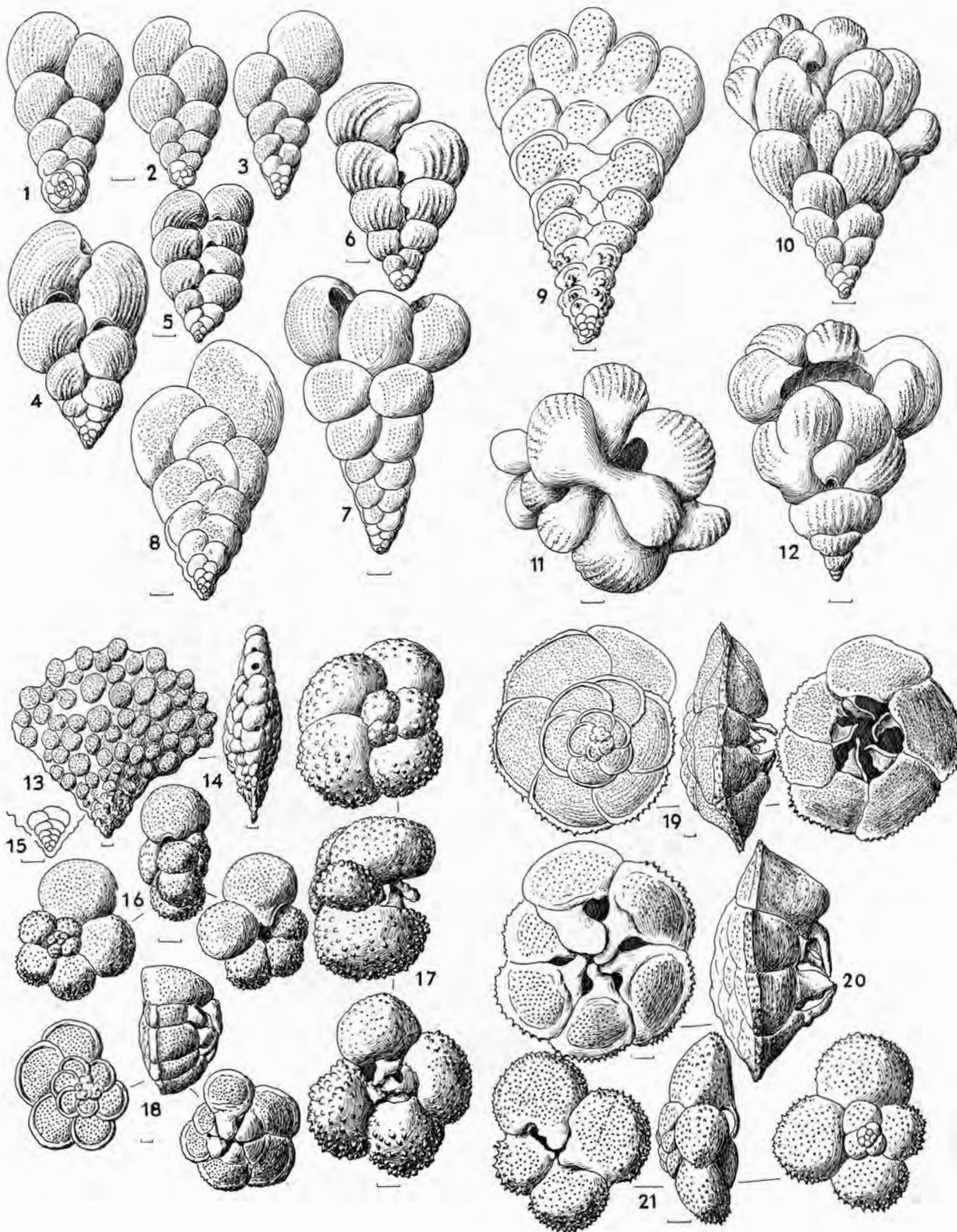




ANALYSIS OF A LARGE SUCCESSION OF SAMPLES THROUGH THE UPPER MAASTRICHTIAN AND THE LOWER TERTIARY OF DRILL HOLE 47.2, SHATSKY RISE, PACIFIC, DEEP SEA DRILLING PROJECT

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ABSTRACT

Samples of coccolithic sediment through the upper Maastrichtian, the Cretaceous-Tertiary boundary and the Paleocene from Hole 47.2, D.S.D.P., proved to be scarcely disturbed. Samples were taken about 50 cm apart, except near the Cretaceous-Tertiary boundary where sample spacing was 10 cm. Most of the Cretaceous planktonic foraminifera extinguished gradually before the boundary was reached; some reached the boundary and a few continued into the Danian. The *Parvularugoglobigerina eugubina* fauna was found in the top of the upper Maastrichtian and forms the base of a distinct aplanktonic zone. Above this zone follows the first Tertiary planktonic foraminiferal zone. The *Eoglobigerina* Zone is a thin but distinct layer with some of its forms continuing into the Danian, *Subbotina trini-*

dadensis Zone. This zone is followed by the *Truncorotalia uncinata* Zone, the *Morozovella angulata* Zone and the *Morozovella velascoensis* Zone. The nannoplanktonic flora of the *Tetralithus murus* Zone is not restricted to the upper Maastrichtian, but continues into the *P. eugubina*, the aplanktonic and the *Eoglobigerina* Zone, and well into the *S. trinidadensis* Zone. There it is followed by a thin zone mixed with the next nannoplanktonic zone, the *Cruciplaculithus tenuis* Zone which is, in turn, followed by the *Heliolithus kleinPELLI* Zone in the *M. velascoensis* foraminiferal zone.

Several gentes¹ of planktonic foraminifera show orthogenetic evolution in this succession of samples.

¹ gens (pl. gentes) = phyletic branch.

PLATE 1

□ = 50 μ

- 1-3 The three generations of *Guembelina* (*Heterohelix*) *navarroensis* Loeblich. Core 13; Section 3, 127/129 cm.
- 4-5 *Pseudoguembelina palpebra* Brönnimann and Brown. Same sample.
- 6 *Pseudoguembelina excolata* (Cushman). Same sample.
- 7 *Pseudotextularia carseyae* (Plummer). Same sample.
- 8 *Gublerina reniformis* (Marie). Core 13; Section 3, 25/27 cm.
- 9 *Gublerina cuvillieri* Kikoine. Same sample.
- 10-12 *Pseudotextularia varians* (Rzehak). Microspheric generation? Core 13; Section 3, 45/47 cm.
- 13-15 *Pseudotextularia multicamerata* De Klasz. Same sample. Initial part enlarged in section.
- 16 *Loeblichella monmouthensis* (Olsson). Core 11; Section 6, 23/25 cm.
- 17 *Rugoglobigerina rotundata* Brönnimann. Core 13; Section 3, 127/129 cm.
- 18 *Marginotruncana gansseri* Bolli, forma *monmouthensis* Olsson. Core 13; Section 3, 127/129 cm. As *M. gansseri* is typical for the lower parts of the Maastrichtian and this form appears in the Upper Maastrichtian, Olsson's name is chosen for it.
- 19 *Marginotruncana stuarti* (de Lapparent). Core 13; Section 3, 45/47 cm. Apertural lips partly ground down; their distal parts bend into the umbilical cavity.
- 20 Same species, with intact apertural lips.
- 21 *Globotruncanella petaloidea* (Gandolfi). Core 11; Section 2, 100/102 cm (Danian). Well-preserved specimens occur throughout the Danian; this is one of them.

The sequence of the *Subbotina trinidadensis-praecursoria* gens and the *Morozovella simulatilis-angulata-velascoensis* gens analyzed here show little or no mechanical disturbance of the samples as has been suspected by several authors. Moreover, *Aragonia velascoensis*, a benthonic species studied here, shows that it was also influenced by the deterioration of the environment at the Cretaceous-Tertiary boundary.

The main result of this investigation is that, in a wholly undisturbed succession of a coccolithic facies of the deep sea at the Cretaceous-Tertiary boundary, the

P. eugubina Zone marks the end of the Cretaceous, and that the Tertiary began with an aplanktonic zone followed by the first Tertiary planktonic, the *Eoglobigerina* Zone.

The following new species and genera, as well as redescrptions of the following established taxa are included: *Marginotruncana* Hofker (new description), *M. arcaformis* n. sp., *Parvularugoglobigerina* n. gen., *Eoglobigerina* Morozova (new description), *Chiloguembelitra* n. gen., *C. danica* n. sp., and *Aragonia velascoensis* (Cushman) (new description).

INTRODUCTION

In 1971 Blow showed that the boundary between the Upper Cretaceous and the lower Tertiary was penetrated in Core 11 of Hole 47.2 (D.S.D.P.) in the Shatsky Rise, east of Japan in the northern Pacific (lat 32°26.9'N, long 157°42.7'E; depth 2,689 m). However, in that study the sampling interval of 1.50 m was too large to give a detailed description of this boundary. In order to more precisely define the boundary, the present author obtained samples from the Cores 9-13 at 50-cm intervals and a continuous set of samples 10 cm apart in the vicinity of the boundary. These samples range from the upper Maastrichtian and the *Morozovella velascoensis* Zone of the Paleocene. Within the 60 samples, from Core 13, Section 3, 127/129 cm to core 10, section 6, 50/52 cm the exact boundary between the Cretaceous and the Tertiary was located.

In all, a column of 35.1 m of coccolithic ooze was studied. The samples collected at 10-cm intervals are between Section 4, 60/62 cm and Section 6, 98/100 cm in Core 11. In the Maastrichtian, only Sections 1 and 2 from Core 12 and Section 3 from Core 13 were studied.

The 10-cc samples of coccolithic ooze were small, but sufficient, composed of yellowish-white to brownish-white soft clays. Contrary to previous reports, these clays did not show much disturbance, as the successive zones were very clearly bordered and the planktonic foraminifera showed the evolutionary changes found in the type Danian of Denmark (Core 11), as indicated by the first appearances of *Subbotina triloculinoides*, *Planorotalia compressa*, *Chiloguembelina midwayensis* and by the evolution of *Subbotina trinidadensis-praecursoria* gens as well as those of *Subbotina pseudobulloides* and *Globoconusa daubjergensis*. In

any case the disturbance cannot have been considerable, and it may be that the material adherent to the inner walls of the fuses was not disturbed and that it was this material which was sent to the present author. The succession of the zones shown in Tables 1 and 2 is regarded as a natural one.

The samples were thoroughly washed in water through a very fine sieve. Small pieces of clay were saved for studying the coccoliths. The amount of foraminifera in the samples varied: few were in the samples from Core 10, Section 1, and Core 11, Sections 6 and 5, and Core 9, Sections 2 and 3; foraminifera were in Core 10, Sections 4 and 5; and true foraminiferal oozes were found in Core 13, Section 3, Core 11, Sections 1-4, Core 10, Sections 1, 2, 3 and 6 and the upper two samples of Core 9, Section 1. Few planktonic foraminifera or none were found in Section 5, 27/29 cm to 5, 127/129 cm. In Core 11, Section 6, 48/50 cm to 11, 5, 127/129 cm the bulk of the foraminifera consisted of very small individuals of planktonic forms (*P. eugubina* Zone). The same is true of zone Core 11, Section 5, 20/22 cm to 11, 5, 10/12 cm (*Eoglobigerina* Zone). Though in all these samples the number of individuals was large, the total amount of foraminiferal material was small. In both instances this was because individuals were small.

All foraminifera figured were drawn under the light microscope with a Zeiss drawing apparatus, in ricinus oil.

THE ZONES

(Tables 1, 2)

THE *Marginotruncana mayaroensis* ZONE

The preservation of the planktonic foraminifera is perfect in the lower part of the samples studied: the

TABLE 1

The Cretaceous-Tertiary boundary in D.S.D.P. Hole 47.2, Leg VI, on the Shatsky Rise in the North Pacific.

CORE SECTIONS	DEPTH in cm	Planktonic foraminiferal zones	Foraminifera
99.4 m	10.6-30/52 cm		
	10.6-100/102 cm		
100.3 m	10.6-127/129 cm		
	11-1-25/27 cm		
	11-1-73/77 cm		
	11-1-125/127 cm		
	11-2-30/32 cm		
	11-2-50/52 cm		
	11-2-100/102 cm		
	11-3-30/32 cm		
	11-3-60/62 cm		
	11-3-125/127 cm		
	11-4-30/32 cm		
	11-4-60/62 cm		
	11-4-70/72 cm		
	11-4-80/82 cm		
	11-4-90/92 cm		
	11-4-98/100 cm		
	11-4-110/112 cm		
	11-4-120/122 cm		
	11-4-130/132 cm		
106.5 m	11-4-138/140 cm		
	11-5-10/12 cm		
106.9 m	11-5-20/22 cm		
	11-5-27/29 cm		
	11-5-30/32 cm		
	11-5-39/41 cm		
	11-5-48/50 cm		
	11-5-60/62 cm		
	11-5-70/72 cm		
	11-5-80/82 cm		
	11-5-90/92 cm		
	11-5-98/100 cm		
	11-5-110/112 cm		
	11-5-120/122 cm		
107.6 m	11-5-127/129 cm		
	11-5-140/142 cm		
	11-6-10/12 cm		
	11-6-23/25 cm		
	11-6-30/32 cm		
108.0 m	11-6-40/42 cm		
	11-6-48/50 cm		
	11-6-60/62 cm		
	11-6-70/72 cm		
	11-6-80/82 cm		
	11-6-90/92 cm		
	11-6-98/100 cm		
	11-6-127/129 cm		
	12-1-25/27 cm		
	12-1-75/77 cm		
	12-1-125/127 cm		
	12-2-25/27 cm		
	12-2-60/70 cm		
	12-2-100-102 cm		
	12-2-125/127 cm		
	13-3-25/27 cm		
	13-3-45/47 cm		
	13-3-73/75 cm		
	13-3-100/102 cm		
123.2 m	13-3-127/129 cm		

Planktonic foraminiferal zones

uncinata zone

P2

trinidadensis Zone

P1

Eoglobigerina zone

Pa

aplanktonic zone

BOUNDARY

eugubina zone

Mw

mayaroensis zone

M

Cruciplaculithus tenuis zone

Foraminifera

z o n e

← Tertiary benthonic

← Cretaceous benthonic

specimens are air-filled (dry) and unbroken. Most of the species involved are well known. All of the globotruncanidae belong to the genus *Marginotruncana* because they do not show the ventral chambers drawn towards the proximal umbilical angle but rounded towards the umbilical cavity. Therefore, one species re-

sembling *Globotruncana arca* (Cushman) had to be renamed *Marginotruncana arcaformis* n. sp. as it has the characteristics of *Marginotruncana*. Similarly, Olson showed that *Globorotalia monmouthensis* belongs to the genus *Loeblichella* Pessagno.

