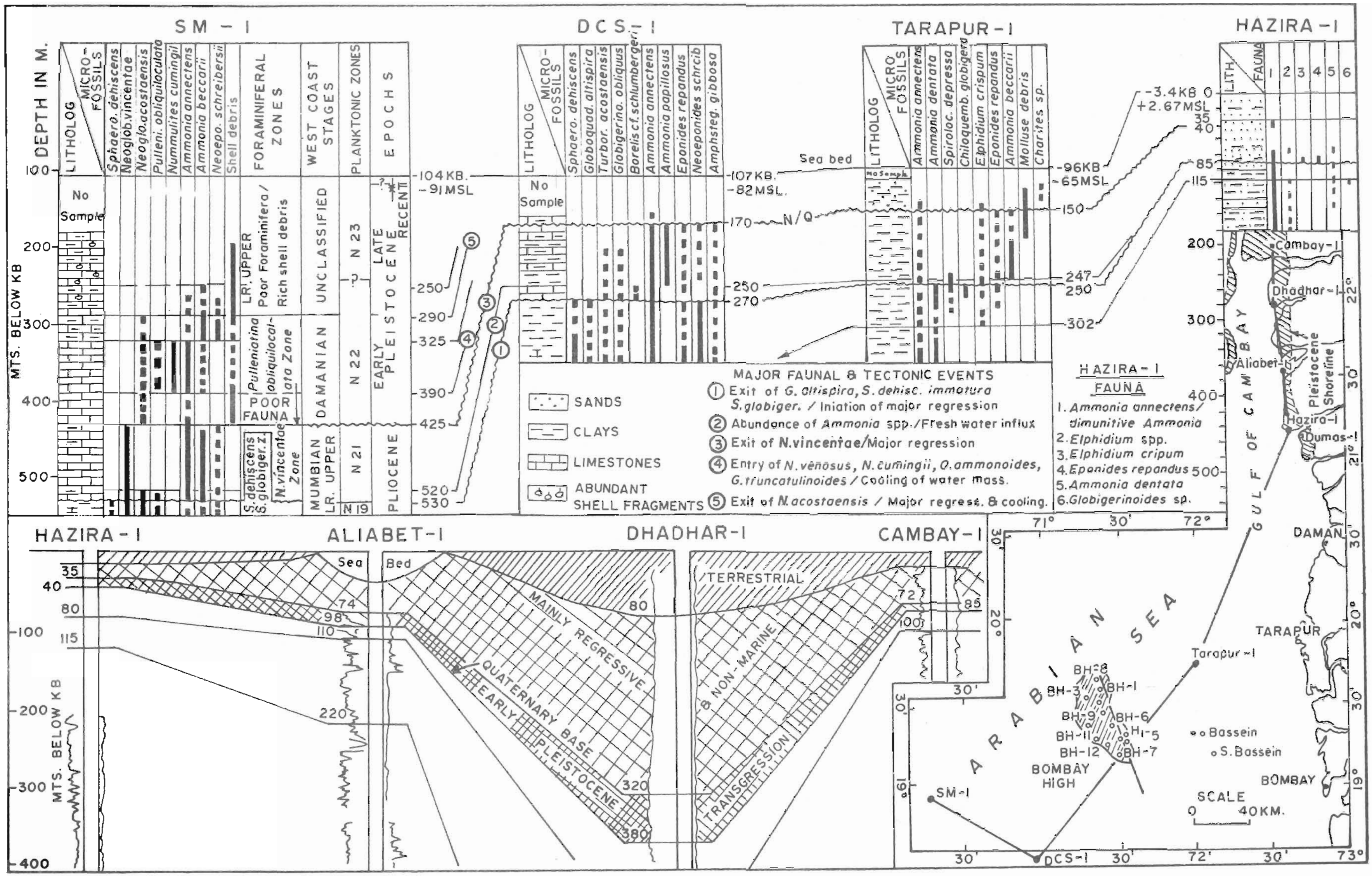

Fig. 3. Correlation of Neogene/Quaternary Boundary of the Western Indian Shelf

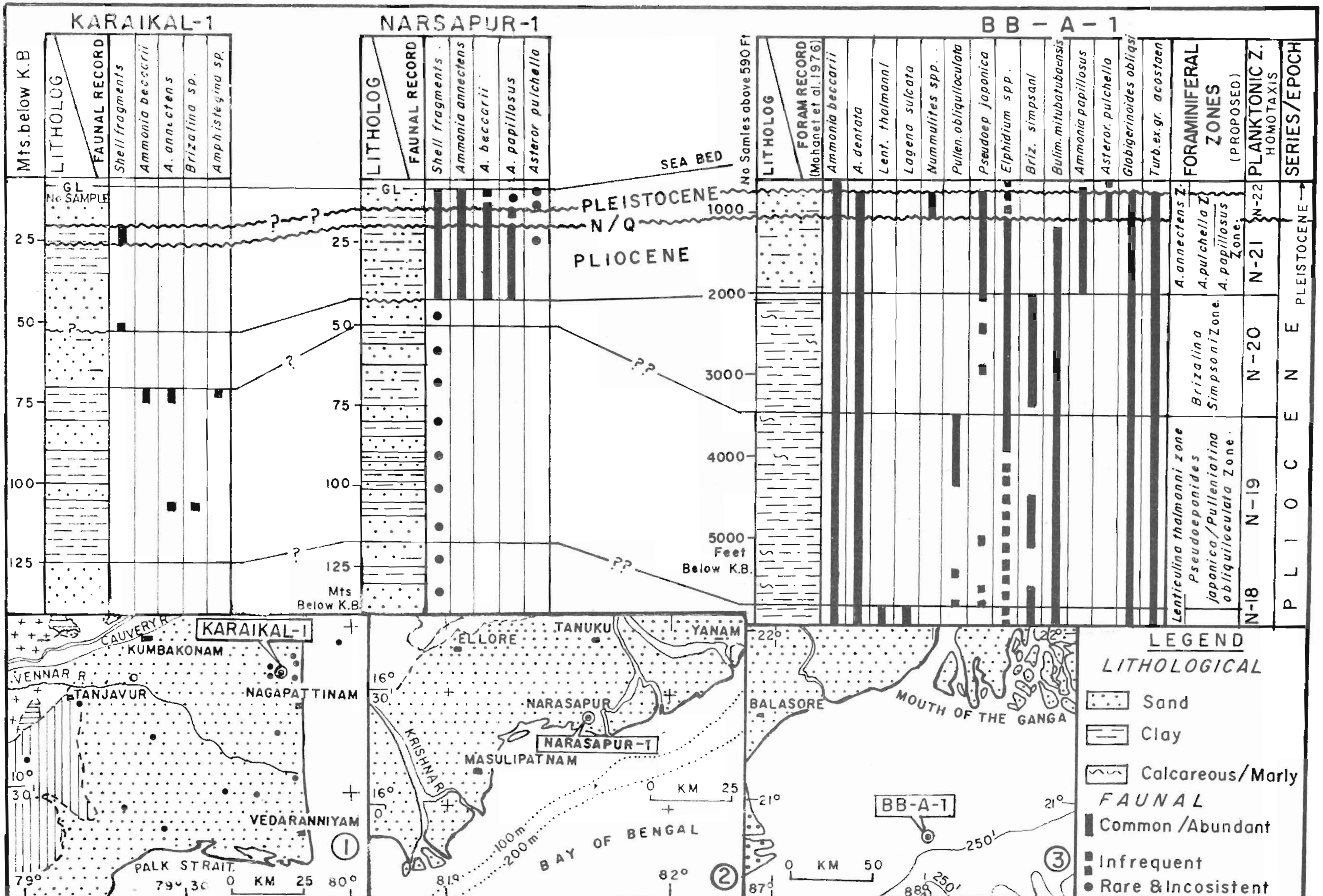

Fig. 4. Demarcation & Correlation of Neogene/Quaternary Boundary of the Eastern Indian Shelf

