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EOCENE AGGLUTINATED FORAMINIFERA FROM THE CAMBAY BASIN, INDIA AND THEIR PALEOECOLOGICAL SIGNIFICANCE

by

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With 3 figures and 4 plates

ZUSAMMENFASSUNG

Aus dem oberen Teil der eozänen Kalol Formation (Indien) wurden aus den Bohrungen von Kalol und aus angrenzenden Strukturen Vergesellschaftungen agglutiniertes Foraminiferen beschrieben. Die Fauna besteht vorwiegend aus Arten der Gattungen *Haplophragmoides*, *Ammobaculites*, *Trochamminoides*, *Arenobulimina* und *Bolivinopsis*. Diese generische Zusammensetzung weicht deutlich von der flyschartigen „*Rhabdammina*-Fauna“ ab. Die Ablagerung der Ton- und Siltsteine der Kalol Formation erfolgte im seichten, neritischen Bereich (0–30 m), wie aus der Größe, Farbe, glatten Wandbildung und dem Überwiegen trochospiraler und multiserialer Formen geschlossen wird.

Da das umgebende Sediment, ein dunkelgrauer Ton, reich an organischem Material und Pyrit ist, wird ein Ablagerungsmilieu mit stagnierenden Bedingungen oder geringer Wasserbewegung angenommen, in dem nur wenig gelöster Sauerstoff und ein hoher CO₂-Gehalt vorhanden ist, der aus der Zersetzung organischer Substanzen kommt.

ABSTRACT

Agglutinated foraminiferal assemblages have been studied from shale and siltstone samples cored from wells in the upper part of the Kalol Formation (Eocene) from Kalol and adjacent structures. The assemblage is comprised of specimens belonging to the genera *Haplophragmoides*, *Ammobaculites*, *Trochamminoides*, *Arenobulimina* and *Bolivinopsis*. The generic composition markedly differs from that of flysch type „*Rhabdammina* fauna“. The small to medium size, light amber to dark gray color, smoothly finished wall, predominance of trochoid and multiserial forms in the assemblage, together with the rare occurrence of calcareous benthic forms in some samples, indicate the deposition of these shales in a shallow inner neritic sea (0–30 m).

Since the enclosing sediment is a dark gray shale with abundant organic matter and pyrite, the possible environment would be under stagnant or slowly moving bottom water with small dissolved oxygen and high CO₂ contents resulting from the decomposition of organic matter.

INTRODUCTION

The foraminiferal assemblages consisting exclusively of agglutinating foraminiferal taxa are found in the Kalol Formation (Middle Eocene) in the north Cambay Basin, Gujarat. Sandstone layers of this formation, which are interstratified with

shales, are hydrocarbon producers in this basin. This section has been cored extensively in many wells in Kalol and in adjoining structures (figure 1). Since no published information exists on the reported occurrence of agglutinated taxa from this formation, we have undertaken a detailed study of core samples for a systematic account of these

assemblages. We feel that this study might be useful in interpreting the environment of deposition and age of this section.

PREVIOUS WORK

So far little work has been done on the agglutinated foraminifera of this region, barring a few records of these arenaceous fauna in unpublished reports. This is the first detailed systematic study on the agglutinated foraminifera of the region. However, calcareous larger and smaller benthic foraminifera of Eocene age of this area have been reported by Datta and Mehrotra (1974) and Singh and Koshal (1970).

STRATIGRAPHY

The Cambay Basin represents a single NS trending long graben, which can be subdivided into four major segments or depressions, separated by transverse faults. The study area falls in the Mehsana-Ahmedabad Block (figure 1). The generalized stratigraphy of this area has been worked out by Chandra and Chowdhary (1969) and Sudhakar *et al.* (1973) which is summarized in figure 2. The Kalol Formation is comprised chiefly of shale, sandstone and coal. This unit has a maximum thickness of 300 m in this part. It is overlain by the Tarapur shale and underlain by the Cambay shale. This unit has been dated as Middle Eocene.