At the top of this zone many of the species extinguish

Planktonic foraminifera of the middle and upper Paleocene in Hole 47.2 on the Shatsky Rise.

9-1-25/27 cm	82,3 m
9-1-50/52 cm	
9-1-100/102 cm	
9-1-127/129 cm	
9-2-25/27 cm	
9-2-50/52 cm	
9-2-100/102 cm	
9-2-127/129 cm	
9-3-25/27 cm	
9-3-50/52 cm	
9-3-98/100 cm	
9-3-127/129 cm	
9-5-25/27 cm	
9-5-50/52 cm	
9-5-100/102 cm	
9-5-127/129 cm	
10-1-25/27 cm	91,4 m
10-1-50/52 cm	
10-1-72/74 cm	
10-1-100/102 cm	
10-1-125/127 cm	
10-2-25/27 cm	
10-2-50/52 cm	
10-2-80/82 cm	
10-2-100/102 cm	
10-2-126/128 cm	
10-3-25/27 cm	
10-3-48/50 cm	
10-3-78/80 cm	
10-3-100/102 cm	
10-3-127/129 cm	
10-4-24/26 cm	
10-4-50/52 cm	
10-4-83/85 cm	
10-4-100/102 cm	
10-4-129/130 cm	
10-5-26/28 cm	
10-5-50/52 cm	
10-5-70/72 cm	
10-5-100/102 cm	
10-5-126/127 cm	
10-6-26/28 cm	
10-6-50/52 cm	
10-6-69/71 cm	
10-6-100/102 cm	
10-6-127/129 cm	
11-1-top	100,6 m
11-1-25/27 cm	

Globigerina trivialis
Subbotina pseudobulloides
Subbotina Varianta
Chiloguembelina daubjergensis
Chiloguembelina morsei
Chiloguembelina paraliola
Chiloguembelitria danica
Subbotina trinidadensis
Subbotina triloculinoides
Planorotalia compressa
Chiloguembelina midwayensis
Globigerina spiralis
Truncorotalia inconspicua
Truncorotalia uncinata
Subbotina praecursoria
Planorotalia ehrenbergi
Morozovella simulatilis
Planorotalites pusilla
Planorotalia pseudomenardii
Morozovella conicotruncata
Truncorotalia convexa
Morozovella angulata
Planorotalites laevigata
Morozovella velascoensis
Morozovella occlusa
Globigerina chagcanona
Glorotalia subphaerica
Glorotalia soldadoensis
Glorotalia broedermannii
Morozovella aequa

velascoensis

zone

P 4

angulata

zone

P 3

uncinata

zone

P 2

trinidadensis

zone

P 1

Heliolithus Kletpell zone

Cruciplaculithus tenuis zone

near the base of Core 11. At this base two species appear for the first time, viz. *Globotruncanella petaloidea* and *Rugoglobigerina rugosa*. A second group of species disappears near the middle of the *Parvularugoglobigerina eugubina* Zone. Only *Loeblichella monmouthensis* and *Globotruncanella petaloidea* attain the top of this latter zone, and they penetrate deeply into the Danian. McGowran (1974) found *L. monmouthensis* continuing into the Danian also, in Hole 217, Indian Ocean D.S.D.P. Near the end of their range, specimens of species of planktonic foraminifera become small, so *M. mayaroensis* ends with small individuals having four chambers in the last-formed whorl, a form named *Globotruncana planata* by Edgell (1957, p. 115, pl. 4, figs. 7–9). As a whole, the planktonic species of this zone appear the same as those found by Herm (1962).

THE *Parvularugoglobigerina eugubina* ZONE

The last specimens of the *M. mayaroensis* Zone continue into this next zone. In this zone the tests are very small, not much more than 0.125 mm in diameter, and they belong to the following species: *P. eugubina* (Luterbacher and Premoli Silva), *P. sabina* (Luterbacher and Premoli Silva), *P. minutula* (Luterbacher and Premoli Silva).

Moreover, here were found abundant, very minute specimens of the following "heterohellicids": *Chiloguembelina taurica* (Morozova) and *Guembelitia irregularis* (Morozova).

The rough surfaces of the *Parvularugoglobigerina* species as well as the finer structure of their test walls remind us of the genus *Rugoglobigerina*; thus the generic name chosen for these species. The umbilical cavities of these species are narrow, and consequently their apertures change in position from umbilical to extraumbilical. Apertures are provided with narrow lips around their borders. In some of its main features *Parvularugoglobigerina* resembles the genus *Hedbergella*. However, this genus extinguished long before this zone. As is known from several evolution ranges of foraminifera, end forms show characteristics of the ancestors. This is also true in the *Hedbergella-Rugoglobigerina-Parvularugoglobigerina* gens. In the *P. eugubina* Zone, two species, *C. taurica* and *G. irregularis*, always first appear as abundant specimens of small individuals. If one were of the opinion that these two species are restricted to the Tertiary, specifically the lowermost Tertiary, then the *P. eugubina* Zone also might belong to the Tertiary. However, the characteristics of *Parvularugoglobigerina* pointing to

Rugoglobigerina and *Hedbergella* strongly suggest that these species of *Parvularugoglobigerina* belong to the uppermost Cretaceous, as discussed by Krasheninnikov and Hoskins (1973, p. 110). It is very likely that the first species of *Chiloguembelina* had already developed in the uppermost Cretaceous.

In this respect one has to bear in mind that the present author described several species of the *P. eugubina* group from the uppermost white chalk (the Cr 4) in the Netherlands and at the same level in the Skrivekrid of Denmark (upper Stevnsian), both definitely of Upper Cretaceous age (Hofker, 1966). Though Luterbacher and Premoli Silva (1964) found their *P. eugubina* fauna intercalated with layers of larger foraminifera (*Siderolites* and *Orbitoides*) that are typically Cretaceous, they concluded that the latter layers were reworked and that the *P. eugubina* Zone was Tertiary. This interpretation was followed by Bolli (1966, p. 13) and by Bolli and Premoli Silva (1973, p. 521, 522). However, they found this fauna in a kind of hard ground, and such hard grounds are formed mostly at the top of a formation and not at its base. As this formation is here Upper Maastrichtian, the faunas in the hard ground that was penetrated in Holes 152 and 153 of D.S.D.P., in the Caribbean Sea, may well belong to the latest Cretaceous and not to the earliest Tertiary. Brotzen wrote (1959, p. 17): "*Globigerina* and related species are extremely rare and small in the part of the section [meaning the upper Stevnsian, auth.]. They belong to *triloculina* types as *G. daubjergensis* and *G. trivialis*, which already begin to appear in the upper part of the Stevnsian." Globigerines of the *G. bulloides* type were mentioned by Wicher (1956) in the Upper Maastrichtian in the basin of Gosau, Austria.

Von Hillebrandt wrote (1965, p. 15) about the Danian above the upper Maastrichtian in the section of Zymaya, Spain: "die erste 25 cm mächtige Kalkbank enthält selten Globigerinen mit einem Durchmesser bis zu 0.125 mm. . . . Sehr ähnliche kleinwüchsige Globigerinen mit einem Durchmesser von 0.1 bis 0.15 mm treten bereits neben grosswüchsigen Globotruncanen des obersten Maastricht auf und werden hier der Gattung *Hedbergella* zugeschrieben."

Blow (1971, p. 1021) wrote about the Hole 47.2: ". . . the 'G.' *eugubina* Zone of Luterbacher and Silva; this latter interval is definitely late Maastrichtian but it is slightly older than the faunal interval $M\omega - P\alpha$."

Krasheninnikov and Hoskins (1973) found the *P. eugubina* Zone in Hole 199, Core 11, Section 1, and say (p. 110): "Thus, it is difficult to draw any conclusion

about the generic affinities of the species of planktonic foraminifera in question; whether they are the last dwarfed representatives of the genus *Hedbergella* or the first primitive representatives of the genus *Globigerina*. In any case, one may suggest the existence of an extremely brief time interval in geological history (at the Cretaceous-Tertiary boundary) where the main mass of late Cretaceous planktonic foraminifera had already become extinct but where typical Tertiary globigerinids and globorotaliids had not yet appeared. This interval is characterised by rather peculiar assemblages of planktonic foraminifera; small heterohelids and forms transitional from *Hedbergella* to *Globigerina* (?) prevail among them."

With all these data in mind, it is obvious that we have to choose an uppermost Cretaceous age for the *Parvularugoglobigerina* Zone.

THE APLANKTONIC ZONE

This zone, consisting of a coccolithic ooze of the *Tetralithus murus* flora and benthonic foraminifera of mostly small size, is next. One might assume that during the time of this zone, estimated by Berggren (1972, p. 203, fig. 5) as having had a duration of some 400,000 years, there might have been an upheaval of the calcium carbonate lysocline (Berger, 1968, p. 35), with the result that most planktonic calcareous tests were dissolved before they reached the sea floor. There are several arguments against this assumption: the thin-shelled benthonic foraminifera of this zone do not show any dissolution; and the sediment consists of coccoliths, which do not show dissolution either. In addition, there is the question of which species of planktonic foraminifera could have lived in the sea between the *P. eugubina* fauna beneath the aplanktonic zone and the

Eoglobigerina fauna just above the aplanktonic zone? Because we know of only these two faunas of planktonic foraminifera at the Cretaceous-Tertiary boundary, it is very probable that there were no intervening planktonic faunas which are now missing by solution.

The benthonic foraminiferal fauna shows some species which are continuing from the Cretaceous; but many other species are typical for the lower Tertiary. They are:

Marssonella conica Olsson
Verneuilina monmouthensis Olsson
Dentalina reflexa Morrow
Marginulina jarvisi Cushman
Stilostomella midwayensis (Cushman and Todd)
Pleurostomella clavata Cushman
Pleurostomella nitida Morrow
Nodosarella monmouthensis Olsson
Bolivina selmaensis Cushman
Bolivina naheolensis Cushman
Nodosaria spinosa Olsson
Gyroidinoides imitata Olsson
Allomorphina navarroensis Cushman
Eponides lotus (Schwager)
Eponides elevatus (Plummer)
Epistominella glabrata (Cushman)
Pullenia americana Cushman
Pseudoclavulina anglica Cushman
Anomalinoidea pinguis Jennings
Osangularia expansa (Toulmin)

The aplanktonic zone thus is a lower Tertiary one with a lower Tertiary benthonic fauna and many dwarfed specimens. This dwarfing is found especially in *Aragonia velascoensis* (Cushman), a species in which megalospheric individuals are heavily ornamented while mi-