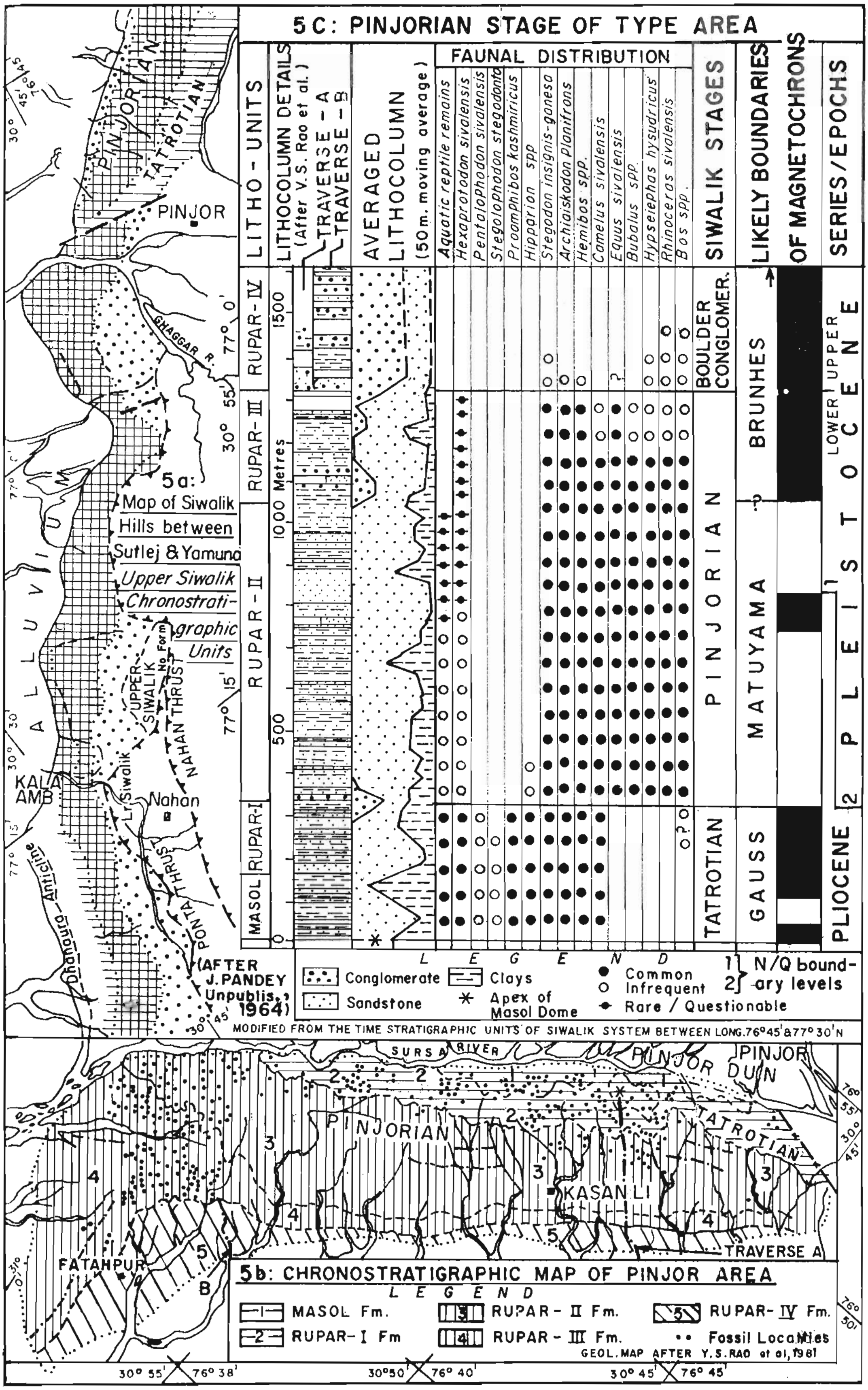

Fig. 5. Chronostratigraphic details of Pinjorian type area

logical events in the two and lately established magnetostratigraphic correlations (Yokoyama, 1981; Tandon *et al.*, 1984; Rao, 1988; Rao *et al.*, 1988).

Based on the entry and disappearance of the mammalian fauna in the Upper Siwalik of Siwalik Hills (Sahni & Khan, 1964; Pandey, 1971) and the magnetostratigraphic record, the following observations can be made:

(a) The first profuse appearance of vertebrate in the Pinjore area includes a large entry of amphibious, swamp-dwelling community of Hippopotami, pigs and reptiles in the Upper Masol-Rupar 1 Formation (Fig. 5).

(b) These elements recede in importance when a second community comprising of *Equus, Rhinoceros, Bos* and *Hypselephas* appears shortly after an uplift marked by post Rupar-1 conglomerates (Fig. 5c) at the Tatrotian/Pinjorian boundary of Sahni and Khan (1964). This boundary coincides with a Normal/Reverse polarity boundary (Yokoyama, 1981; Fig. 4) that may be taken as Gaus/Matuyama boundary in view of the observations of Rao *et al.*, (1988) and Rao (1988) on the FAD of *Equus* in India.

(c) A near annihilation of the mammalian fauna occurs at the top of the Pinjorian Stage (including Lower Boulder Conglomerate of Sahni & Khan, 1964-Rupar IV formation of Fig. 5c) whereafter, only rare forms are seen in the "Boulder Conglomerate" stage.

(d) Rarefaction of *Hippopotams* and appearance of *Equus* has been construed as evidence of decreased rainfall and a likely fall of temperature in the northerly latitudes pushing the horses to the South, i.e. in India.

(e) The post-Pinjorian disappearance of the mammals from the Himalayas, commencing with widespread "Boulder Conglomerate Stage", has been generally attributed to the excessive fall of temperature (Sahni & Khan, 1964). This episode could also mark a major Himalayan uplift corresponding to the post *G. extremus* shallowing of the West Coast, although the base of conglomerates formation in the higher Siwalik is considerably time-transgressive between 1.66 and 0.6 Ma (Rao, 1988).

A correlation between the Plio-Pleistocene events of the Upper Siwalik and those on the Western Indian Shelf indicate the following:

i) The dilution of salinities in the waters of the Indian shelf, marking regional abundance of *Ammonia* during N21 (3.4 to 1.9 Ma) is correlatable with abundance of rain forest and swamp-dwelling *Hippopotamus* dominated fauna in the Siwalik during the Upper Tatrotian of Pinjore area.

ii) The first entry of *Equus* has been consistently dated around 2.4 Ma by paleomagnetic data in the Jammu-Nagrota section (Rao, 1988; Rao *et al.*, 1988), although some older dates are available in Pakistan. This level correlates well with Tatrotian/Pinjorian boundary of Pinjore area in view of magnetic anomaly picture by Yokoyama (1981) who seems to have erred in identification of long normal subchron of Tatrotian as Olduvai (corrected position shown in Fig. 5c).

Olduvai Normal lies, apparently, close to the top of Rupar-II Formation (Fig. 5c) in view of its position elsewhere (Tandon *et al.*, 1984; Rao *et al.*, 1988).

The first appearance of *Equus* marking the boundary between Tatrotian and Pinjorian stages (Fig. 5c) around 2.4 Ma is close to what may be called a Post-Pliocene (post N21) regression on the Western Indian Shelf. The latter is a significant datum of sea level change in India, including Andaman Islands.

iii) The Olduvai subchron is seemingly a hiatus in the foraminifer assemblage on Indian shelf and Andaman. There is also no change in the fresh-water Siwalik faunas except its total annihilation.

iv) Introduction of *Equus* in India, widespread volcanic activity responsible for bentonitic clay sedimentation in Jammu (Rao, 1988; Fig. 4) and Post-Pliocene regression on the Indian shelf provide a considerably strong geologic event in India around 2.2 ± 2 Ma, close to the Gauss/Matuyama boundary. This level, as already suggested by Rao (1988), could be chosen, as the one defining N/Q boundary in India. Faunistically, it is the best datum recognizable closely corresponding to the N/Q boundary of Europe.

v) The rapid disappearance of the mammalian fauna in the post-Pinjorian period may be attributed to the severe cold in the Himalayas and this event may be correlated with the disappearance of *Globigerinoides extremus* on the Western Indian Shelf in the Brunhes Chron. At this level, some cooling of the water-mass and wide spread regression of late Pleistocene is seen on the shelf.

SUMMARY AND CONCLUSIONS

A summarised correlation of the Neogene/Quaternary boundary in some of the major Indian basins alongwith major faunal and tectonic elements is presented in Fig. 6. The data from Andaman Islands (Srinivasan, 1979, 1981) is also included in this figure.

The following are the major geological events that can be established during the later Pliocene and Pleistocene in the Indian subcontinent:

a) Around 3.3 Ma a prominent tectonic change brings the shallowing on the shelf, uplift in the Himalayas and sudden appearance of Brahmaputra-Ganges delta system in the Bay of Bengal.

b) The above event is closely followed by the introduction of luxuriant rain forest fauna in the Siwalik, with several new entries of mammals (which might be an influx due to a general global cooling in the northern latitudes); and, a contemporaneous abundance of *Ammonia* fauna on the Indian Shelf.

c) The Neogene/Quaternary boundary at the N22 base, marked by first appearance of *Globorotalia truncatulinoides* in the marine sequences with concurrent *G. tosaensis*, is not seen on Indian Shelf. The concurrent zone of the two species, spanning between 1.9 and 0.6 Ma, is a hiatus on the Indian Shelf. Also, in Andaman a hiatus of lesser(?) magnitude is seen.

d) There is an event of major geological and biostratigraphic change around 2.2 ± 0.2 Ma, introducing a marine regression and volcanism on one hand, and *Equus* — *Cervus* assemblage on the other. The event, nearly coinciding with Gauss — Matuyama boundary is the best available datum for the N/Q boundary in the country as already pointed out by Rao (1988).

e) The major cooling event and tectonism around 0.5 Ma level constitutes another pronounced event in Indian Geology. At this level, *Globigerinoides extremus* and *Neogloboquadrina vincentae* disappear in the marine realms, whereas a number of Siwalik mammals become extinct in the Himalayan belt with onset of cold during "Boulder Conglomerate" stage. A regression in the seas and enhanced orogenic impulse heralding of Upper "Boulder conglomerate" in Himalayas may be homotaxial tectonic events of regional scale duriang Late Pleistocene.

TAXONOMIC NOTES

Pandey (1982) has drawn the ranges of twenty one planktonic foraminiferal species occurring in the Late Miocene to Recent sediments of the Western Indian shelf. Scanning electron photographs and taxonomic notes on most of them and some additional species are provided here to substantiate the earlier report. Twenty five well known species or subspecies of planktonic foraminifera belonging to *Globigerina, Hastingerina, Globoquadrina, Globorotalia Globorotaloides, Neogloboquadrina, Pulleniatina, Turborotalia* and *Sphaeroidenella* are arranged in the taxonomic notes in alphabetical order wherein the generic arrangement is same as listed here.