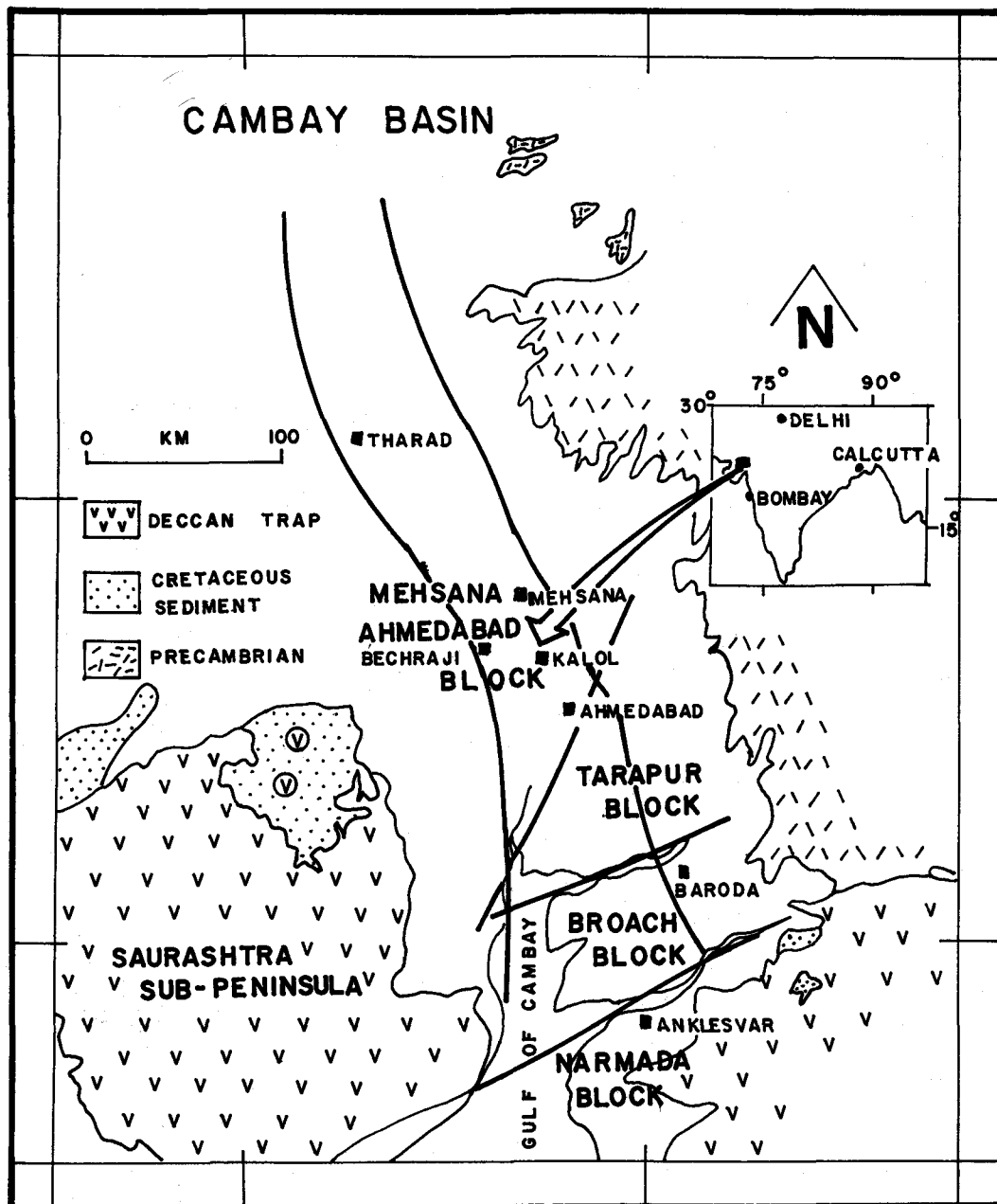


Fig. 1.
Location map of study area.

FORMATION	LITHOLOGY	AGE	
GUJARAT ALLUVIUM	SAND	RECENT	
JAMBUSAR	CLAY, SAND	PLEISTOCENE	
BROACH	SAND, CLAY	PLIOCENE	
JAGADIA	CLAY STONE SAND STONE	MIOCENE	
KAND	SHALE SAND STONE		
BABAGURU	CLAY STONE SAND STONE	OLIGOCENE	
TARAPUR	SHALE	LATE	E
KALOL / KADI	SAND STONE SILT STONE SHALE COAL	MIDDLE	O C E
	SAND STONE SHALE	EARLY	N E
CAMBAY	SHALE	-----	
OLPAD	TRAP WASH	PALEOCENE	
DECCAN TRAP	TRAP	U. CRE TACEOUS	

Fig. 2.
Subsurface stratigraphy of North Cambay Basin.

MATERIAL AND METHODS

Fourty-two core samples from the Kalol Formation in the Kalol A-F and Bacharaji-A wells were examined for microfauna. The samples are mainly dark gray, silty, pyritiferous, fissile shale. They were processed by treating with hydrogen peroxide, and the samples were picked for foraminifera. Agglutinated foraminifera are conspicuously and persistently seen in a 70-80 m thick section, from the top of the Kalol Formation (figure 3). Samples from the remaining section of this formation are devoid of fauna.

All the foraminiferal taxa were identified using the taxonomy outlined by Loeblich and Tappan (1964). The foraminiferal assemblages were described and illustrated (plates 1-3) with the help of a Cambridge Scanning Electron Microscope. Specimens were coated with gold for photography. Figures for plate 4 were drawn using a *camaera lucida*. All the illustrated specimens are deposited in the museum of the Regional Geology Laboratory, Oil & Natural Gas Commission, Baroda, and reference to them is designated by BF catalogue numbers in the text and in the plate explanations. Some types will be deposited later in the British Museum Natural History, London and U.S. National Museum, New York.

COMPOSITION, AFFINITY, AGE AND BIOZONATION OF AGGLUTINATED FORAMINIFERA

The agglutinated foraminifera are assigned to 11 species representing 6 genera and 4 families. Of

these, four are new species and one is described as a new variety. These are: *Arenobulimina talukdari* n. sp., *Trochammina indica* n. sp., *Ammobaculites cambayensis* n. sp., *Bolivinospis distinctus* n. sp., and *Arenobulimina d'orbignyi* (Reuss) *eocenica* n. ssp. The most abundant species in the assemblage are: *Trochamminoides subtrullissatus*, *Trochammina indica* n. sp., and *Arenobulimina talukdari* n. sp. Some well known cosmopolitan species occurring in the assemblage include *Trochamminoides subtrullissatus*: Late Eocene, Poland (Grzybowski 1898); Maastrichtian to Early Paleocene, Labrador Shelf and North Sea (Gradstein and Berggren 1981); Early Eocene, Belgium (Willems 1983); *Haplophragmoides walteri*: Early Eocene, Belgium (Willems 1983); Eocene to Oligocene of the Central Norwegian-Greenland Sea (Verdenius and Van Hinte 1983); Maastrichtian to Eocene, Labrador Shelf (Gradstein and Berggren 1981); *Trochammina deformis*: Late Eocene, Poland (Grzybowski 1898); Maastrichtian to Eocene, Labrador Shelf and North Sea (Gradstein and Berggren 1981); *Trochamminoides elegans*: Late Eocene, Poland (Grzybowski 1898) and *Arenobulimina d'orbignyi*: Late Cretaceous, Labrador Shelf (Gradstein and Berggren 1981). In the absence of marker species in this assemblage, it has not been possible to assign a precise age to this section but the overall predominance of Eocene forms is apparent.

Further, this fossiliferous section is overlain by the Tarapur shale, the base of which has been dated on the basis of faunal evidence as Middle Eocene, hence, considering the stratigraphical position, this section of the Kalol Formation containing an agglutinated foraminiferal assemblage has been assigned to the Middle Eocene in this study.

