

OBSERVATIONS ON THE UPPER CRETACEOUS FORAMINIFERA FROM VRIDHACHALAM, SOUTH INDIA*

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ABSTRACT—The Lower Ariyalur Stage (Upper Cretaceous) exposed in the north of Vridhachalam has yielded a rich foraminiferal assemblage. In this report, the stratigraphic occurrences of the smaller Foraminifera in several biostratigraphic Zones and sub-Zones of this Stage are noted. The faunal elements are grouped into four different categories, depending upon their relative abundance, with the view to achieve precise correlation and ecological interpretations. Several new and good fossil indices are defined for the detailed biostratigraphic work.

INTRODUCTION

In course of investigations on the foraminiferal biostratigraphy of Upper Cretaceous sequence in Vridhachalam, a rich foraminiferal assemblage represented by a large number of planktonic and benthonic species is recorded. The present study is the determination of the stratigraphic occurrences of smaller Foraminifera found in a sequence of Coniacian to Lower Maestrichtian strata, known as the Lower Ariyalur Stage, exposed in the north of Vridhachalam town. The sequence is subdivided into five biostratigraphic zones and two sub-zones (Table 1) based on the restricted vertical distribution of planktonic species and sub-species of the genus *Globotruncana* (Banerji, 1964). The lowermost zone is unfossiliferous in nature. Not much attention has so far been

paid to the space-time distribution of the smaller Foraminifera other than *Globotruncana*, as they are sometimes considered to be of limited biostratigraphic significance. An attempt is here made to register the variation in their stratigraphic distribution for precise correlation of this Stage with adjoining areas and ecological interpretations of the basin.

The principal reason for interest in Vridhachalam Foraminifera is multifold: (i) regionally Vridhachalam is situated in the centre of the exposed Cretaceous outcrops of South India (Pondicherry in north and Ariyalur in south) and is considered important for detailed studies; (ii) in general, Upper Cretaceous foraminiferal assemblage of this area have received little attention in published literature, especially to its benthonic elements; (iii) the Foraminifera

*This work was carried out at the Department of Geology and Geophysics, Indian Institute of Technology, Kharagpur.

TABLE 1

BIOSTRATIGRAPHY OF THE LOWER ARIYALUR STAGE OF VRIDHACHALAM

European Equivalents	Biostratigraphic Zones & Sub-Zones	Lithology
Lower Maestrichtian	<i>Globotruncana linneiana tricarinata</i>	Hard greyish to yellowish-white limestone with thin shale inter-calations and a thin sandstone band at top.
Campanian	<i>Globotruncana globigerinoides</i>	<i>G. ventricosa</i> sub-Zone
		<i>G. marginata</i> sub-Zone
Santonian	<i>Globotruncana concavata</i>	Soft medium grained weathered yellowish grey arenaceous limestone and marls.
Coniacian	<i>Globotruncana linneiana coronata</i>	Hard white to yellowish arenaceous limestone with marl bands at top and more sandy towards bottom.
? Upper Turonian	Unfossiliferous sandstone	Medium grained sandstone.

of this region bears striking resemblance to the forms of many well known Upper Cretaceous sediments of the Indo-Pacific regions and thus may suggest the routes of the migration of these forms; (iv) the study of its Foraminifera is especially commendable, since this sequence of strata (Lower Ariyalur Stage) may be of considerable importance in the sub-surface petroleum exploration in the Ariyalur basin and (v) it will aid in better understanding of stratigraphic and faunal relationship in related areas.

The other details of the lithostratigraphy and biostratigraphy of the Lower Ariyalur Stage of Vridhachalam are discussed elsewhere (Banerji, 1966 a).

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GENERAL FAUNAL CHARACTERS

The most interesting feature of the Foraminifera studied here is their cosmopolitan nature

in the Upper Cretaceous tropical and subtropical regions with minor local elements. It can be best compared with the forms of Pondicherry and other areas of South India. Some affinities may be traced with those of Assam and West Pakistan (Banerji, 1966 b). The same statement holds good for the Upper Cretaceous foraminiferal fauna of Gulf Coastal areas of the United States and Mexico, California, Colombia, New Jersey and Trinidad in the west and Indonesia and NW Australia in the east. At the locality Patti (about 4 kms. WNW of Vridhachalam town), more than 65% forms of the total assemblage are found in common to the Gulf Coastal areas (compare with Cushman, 1946). They also resemble with the forms from Caucasus and other regions of Southern U. S. S. R., however, the European elements in Vridhachalam fauna is very little, except those reported by Reuss in the nineteenth century. The vertical change in the foraminiferal assemblage of Vridhachalam and incoming of a few new species and many *indet* forms may be attributed due to local environmental set-up and fluctuations in the depth of the basin. It may be otherwise suggested that during the Upper Cretaceous times, South India, NW Australia and Central America belonged to one zoo-geographic province or the migratory routes for this fauna and other connections to these regions were well established.

Over 300 surface samples collected from about 80 sq. kms. area north of Vridhachalam town during 1960-62, have been analyzed for the faunal study. Most of the samples are from two stratigraphic sections—Patti Nala (11° 33' 20"N : 79° 15' 30"E) and Chendamangalam (11° 44' 30"N : 79° 20' 00"E) (fig. 1). More than 30 genera and 110 species of smaller foraminifera belonging to 14 foraminiferal

families are identified, out of which 8 species are new (Banerji, 1966 a, 1967). Families represented by good numbers of species and specimens are : Anomalinidae, Globotruncanidae, Nodosariidae, Rotaliidae and Textulariidae.