PLATE 2

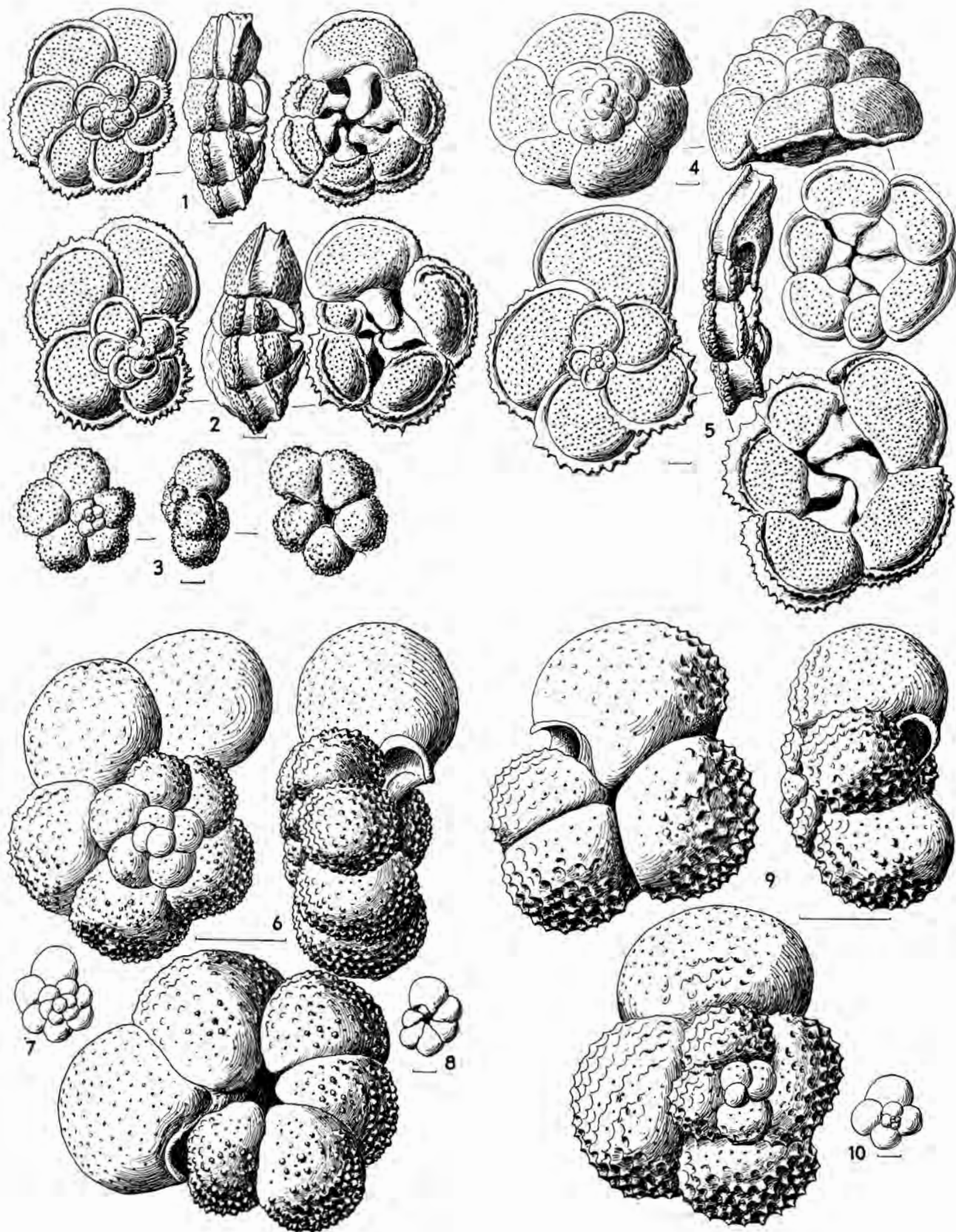
□ = 50 μ

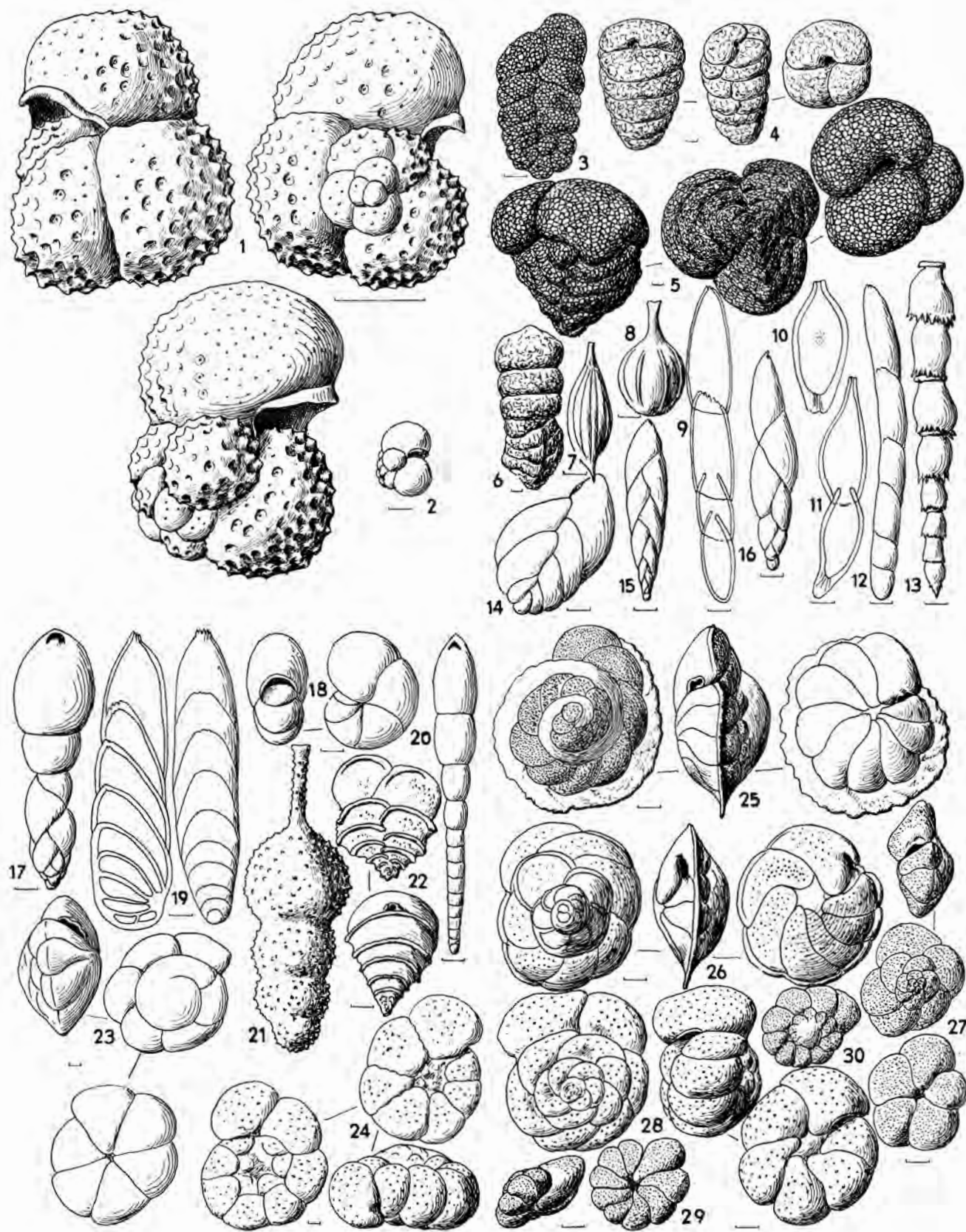
- 1 *Marginotruncana arcaformis* nov. spec. Core 13; Section 3, 127/129 cm.
- 2 *Marginotruncana aegyptiaca* (El-Naggar). Core 12; Section 1, 125/127 cm.
- 3 *Loeblichella monmouthensis* (Olsson). Core 11; Section 4, 90/92 cm, *S. trinidadensis* zone, Danian. This is one of the two species which continues into the Danian in unworked state.
- 4 *Marginotruncana contusa* (Cushman). Core 13; Section 3, 45/47 cm. Small specimen.
- 5 *Marginotruncana mayaroensis* (Bolli). Core 11; section 6, 48/50 cm. This species was said to belong to

a distinct genus, *Abathomphalus* (Bolli, 1957a) with a kind of "continuous umbilical tegulum of irregular outline"; the well-preserved specimens found in Drill Hole 47.2, however, show the normal apertural lips without such a covering.

- 6 *Parvularugoglobigerina eugubina* (Luterbacher and Premoli Silva). Core 11; Section 6, 23/25 cm.
- 7-8 Same species, from two sides, less enlarged.
- 9 *Parvularugoglobigerina sabina* (Luterbacher and Premoli Silva). Same sample.
- 10 Same species, in lower enlargement.

→





microspheric individuals remain nearly smooth. At its first appearance in the Upper Cretaceous, specimens of this species are of normal size; but from the uppermost Cretaceous on, where planktonic species are also small, specimens of *A. velascoensis* are very small and, for the most part, microspheric (Pl. 9, Figs. 25, 26). This continues into the aplanktonic zone, where all specimens are small and microspheric. The present author found, when dealing with *Ammonia* (*Streblus*) *flevensis* (Hofker, 1954), that in winter only microspheric specimens were found living, whereas in summer and autumn only megalospheric forms were found living. One might conclude that the microspheric diploid generation is the one able to resist unfavorable conditions.

This is another argument against dissolution of planktonic foraminifera during the aplanktonic zone: during the uppermost Cretaceous and the *P. eugubina* Zone, conditions became unfavorable and continued even moreso during the aplanktonic zone. Where the *Eoglobigerina* Zone starts, *A. velascoensis* again becomes larger and megalospheric specimens occur. At the beginning of this zone, the onslaught characterizing the Cretaceous-Tertiary boundary suddenly came to an end; and these features of *Aragonia* as well as the sudden appearance of the *Eoglobigerina* fauna show it.

One might ask about the species *Chiloguembelina taurica* and *Guembelitra taurica* which began to appear in

the *P. eugubina* Zone and continued in the *Eoglobigerina* Zone. From the study of samples from the type Danian of Denmark, the present author knows that the species of *Chiloguembelina* very often are found in large numbers in sediment which shows the conditions of neritic environment. Moreover, Christiansen (1965) found the microspheric generation of *Globigerina rubra*, the generation which makes migration possible, living imbedded in neritic mud. Propagation would seem to occur here, in these muds. It is quite possible that while conditions in the open ocean deteriorated, *Chiloguembelina* could survive the onslaught in some neritic bays. After the aplanktonic period, microspheric individuals migrated into the open planktonic environment and formed part of the neoplankton of that time (see Hofker, 1962a).

In Denmark, the Fiske-Ler at the base of the type Danian and, where it is not found, the so-called Ded Lag at its base, both lack planktonic foraminifera, and may be counterparts of this aplanktonic zone. Furthermore, in Trinidad the base of the Tertiary is formed by the *Rzehakina epigona* Zone which also lacks planktonic foraminifera.

THE *Eoglobigerina* ZONE

This short zone (thickness about 30 cm) consists of coccolithic ooze of the *Tetralithus murus* floral zone and contains a rich fauna of small and mostly smooth-

PLATE 3

[] = 50 μ

- 1 *Parvularugoglobigerina minutula* (Luterbacher and Premoli Silva). Core 11; Section 6, 23/25 cm.
- 2 Same species, lower enlargement.
- 3 *Spiroplectammona kelleri* Dain. Core 11; Section 5, 98/100 cm. Aplanktonic zone.
- 4 *Marssonella conica* Olsson. Same sample.
- 5 *Verneuilina monmouthensis* Olsson. Core 11; Section 6, 48/50 cm. *P. eugubina* zone and continues into the aplanktonic zone.
- 6 *Pseudoclavulina anglica* Cushman. Core 11; Section 5, 98/100 cm. Aplanktonic zone.
- 7 *Lagena sulcata* (Walker and Jacob). Same sample.
- 8 *Lagena acuticosta* Reuss. Same sample.
- 9 *Dentalina lorneiana* d'Orbigny. Same sample.
- 10-11 *Dentalina reflexa* Morrow. Same sample.
- 12 *Dentalina wilcoxensis* Cushman. Same sample.
- 13 *Stilostomella midwayensis* (Cushman and Todd) Same sample.
- 14 *Bolivina selmaensis* Cushman. Same sample. This species is known from the upper Maestrichtian to the lower Tertiary.
- 15 *Bolivina naeolensis* (Cushman). Same sample.
- 16 *Pleurostomella nitida* Morrow. Same sample.
- 17 *Pleurostomella clavata* Cushman. Same sample.
- 18 *Pullenia angusta* Cushman and Todd. Same sample.
- 19 *Marginulina jarvisi* Cushman. Backside and transparent section.
- 20 *Nodosarella monmouthensis* Olsson. Same section.
- 21 *Nodosaria spinosa* Olsson. Same sample.
- 22 *Aragonia velascoensis* (Cushman). This is the microspheric unornamented form as found in the aplanktonic zone. Same sample.
- 23 *Eponides lotus* Schwager. Same sample.
- 24 *Anomalinoides pinguis* Jennings. Core 11; Section 5, 30/32 cm. Aplanktonic zone.
- 25 *Osangularia expansa* (Toulmin). Same sample.
- 26 *Epistominella glabrata* (Cushman). Core 11; Section 5, 98/100 cm. Aplanktonic zone.
- 27 *Eponides elevata* Plummer. Same sample.
- 28 *Eponides involuta* Hofker. Same sample.
- 29-30 *Gyroidinoides imitata* Olsson. Same sample.

walled species described by Morozova (1961). The fauna consists of:

Eoglobigerina tetragona Morozova
Eoglobigerina pentagona Morozova
Eoglobigerina eobulloides Morozova
Eoglobigerina taurica Morozova
Eoglobigerina hemisphaerica Morozova
Globigerina (*Eoglobigerina*?) *microcellulosa* Morozova
Guembelitra irregularis Morozova
Chiloguembelina taurica Morozova

This fauna is a striking instance of a neoplanktonic fauna. The typical *Eoglobigerina* species have thin and smooth walls, consisting of one lamella, and a circular extraumbilical sutural aperture without any trace of a thickened border or lip. *Eoglobigerina microcellulosa* shows different characteristics: 1) the walls are thicker; 2) in more initial chambers a kind of honeycomb is developed around the pores; and 3) the aperture, though rounded, shows a crenulated border or narrow lip. *Globigerina irregularis* and *C. taurica* are the only species which were present in the *P. eugubina* Zone. Several species of *Eoglobigerina* continue into the next zone.

The *Eoglobigerina* Zone is found in the Kopet-Daga area east of the Caspian Sea as the only lowest zone of the Tertiary above the Upper Cretaceous by Morozova, Kozhevnikova, and Kurylova (1967, Table 2). Because the genus *Eoglobigerina* shows little relationship

with *Parvularugoglobigerina*, both genera must have had different ancestors.

THE *Subbotina trinidadensis* ZONE

Common species in this zone are:

Eoglobigerina eobulloides Morozova
Eoglobigerina danica (Bang)
Globigerina trivialis Subbotina
Subbotina varianta (Subbotina)
Chiloguembelitra danica n. gen., n. sp.
Chiloguembelina morsei (Kline)
Chiloguembelina parallela Beckmann
Subbotina trinidadensis (Bolli)

Not so common are:

Subbotina pseudobulloides (Plummer)
Globoconusa daubjergensis (Brönnimann)

Found in the upper part of the zone are:

Chiloguembelina midwayensis
Subbotina triloculinoides (Plummer)
Planorotalia compressa (Plummer)

The lower part of this zone shows the *Tetralithus murus* flora, the upper part shows the *Cruciplaculithus tenuis* flora as sediment.