The vertical and lateral distribution of the fauna in the studied area is shown in figure 3. The stratigraphic distribution of the foraminiferal fauna

ARENACEOUS FORAMINIFERA		KALOL #A	KALOL #B	KALOL #C	KALOL #D	KALOL #E	KALOL #F	BECHARAJI #A
a	ARENABULIMINA D'ORBIGNYI VAR. EOCENICA N. VAR.							X
b	ARENABULIMINA TALUKDARI N. SP.							X
c	TROCHAMMINOIDES SUBTRULLISSATUS			X		X	X	
d	TROCHAMMINA DEFORMIS	X	X	X			X	
e	TROCHAMMINA INDICA N. SP.	X	X	X	X	X	X	X
f	AMMOBACULITES CAMBAYENSIS N. SP.						X	
g	AMMOBACULITES SP.						X	
h	BOLIVINOPSIS DISTINCTUS N. SP.				X	X		X
i	HAPLOPHRAGMOIDES AFF. WALTERI			X	X	X	X	X
j	TROCHAMMINOIDES AFF. ELEGANS							X
k	TROCHAMMINA AFF. STOMATA		X		X	X	X	X

Fig. 3.
Distribution of agglutinated foraminifera in Kalol Formation, North Cambay Basin, Gujarat.

permits the recognition of three biostratigraphic zones: the *Bolivinopsis distinctus* zone, the *Trochamminoides subtrullissatus* zone and the *Arenobulimina talukdari* zone in ascending order. These zones are described in brief:

1. *Bolivinopsis distinctus* zone: This zone is characterized by the presence of *Bolivinopsis distinctus*, the nominate taxon. *B. distinctus* is restricted to this zone only, and is absent in the overlying zones. The other important agglutinated foraminifera occurring in this zone include: *Ammobaculites* sp., *Ammobaculites cambayensis* n. sp., *Trochammina indica* n. sp., *Trochamminoides elegans*, *Trochammina deformis*, *Trochamminoides subtrullissatus*, *Trochammina* aff. *stomata* and *Haplophragmoides walteri*. This zone has been traced laterally in many wells and it is 25 m thick in the Kalol well F.

2. *Trochamminoides subtrullissatus* zone: *Trochamminoides subtrullissatus* is most dominant species in this zone to the virtual exclusion of the other arenaceous forms in some core samples. Most of the species of the underlying zone continue up into this zone. The characteristic taxa recorded include: *Trochammina deformis*, *T. indica* n. sp., *T.* aff. *stomata* and *Haplophragmoides walteri*. This zone is 42 m thick in the Kalol well F.

3. *Arenobulimina talukdari* zone: This zone is characterized by the presence of *Arenobulimina* species, i.e. *Arenobulimina talukdari* n. sp. and *Arenobulimina d'orbignyi eocenica*. All the species of the underlying zones are absent in this zone. This zone is 4 m thick in the Kalol well F.

At present the *T. subtrullissatus* and *Arenobulimina talukdari* zones have been traced only in Kalol well F. Their lateral extent could not be verified due to non-availability of core samples at corresponding levels in other wells. The possibility of tracing these zones in other wells cannot be ruled out.

PALEOENVIRONMENT

Faunas comprised exclusively of agglutinated foraminifera could have lived from abyssal depths to shallow seas (Moorkens 1976). The agglutinated foraminifera in the studied samples are small to medium in size, light amber to dark gray in color, have a smoothly finished wall and the predominance of trochoid and multiserial forms in the assemblage indicates that these shales were deposited in a shallow inner neritic sea (0-30 m). Since the enclosing sediment is a dark gray shale with abundant organic matter and pyrite, the physico-

chemical conditions favorable for their environment could be a low alkalic or even neutral pH resulting in non-secretion of CaCO_3 . This type of environment generally originates under stagnant or slowly moving bottom water with small quantities of dissolved oxygen and a high content of CO_2 resulting from the decomposition of organic matter. Such reducing conditions are ideally suited for the generation of hydrocarbons. The absence of single-chambered "*Rhabdammina*-like" forms in the assemblage suggests that these are not "flysch-type" forms.

The occurrence of multiserial trochoid forms in abundance in the upper part indicates that this section of the Kalol Formation has been deposited under deep inner shelf condition.

CONCLUSIONS

1. Foraminiferal assemblages consisting exclusively of agglutinated taxa are found in the core samples from the upper part of the Kalol Formation (Middle Eocene) in north Cambay Basin. In the samples studied several agglutinated species are recognized, that can be traced in many wells.

2. The fauna is characterized by planispiral forms (*Haplophragmoides*, *Trochamminoides*), trochospiral forms (*Trochammina*), multiserial forms (*Arenobulimina*) and representatives of *Ammobaculites* and *Bolivinopsis*. The generic composition markedly differs from that of flysch-type "*Rhabdammina* fauna".

3. The occurrence of agglutinated assemblages consisting of predominantly multiserial and trochoid forms suggests the deposition of these shales in a shallow inner neritic sea (0-30 m). Since the enclosing sediment is an organic-rich, dark gray shale with pyrite, the possible environment would be under stagnant or slowly moving bottom water with small dissolved oxygen and high CO_2 contents resulting from the decomposition of organic matter. Such reducing conditions are ideally suited for the generation of hydrocarbons.

SYSTEMATIC PALEONTOLOGY

Genus *Haplophragmoides* Cushman, 1910.

Haplophragmoides aff. *walteri* (Grzybowski)

Plate 2, figure 6; plate 4, figure 8.

Trochammina walteri Grzybowski, 1898, p. 290, plate 11, figure 31.

Haplophragmoides walteri (Grzybowski), Gradstein and Berggren 1981, p. 250, plate 6, figures 5-7.

Remarks: The Cambay Basin forms somewhat resemble *H. walteri* (Grzybowski) in having circular planispiral involute test, seven to eight gradually

increasing chambers in the last whorl, nearly straight, flush to gently depressed sutures particularly in the last 2 to 3 chambers and a slit-like extra-umbilical equatorial aperture. This species differs from the original types in having a less smooth wall. The types are from the Upper Eocene of the Polish Carpathians. The stratigraphic range of this species appears to be Maastrichtian through Eocene. In the Cambay Basin this form is common in the upper part of the Kalol Formation in several well samples in the Kalol structure.

Hypotype: Maximum diameter 0.25 mm; illustration plate 2, figure 6; depository no. BF 535

Genus *Trochamminoides* Cushman, 1910.

Trochamminoides subtrullissatus (Grzybowski)

Plate 2, figures 7-9; plate 4, figure 9.

Trochammina subtrullissata Rzehak, 1887, p. 88 (nomen nudum).

Trochammina subtrullissata Rzehak, Grzybowski, 1898, p. 289, plate 11, figure 24.

Trochammina subtrullissatus (Grzybowski), Gradstein and Berggren 1981, p. 252, plate 6, figure 5.

Remarks: This species of *Trochamminoides* is distinguished by its partially evolute coil, six to seven gradually increasing chambers in the final whorl, nearly circular outline, lobulate periphery and moderately coarse wall. The Cambay Basin forms are closely similar to the figured types of this species in having six to seven gradually increasing chambers in the final whorl and gently depressed sutures, but differs from it in having a coarse-grained rough wall as opposed to smooth.