The shelf sediments, explored todate, do not show the full range of the illustrated species as seen in the deep sea cores (Kennett and Srinivasan, 1983) for different paleoecological and tectonic reasons. Observed range of every one of them, as recorded on the Western Indian Shelf, is therefore also provided.

Globigerina quinqueloba NATLAND
(Plate III — 2, 3, 5)

Globigerina quinqueloba Natland, 1938: New species of foraminifera from off the West Coast of North America and from later Tertiary of the Los Angeles Basin. *Calif. Univ. Inst. Oceangr. Bull. Tech. Ser.* 4(5), p. 149, pl. 6, figs. 7a-c.

Remarks: The species, abundant in temperate and subtropical latitudes (Kennett and Srinivasan, 1983)

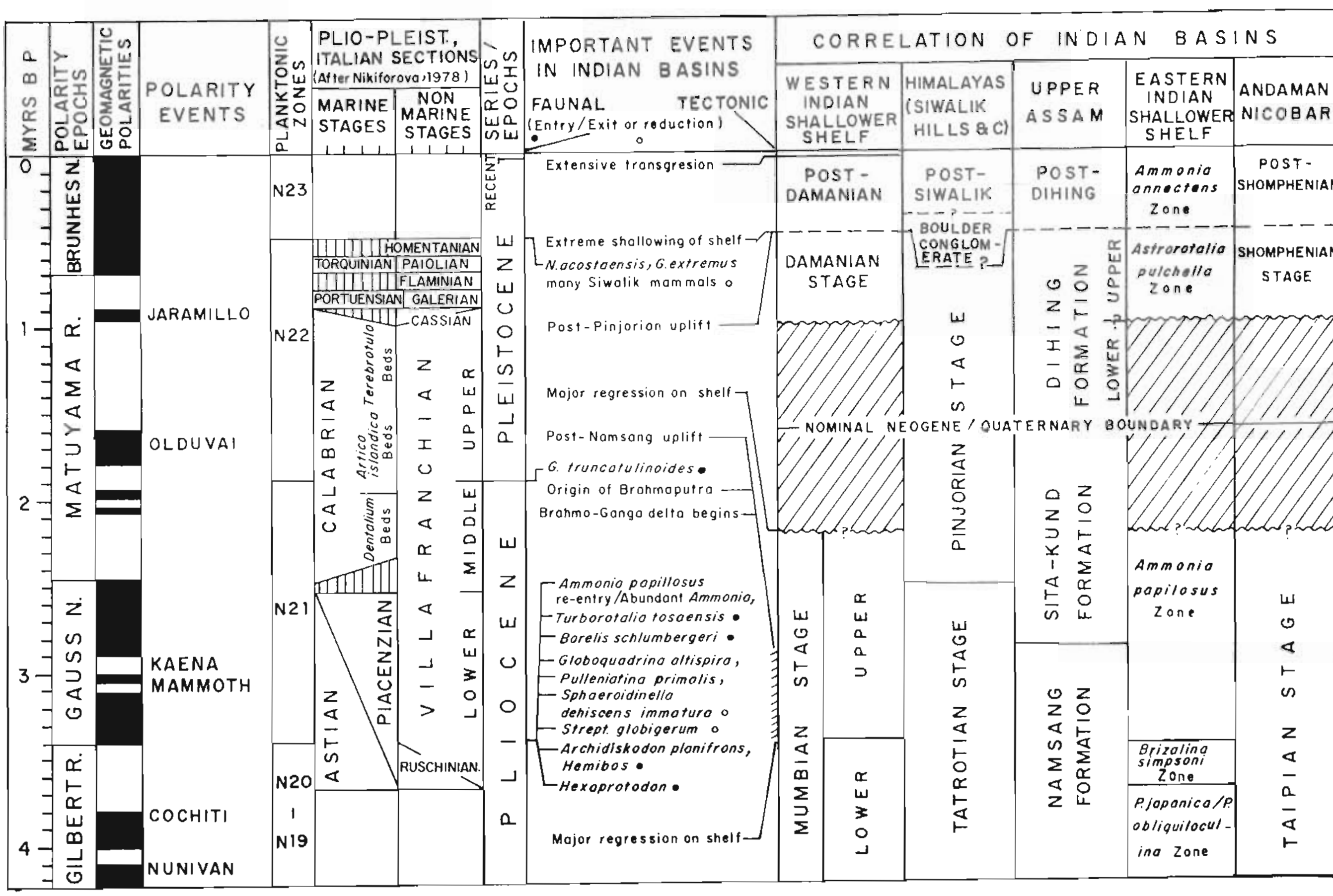

Fig. 6. Correlation of Neogene/Quaternary Boundary in Indian Basins

is characterised by five chambers in the last whorl, with slightly high spired test. It appears with *N. pachyderma* on the west coast in the late Pleistocene.

Range and distribution on the Western Indian Shelf: Recorded only from a single horizon of SM-1, in the outermost shelf, N22.

Globigerina woodi JENKINS
(Plate I — 4-6)

Globigerina woodi Jenkins, 1960: Planktonic foraminifera from the Lakes Entrance Oil Shaft, Victoria, Australia. Micropaleontology, v. 6, p. 352, pl. 2, figs. 2a-c.

Remarks: The species with four chambers in the last whorl, high arch aperture and with closely pitted surface is postulated, by Kennett and Srinivasan, to have evolved during Late Oligocene (N3) and continued upto Late Pliocene (N21).

Range and distribution on the Western Indian Shelf: Rather uncommon in the Pliocene (N18-N21) of outershelf wells.

Globigerinoides conglobatus BRADY
(Plate VI — 7, 8)

Globigerina conglobata Brady, 1879: notes on some of the reticularian Rhizopoda of the "Challenger" expedition; Quart. Jour. Micr. Sci. v. 19, p. 286, pl. 80, figs. 1-5; pl. 82, fig. 5.

Remarks: Thick, tightly coiled test with four chambers in the last whorl showing distinct depressed ventral sutures distinguish this species from similar but light tested *G. obliquus*.

Range and distribution on the Western Indian Shelf: Middle Miocene to Pleistocene in the wells of Middle to outer shelf. Also in Recent sediments of outer shelf.

Globigerinoides extremus BOLLI AND BERMUDEZ
(Plate V — 2, 3; Plate VI — 1, 5, 6)

Globigerinoides obliquus extremus Bolli and Bermudez, 1965: Zonation based on Planktonic foraminifera of Middle Miocene to Pliocene warm water sediments. Bol. Infor. Assoc. Vertez. Geol. Miner. Petr., 8(5), p. 139, pl. 1, figs. 10-12.

Remarks: The species as pointed out by Haq *et al.* (1977), disappears on Neogene/Quaternary boundary in type Calabrian. However, in the Arabian sea, rare occurrence of the species continues in the N22 much above the N/Q boundary defined by the first appearance of *G. truncatulinoides* (Fleisher, 1974).

Range and distribution on the Western Indian Shelf: Middle Miocene (N13) to Early Pleistocene (Lower N22) in the wells of Middle and outer shelf.

Globigerinoides fistulosus (SCHUBERT)
(Plate V — 1)

Globigerina fistulosa Schubert, 1910: Uber Foraminiferen und einen Fischotolithen aus dem fossiler Globigerinen Schlamm von Neu-Guinea. Geol. Reichsanst., verh. Wien, p. 323, text fig. 2

Remarks: Multiple digitations in the last chambers of this *Globigerinoides* make it one of the most easily identifiable forms in the later Pliocene and Pleistocene.

Range and distribution on the Western Indian Shelf: Late Pliocene (N21) in outer wells of the Bombay Offshore.

Globigerinoides immaturus LEROY
(Plate VI — 9)

Globigerinoides sacculiferus (Brady) var. *immatura* Le Roy, 1939: Some small foraminifera, ostracoda and otoliths from the Neogene (Miocene) of Rokan Taponoeli area, Central Sumatra. Natuurk. Tijdsch. Neden. Indie, Batavia, Java, v. 99, p. 263, pl. 3, figs. 19-21.

Remarks: As observed by Kennet and Srinivasan (1983) this species is closely related to *G. trilobus* on one hand and *G. sacculifer* on the other. The specimen illustrated here is close to *G. sacculifer* but it lacks full development of terminal sack-like chamber.

Range and distribution on the Western Indian Shelf: Common on the middle and outershelf from Early Miocene (N8) to Recent.

Globigerinoides ruber D'ORBIGNY)
(Plate V — 8, 9)

Globigerina rubra d'Orbigny, 1839: Foraminiferes. In: *De la Segra Histoire physique. politique et naturelle de L'lle de Cuba*, 8, p. 82. pl. 4, figs. 12-14.

Remarks: As Kennett and Srinivasan (1983) have already observed, this species is easily distinguished by the position of the primary and supplementary sutural apertures, which are always symmetrically placed above the suture between two earlier chambers. Also, there is considerable variation in the height of the spire in this species.

Range and distribution on the Western Indian Shelf: Common in the N18 to N22 sediments of the outer wells of the shelf. Also in the Recent sediments of the outer shelf.

Globigerinoides sacculifer (BRADY)
(Plate V — 4-7)

Globigerina sacculifera Brady, 1877: Supplementary note on the foraminifera of the chalk (?) of the New Britain Group. *Geol. Mag.*, n.s., decade 2, vol. 4, no. 12, p. 535 (figures in Brady, 1884: *Rep. voy. Challenger, Zool.*, 9, p. 604, pl. 8D, figs. 11-17; pl 82, fig. 4).

Remarks: The last non-spherical, elongate or compressed chamber of the species is characteristic enough to distinguish it from other species of *Globigerinoides*.