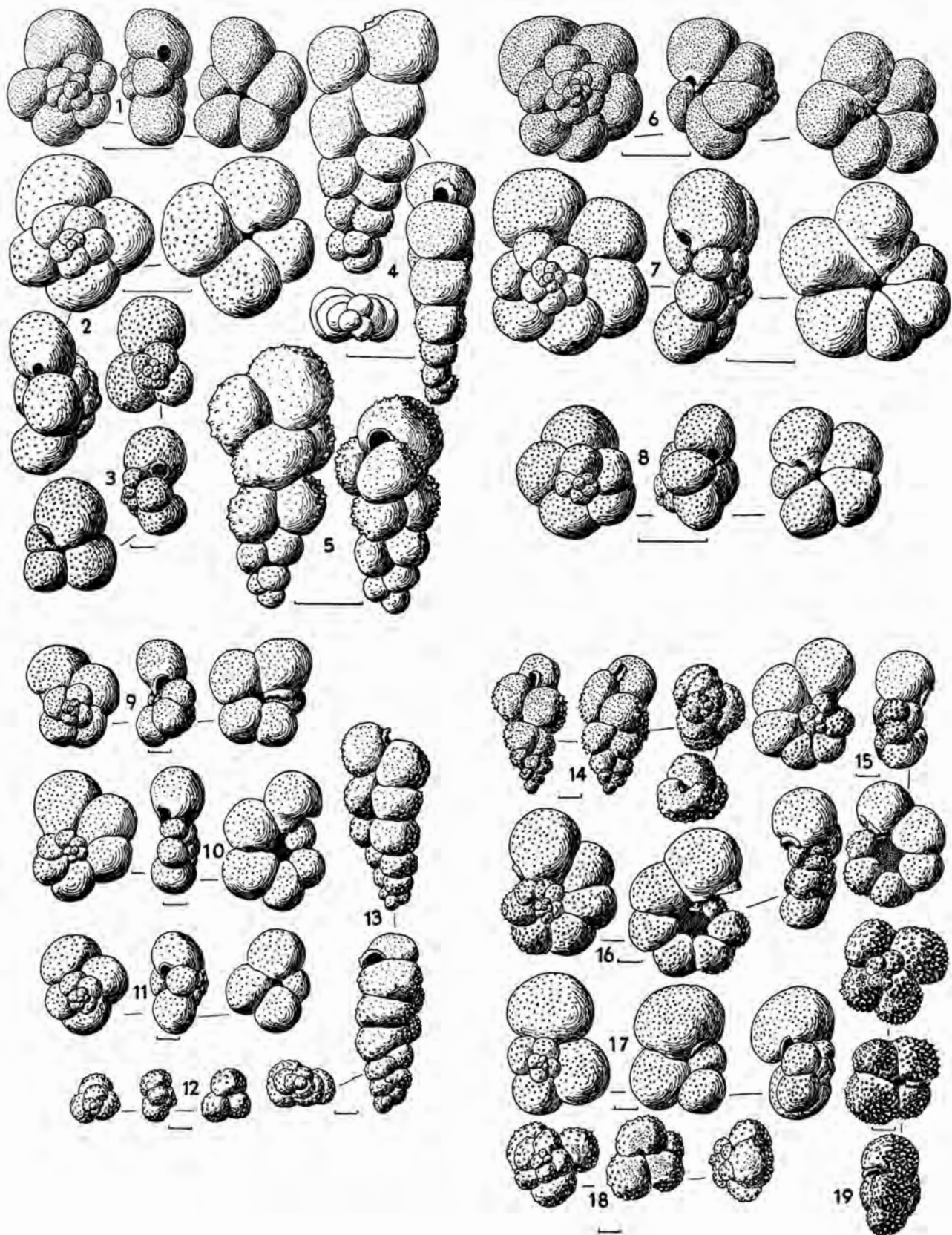
THE *Turborotalia uncinata* ZONE

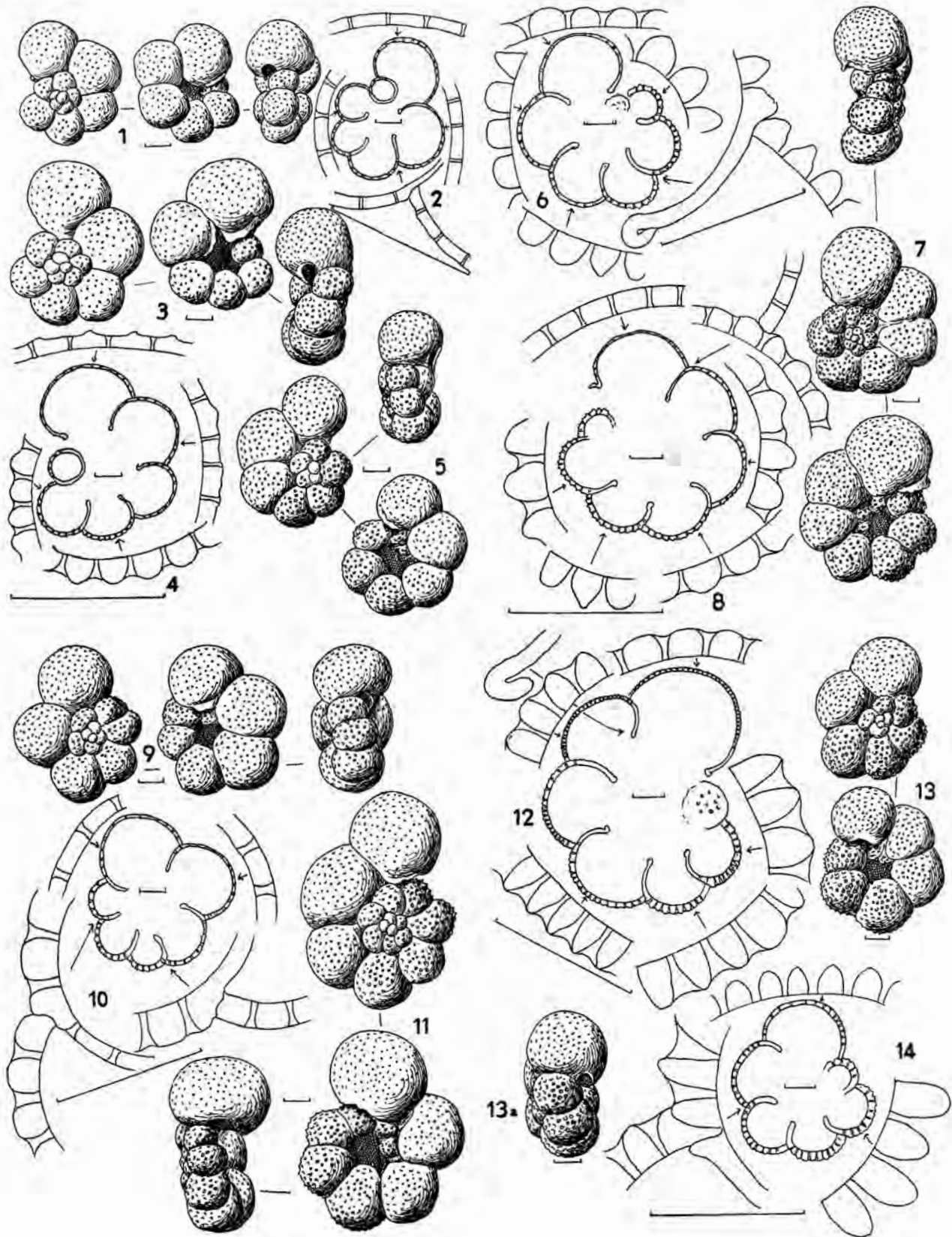
This zone, in the coccolithic ooze of the *Cruciplaculithus tenuis* floral zone, forms a distinct border with the *S. trinidadensis* Zone and is believed by some

PLATE 4

— = 50 μ

- 1 *Eoglobigerina eobulloides* Morozova. Core 11; Section 5, 10/12 cm.
- 2 *Eoglobigerina tetragona* Morozova. Same sample.
- 3 *Globigerina* (*Eoglobigerina*?) *microcellulosa* Morozova. Same sample.
- 4 *Chiloguembelina taurica* Morozova. Same sample. This oldest species of this genus shows the same triserial initial part as found in all other species of *Chiloguembelina*. For such species Loeblich and Tappan created the genus *Woodringia* which is a synonym of *Chiloguembelina*.
- 5 *Guembelitra irregularis* Morozova. Same sample.
- 6 *Eoglobigerina hemisphaerica* Morozova. Same sample.
- 7 *Eoglobigerina taurica* Morozova. Same sample.
- 8 *Eoglobigerina pentagona* Morozova. Same sample.
- 9 *Subbotina pseudobulloides* (Plummer). Core 11; Section 4, 130/132. Danian; primitive form of this species.
- 10 *Subbotina trinidadensis* (Bolli). Same sample. Primitive form of this species.
- 11 *Subbotina varianta* (Subbotina). Same sample. Primitive form.
- 12 *Globoconusa daubjergensis* (Brönnimann). Same sample. Primitive form without dorsal sutural openings.
- 13 *Chiloguembelina morsei* (Kline). Same sample. Triserial initial part.
- 14 *Chiloguembelitra danica* nov. spec. Same sample.
- 15 *Subbotina trinidadensis* (Bolli). Core 11; Section 4, 60/62 cm. The earlier chambers begin to have a rough surface.
- 16 *Subbotina trinidadensis* (Bolli). Core 11; Section 4, 30/32 cm. The roughening is yet more prominent.
- 17 *Subbotina triloculinoides* (Plummer). Same sample. This is the first smooth-walled stage of this species.
- 18 *Globoconusa daubjergensis* (Brönnimann). Core 10; Section 6, 127/129 cm. The form becomes larger and shows the dorsal sutural openings.
- 19 *Subbotina varianta* (Subbotina). Same sample. The species shows the rough surface of the later stages of evolution.





authors to be the upper part of the Danian s.l. However, in this zone the genus *Morozovella*, with *M. simulatilis* (Schwager) is found for the first time, and *Turborotalia uncinata* (Bolli) shows the characteristics of a more advanced group of planktonic foraminifera. As in the type Danian of Denmark, such forms are missing; it is believed to be best to separate this zone from the Danian and to consider it as the lower part of the middle Paleocene. Many other species first appear in this zone. The more common species of this zone are:

Globigerina spiralis Bolli
Truncorotalia inconstans (Subbotina)
Truncorotalia uncinata (Bolli)
Subbotina praecursoria (Morozova)
Planorotalia ehrenbergi (Bolli)

In the upper part of this zone, two species become common:

Morozovella simulatilis (Schwager)
Planorotalites pusilla (Bolli)

The top of this zone changes somewhat gradually into the overlying *Morozovella angulata* Zone. None of these species is found in the type Danian.

SYSTEMATICS

Genus *Marginotruncana* Hofker 1956

In the *M. mayaroensis* Zone of the upper Maastrichtian, globotruncanids with the characteristics of *Marginotruncana* are the only species found. This genus

is characterised in that the ventral chamber walls are rounded or trapezoidal and the pore fields are rounded towards the umbilical cavity. In *Globotruncana* s.s. the chamber walls at the ventral side are petaloid, because they form a proximal, umbilical, drawn-out angle and the pore fields follow this pattern. These two genera of globotruncanid species have demonstrably different ancestors.

Marginotruncana arcaformis n. sp.

(Pl. 2, Fig. 1)

Globotruncana leopoldi Bolli. OLSSON, 1960, p. 50, pl. 11, fig. 1-3.

Globotruncana arca (Cushman). OLSSON, 1964, fig. 3 a-c. EDGELL, 1957, pl. 3, fig. 13-15 (not pl. 3, figs. 1,3). HERM, 1962, pl. 7, fig. 3.

In available topotype specimens from the Mendez Shale, Mexico, *Globotruncana arca* (Cushman), the genotype of *Globotruncana*, shows the characteristics of *Globotruncana*. However, all of the specimens from the *M. mayaroensis* Zone have the characteristics of *Marginotruncana*. Such a specimen was figured by Olsson and it is obvious that this is a species which greatly differs from the type.

Test rounded, compressed, with 5-6 chambers in the last-formed whorl; dorsal side slightly more convex than the ventral one; periphery lobulate. At the dorsal side the strongly rounded and thickened sutures go over into the dorsal keel of the marginal poreless plate; the ventral keel of that plate is slightly more centrally placed and thus seen together with the dorsal keel at

PLATE 5

[] = 50 μ

- 1 *Subbotina trinidadensis* (Bolli). Sample H 1055, Wind's zone I, Stevns Klint, Lower Danian, Denmark. The pores are small, surface smooth.
- 2 Horizontal section through specimen of Fig. 1, with enlarged wall parts.
- 3 Same species. D.S.D.P., 47.2; Core 11; Section 4, 90/92 cm. Initial chambers not yet roughened.
- 4 Horizontal section through specimen Fig. 3. Walls slightly thicker than in Fig. 2.
- 5 Another specimen of sample mentioned in Fig. 3.
- 6 Horizontal section through specimen of Fig. 5. Walls slightly more thickened and slightly more roughened.
- 7 Same species, from D.S.D.P., Hole 47.2; Core 11; Section 3, 30/32 cm. Walls of more initial chambers distinctly roughened.
- 8 Horizontal section through specimen of Fig. 7. Walls of older chambers distinctly thickened and roughened by the pore pits.
- 9 Same species. Dalbiez's sample Zebbeus Le Kef, 2199, Tunisia, Paleocene.
- 10 Horizontal section through specimen of Fig. 9, with enlarged wall parts.
- 11 Same species. D.S.D.P., 47.2; Core 11; Section 2, 60/62 cm, younger Danian.
- 12 Horizontal section through specimen Fig. 11. Though the septum remained simple, all walls of chambers are secondarily thickened, more than in the formerly figured specimens. Such specimens are found in tropical localities at the boundary Danian-Paleocene.
- 13 Same species. Bolli's sample 192.632, Trinidad, the type locality. Lowest Paleocene. The pores of the older chambers of the last-formed whorl show distinct pits, the walls are strongly thickened secondarily.
- 14 Horizontal section through specimen Fig. 13. Pores distinctly funnel-shaped.

the ventral side. Older chambers show a more or less distinct pustulous keel bordering the ventral chamber wall from the apertural lips which partly cover the umbilical hollow. Pores distinct, at the ventral side not drawn into an angle towards the proximal side of the chamber wall, but forming a rounded pore field. Keels of the marginal plate crenulate. Longer diameter of the tests about 45 mm, thickness about 15 mm, with the distinctly protruding apertural lips somewhat thicker. The species was found in Hole 47.2 in the lower part of the *M. mayaroensis* Zone.

Genus **Parvularugoglobigerina** n. gen.

(Pl. 2, Figs. 6–10; Pl. 3, Figs. 1, 2)

Genotype: *Globigerina eugubina* LUTERBACHER and PREMOLI SILVA, 1964.

Very small species with 3–6 chambers in the last-formed whorl; at the dorsal side all chambers visible; at the ventral side only those of the last-formed coil; chambers globular, with sutures depressed on both sides; umbilical cavity very small; walls thin, consisting of one lamella, with small pustules in between the pores; often the pustules are found in rows, as in *Rugoglobigerina*. Pores fine, pipelike, at the surface ending in a funnel, as in some species they end in pits of the wall. Aperture an umbilical-extraumbilical, crescentlike opening, with slightly thickened border, or a narrow poreless lip.

The genus is found in a short period just at the end of the uppermost Maastrichtian.

The extraumbilical aperture may be explained as caused by the small umbilical hollow and seems to be due to a slight torsion of the chambers; in initial chambers the apertures are umbilically placed; as a whole the genus is not unlike *Hedbergella*, though there are some different characteristics. *Parvularugoglobigerina* seems to be the atavistic end of the *Hedbergella-Rugoglobigerina* lineage. The structural features of the test walls in these genera are alike: the walls consist of fine radial crystals.