T. subtrullissatus, which was originally described from Krosno, Poland in Late Eocene, is well represented in many samples in the Cambay Basin in the upper part of the Kalol Formation.

Hypotype (A): Diameter of the test 0.31 mm; illustration plate 2, figure 7; depository no. BF 536.

Hypotype (B): Diameter of the test 0.37 mm; illustration plate 2, figure 8; depository no. BF 537.

Hypotype (C): Diameter of the test 0.39 mm; illustration plate 2, figure 9; depository no. BF 538.

Trochamminoides aff. *elegans* (Grzybowski), plate 1, figure 7.

Trochammina elegans Rzehak, 1887, p. 88 (nomen nudum).

Trochammina elegans Rzehak, Grzybowski, 1898, plate 11, figure 10.

Trochammina sp. Miller, Gradstein and Berggren, 1982, p. 21, plate 2, figure 12.

Remarks: This is a species of *Trochamminoides* having a partially evolute compressed test, 14-17 gradually increasing chambers in the final whorl, a centrally depressed initial whorl, radial to gently arcuate depressed sutures and nearly smooth wall. Higher number of chambers in the final whorl, initially depressed chambers, radial sutures and lobulate periphery clearly distinguish this form from the other species of *Trochamminoides* in the assemblage.

The Cambay Basin forms are closely similar to the illustration of the species given by Grzybowski (1898, plate 11, figure 10) in its shape and in the arrangement of the chambers. They differ from the latter, however, in having a greater number of chambers in the final whorl.

Grzybowski (*op cit.*) reports this form from the Late Eocene of Krosno, Poland. This form is commonly represented in the upper part of the Kalol Formation in Becharaji-A and in Kalol wells in the Cambay Basin, Gujarat.

Hypotype: Length of the test 0.37 mm; width of the test 0.25 mm; illustration plate 1, figure 7; depository no. BF 528.

Genus *Ammobaculites* Cushman, 1910.

Ammobaculites cambayensis n. sp.

Plate 3, figure 6.

Description: Test small, laterally compressed with planispirally coiled early portion consisting of six to seven chambers gradually increasing in size. The uncoiled uniserial later portion is gently arcuate and consists of two or three much broader than higher chambers gradually increasing in size. Sutures in the planispiral portion are indistinct, flush to gently depressed and in the uncoiled portion distinct, transverse and depressed. The agglutinated wall is smoothly finished with much cement. The aperture is terminal, elongate opening in the middle of the apertural face.

Remarks: The species differs from *Ammobaculites fortunens* (Terquem) illustrated from the Eocene of the Polish Carpathians by Grzybowski (1898, plate 19, figures 21-22) in having a more compressed test, depressed sutures in the later uncoiled portion, lobulate periphery and much broader than high chambers. *A. fontinensis* possesses chambers nearly as broad as high and a less depressed surface. The species differs from *Ammobaculites strathaernensis* Cushman and Le Roy (*in*: Verdenius and Van Hinte 1983) in having a more arcuate uniserial portion and comparatively smooth wall.

Type level: Gray silty shale, Kalol well F, WLC-19 (1371-1375), upper part of Kalol Formation, Middle Eocene.

Hypotype: Maximum length of the test 0.43 mm; maximum width of the uncoiled portion 0.25 mm; maximum diameter of coiled portion 0.31 mm; illustration plate 3, figure 6; depository no. BF 544.

Derivation of name: The species has been named after the Cambay Basin, Gujarat, where it is first reported.

Ammobaculites sp.

Plate 3, figure 5.

Description: The test is moderately compressed with a planispiral coiled early portion having six to seven gradually increasing chambers. The uncoiled portion is large with seven to eight chambers

arranged in rectilinear series. The chambers are increasing gradually in size, four times broader than high and laterally compressed. Sutures are distinct, limbate and depressed, more so in the uncoiled portion. Aperture is an elongate opening in the middle of the apertural face. The wall is finely arenaceous with a moderate amount of siliceous cement.

Remarks: The small coiled early portion, large compressed, later uncoiled portion, broad and high chambers and lobulate periphery are the distinguishing characters of this species. This species in the Cambay Basin material markedly differs from other *Ammobaculites* species in its morphological characters. It is rare in occurrence. In the absence of a sufficient number of specimens this species is left in open nomenclature.

Hypotype: Length of the test 0.62 mm; maximum width of uncoiled portion 0.19 mm; maximum diameter of coiled portion 0.31 mm; illustration plate 3, figure 5; depository no. BF 543.

Genus *Bolivinopsis* Yakovlev, 1891.

Bolivinopsis distinctus n. sp.

Plate 2, figures 1-5; plate 4, figures 10-11.

Description: The elongate test is compressed laterally with moderately large planispiral initial whorl and short incomplete biserial later part. The initial planispiral whorl consists of eight to nine gradually increasing subtriangular chambers encircling the small proloculus. The incomplete biserial part consists of 3 to 4 pairs of biserially arranged chambers. The width of the biserial part remains the same throughout. Sutures in the planispiral part are gently arcuate and depressed. In the biserial part, sutures are limbate and flush to gently depressed. The periphery is lobulate in the later part. The wall is fine-grained and nearly smooth. The apertural end is ill preserved. Aperture is an elongate slit-like opening in the apertural face.

Remarks: This species differs from *Spiroplectammina spectabilis* (Grzybowski) in having much larger planispiral initial whorl, and lower number of pairs of biserial chambers in the uncoiled part. Further, it differs from the latter in having a less compressed and more rounded periphery. *Bolivinopsis parvissimus* Krasheninnikov, a closely similar form described from the Late Cretaceous sediments of the Indian Ocean differs from the Cambay Basin form in having lower number of chambers in the initial planispiral coil.

Type level: Silty shale, Kalol well D, C.C.1-1343-1346 m., Kalol Formation, Middle Eocene.

Hypotype: Maximum length of the test 0.37 mm; maximum width of the uncoiled portion 0.19 mm; maximum diameter of coiled portion 0.29 mm; illustration plate 2, figure 1; depository no. BF 530.

Paratype A: Maximum length of the test 0.31 mm;

maximum width of the uncoiled portion 0.12 mm; maximum diameter of coiled portion 0.25; illustration plate 2, figure 2; depository no. BF 531.