Range and distribution on the Western Indian Shelf: Pliocene (N14-N21) of the outershelf wells. Also Recent.

Globigerinoides subquadratus BRONNIMANN
(Plate VI — 2-4)

Globigerinoides subquadrata Bronnimann 1954: Appendix: Description of new species. In Todd, R., Cloud, P.E., Jr., Low, D. and Schimidt, R.G., Probable occurrence of Oligocene in Saipan. *Amer. Jour. Sci.*, 252(11), p. 680, pl. 1, figs. 2a-c.

Remarks: Differentiation between *G. subquadratus* and *G. ruber* looks somewhat artificial since one is believed to be terminating in N15 and the other taking off from this zone on the same lineage (Kennett and Srinivasan, 1983) and more importantly, hypsospiry (elongation of spire) is a well known trait in the group. At the present, low spired, subquadrate tests have been placed in this species till further studies, irrespective of the range.

Range and distribution on the Western Indian Shelf: Rather rare in the N18-N22 sediments of the outer wells cf the Western Indian Shelf.

Globoquadrina altispira (CUSHMAN & JARVIS)

Globigerina altispira Cushman and Jarvis, 1936: Three new foraminifera from the Miocene Bowden marl of Jamaica. *Contr. Cushman Lab. Foram. Res.* 12(1), p. 5, pl. 1, figs. 13a-c.

Remarks: The species, evolving from *G. altispira globosa* by increase in the height of spire and laterally compressed chambers, is rather common in the outer wells of the Western Indian Shelf.

Range and distribution on the Western Indian Shelf: Middle Miocene (N14) to Late Pliocene (N21).

Globorotalia limbata (FORNASINI)
(Plate VIII — 8-10)

Rotalia limbata Fornasini, Sirossi metodica dei foraminiferisinqui rinvenuti nella sabbia del lido di Rimini *R. Akad. Sci. Ist. Bologna, Mem. Sci. Nat. Bologna*, Ser. 5, tomo 10 (1902-1904), p. 56, tf. 55.

Remarks: The forms referred to this species on the Western Shelf differ from ancestoral population *G. menardii* in possessing usually six to seven chambers in the final whorl, in the dorsal view somewhat peta loid chambers in final whorl in contrast to the wedge-shaped ones in *G. menardii* and also in the gradually curved intercameral sutures in the peripheral part, whereas those in *G. menardii* are abutting the periphery rather abruptly.

Range and distribution on the Western Indian Shelf: Rather uncommon in the N17-N18 sediments of the outer continental shelf.

Globorotalia menardii (D'ORBIGNY)
(Plate VIII — 7)

Rotalia (Rotalie) menardii d'Orbigny, 1826: Tableau methodique de la classes des Cephalopodes. *Ann. Sci. Nat., Paris*, Ser. I, tome 7, p. 273.

Remarks: Kennett and Srinivasan (1983) have summed up the controversy in the nomenclature priorities of *G. menardii* (d'Orbigny) versus *G. cultrata* (d'Orbigny) and adopted *G. menardii* as valid name. This view is followed in the present work.

Range and distribution on the Western Indian Shelf: Infrequent in outershelf wells between N17 and N22, frequent in the Recent outershelf and slope sediments.

Globorotalia tumida (BRADY)
(Plate VIII — 5, 6)

Pulvinulina menardii (d'Orbigi y) var. *tumida* Brady, 1877: Supplementary note on the foraminifera of Chalk (?) of the New Britain Group. *Geol. Mag., n.s.*, Dec. 2, vol. 4, p. 535.

Remarks: The species, marking the base of N18 in the outer continental shelf wells, is rather infrequent in N18-N22 sediments of the studied wells. It is common in the deeper continental shelf sediments of Recent.

Range and distribution on the Western Indian Shelf: N18 to Recent, rather uncommon.

Globorotalia truncatulinoides (D'ORBIGNY)
(Plate VIII — 4)

Rotalia truncatulinoides d'Orbigny, 1839: Foraminiferes des Iles Canaries. In: Barker-Webb, P., and Berthelot, S., *Hist. Naturelle des Iles Canaries.* Paris: Bethune, v. 2, pt. 2, Zool., p. 132, pl. 2, figs. 25-27.

Remarks: Only a solitary form of this species was recorded from the well SM-1 at a well depth 340-345 m.

Range and distribution on the Western Indian Shelf: Extremely rare in N22, also occurs rarely in the Recent sediments of outer continental shelf and slope.

Globorotaloides variabilis BOLLI
(Plate I — 9-12)

Globorotaloides variabilis Bolli, 1957: Planktonic foraminifera from the Oligocene-Miocene Cipero and Lengua formations of Trinidad, *Bull., U.S. Nat. Mus. 215, p. 117, p. 27, figs. 15a-20c.*

Remarks: The species is distinguished from its ancestor in possessing compressed earlier chambers and much curved dorsal sutures.

Range and distribution on the Western Indian Shelf: Early Pliocene N18-N19 of the Western Indian Shelf.

Hastigerina aequilateralis (BRADY)
(Plate I — 1-3)

Globigerina aequilateralis Brady, 1879: Notes on the some of the reticularian Rhizopoda of the "Challenger" (expedition; II). Addition to the knowledge of porcellanous and hyaline types. *Quart. Jour. Micr. Sci., n.s.*, 19, p. 285 (Figs. in Brady, 1884: *Rep. Voy. Challenger, Zool*, 9, p. 80, figs. 18-21.

Remarks: This species of *Hastigerina*, characterized by four or five assymetrically placed, evolute chambers of last whorl showing minor trochospiral coiling and asymmetrically placed interiomarginal aperture of wide equatorial arch without a lip.

Range and distribution on the Western Indian Shelf: Middle Miocene (N13) to Pliocene (N21) in wells of central and outer shelf.

Neogloboquadrina acostaensis (BLOW) (Plate II — 7-9; Plate III — 1-4)

Globorotalia acostaensis Blow, 1959: Age, correlation and biostratigraphy of the Upper Tocuyo (San Laranzo) and Pozon Formations, eastern Falcon, Venezuela. *Bull. Amer. Pal.*, Ithaca, N.Y., 39(178), p. 208, pl. 17, figs. 106a-c.

Remarks: Fleisher (1974) has illustrated from the DSDP 219 a more typical *N. acostaensis* with rounded equatorial periphery (Pl. 18, figs. 7) and also somewhat elongate population referred as *Turborotalia (Turborotalia) acostaensis tegillata* Bronnimann and Resig — both from zone N17. Both of the types have been included here under *N. acostaensis*.

Range and distribution on the Western Indian Shelf: N16 to N22 in the outer wells of the Western Indian Shelf. The disappearance level of the species is coincident with that of regression of Later Pleistocene and marks conveniently the top of N22 in the outershelf wells. Fleisher (1974) has already established the range of the species upto N21 in DSDP-219 when Kennett and Srinivasan (1983) restrict it up N20.

Neogloboquadrina dutertrei (D'ORBIGNY) (Plate III — 6-9)

Globogerina dutertrei d'Orbigny, 1839: Foraminifers, in Sagra, R. Dela, Histoire physique at naturelle de l'Ile de Cuba. Paris. A. Bentrand, v. 8, p. 84, pl. 4, figs. 19-21.

Remarks: Large forms of *N. dutertrei* are quite characteristic and easily identified. Many of them (Pl. 3, fig. 7-9) contain well preserved umbilical plates.

Range and distribution on the Western Indian Shelf: N21-N22 in outer wells of the shelf. Also, Recent sediments of far offshore.

Neogloboquadrina humerosa (TAKAYANAGI & SATIO) (Plate II — 1-6)

Globorotalia humerosa Takayanagi and Saito, 1962: Planktonic foraminifera from the Nobori formation, Shikoku, Japan. *Science Rep. Tohoku Univ. Second Ser. Spl.* vol., 5, p. 78, pl. 28, figs. 1a-2b.

Remarks: N. humerosa, an intermediate taxon between *N. acostaensis* and *N. dutertrei* differs from the former in possessing six or more chambers in the final whorl and a better developed umbilicus in contrast to usually five chambers seen in *N. acostaensis*. Its distinction from *N. dutertrei* includes its extraumbilical aperture and absence of umbilical plates in the end member of the lineage.

Range and distribution on the Western Indian Shelf: N18 to N20 of the Western Indian Shelf.

Neogloboquadrina cf. *pachyderma* (EHRENBERG) (Plate III — 1)

Aristerospira pachyderma Ehrenberg, 1861: Elemente des tiefen Meeresgrundes in Mexikanischen Golfstrome bei Florida, *K. Preuss Akad. Wiss. Berlin, Monatsber.* p. 276, 277, 303.

Remarks: Typical forms of *N. pachyderma* as illustrated by Kennett and Srinivasan (1983) are not encountered in the wells of the Western Indian Shelf. However, occasionally forms falling in the variation range of species (Kennett, 1968) do occur in a horizon high up in Pleistocene. Such forms are placed here under *N.* cf. *pachyderma* —a usual cold water marker.

Range and distribution in the Western Indian Shelf: Rare in N22 upper N22 of the outer shelf wells.

Neogloboquadrina vincentae (FLEISHER) (Plate IV — 1-5)

Turborotalia (Turborotalia) vincentae Fleisher, 1974, Cenozoic planktonic foraminifera and biostratigraphy, Arabian Sea, Deep Sea Drilling Project, Leg 23A, In Whitmarsh *et al. Initial Reports of the Deep Sea Drilling Project*, vol. 23, p. 1036, pl. 21, figs. 1-5.