Redescription of the genus **Eoglobigerina** Morozova, 1961

(Pl. 4, Figs. 1–3, 6–8)

In 1961, Morozova described this fauna of the *Eoglobigerina* Zone from internal casts. In the present study all specimens were air-filled in a dry state and preserved as if from the Recent.

Very small planktonic foraminifera of trochoidal structure, diameters not over 16 mm. In the last-

formed whorl, 4–6 chambers visible which are always globular, with depressed sutures on the dorsal side as well as on the ventral one. On the ventral side, chambers somewhat pointed towards the umbilical cavity, leaving a very small umbilical hollow free. Test walls smooth and thin, consisting of one lamella, without secondary thickening, pierced by fine pores which are densely placed in some species and are more scattered and more distinct in other species. Sutures on the dorsal side rounded and continuing into the lobulate periphery, on the ventral side radial and straight. Apertures consisting of a very small nearly circular, extraumbilical opening, resting on the suture, without any trace of a lip or of a thickened border, but for one species, "*Globigerina*" *microcellulosa* Morozova, which may not belong to *Eoglobigerina*.

Berggren's (1960, p. 115) supposition to identify the first forms of *Subbotina pseudobulloides* (Plummer) as found in the lowermost type Danian with *Eoglobigerina eobulloides* Morozova seems to be erroneous. The same may be said about the idea of Loeblich and Tappan (1964, p. 671) to place *Eoglobigerina* Morozova as a synonym into the genus *Globorotaloides* Bolli. Nor is it right to suppose it to be a subgenus of *Globigerina*, as Morozova did. *Eoglobigerina* is a genus without spines, with small, extraumbilical apertures as in *Globorotalia*, with smooth surface and with a very small diameter. The genus *Planorotalia* may have evolved in the Danian from a species of *Eoglobigerina* with scattered pores.

Genus **Chiloguembelitra** n. gen.

Genotype: *Chiloguembelitra danica* n. sp.

Tests small, elongate, wholly triserial. All foramina and the aperture are placed axially and perpendicular to the sutures, are slit-like elongate, with a distinct lip which is crenulate at the axial side of the border of the apertures, as in *Chiloguembelina*. It is like a *Guembelina* in which the biserial part is not yet developed, and may be the true ancestor of that genus. Both *Chiloguembelitra* and *Chiloguembelina* are monolamellar.

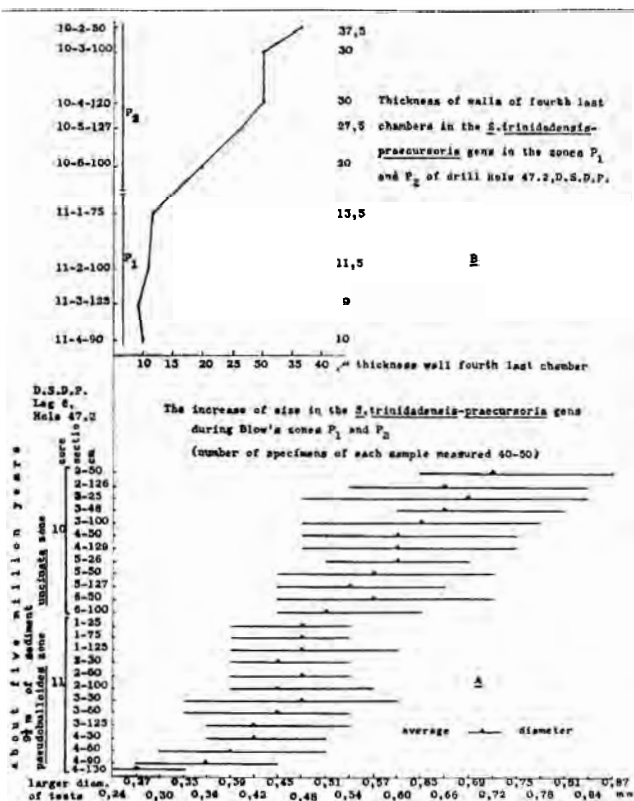
Chiloguembelitra danica n. sp.

(Pl. 4, Fig. 14)

Test small, elongate, with triserially arranged chambers throughout. Chambers globular, with distinctly depressed sutures in between, gradually increasing in size so that the whole test remains slender. Walls thin, consisting of only one lamella, without secondary

TABLE 3

Morphologic changes in the *S. trinidadensis-praecursoria* gens. A. The increase of size in the *S. trinidadensis-praecursoria* gens during Blow's zones P.1 and P.2. B. Thickness of walls of fourth last chambers in the *S. trinidadensis-praecursoria* gens in Blow's zones P.1 and P.2.



thickening. Walls finely perforate, with small blunt pustules. Aperture high, elongate, narrow, with protruding lip at the axial side of the aperture, as in *Chiloguembelina*. Length of test up to 0.1 mm; larger breadth near the apertural end 0.05 mm.

The species is extremely common in the lower half of the *S. trinidadensis* zone (Danian) and becomes rare at the end of its range at the top of this zone.

Several gentes of planktonic and benthonic foraminifera could be studied in the material from the Danian-Paleocene sequence of samples from drill hole 47.2. They show that significant mechanical disturbance of the Paleocene-Danian from this drill hole, as supposed by some authors, is not likely.

THE *Subbotina trinidadensis-praecursoria* GENS (Tables 2, 3; Pls. 6, 7)

Globorotalia trinidadensis BOLLI, 1957, p. 73, pl. 16, fig. 19-23. BOLLI and CITA, 1960, p. 389, pl. 53,

fig. 10. LUTERBACHER, 1964, p. 651, fig. 26-29. EL-NAGGAR, 1966, p. 236, pl. 18, fig. 7.

Acarina praecursoria MOROZOVA, 1957, p. 1111, fig. 1. *Globorotalia praecursoria* (MOROZOVA). LUTERBACHER, 1964, p. 652, fig. 25.

Transitional form between *Globorotalia pseudobulloides* (Plummer) and *Globorotalia uncinata* Bolli, BOLLI, 1957b, p. 74, pl. 17, fig. 16-18 (= *Subbotina praecursoria* (MOROZOVA)).

In Hole 47.2, D.S.D.P., typical specimens of *Subbotina trinidadensis* were found in the *S. trinidadensis* Zone; but in the higher levels of this zone the species changes gradually into the form which is found mainly in the *T. uncinata* Zone and ends with very large specimens known as *Subbotina praecursoria* (MOROZOVA) near the top of this zone. It is not an *Acarina* nor a *Globorotalia* because the walls in section show the fine radial crystals between the large conical crystals characteristic of the genus *Subbotina* (see Brotzen and Pozaryska, 1961, p. 160, fig. 2 and pl. 4, fig. 3, 4 and Lipps, 1966, p. 1263, text fig. 4B, and p. 1268).

That the two "species" belong together in a single taxonomic unit is proven by the gradual change in ornamentation of the tests, especially on the dorsal side, due mainly to an increase of thickness of the walls and the gradual increase in the average diameter of the test. With this increase in diameter, the number of chambers in the last-formed whorl of typical *S. praecursoria* increases from 6 to 8. During the five million years, no change in the direction of coiling took place in this gens. About 50 percent of the specimens coil to the left, the same as *S. pseudobulloides* (Plummer) during the Danian (Hofker, 1962b, p. 125, fig. 64).

Such an orthogenetic increase in size is shown by many gentes of foraminifera and is known from many other organisms as well. It seems to be a natural law (the law of Cope and Déperet) that is expressed in gentes during their evolution. This increase in size invariably ends in the extinction of the gens.

In the case of the *S. trinidadensis-praecursoria* gens it is remarkable that within zone P.1 (Blow's zonation in 1971, Leg VI, D.S.D.P., p. 1013), size increases less than in zone P. 2.

S. trinidadensis size: 0.27 to 0.48 mm; increase 0.21 in 5½ m.y. Thickness wall: 10 to 13.5 mm; increase 3.5 mm in 5½ m.y.

S. praecursoria size: 0.51 to 0.72 mm; increase 0.21 mm in 6 m.y. Thickness wall: 20 to 37.5 mm; increase 17.5 mm in 6 m.y.

One might infer that between *S. trinidadensis* and *S. praecursoria* a slight mutation took place, but it is more reasonable to think of an increase in temperature or a change in the density of the sea water at the boundary between the *S. trinidadensis* and *T. uncinata* zones.

The *Subbotina trinidadensis* group of forms.

The tests are close to *S. pseudobulloides* (Plummer), but in most of the specimens the lip over the aperture is missing or poorly developed and the number of chambers of the last-formed whorl is not 5 but 6 or 7, and the umbilicus is open. In more evolved specimens there is a strongly roughened structure around the pores in more initial chambers. In the beginning of its evolution, specimens show a smooth surface and very thin chamber walls, with no trace of secondary thickening (monolamellar); the pores are pipelike in all the chambers, with a diameter of $1\ \mu$. Space between pores is about $12.5\ \mu$. Specimens later in the evolution are larger and show the typical last-formed chamber bending slightly toward the ventral side so that the dorsal side becomes flattened. The wall of the last formed chamber consists of the primary calcareous lamella only and shows small pustules between the pores; the walls of former chambers are slightly thickened and the earlier chambers show pores which become slightly funnel-shaped at the surface. In later forms the chamber walls are more thickened and the pores are distinctly funnel-shaped with pointed parts between, producing a honeycomb structure in the earlier chambers. Higher in the evolutionary sequence the tests become distinctly larger, with flat dorsal sides; the thickening of the chambers is more pronounced, and the rough surface more distinct.

The pointed pustules between the pores are formed by solid crystals which are typical for *Subbotina*, and very fine calcareous crystals surround these larger crystals. The septa formed by the primary calcareous lamella remain thin but the outer walls show traces of lamellar thickening.

The *Subbotina praecursoria* group of forms.

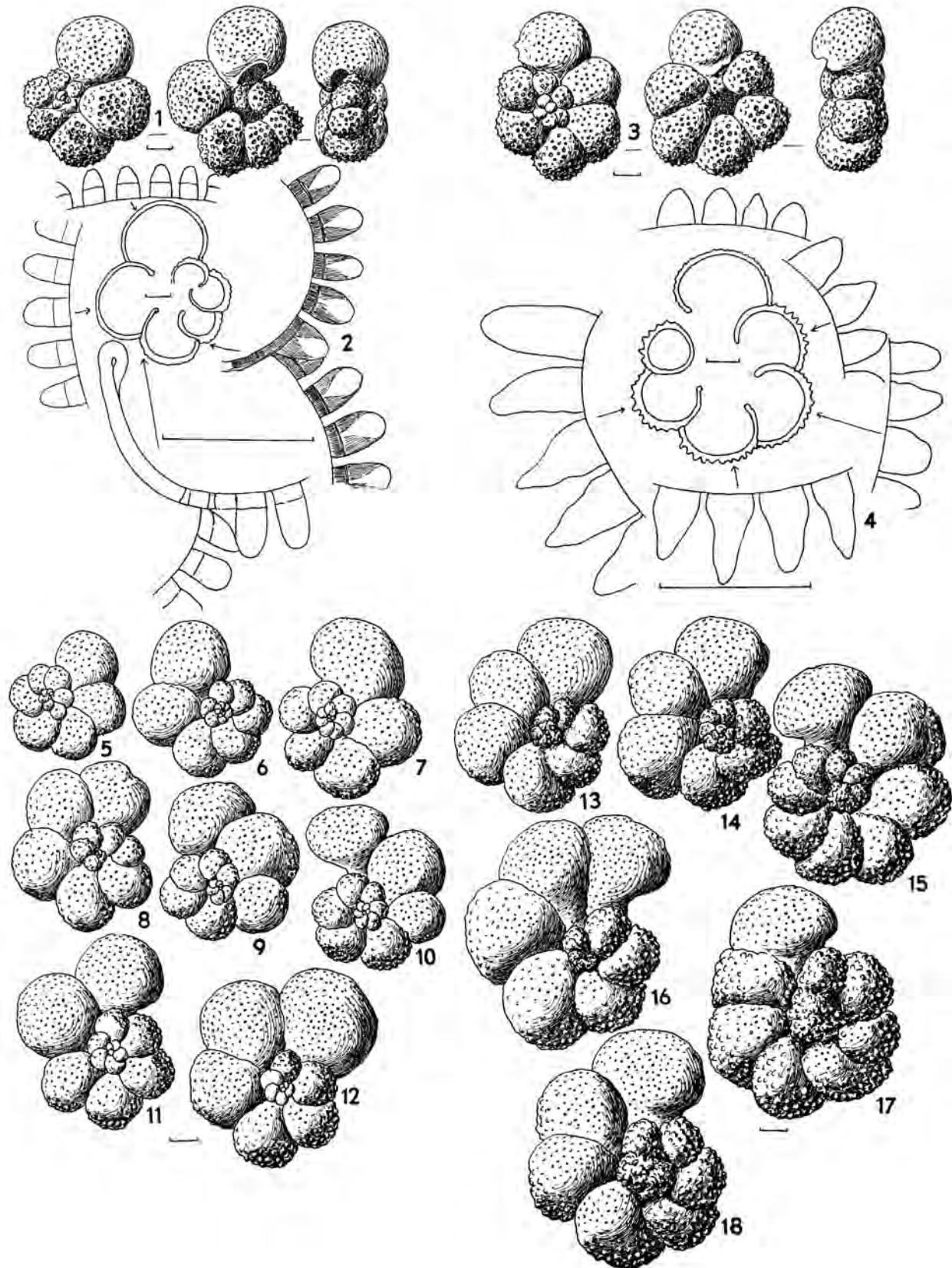
Test low trochospiral, with more or less flattened dorsal sides; tests becoming large (up to a diameter of 0.87 mm) toward the end of evolution of the group, with 7–8 chambers in the last-formed whorl. Periphery lobulate; sutures radial and depressed on the ventral side, depressed and slightly curved on the dorsal. In highly advanced specimens, the more initial chambers become angular-conical but the last chambers remain globular. Umbilicus fairly wide. Aperture often crescent-shaped, with a narrow lip which may continue into the umbilical cavity. Wall in later specimens relatively thick, with many protuberances between the pores giving rise to a roughening which conceals the sutures in the central dorsal part; in some chambers a ventral roughening may become spinose. Walls distinctly porous, pores pipe-like to slightly funnel-shaped. Walls of last-formed chambers not thickened, consisting of one lamella; older chambers may be thickened by additional lamellae. The pustules between the pores consist of one single crystal which is surrounded by many very fine crystals with their c-axes perpendicular to the inner surface of the walls.