Paratype B: Maximum length of the test 0.25 mm; maximum width of the uncoiled portion 0.12 mm; maximum diameter of coiled portion 0.19; illustration plate 2, figure 3; depository no. BF 532.

Paratype C: Maximum length of the test 0.68 mm; maximum width of the uncoiled portion 0.25 mm; maximum diameter of coiled portion 0.43; illustration plate 2, figure 5; depository no. BF 534.

Derivation of name: The species has been named after its distinctive identifying characters.

Genus *Trochammina* Parker and Jones, 1859.

Trochammina deformis Grzybowski

Plate 1, figure 6; plate 4, figure 5.

Trochammina deformis Grzybowski, 1898, p. 288, plate 11, figures 20-22, Gradstein and Berggren 1981, p. 256, plate 8, figures 8-10.

Remarks: Four to five laterally compressed chambers in the final whorl, deformed test and coarse-grained wall are the distinguishing characters of this *Trochammina* species. The figured specimen is a less deformed one. Several specimens in the studied material are more deformed, nearly flattened due to post-burial chamber collapse. The types are from the Late Eocene, red and gray clays from the Krosno area, Poland. This species is more common and well represented in the upper part of the Kalol Formation in north Cambay Basin wells.

Hypotype: Maximum diameter of test 0.37 mm; illustration plate 1, figure 6; depository no. BF 527.

Trochammina indica n. sp.

Plate 1, figures 1-5; plate 4, figures 1-4.

Description: The test is small, trochospiral with more convex spiral side and less convex to flat umbilical side. On the spiral side, $2\frac{1}{2}$ to 3 narrow whorls are visible, each with 4 to $4\frac{1}{2}$ moderately increasing chambers. Inner whorls on spiral side are distinctly raised. In the umbilical side the chambers of the last whorl only are visible. Chambers are broadly oval, moderately increasing in size and slightly depressed. Sutures on the spiral side are radial to slightly arcuate and depressed, and on the umbilical side radial and depressed. Umbilicus is narrow and nearly closed with material. The periphery is lobulate. Agglutinated wall is smoothly finished. Aperture is a narrow slit like opening at the base of apertural face.

Remarks: This species differs from *Trochammina globigeriniformis* var. *altiformis*, a four-chambered form, described originally from the Upper Cretaceous-Paleocene of Trinidad, in having narrow subspherical chambers in the spiral side rather than reniform chambers arranged at right angles to one another and in having convex dorsal side with raised inner whorls.

This species also differs from *Trochammina pseudovesicularis* Krasheninnikov described from the Late Cretaceous of the Indian Ocean in having nearly subspherical chambers in dorsal side and less compressed chambers in the ventral side. In the studied material, this form occurs frequently in many well samples in Kalol.

Type level: Gray shale, Kalol well B, WLC-3; 1354.9 to 1358.9 m; Kalol Formation, Middle Eocene.

Hypotype: Maximum diameter 0.31 mm; illustration plate 1, figure 1; depository no. BF 522.

Paratype A: Maximum diameter 0.31 mm; illustration plate 1, figure 2; depository no. BF 523.

Paratype B: Maximum diameter 0.19 mm; illustration plate 1, figure 4; depository no. BF 524.

Paratype C: Maximum diameter 0.25 mm; illustration plate 1, figure 5; depository no. BF 525.

Paratype D: Maximum diameter 0.25 mm; illustration plate 1, figure 3; depository no. BF 526.

Derivation of name: This species is named after India, where it is first reported.

Trochammina aff. *stomata* Grzybowski

Plate 1, figures 8-9; plate 4, figures 6-7.

Trochammina stomata Grzybowski, 1898, p. 281, plate 11, figures 26-27.

Remarks: This species resembles *Trochammina stomata* Grzybowski, described from the Late Eocene of Krosno, Poland, in general appearance. However, it differs from *T. stomata* in having more inflated chambers on the umbilical side and a nearly closed umbilicus. This species is seen frequently in the studied samples from the upper part of the Kalol Formation.

Hypotype A: Maximum length of the test 0.25 mm; width of the test 0.19 mm; illustration plate 1, figure 8; depository no. BF 529.

Hypotype B: Maximum length of the test 0.25 mm; width of the test 0.19 mm; illustration plate 1, figure 9; depository no. BF 545.

Genus *Arenobulimina* Cushman, 1927.

Arenobulimina d'orbignyi (Reuss) *eocenica* n. subspecies

Plate 3, figures 3-4; plate 4, figure 12.

Description: The test is small, elongate, trochoid, broadly fusiform and tapering at the initial end. The chambers are arranged in a trochoid spire with five chambers per whorl in the proximal end. In the distal end, chambers are subspherical, inflated, four per whorl, separated by depressed sutures. Both septal and spiral sutures are distinct and depressed. The periphery is lobulate. Surface is typically agglutinated, fine-grained, and smooth. The aperture is interiomarginal, loop-like opening without any tooth at the base of apertural face.

Remarks: This species somewhat resembles *Arenobulimina d'orbignyi* (Reuss) described from the Late Cretaceous of Bohemia in its shape and in

the arrangement of the chambers. However, the Indian forms differ from *A. d'orbignyi* in having inflated subspherical chambers and more depressed sutures in the adult portion of the test. In addition, this form is well represented in younger stratigraphic level, i.e. Middle Eocene. Because of morphological differences and different stratigraphic level of occurrence, a new variety has been proposed for the Indian *A. d'orbignyi*-like form.

Type level: gray shale, Kalol well F, WLC-3; 1308-1312 m, upper part of Kalol Formation, Middle Eocene.

Hypotype: Maximum length of the test 0.37 mm; maximum width 0.25 mm; illustration plate 3, figure 3; depository no. BF 541.

Paratype: Maximum length of the test 0.37 mm; maximum width 0.25 mm; illustration plate 3, figure 2; depository no. BF 542.

Derivation of name: The variety has been named after its stratigraphic level, i.e. Middle Eocene age in Indian Basin.

Arenobulimina talukdari n. sp.

Plate 3, figures 1-2.

Description: The test is small, trochoid, tapering at the initial end and broad at the apertural end. The chambers are arranged in a trochoid spire with five to six chambers per whorl. The whorls rapidly increase in width. The chambers are subspherical, inflated and increase in size rapidly. Septal and spiral sutures are short, distinct and depressed. The agglutinated wall is fine-grained and smoothly finished. The periphery is lobulate. The aperture is a loop-like opening at the base of apertural face.