Remarks: N. vincentae (Fleisher) is characterized by much inflated subglobular and closely appressed chambers producing, particularly in four chambered forms, a highly compact test. As Fleisher (1974) points out the most distinctive feature of this species is an elongate and imperforate flap or flange, commonly bordered along part or all its length by a thickened sieve, which covers the umbilical region and extends in an anterior direction part or all of the way to the periphery. It is a rather common species of the Western Indian Shelf during the Plio-Pleistocene.

Range and distribution on the Western Indian Shelf: Common in N18 to N21 in the outer shelf wells.

Pulleniatina obliquiloculata (PARKER & JONES) (Plate V — 9-11)

Pullenia sphaeroides (d'Orbigny) var. *obliquiloculata* Parker and Jones, 1865: On some foraminifera from the North Atlantic and Arctic Oceans, including Davis straits and Baffin's Bay. *Roy. Soc. Lond. Philos. Trans.* 155, p. 368, pl. 19, figs. 4a-b.

Remarks: Postuma (1971) suggests the easiest way to distinguish *P. primalis* (Parker and Jones) *P. praecursor* Banner and Blow and *P. obliquiloculata* (Parker and Jones) by the position of apertures. Aperture of *P. primalis* is confined to the umbilical part, not reaching the periphery of the preceding whorl; that cf *P. praecursor* reaching upto the periphery and in *P. obliquiloculata* extending beyond the periphery. This criterion has been followed here.

Range and distribution on the Western Indian

Shelf: N19 to N22 in the far outer wells of the shelf; Recent sediments.

Pulleniatina primalis BANNER & BLOW
(Plate IV — 6-8)

Pulleniatina primalis Banner and Blow, 1967: The origin, evolution and raxonomy of the foraminifera genus *Pulleniatina* Cushman, 1927: *Micropaleontology*, 13(2), p. 142, pl. 1, figs. 3-8; pl. 3, figs. 2a-c.

Remarks: The primitive species of *Pulleniatina* resembling somewhat, in appearance, glossiness and umbilical-extraumbilical aperture with the *Turborotalia centralis* (Cushman) of Eocene. The aperture of the species is restricted essentially to the umbilical side and does not extend to the spiral side as already noted.

Range and distribution on the Western Indian Shelf: Common in the N18-N19 sediments of the outershelf wells. Rare above. Top of N19 marked on the common occurrence of the species as this datum is shortly followed by appearance of *T. tosaensis* signifying the base of N21.

Turborotalia tosaensis (TAKAYANAGI & SAITO)
(Plate VIII — 1-3)

Globorotalia tosaensis Takayanagi and Saito, 1962: Planktonic foraminifera from the Nobori Formation, Shihoku, Japan. *Science Rep. Tohoku Univ., Second Ser., Spl.* v. 5, p. 81, pl. 28, figs. 11a-12c.

Remarks: T. tosaensis, easily distinguished from Pleistocene marker *G. truncatulinoides* due to their absence of a peripheral keel, is a characteristic Late Pliocene (N21) species continuing in the basal Pleistocene (Lower N22) where it is a associated with *G. truncatulinoides*. On the west coast, a regression ensues in upper N21 and when the new transgression occurs, *T. tosaensis* is absent though extremly rare. *G. truncatulinoides* is seen in this, late N22 assemblage.

Range and distribution on the Western Indian Shelf: Uncommon in N21 of outermost wells of the Western Indian Shelf.

Sphaeroidinella dehiscens (PARKER & JONES)
(Plate VIII — 4-7)

Sphaerodina bulloides d'Orbigny var. *dehiscens* Parker and Jones, 1865: On some foraminifera from the North Atlantic and Arctic Oceans, including Davies Straits and Baffin's Bay. *Roy. Soc. Lond., Philos. Trans.*, v. 155, p. 369, pl. 19, fig. 5.

Remarks: It is a widely varying population wherein the primary and secondary apertures spread laterally from small, elongate, narrow openings (Pl. 7, figs. 4, 5) to a circular slits with flanges (Pl. 7, figs. 6, 7). Among these, *S. ionica ionica* Cita and Ciaranfi represents the primitive type and *S. dehiscens excavata* Banner and Blow is made of much advanced forms. The evolutionary ra e of the population, however, is too rapid and all the variants develop during N19. Kennett and Srinivasan (1983) include them all in *S. dehiscens*. This view is followed here.

Range and distribution on the Western Indian Shelf: Common in outer shelf wells, N19/N20; Deeper offshore: Recent.

Sphaeroidinella dehiscens immatura (CUSHMAN)
(Plate VII — 1-3)

Sphaeroidina dehiscens Parker and Jones var. *immatura* Cushman, 1919, Fossil foraminifera from West Indies. In Vaughan, T.W., Contributions to the Geology and Paleontology of the West Indies, Carnegie Institute, Washington, Publ. No. 291, p. 40, pl. 14, fig. 2.

Remarks: Blow (1970), while recognizing the stratigraphic importance of this population as a restricted taxon of N19, retained it merely as a *forma* of *S. dehiscens dehiscens*. Kennett and Srinivasan (1983) have included the species within *S. dehiscens* considering it merely as an initial stage of development. On the West Coast, this *Sphaeroidinella* with small, circular supplementary apertures with a rim (Pl. 7, fig. 3) constitute a distinctive population restricted to N19 and prove very useful in marking this chronozone. As such, the scope of *S. dehiscens immatura* is restricted here to include only those forms with small circular supplementary aperture for the purposes of age characterization. Elongation of small opening is taken to mark the transition to *S. dehiscens* (Pl. 7, fig. 5).

Range and distribution on the Western Indian Shelf: N19 of the outer Western Indian Shelf.

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EXPLANATION OF PLATES

PLATE I

1-3. *Hastigerina aequilateratis* (Brady)
1, 3 lateral views X 70; 2 side view X 170
Well DCS-1, 480-485 m, Early Pliocene

4-6. *Globigerina woodi* Jenkins
4 spiral view X 165; 5 lateral view X 215;
6 umbilical view X 175
Well DCS-1, 480-485 m, Early Pliocene

7-8. *Globoquadrina altispira* (Cushman & Jarvis)
7 lateral view X 200; 8 umbilical view X 200
Well DCS-1, 480-485 m, Early Pliocene

9-12. *Globorotaloides variabilis* Bolli
9 spiral view X 205; 10 spiral view X 170;
11 umbilical view X 200; 12 lateral view X 200
Well DCS-1, 480-485 m, Early Pliocene

PLATE II

1-3. *Neogloboquadrina humerosa* (Takayanagi & Saito)
1 Spiral view X 145; 2 Umbilical view X 85; 3 Lateral view X 140
Well SM-1, 300-305 m

4-6. *Neogloboquadrina humerosa* (Takayanagi & Saito)
4 Spiral view X 80; 5 Umbilical view X 80; 6 Lateral view X 80
Well SM-1, 300-305 m

7-9. *Neogloboquadrina acostaensis* (Blow)
7 Spiral view X 210; 8 Lateral view X 170; 9 Umbilical view X 200
Well SM-1, 300-305 m

PLATE III

1. *Neogloboquadrina* cf. *pachyderma* (Ehrenberg)
umbilical view X 20
Well SM-1, 300-305 m

4. *Neogloboquadrina acostaensis* (Blow)
umbilical view X 265
Well SM-1, 300-305 m

2, 3, 5. *Globigerina quinqueloba* Natland
2 umbilical view X 165; 3 lateral view X 205;
5 umbilical view X 170
Well SM-1, 300-305 m

6-9. *Neogloboquadrina dutertrei* (d'Orbigny)
6 lateral view X 205; 7 umbilical view X 200;
8 lateral view X 200; 9 umbilical view X 205
Well SM-1, 300-305 m

PLATE IV

6-9. *Neogloboquadrina vincentae* (Fleisher)
1 Spiral view X 140; 2 Umbilical view X 220; 3 Lateral view X 140; 4 Umbilical view X 195; 5 Oblique umbilical view X 215
Well DCS-1, 605-610 m, Early Pliocene

6-8. *Pulleniatina primalis* Banner & Blow
6 Spiral view X 195; 7 Umbilical view X 210; 8 Lateral View X 225
Well SM-1, 530-535 m, Early Pliocene

9-11. *Pulleniatina obliquiloculata* (Parker & Jones)
9 Spiral view X 195; 10 Umbilical view X 135; 11 Lateral view 140
Well SM-1, 460-465 m (9, 10), 530-535 m (11)

PLATE V

1. *Globigerinoides fistulosus (Schubert)*
   Spiral view X 175
   Well DCS-1, 480-485 m, Early Pliocene
2, 3. *Globigerinoides extremus* Bolli
   2 Lateral view X 70; 3 Oblique spiral view of same specimen X 90
   Well SM-1, 300-305 m, Pleistocene
4-7. *Globigerinoides sacculifer* (Brady)
   4 Spiral view X 110; 5 Spiral view X 135; 6 Spiral view X 205: 7 Umbilical view X 80
   Well DCS-1, 480-485 m, Early Pliocene
8. 9. *Globigerinoides ruber* (d'Orbigny)
   8 Spiral view X 225; 9 Umbilical view X 215