This form evolves gradually from *S. trinidadensis* in the higher part of the *S. trinidadensis* Zone (Blow's

PLATE 6

□ = 50 μ

- 1 *Subbotina trinidadensis* (Bolli). Specimen from Wills Point Formation, Texas, upper part of the formation. All walls show distinct pits.
- 2 Horizontal section through specimen Fig. 1, with enlarged wall parts. The walls are strongly secondarily thickened, with the primary calcareous lamella visible, whereas the septa are formed by the primary lamella only. A wall part is seen in polarized light, to show the wall structure which is that of the genus *Subbotina*.
- 3 Same species, from Haidhof, near Bruderndorf, Austria. The surface is very distinctly pitted.
- 4 Horizontal section through this specimen of Fig. 3. Enlarged wall parts show extreme thickening found only in beds above the typical Danian. The locality must be younger than the highest Wills Point Formation.
- 5–12 *Subbotina trinidadensis* (Bolli) from D.S.D.P. Hole 47.2. 5. Core 11; Section 4, 90/92 cm. 6. Core 11; Section 4, 60/62 cm. 7. Core 11; Section 4, 30/32 cm. 8. Core 11; Section 3, 125/127 cm. 9. Core 11; Section 3, 60/62 cm. 10. Core 11; Section 2, 100/102 cm. 11. Core 11; Section 2, 30/32 cm. 12. Core 11; Section 1, 75/77 cm.
- 13–18 *Subbotina praecursoria* (Morozova), the continuation of *S. trinidadensis* in the evolution of the gens. 13. Core 10; Section 6, 100/102 cm. 14. Core 10; Section 6, 26/28 cm. 15. Core 10; Section 5, 127/129 cm. 16. Core 10; Section 5, 50/52 cm. 17. Core 10; Section 4, 100/102 cm. 18. Core 10; Section 4, 24/26 cm.



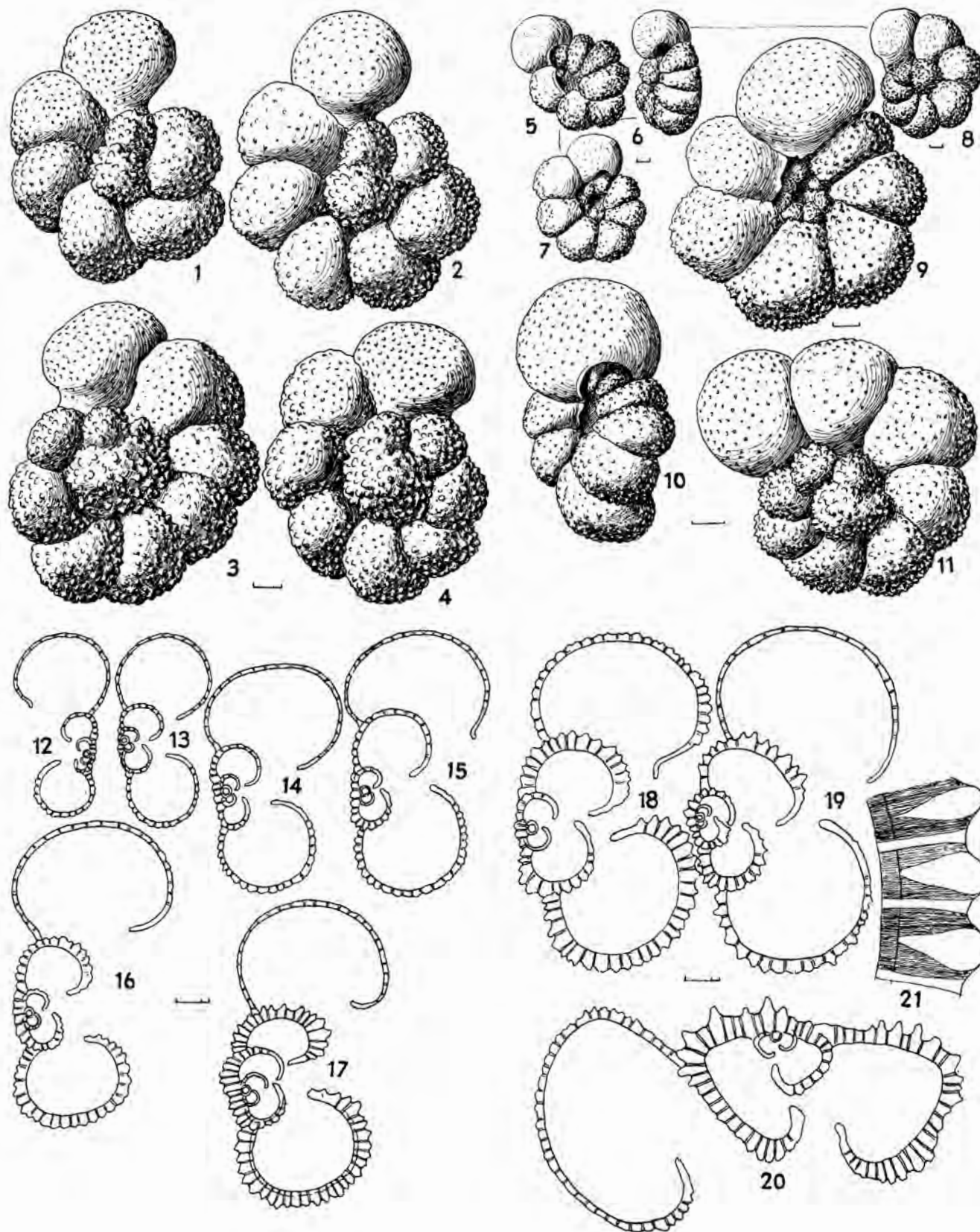


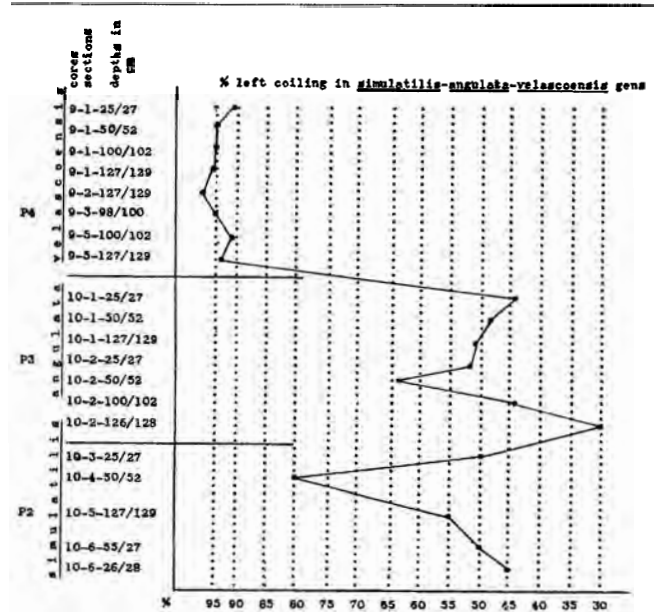
TABLE 4

The increase in size of the *M. simulatilis-angulata-velascoensis* gens.

Species	Cores	Sections	Depth in cm	Specimens	Average size per sample
<i>M. simulatilis-angulata-velascoensis</i>	9-1-50/52	66			0.57
	9-2-25/27	42			0.50
	9-2-127/129	41			0.55
	9-3-98/100	48			0.54
	9-5-100/102	42			0.52
<i>M. simulatilis-angulata-velascoensis</i>	9-5-127/129	63			0.51
	10-1-25/27	19			0.43
	10-1-50/52	31			0.42
	10-1-127/129	22			0.39
	10-2-25/27	11			0.38
<i>M. simulatilis-angulata-velascoensis</i>	10-2-50/52	12			0.41
	10-2-100/102	12			0.40
	10-2-126/128	8			0.41
	10-3-25/27	7			0.33
	10-3-50/52	13			0.37
<i>M. simulatilis-angulata-velascoensis</i>	10-4-50/52	16			0.35
	10-5-127/129	16			0.35
	10-6-25/27	11			0.35
	10-6-50/52	12			0.35
	10-6-100/102	10			0.35

TABLE 5

Direction of coiling in the *M. simulatilis-angulata-velascoensis* gens.



zone P.1) and is common in the *T. uncinata* zone (P.2); and it ends abruptly at the top of this zone with scattered specimens many of which are abnormal with small end chambers.

THE *Morozovella simulatilis-angulata-velascoensis* GENS (Tables 4, 5; Pl. 8)

For this study, Cores 9 and 10 have been examined (see Table 4). The zones represented by these cores are: Core 10, *T. uncinata* Zone and *M. angulata* Zone; Core 9, *P. pseudomenardii* Zone and *M. velascoensis* Zone which ends in the lowest sections of Core 8 (Fischer, A. G. and others, 1971, p. 116-127). This was con-

firmed by Blow in the same report (1971, p. 1020) where he described zones P.2 and P.3-P.4. From each 10-cc sample of coccolithic ooze, all undamaged specimens were selected and measured.

In this succession of samples, *Truncorotalia uncinata*, *Globigerina spiralis*, *Truncorotalia inconstans*, *Subbotina praecursoria*, *Planorotalia ehrenbergi*, and *Morozovella simulatilis* were common in the *T. uncinata* Zone; *Planorotalites pusilla*, *Planorotalia pseudomenardii*, *Morozovella conicotruncata* (= *M. angulata*), *Truncorotalia convexa*, *Morozovella angulata*, and *Planorotalites laevigata* were common in the *M. angulata* Zone; and *Morozovella velascoensis*, *Morozovella occlusa*, and

PLATE 7

□ = 50 μ

- 1-11 *Subbotina praecursoria* (Morozova). From D.S.D.P. Hole 47.2. 1. Core 10; Section 3, 100/102 cm. 2. Core 10; Section 3, 25/27 cm. 3. Core 10; Section 2; 126/128 cm. 4. Core 10; Section 2, 50/52 cm. 5-8. Four views of specimen, in low enlargement. Core 10; Section 3, 25/27 cm. 9-11. Specimen from three sides, normal enlargement, showing the strongly pustulous chamber walls, especially in the dorsal centre. Core 10; Section 2, 126/128 cm.
- 12-21 Transverse sections through successive specimens of the *Subbotina trinidadensis-praecursoria* gens in Drill

- Hole 47.2. 12. Core 11; Section 3, 125/127 cm. 13. Core 11; Section 4, 90/92 cm. 14. Core 11; Section 2, 100/102 cm. 15. Core 11; Section 1, 75/77 cm. 16. Core 10; Section 6, 100/102 cm. 17. Core 10; Section 5, 127/129 cm. 18. Core 10; Section 4, 127/129 cm. 19. Core 10; Section 3, 100/102 cm. 20. Core 10; Section 2, 50/52 cm. 21. Enlarged Section of wall of *Subbotina praecursoria* (Morozova) in polarized light, showing the structure of the genus *Subbotina*.

Globigerina chascoensis were commonest in the *M. velascoensis* Zone. There is general agreement with respect to these zones.

The transitional forms might be placed either in *M. abundocamerata* Bolli, in *M. conicotruncata* Subbotina, or in a number of other species described by several authors. However, the present author believes that this would only confuse the evolution of the gens; and the two forms mentioned seem to be *M. angulata* under different conditions. Under more boreal or other unfavorable conditions *M. angulata* remains small with four chambers in the last-formed whorl. In favorable environments this species has five to six chambers in the last whorl.

It seems that the three zones mentioned above, following the *S. trinidadensis* zone, have more or less abrupt beginnings, because several other gentes change abruptly at these zonal boundaries. These are the *Subbotina trinidadensis-praecursoria* gens and the *Planorotalia compressa-ehrenbergi-pseudomenardii* gens. Several other planktonic species appear suddenly: *Truncorotalia inconstans* and *T. uncinata* in the *T. uncinata* Zone; *Morozovella angulata* and *T. convexa* in the *M. angulata* Zone; and *Morozovella occlusa* and *Globigerina chascanona* in the *M. velascoensis* Zone. It may be that the small incremental increases in the size of the *M. simulatilis-angulata-velascoensis* gens are due to the same cause, viz, to slight gaps between the zones or to changes in environmental conditions.

Just as Blow and Banner (1966, pl. 2) described and figured the gradual change from specimens with rounded margins into specimens with keeled margins in the *Turborotalia foehsi* gens, a comparable change is found in the *M. simulatilis-angulata-velascoensis* gens. The first specimens of *M. simulatilis* show rounded margins in Core 10, Section 6. In Core 10, Section 3, the specimens begin to have a subacute margin in the last-formed chambers, thus pointing toward *M. angulata*. In Core 10, Section 2, the last-formed chambers

have a subacute to acute margin, but older chambers may have a more rounded margin. In Core 10, section 1, the entire last-formed whorl has distinctly acute margins. In Core 9, the specimens of Section 5 show subacute margins to acute margins, whereas in Sections 4–1 of this core they have the keeled margins typical of *M. velascoensis*. Together with this change in the margins, there is a change in the inflation of the ventral walls. The slightly convex outer walls of typical *M. simulatilis* gradually become flat; and in the last-formed chambers of *M. angulata* and in *M. velascoensis* they become distinctly concave towards the margin. The shoulders around the umbilical cavity are rounded in *M. simulatilis*, have more pointed pustules in *M. angulata*, and have distinctly pointed and highly ornamented pustules in *M. velascoensis*. All these changes are gradual and transitional.

Luterbacher (1964, p. 679) tentatively identified some lower Eocene species as *Morozovella aragonensis*, and placed them in the *M. velascoensis* group. But he mentioned that "further investigations are needed to decide if this group has to be subdivided into an upper Paleocene *G. velascoensis* s.s. and a lower middle Eocene *G. aragonensis* group." It seems certain that the Eocene group did not derive from the extremely evolved end of the *M. simulatilis-angulata-velascoensis* gens which ended with the very large and highly specialized forms of *M. velascoensis*.

***Morozovella simulatilis* (Schwager)**

Discorbina simulatilis SCHWAGER, 1883, p. 120, pl. 29, fig. 15.