Remarks: This species differs from *Arenobulimina d'orbignyi* (Reuss) in having a much shorter and more flaring test and greater number of more inflated chambers per whorl. It resembles *Uvigerinammina jankoi* Majzon in general appearance (Gradstein and Berggren 1981, plate 5, figures 10-11) but differs from the latter because of much flaring test, higher number of chambers per whorl (5 to 6 in the former, 3 in the latter) and in the presence of simple loop-like aperture rather than terminal aperture drawn on a neck. The species is well represented in the studied material.

Type level: Gray shale, Kalol well F, WLC 3; 1308-1312 m, upper part of Kalol Formation, Middle Eocene.

Hypotype: Maximum length of the test 0.31 mm; maximum width 0.31 mm; illustration plate 3, figure 1; depository no. BF 539.

Paratype: Maximum length of the test 0.31 mm; maximum width 0.25 mm; illustration plate 3, figure 2; depository no. BF 540.

Derivation of name: This species has been named in honor of Mr. S.N. Talukdar, Member (Exploration), ONGC, in recognition of his contributions to the stratigraphy of Indian sedimentary basins.

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PLATE 1

- Figures 1-5 *Trochammina indica* n. sp.
 1. Holotype, BF 522, spiral view showing raised inner whorl, x190.
 2. Paratype A, BF 523, umbilical view showing $4\frac{1}{2}$ chambers, x190.
 3. Paratype B, BF 526, spiral view, x240.
 4. Paratype C, BF 524, spiral view, x320.
 5. Paratype D, BF 525, umbilical view showing 4 chambers, x240.
- Figure 6 *Trochammina deformis* Grzybowski
 Hypotype, BF 527, spiral view, x160.
- Figure 7 *Trochaminoides* aff. *elegans* (Grzybowski)
 Hypotype, BF 528, side view showing depressed inner whorls, x160.
- Figures 8-9 *Trochammina* aff. *stomata* Grzybowski
 8. Hypotype, BF 529, side view, x240.
 9. Hypotype, BF 545, side view, x240.

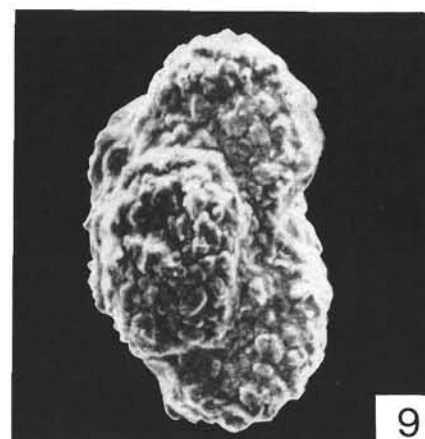
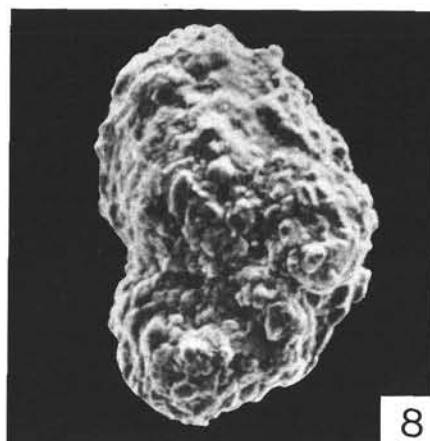
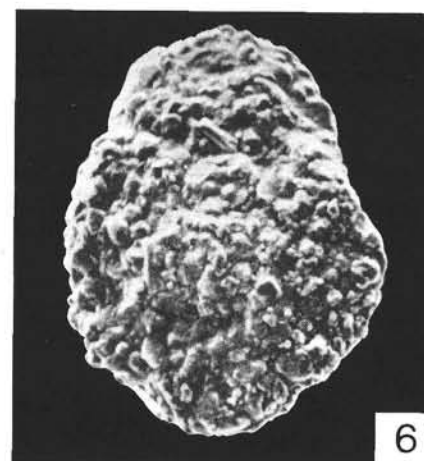
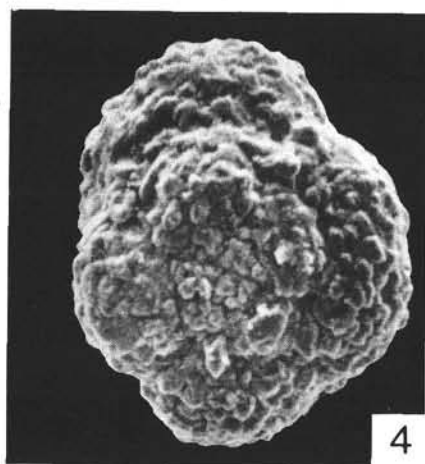
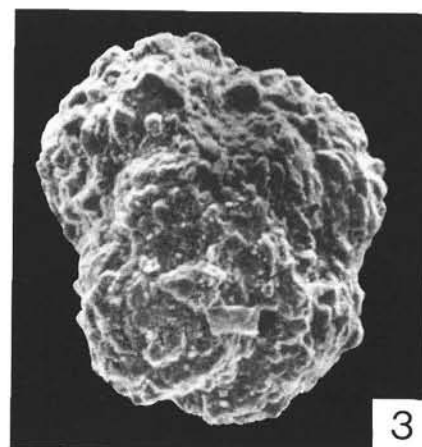
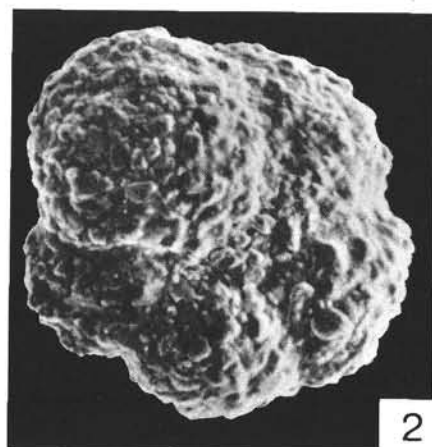
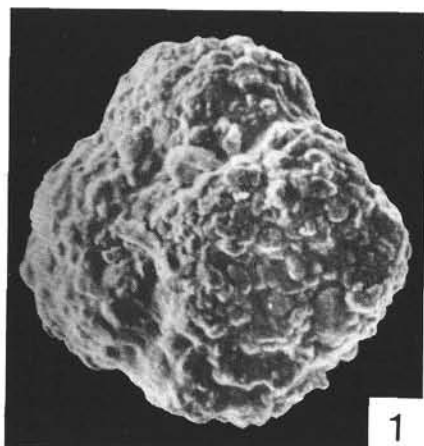