PLATE VI

1. *Globigerinoides extremus* Bolli
   Apertural view of the specimen in Pl. 5, Fig. 2, X 95
2-4. *Globigerinoides subquadratus* Bronnimann
   2 Spiral view X 85; 3 Oblique lateral view X 85; 3 Umbilical view X 85
   Well SM-1, 300-305 m, Pleistocene
5, 6. *Globigerinoides extremus* Bolli
   5 Spiral view X 190, 6 Lateral view X 255
   Well SM-1, 300-305 m, Pleistocene
7, 8. *Globigerinoides conglobatus* (Brady)
   7 Umbilical view X 50; 8 Umbilical view X 220
   Well DCS-1, 480-485 m, Early Pliocene
9. *Globigerinoides immaturus* Le Roy
   Umbilical view X 220
   Well DCS-1, 480-485 m

PLATE VII

1-3. *Sphaeroidinella dehiscens immatura* (Cushman)
   1 Umbilical view X 205; 2 Spiral view X 215; 3 Enlargement of aperture in Fig. 2, X 870
   Well SM-1, 530-535 m, Early Pliocene
4-7. *Sphaeroidinella dehiscens* (Parker & Jones)
   Aperture in varying developmental stages 4 X 220; 5 X 140; 6 X 175; 7 X 205
   Well DCS-1, 460-465 m, Early Pliocene

PLATE VIII

1-3. *Turborotalia tosaensis* (Takayanagi & Saito)
   1 Spiral view X 475; 2 Umbilical view X 220; 3 Apertural view X 390.
   1, 3 Well SM-1, 460-465 m; 2 Well SM-1, 430-435 m, Late Pliocene
4. *Globorotalia truncatulinoides* (d'Orbigny)
   Lateral view X 200
   Well SM-1, 340-345 m, Pleistocene
5, 6. *Globorotalia tumida* (Brady)
   5 Spiral view X 40; 6 Lateral view X 210
   Well SM-1, 300-305 m, Pleistocene
7. *Globorotalia menardii* (Parker, Jones & Brady)
   Umbilical view X 95
   Well DCS-1, 605-610 m, Early Pliocene
8-10. *Globorotalia limbata* (Fornasini)
   8 Dorsal view X 160; 9 Umbilical view X 140; 10 Lateral view X 185
   Well DCS-1, 480-485 m, Early Pliocene

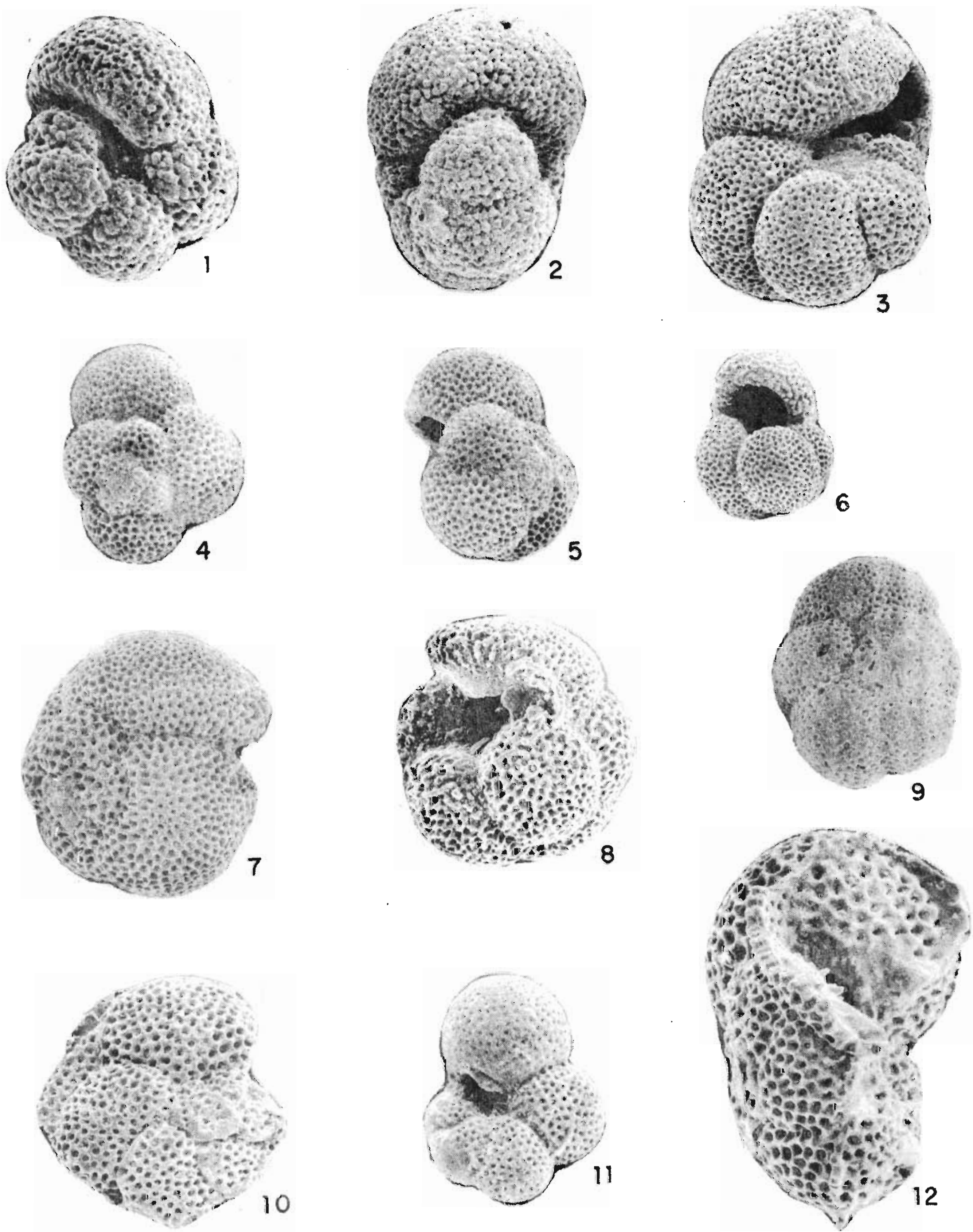
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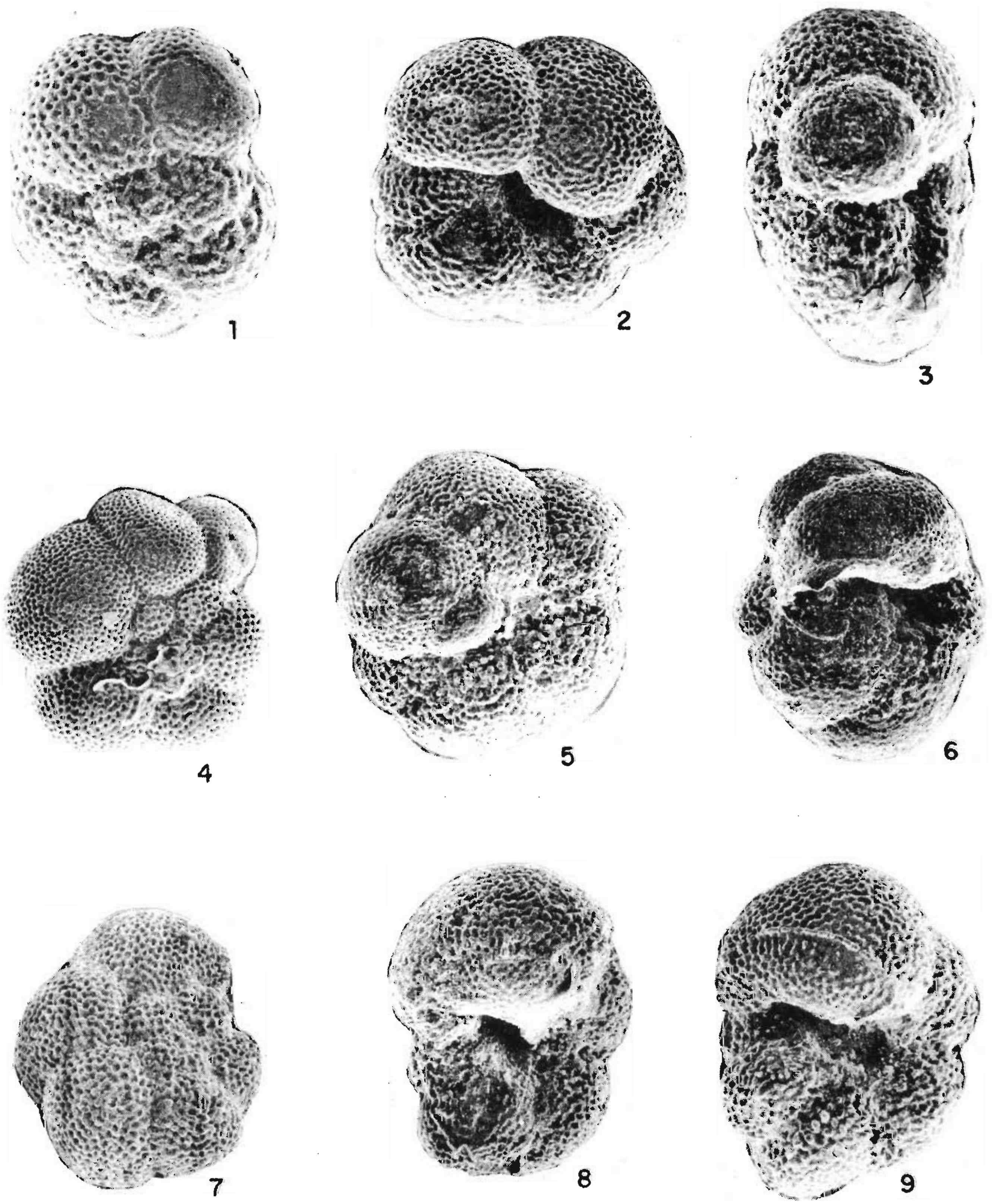
Plate II