Globorotalia simulatilis (Schwager). LUTERBACHER, 1964, p. 665, fig. 53–60. NAKKADY, 1959, p. 462, pl. 4, fig. 2. LEROY, 1953, p. 32, pl. 9, fig. 1, 3.

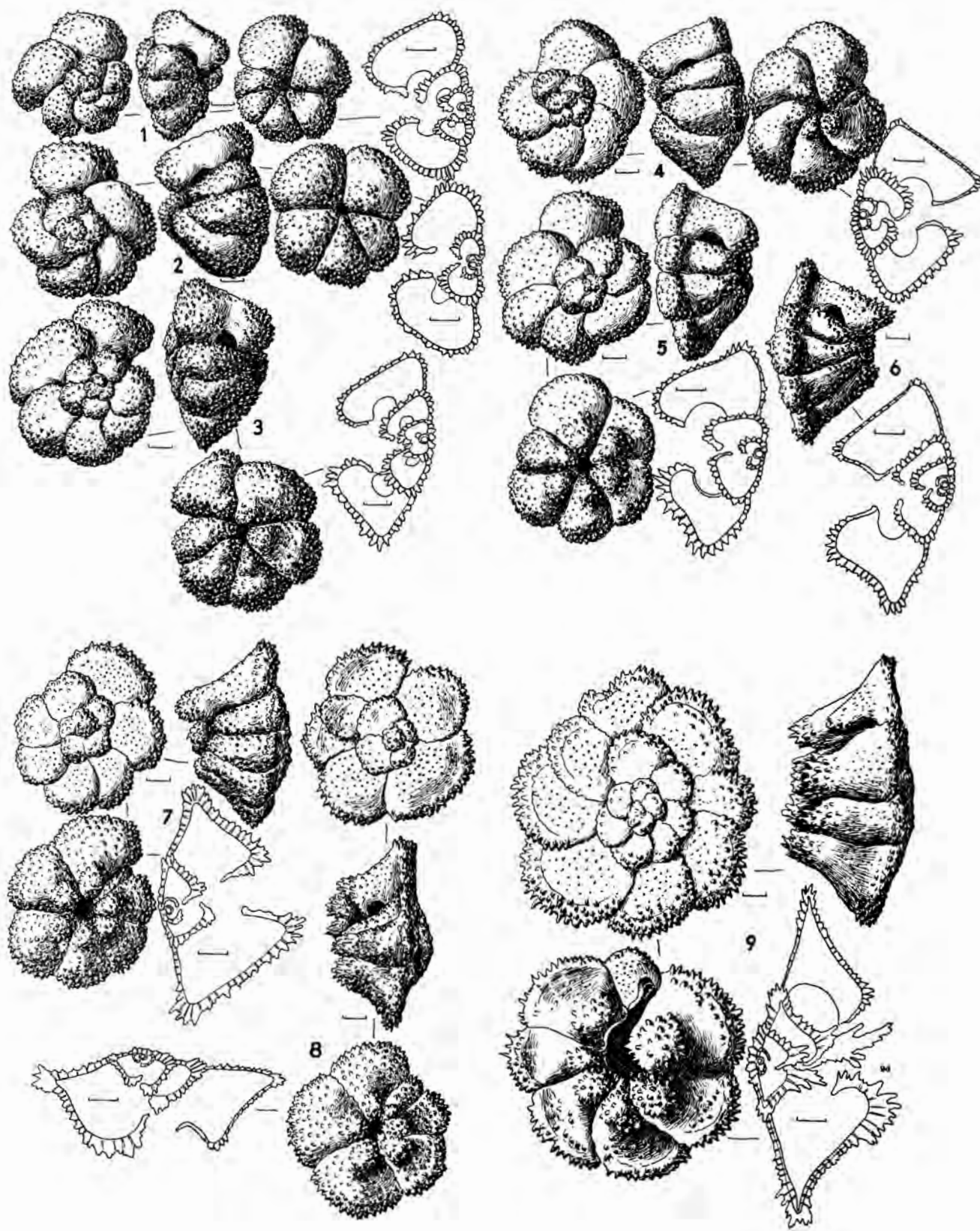
Globorotalia (Truncorotalia) aequa simulatilis (Schwager). VON HILLEBRANDT, 1962, p. 134, pl. 13, fig. 6–8 (?).

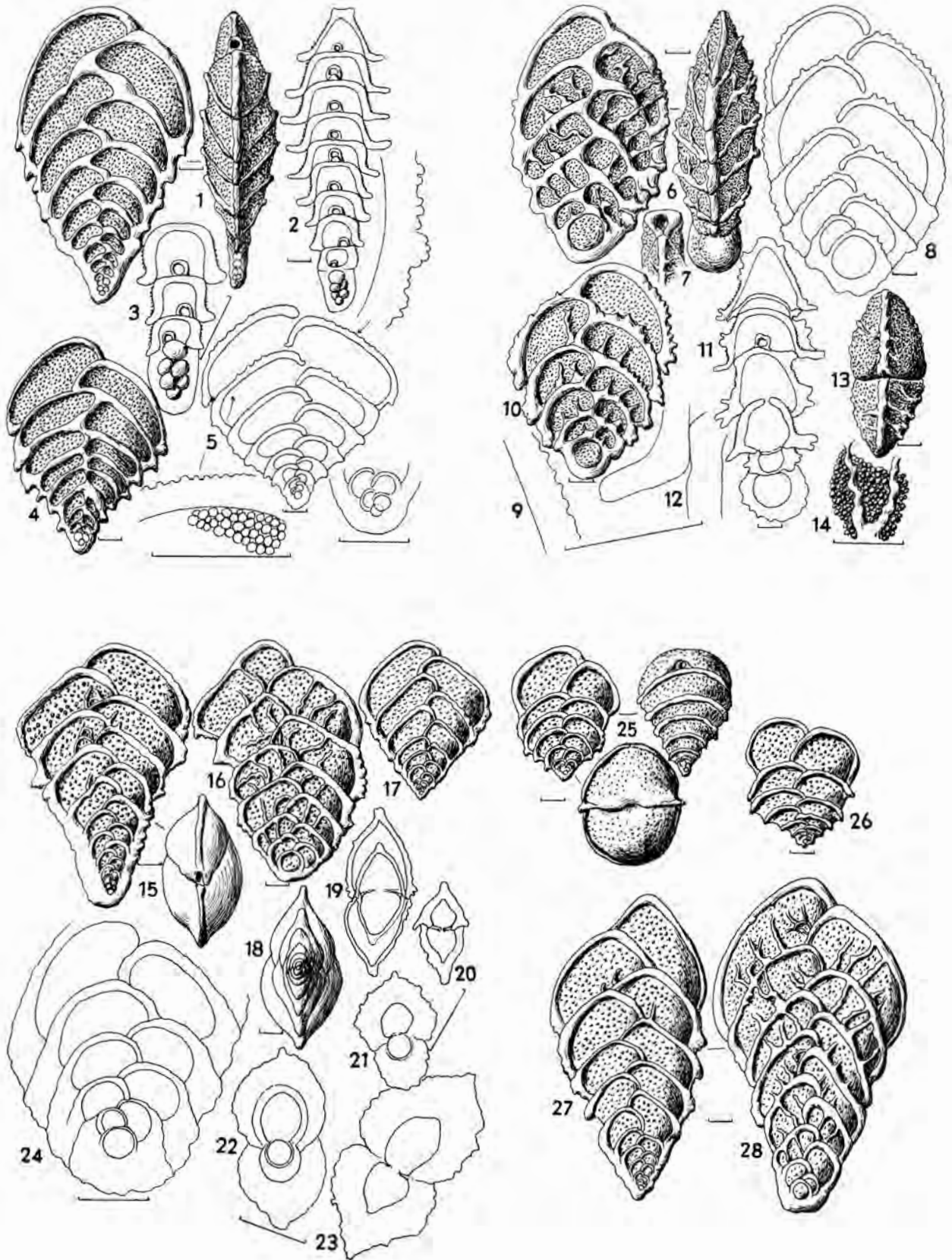
PLATE 8

□ = 50 μ

- 1 *Morozovella simulatilis* (Schwager). Core 10; Section 6, 100/102 cm.
- 2 Same species. Core 10; Section 6, 26/28 cm.
- 3 Same species. Core 10; Section 3, 25/27 cm. Transition towards *M. angulata*.
- 4 *Morozovella angulata* (White). Core 10; Section 2, 100/102 cm.

- 5 Same species. Core 10; Section 1, 127/129 cm.
- 6 Same species. Core 10; Section 1, 25/27 cm.
- 7 Same species. Core 9; Section 5, 127/129 cm. Transitional form towards *M. velascoensis*.
- 8 *Morozovella velascoensis* (Cushman). Core 9; Section 5, 127/129 cm.
- 9 Same species. Core 9; Section 1, 50/52 cm. Outgrown last form, with "kummerform" final chamber.





Test biconvex, slightly so at the dorsal side, strongly at the ventral one. Mostly 5–6 chambers visible in the last-formed whorl, with narrow ventral umbilical cavity. Dorsal sutures distinctly rounded and continuing in the periphery; ventral sutures radial, at both sides depressed; at the dorsal side chambers somewhat overlapping. Margin rounded, becoming subacute in the end of the species' evolution. Walls ornamented by pointed pustules, especially at the ventral shoulders of the chambers, near the umbilical cavity. Apertures more or less crescent-shaped, small, often reaching the umbilicus. Tests small, from 0.30–0.42 mm in larger diameter. Found abundantly in Sections 3–6 of Core 10 in Hole 47.2, *T. uncinata* Zone. Near the end of its evolution, specimens tend to have the characteristics of small *Morozovella angulata*. Small specimens of the latter species may have the characteristics of *M. simulatilis* throughout the *M. angulata* Zone, Sections 1–2 of Core 10. The form is absent in the *M. velascoensis* zone.

Morozovella angulata (White)

Globigerina angulata WHITE, 1928, p. 191, pl. 27, fig. 13.

Globorotalia angulata (White). GLAESSNER, 1937, p. 383, pl. 4, fig. 35. BOLLI, 1957b, p. 74, pl. 17, fig. 10–12. LOEBLICH and TAPPAN, 1964, pl. 45, fig. 7; pl. 48, fig. 2; pl. 55, fig. 6, 7; pl. 64, fig. 5. BOLLI and CITA, 1960, p. 378, pl. 35, fig. 8. GOHR-BANDT, 1963, p. 57, pl. 4, fig. 4–6. SCHUTSKAYA, 1956, p. 92, pl. 3, fig. 2. OLSSON, 1960, p. 44, pl. 8, fig. 14–16. GARTNER and HAY, 1962, p. 559,

pl. 1, fig. 6. EL-NAGGAR, 1966, p. 197, pl. 22, fig. 1.

Globorotalia (Truncorotalia) angulata (White). LEONOV and ALIMARINA, 1961, pl. 5, fig. 2, 7. VON HILLEBRANDT, 1962, p. 131, pl. 13, fig. 14, 15.

Globorotalia (Morozovella) angulata (White). MCGOWRAN, 1968, pl. 1, fig. 13–18 (mostly transitions from *M. simulatilis* to *M. angulata*).

Tests at the dorsal side slightly convex, strongly convex at the ventral side. Mostly 5 or 6 chambers in the last-formed whorl, in more boreal regions with 4 chambers, with narrow umbilical cavity. Dorsal sutures rounded and continuing in the periphery, slightly depressed. Ventral sutures slightly rounded to radial, strongly depressed. At the dorsal side mostly the central part of the test is convex, whereas the dorsal walls of the chambers of the last-formed whorl are flattened. Margin more or less subacute, strongly so at the end of the evolution. Shoulders of the later chambers well developed around the umbilical cavity, and the last-formed chambers have the outer walls flattened. Umbilicus deep within the shoulders of the chambers. Aperture a low arch below the middle of the ventral suture. Walls strongly ornamented by sharp, densely placed pustules, especially at the ventral shoulders of the chambers. Tests of medium size, from 0.34 to 0.48 mm in larger diameter. Found abundantly in sections 1 and 2 of Core 10 in Hole 47.2, *M. angulata* Zone. In the beginning of their evolution, specimens may have characteristics tending to *M. simulatilis*; in the end of it more and more specimens show tendencies towards *M. velascoensis*.

PLATE 9

□ = 50 μ

1–5 *Aragonia velascoensis* (Cushman), microspheric generation. Core 11; Section 2, 30/32 cm. 1. Large specimen, identical with *A. monilifera* (Galloway and Morrey). 2. Transverse longitudinal section; twisted initial chambers; small foramina, first foramina biserially placed. 3. Initial part more enlarged. 4. Smaller specimen, with characteristics of *A. ouezanensis* (Rey). 5. Longitudinal section of a specimen as in Fig. 4, with enlarged initial end and some wall parts.

6–14 *Aragonia velascoensis*, megalospheric generation. Same sample. 6. Large specimen with the strong ornamentation on the 7. Aperture. 8. Longitudinal section. 9. Wall part of section Fig. 8. 10. Another specimen of the megalospheric generation. 11. Transversal longitudinal section. 12. One of the raised sutures.

13. Apertural face. 14. Part of wall structure, enlarged.

15–24 *Aragonia velascoensis* (Cushman). Core 13; Section 3, 100/102 cm. Upper Maestrichtian. 15. Microspheric specimen. 16. Megalospheric specimen. 17. Smaller microspheric specimen. 18. Initial face of specimen of Fig. 17. 19. Transverse section through this specimen. 20–23. Successive transverse sections through microspheric specimen from Core 13; Section 3, 47/49 cm. 24. Longitudinal section through the initial end of microspheric specimen, same sample.

25 Microspheric specimen from Core 11; Section 6, 23/25 mm, aplanktonic zone.

26 Another microspheric specimen, same sample.

27 Microspheric specimen from Core 9; Section 5, 127/129 cm; the elongate end form.

28 Megalospheric specimen from the same sample.

sis, especially in Core 9, Section 5, depth 127/129 cm. The typical form is absent in the *M. velascoensis* Zone.