PLATE 2

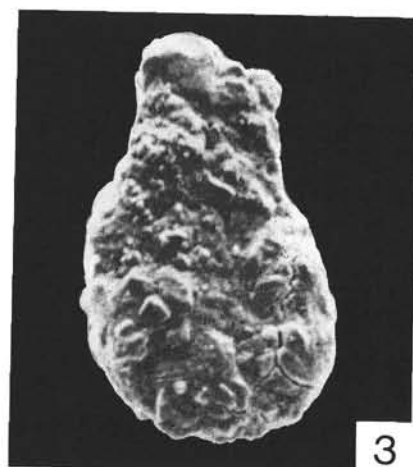
- Figures 1-5 *Bolivinopsis distinctus* n. sp.
1. Holotype, BF 530, side view showing biserially arranged chambers in the adult portion, x160.
2. Paratype A, BF 531, side view, x190.
3. Paratype B, BF 532, side view, x230.
4. Paratype C, BF 534, side view, x100.
5. Paratype D, BF 533, side view, x200.
- Figure 6 *Haplophragmoides* aff. *walteri* Grzybowski
Hypotype, BF 535, side view showing extra-umbilical equatorial aperture, x230.
- Figures 7-9 *Trochamminoides subtrullissatus* (Grzybowski)
7. Hypotype, BF 536, side view, x190.
8. Hypotype, BF 537, side view, x170.
9. Hypotype, BF 538, side view, x170.



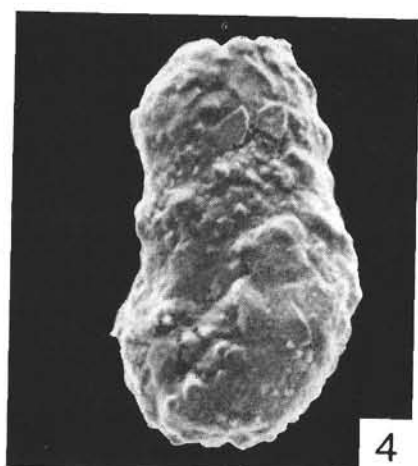
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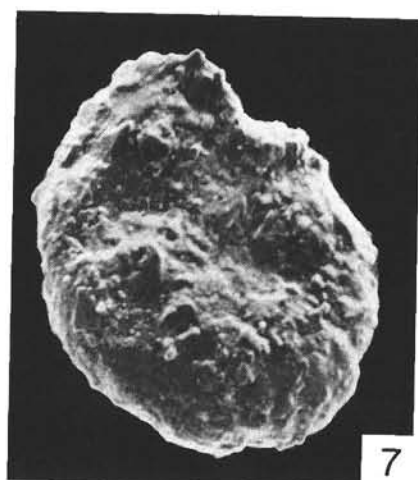
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PLATE 3

- Figures 1-2 *Arenobulimina talukdari* n. sp.
1. Holotype, BF 539, side view showing subspherical chambers and depressed sutures, x190
2. Paratype, BF 540, view from the initial end showing flaring trochoid test, x190.
- Figures 3-4 *Arenobulimina d'orbignyi* (Reuss) *eocenica* n. ssp.
3. Holotype, BF 541, side view, x160.
4. Paratype A, BF 542, side view, x160.
- Figure 5 *Ammobaculites* sp.
Hypotype, side view, x100.
- Figure 6 *Ammobaculites cambayensis* n. sp.
Holotype, BF 544, side view, x240.