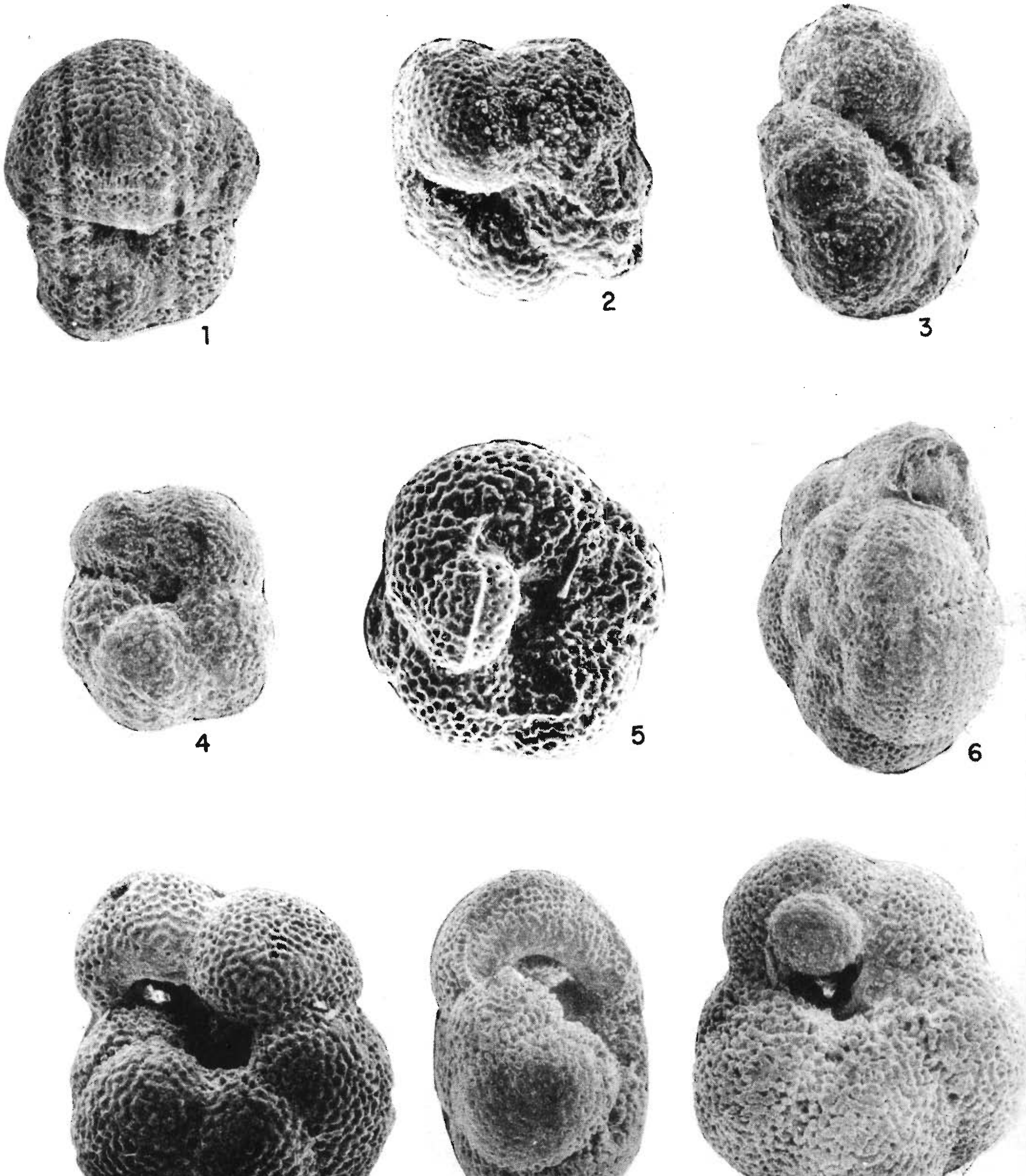

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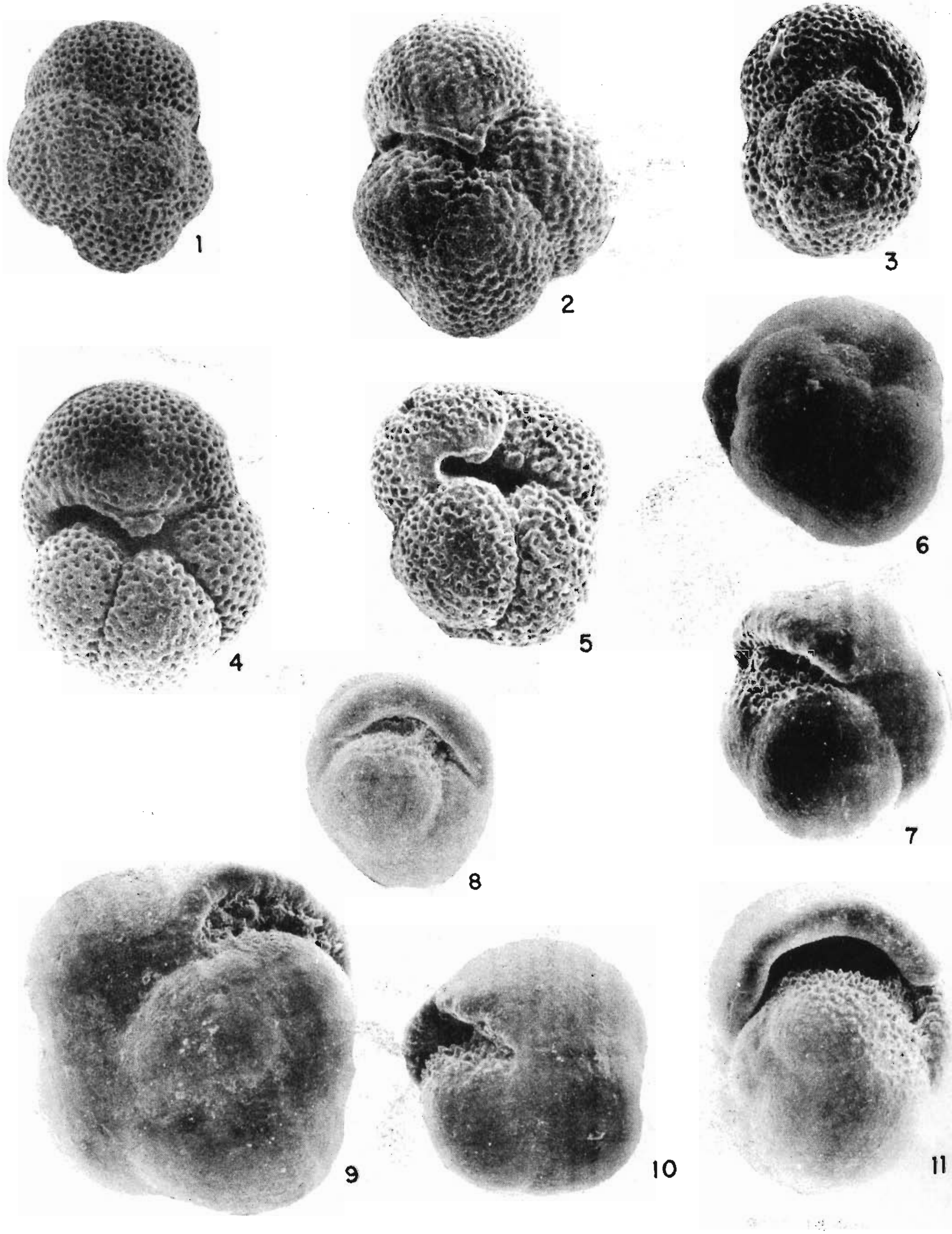
Plate IV