Berggren (1960, p. 106–107) wrote about the forms of *Morozovella angulata*: “particular attention was devoted to a study of the phylogeny of the globorotalids in the lower Paleogene sediments of the Sub-Caucasus (Schutskaya, 1956, p. 104–108), and the results will be treated in some detail here because of their general significance. *Globorotalia angulata* (White) was considered the index-form of the Paleocene in this region. In its synonymy was placed *Globorotalia conicotruncata* Subbotina, a conclusion reached independently by this writer after studying typical material of both species. The strong variation found in this species was used to justify the erection of two varieties, *G. angulata* var. *praepentacamerata* (differing from the central form in having inflated chambers and a rounded periphery) and *G. angulata* var. *kubanensis* (characterized by a convex spiral side and more angular periphery). Both forms are said to occur together with the central form in the Elburgan formation; in the Mal’chik horizon (group) they were said to be rare. This writer has noted identical features in *G. angulata* in the Paleocene of Nigeria (West Africa). However, this marked variation (observed through a stratigraphic interval of over 175 m in a Nigeria bore-hole) would appear to represent a high level of infraspecific variation and is not considered of taxonomic significance.”

We may assume that some of these “variations” tend more to *M. simulatilis* and others more to *M. angulata*, and that the form found in the middle of the range in Hole 47.2 is identical with what was named *G. conicotruncata*. In the undisturbed and continuous sedimented tropical environment of the latter drill hole the so-called “central form,” viz. the form with four chambers in the last-formed whorl, does not occur, due to the favorable conditions of this locality. Such “variations,” obviously found in different localities with different environmental conditions, did not occur here and the phylogeny of the gens was performed in one orthogenetic line. This line was proved by transitional forms just at the boundaries of the three “species.” In a gens the successive “species” flow into each other, and the “gens” indicates that there is only one biologic unity, the “gens.” That there exists a sudden jump in the evolution line on the table 4 is due to an hiatus of at least 2 m in the sampling.

***Morozovella velascoensis* (Cushman)**

Pulvinulina velascoensis CUSHMAN, 1925, p. 19, pl. 3, fig. 5.

Globorotalia velascoensis (Cushman). WHITE, 1928, p. 281, pl. 38, fig. 2. BOLLI, 1957b, p. 76, pl. 20, fig. 1–3. LOEBLICH and TAPPAN, 1957, pl. 64, fig. 1, 2. SACAL and DEBOURLE, 1957, p. 64, pl. 29, fig. 7–9. BOLLI and CITA, 1960, pl. 31, pl. 33, fig. 7. SAID and KERNADY, 1961, p. 330, pl. 1, fig. 10. LUTERBACHER, 1964, p. 681, fig. 92–94, 98, 99. EL-NAGGAR, 1966, p. 246, pl. 20, fig. 3. MCGOWRAN, 1968, pl. 2, fig. 1–4.

Tests at the dorsal sides nearly flat, at the ventral sides strongly convex. Number of chambers in the last-formed whorl 5–8; 8 especially in the later part of the evolution. Dorsal sutures rounded and continuing in the periphery, ventral sutures nearly straight and radiate; umbilicus open and in the later part of the evolution often elongate towards the last-formed chamber which is often smaller than the other chambers. Margin acute to keeled, ventral sutures near to the margin slightly depressed, towards the umbilicus strongly so, with pronounced shoulders with heavy bosses of spinous pustules, forming a craterlike structure with the open umbilicus. Aperture an open crescent towards the ventral side, often opening into the umbilical cavity with a distinct thickened border. Outer ventral walls distinctly concave and forming the keeled margin at the periphery, which keel is mostly ornamented by strong pointed pustules. Tests often of large size, larger diameters from 0.38 to 0.75 mm, in each sample with great variation of the size. Found abundantly in Core 9 of Hole 47.2 with an average diameter of 0.52 to 0.57 mm. In many genses the later forms show a much larger variation in size than in the beginning of the evolution of the gens. This is true here also. The species is closely allied to *M. angulata* since the specimens in the end of the evolution of the latter species show many transitions to *M. velascoensis*.

The evolutionary trends in the *M. simulatilis-angulata-velascoensis* gens are clearly seen, particularly in transverse view:

1. gradual increase in size of the test;
2. rounded margins in all chambers in *M. simulatilis*; subacute to rounded margins in the later chambers in *M. angulata*, whereas the former whorls show rounded margins; acute to keeled margins in most chambers, also in the initial ones, in the end-forms of *M. velascoensis*;
3. gradual pronouncing shoulders of the ventral chamber walls;
4. enlargement of the ventral cavity;

5. gradual flattening of the dorsal sides of the tests;
6. enlargement of the apertures towards the umbilical cavity;
7. gradual increase of ornamentation, especially on ventral side and margin;
8. remarkable change in coiling direction.

The remarkable changes in coiling direction were already stated by Bolli (1971, p. 642, fig. 48, 3). *Morozovella simulatilis* begins with a left coiling of 45 percent, changes its coiling direction up to 80 percent left coiling, but ends with 50 percent left coiling; *M. angulata* begins with 30 percent left coiling, changes its direction up to 66 percent, but ends with 46 percent left coiling; both "species" thus show the same pattern in the change of coiling direction. Then, probably at the boundary between Blow's zones P.3 and P.4 (there is a hiatus in the samples here) the next stage of the gens, *M. velascoensis*, suddenly shows another pattern, as its coiling direction has a nearly invariable 95 percent left coiling. Bolli believed that *M. angulata* was allied to *Morozovella aequa* and thus would end with that form with a left-coiling direction of about 3 percent; but the latter species cannot be derived from *M. velascoensis*.

Bandy showed that in *Globorotalia pachyderma* sinistral coiling is associated with low temperature, whereas dextral coiling is associated with higher temperature (1960). However, there are no indications that the temperature was lower in Blow's zone P.4. Bandy rightly remarked (p. 680) that "perhaps there is a genetic linkage between coiling traits and the ability to cope with different temperatures."

THE *Aragonia velascoensis* GENS

Table 6; Pl. 9

There is considerable confusion in the taxonomy of *Aragonia*; in the Upper Cretaceous and the Paleocene there is only one species, *A. velascoensis* (Cushman). Strongly ornamented specimens always belong to the megalospheric generation, whereas specimens without irregular costae on the chamber walls or nearly unornamented specimens belong to the microspheric generation. The microspheric generation is much more common than the megalospheric one in Hole 47.2. For 251 specimens studied from the upper Maastrichtian *M. mayaroensis* zone up to the upper Paleocene *M. velascoensis* zone, the ratio of microspheric to megalospheric forms is 167:84.

Many authors believed that elongate forms, as they

occur at the end of the evolutionary range, form another species different from the more kite-formed specimens found in the Maastrichtian and the lower Paleocene. Moreover, unornamented specimens were believed to form species separate from the strongly ornamented specimens. However, all of these forms belong to one species with only a very small increase in size. This species is dealt with here because it shows a very remarkable reduction in size and reduction of the megalospheric generation during the *P. eugubina* and aplanktonic zones. Analysis of this species shows the following synonyms:

- Textularia velascoensis* CUSHMAN, 1925, p. 18, pl. 3, fig. 1.—, 1926, p. 584, pl. 15, fig. 8.
- Bolivinoidea trinitatis* CUSHMAN and JARVIS, 1928, p. 99, pl. 14, fig. 10. —, 1932, p. 43, pl. 13, fig. 3. CUSHMAN and RENZ, 1946, p. 114, pl. 48, fig. 16, 17.
- Gumbelina velascoensis* (Cushman). WHITE, 1929, p. 39, pl. 4, fig. 14.
- Textularia excolata* Cushman. GLAESSNER, 1937, p. 362, pl. 2, fig. 12. HILTERMANN, 1943, p. 751, fig. 7. NOTH, 1951, p. 33.
- Spiroplectammia excolata* (Cushman). HAGN, 1952, p. 208.
- Bolivinoidea ouezzanensis* REY, 1954, p. 240, pl. 12, fig. 2.
- Aragonia ouezzanensis* (Rey). WICHER, 1956, p. 107, pl. 13, fig. 15. HAGN, 1957, p. 32. REYMENT, 1959, p. 110, fig. 4, 2. VON HILLEBRANDT, 1962, p. 73, pl. 5, fig. 15.
- Aragonia velascoensis* (Cushman). WICHER, 1956, p. 107, pl. 13, fig. 9–14. REYMENT, 1959, p. 110, fig. 6. VON HILLEBRANDT, 1962, p. 74, pl. 5, fig. 16. BECKMANN and KOCH, 1964, p. 50, pl. 7, fig. 6–8. BETTENSTAEDT and WICHER, 1956, pl. 1, fig. 10. BECKMANN and KOCH, 1964, p. 52, pl. 7, fig. 9–13 (partim).
- Aragonia excolata* (Cushman). BETTENSTAEDT and WICHER, 1956, pl. 2, fig. 11.
- Bolivinoidea stewarti* MALLORY, 1959, p. 203, pl. 16, fig. 27.
- Bolivina monilifera* GALLOWAY and MORREY, 1931, p. 349, pl. 40, fig. 3.

It was Reyment (1959) who showed that the test wall of *Aragonia* lacks any pores and that it is constructed of very fine, somewhat globular, calcareous grains. *Aragonia* seems to be agglutinate.

The plate given here shows the variation, the difference between microspheric and megalospheric forms,

TABLE 6
Occurrence and test lengths of *Aragonia velascoensis* in Hole 47.2.

cores sections depths in cm	average length	specimens	microspheric	megalospheric	lengths of tests in 0.01 mm	zone	code
9-1-25/27	0.53	3				<i>velascoensis</i>	P4
9-2- 25/127	0.49	7	4	3			
9-3- 25/127	0.52	7	6	1			
9-5-100/102	0.55	3					
9-5-127/129	0.67	4					
10-1-100/102	0.48	20	14	6			
10-2-25/27	0.50	5					
10-2-50/52	0.47	4				<i>angulata</i>	P3
10-2-125/127	0.49	2					
10-3-25/27	0.52	1					
10-3-100/102	0.45	5					
10-4-25/27	0.49	8				<i>uncinata</i>	P2
10-4-50/52	0.44	8					
10-4-129/131	0.47	20	11	9			
10-5-50/52	0.50	19	10	9			
11-1-125/127	0.45	11					
11-2-30/32	0.50	31	12	19			
11-2-60/62	0.48	17	12	5			
11-2-100/102	0.45	13	8	5		<i>trinidadensis</i>	P1
11-3-30/32	0.51	11					
11-3-125/127	0.43	15	6	9			
11-4-30/32	0.43	5	2	3			
11-4-90/92	0.45	11	6	5			
11-5-10/12	0.46	8	5	3		<i>Eoglob.</i>	Pa
11-5-27/29	0.32	1	1	0			
11-5-48/50	0.34	3	3	0		<i>aplanktonic</i>	Pa
11-5-90/92	0.29	10	10	0		<i>eugubina</i>	zone M
11-5-98/100	0.31	2					
11-6-23/25	0.27	4	4	0			
11-6-98/100	0.28	6	6	0			
11-6-127/129	0.28	14	14	0			
12-1-25/27	0.28	6					
12-2-125/127	0.28	7	6	1			
13-3-25/27	0.45	9	8	1			
13-3-45/47	0.49	9	8	1			
13-3-100/102	0.53	8	6	2		<i>mayaroensis</i>	M
13-3-127/129	0.50	9	8	1			

Appearance of ARAGONIA VELASCOENSIS in the drill hole 47.2, Shatsky Rise, Pacific, of Deep Sea Drilling Project in samples through the Upper Maestrichtian, the Cretaceous-Tertiary boundary and the Paleocene.

and the inner structure of this species. Table 6 shows the generation ratios and the variation as found in those samples of Hole 47.2 which yielded enough specimens to show it.

In the samples of the lower part of the *M. mayaroensis* Zone, the mean length of the tests is 0.50 mm; the ratio of microspheric to megalospheric is 7:1; in the upper part of this zone and in the *P. eugubina* Zone, characterized by small planktonic and benthonic foraminifera, *Aragonia* is very small, with a mean length of 0.28 mm; especially in the samples from higher in this zone and in the aplanktonic zone, megalospheric specimens are absent and specimens have an average length of 0.29 mm. Suddenly, with the beginning of the *Eoglobigerina* Zone the length increases to a mean length of 0.46 mm, and megalospheric specimens reappear (ratio of microspheric to megalospheric is 5:3). In the Danian and Paleocene samples the mean lengths increase

slightly from 0.43 to 0.53 mm, and megalospheric specimens are found in all samples. Obviously the environmental conditions in the upper *M. mayaroensis* Zone, in the *P. eugubina* Zone, and the aplanktonic zone were rather bad. The fact that all small specimens of *Aragonia* were microspheric has already been discussed in the section of the aplanktonic zone. *Aragonia* clearly shows the deterioration of conditions at the Cretaceous-Tertiary boundary and is valuable in other discussions related to this change in conditions, such as the fact that not only planktonic species were affected. Thus, *Aragonia velascoensis* became a sensitive indicator of the deterioration of conditions at the Cretaceous-Tertiary boundary. *Aragonia* was a bottom dweller in deep water of the open ocean and unlike the planktonic foraminifera, it outlived the onslaught at this boundary. The deterioration indicated by *Aragonia* is from Core 12, Section 2, 125/127 cm to Core 11, Section 5, 27/29 cm,

a time span which, according to Berggren's timetable, might be six m of coccolithic ooze or about 2,250,000 years. This demonstrates that the faunal break at the Cretaceous-Tertiary boundary is not so abrupt as may be gathered from some sections in which smaller or larger gaps occur in the succession. This deterioration ended with the aplanktonic zone and ended abruptly with the base of the *Eoglobigerina* Zone.

What calamities caused the onslaught are not certain. It was not caused by a shortage of food such as a sudden decline in the nannoplankton, as Tappan (1968) has suggested. A rich nannoplankton life is evidenced by the coccolithic sediment of the samples during this time span. Moreover, planktonic foraminifera seem to feed on copepods, as Rhumbler (1911, p. 238) stated. Hard grounds and sedimentary gaps just at the Cretaceous-Tertiary boundary (Premoli Silva and Luterbacher, 1966) certainly show that bottom subsurface ocean currents were strong at that time (sudden migrations of tropical faunas in boreal areas; gaps in sedimentation, hard grounds). These oceanic currents may have prevented the normal course of the life cycle of the planktonic foraminifera.

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