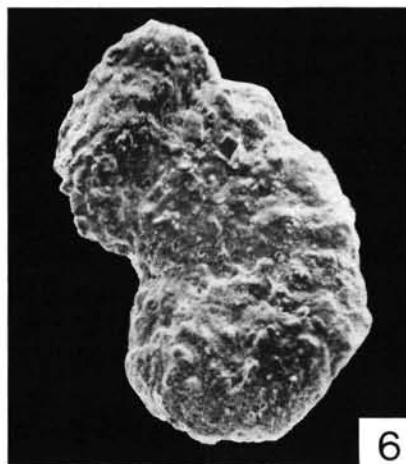
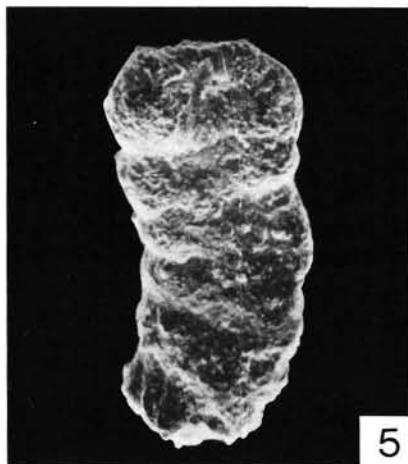
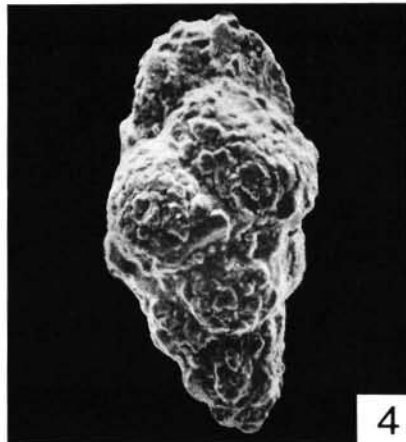
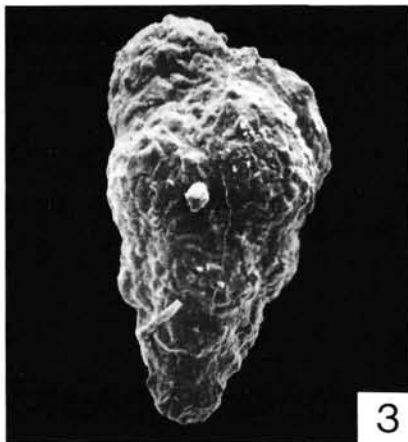
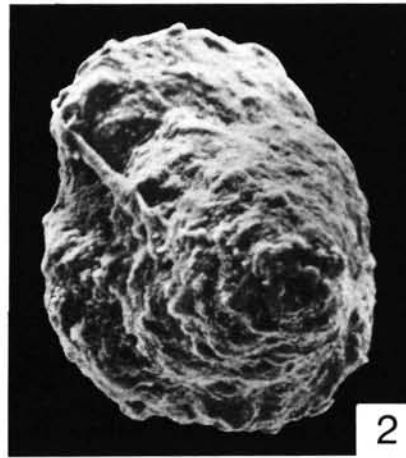
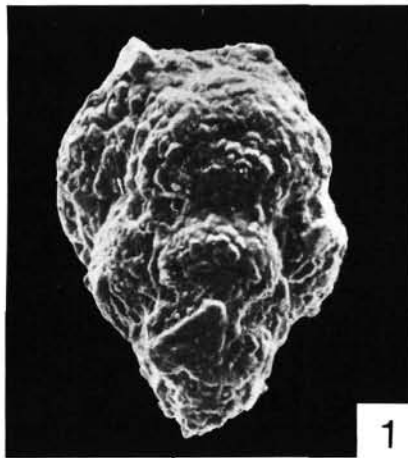
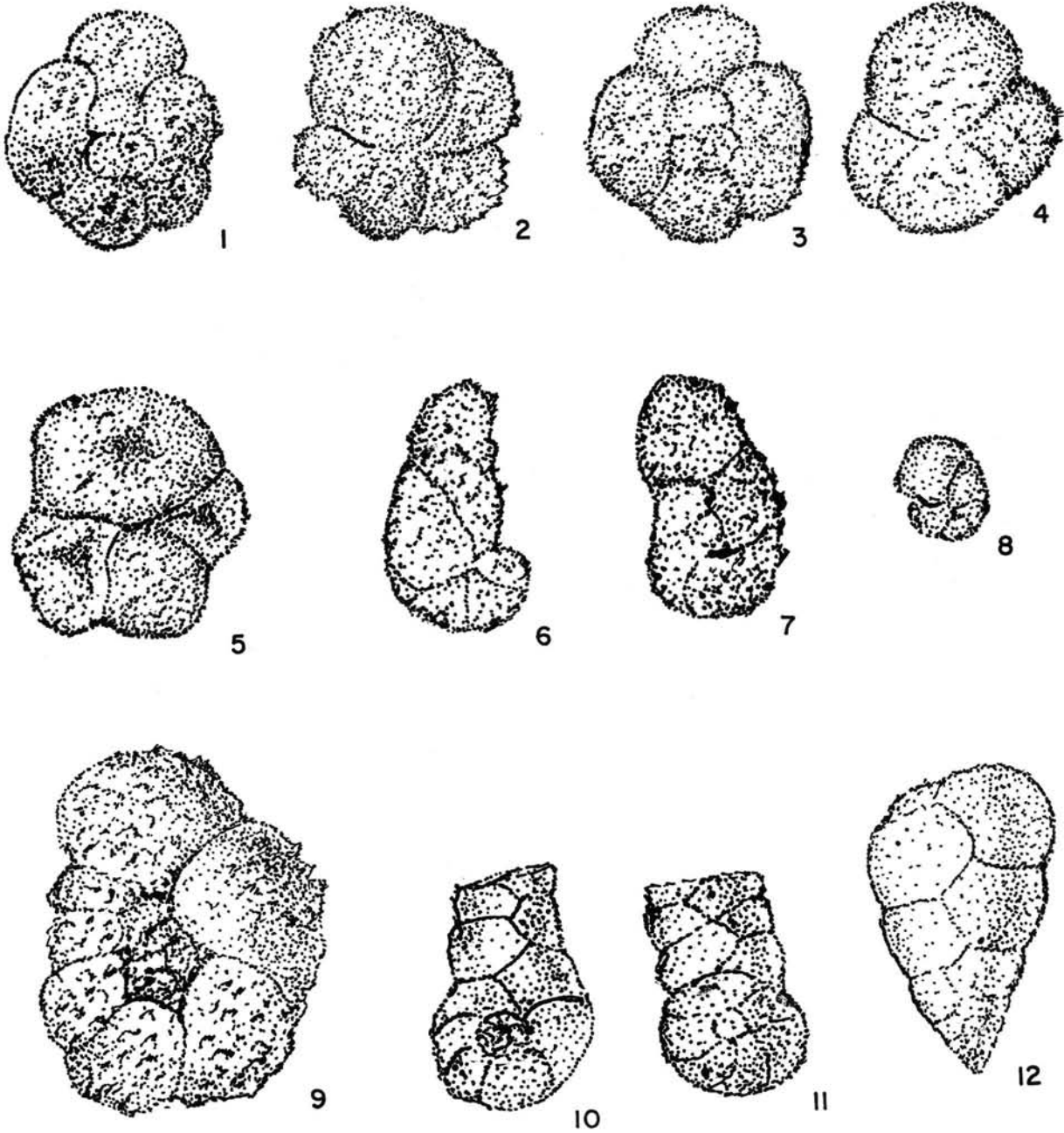


PLATE 4

- Figures 1-4 *Trochammina indica* n. sp.
 1-2. Paratype E, BF 546. 1. spiral view; 2. umbilical view, x60.
 3-4. Paratype F, BF 547. 3. spiral view; 4. umbilical view, x60.
- Figure 5 *Trochammina deformis* Grzybowski
 Hypotype, BF 548, spiral view, x60.
- Figure 6-7 *Trochammina* aff. *stomata* Grzybowski
 6. Hypotype 9, BF 549, side view, x60.
 7. umbilical view, x60.
- Figure 8 *Haplophragmoides* aff. *walteri* Grzybowski
 Hypotype, BF 550, side view, x60.
- Figure 9 *Trochamminoides subtrullissatus* (Grzybowski)
 Hypotype, BF 551, side view, x60.
- Figure 10-11 *Bolivinopsis distinctus* n. sp.
 10. Paratype E, BF 552, side view, x60.
 11. Paratype F, BF 553, side view, x60.
- Figure 12 *Arenobulimina d'orbigny* (Reuss) *eocenica* n. ssp.
 Paratype B, BF 554, side view, x60.



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