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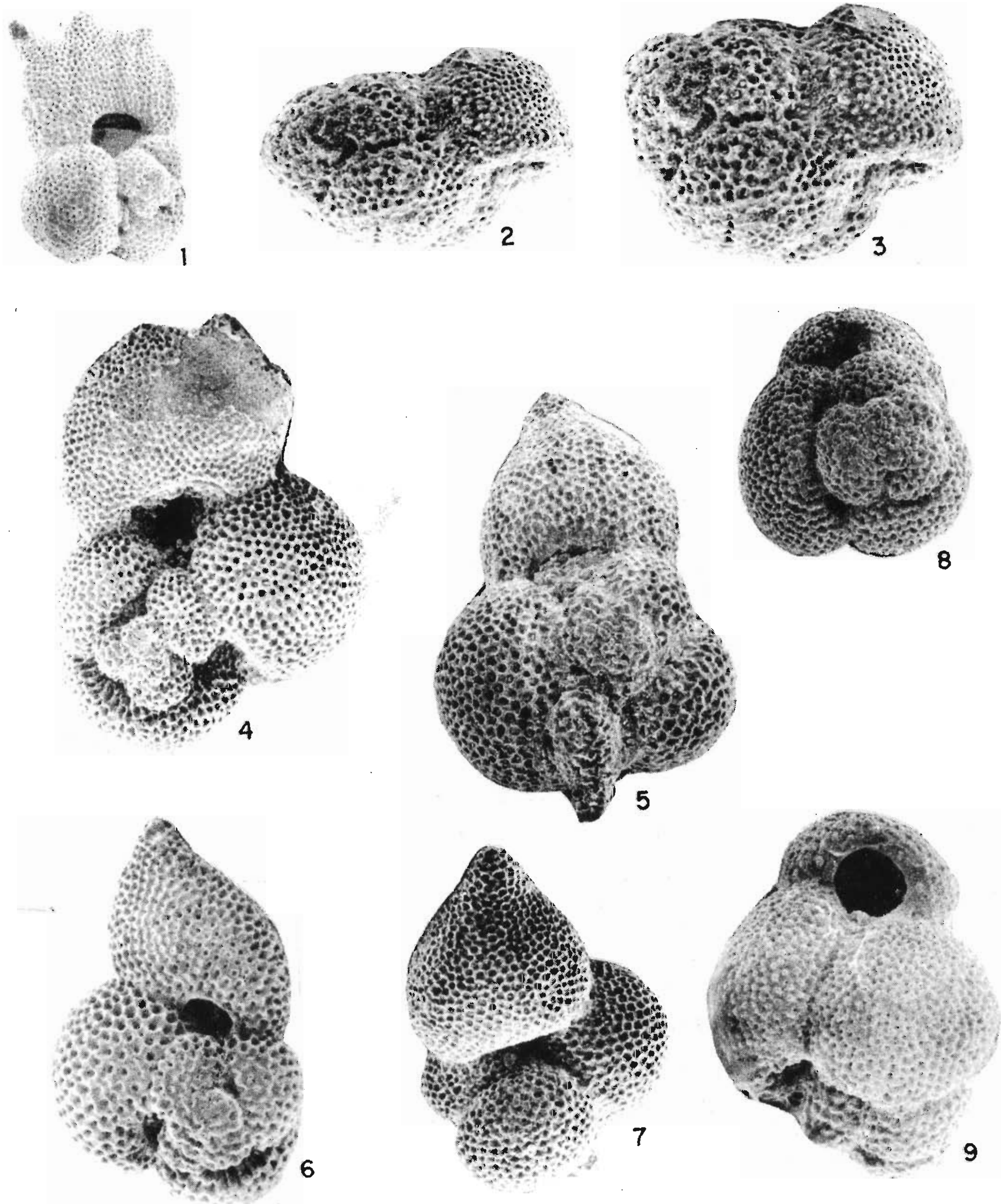
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Plate VI

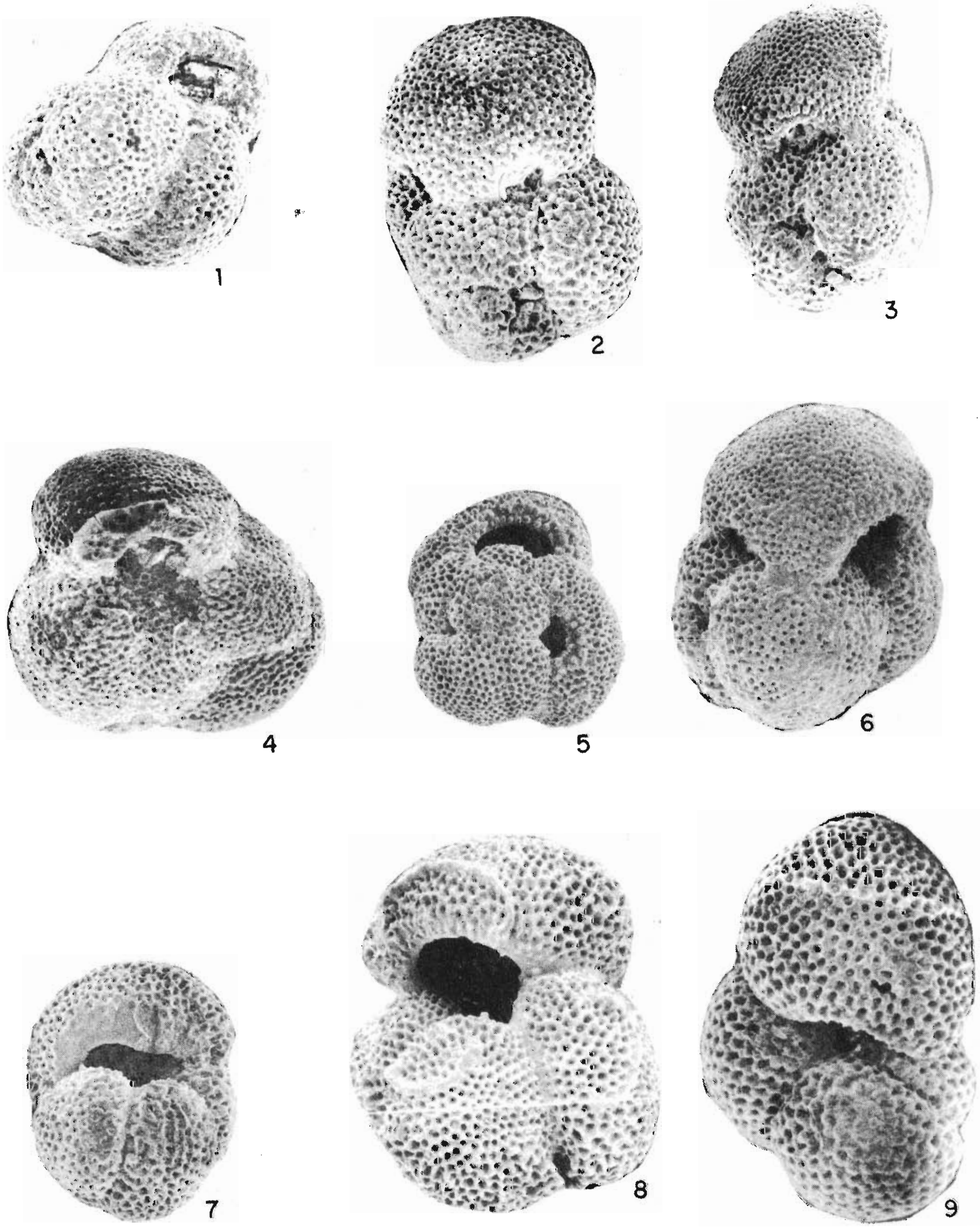

Plate VII

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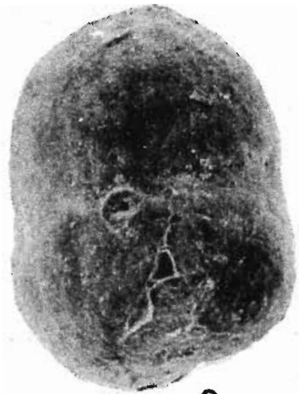

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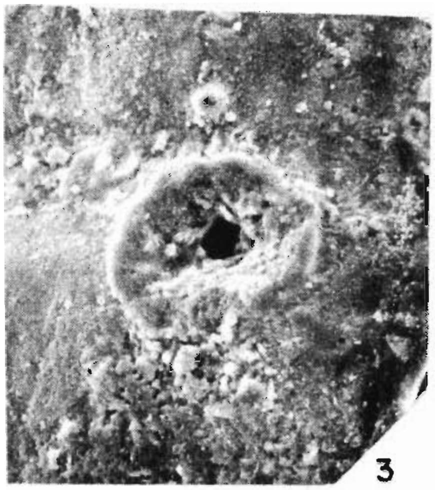

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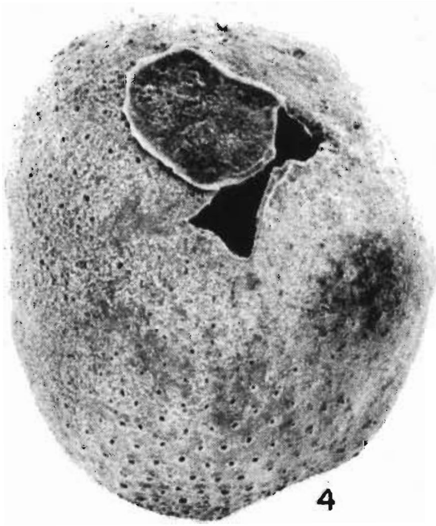

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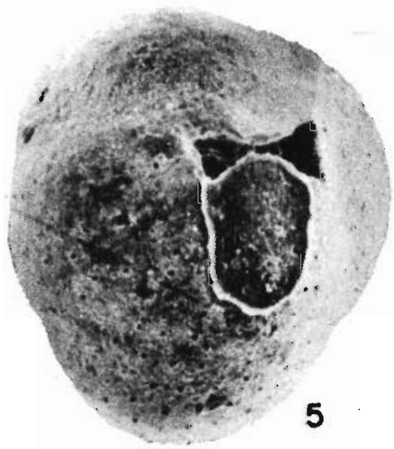

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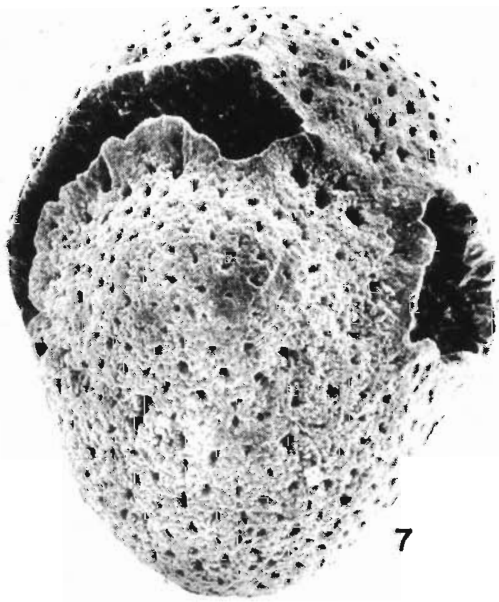

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Plate VIII