Although most of samples contain a fairly large number of species but they generally show a very low frequency of distribution and very few species are observed to dominate quantitatively the whole assemblage. In all less than 10 identifiable species are found to occur consistently throughout the stratigraphic succession. A large number of forms could not be identified because of their at times poor preservation, silicification, abnormal growths and high extent of variations in their morphological characters. In most cases, they are identified up to their generic level.

In general, the fauna is represented by a good percentage of planktonic forms, but they are composed of a few genera like *Globotruncana*, *Heterohelix*,[?] *Pseudotextularia* and *Rugoglobigerina*. In some samples, especially the shales, the planktons are abundant, but quantitatively they never mask the benthos. Bionomically, the calcareous perforate forms dominate, whereas the imperforate forms are least in order of abundance. The fluctuations in abundance of arenaceous forms in different Zones and sub-Zones are well marked. This type of species are few and mostly represented by simple forms (in morphology) but with numerous specimens in some samples especially from the lowermost part of the fossiliferous sequence of the Lower Ariyalur Stage.

Two interesting observations can be made from a comparative study of the foraminiferal fauna and the rock types—(i) a close control by facies on the distribution of species and (ii)

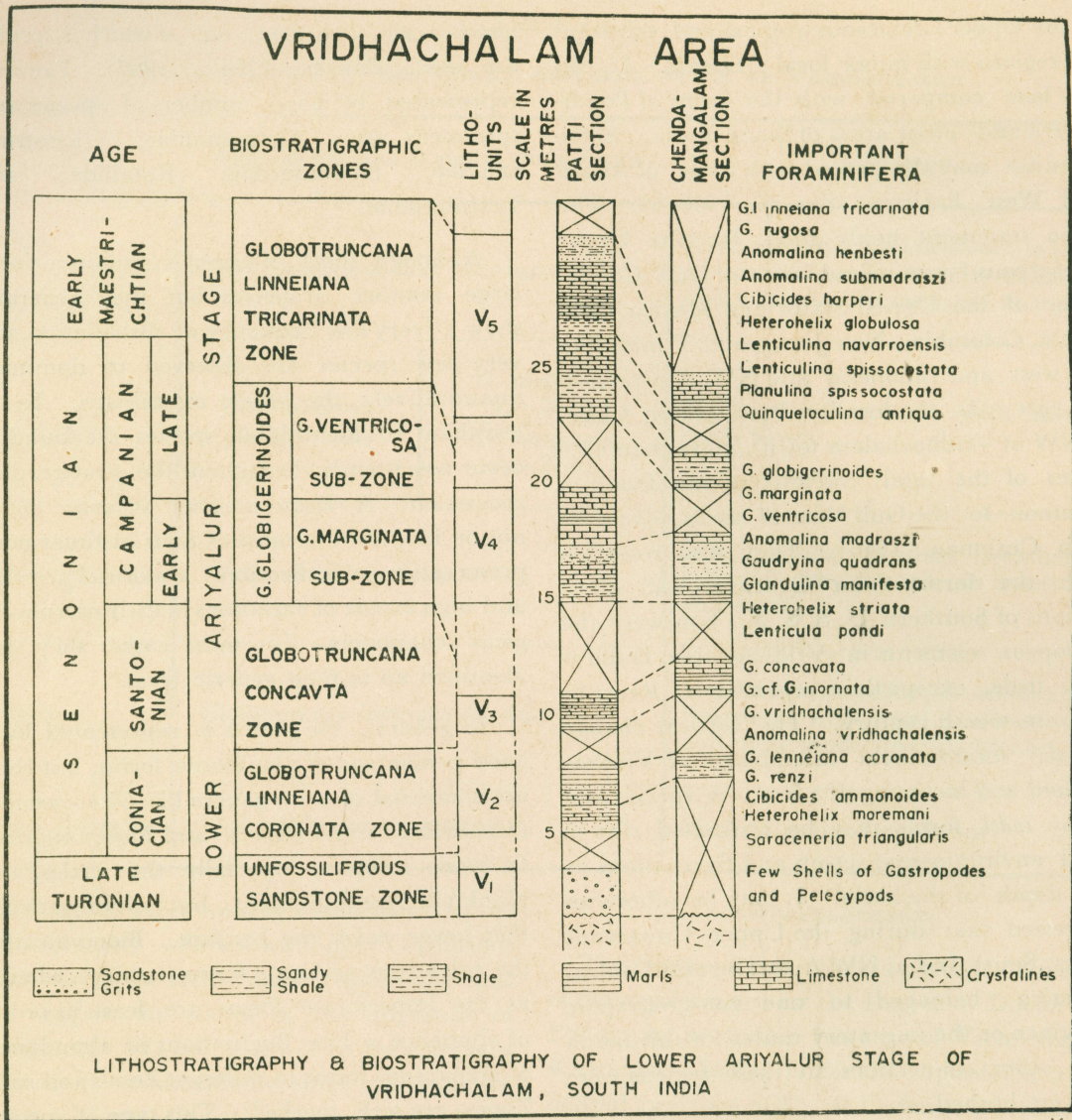


Figure 1

similar facies reappearing at different levels in the sequence contain different species. Thus it may be suggested that the ranges of species in a particular facies act as a fairly accurate guide to the biostratigraphic work in this area. This difference in bio-facies may also be due to the different phases of minor trans-

gressions and regressions of the Cretaceous sea. The best part of the faunal elements is found interlocked with the shale bands of varying thickness occurring alternately with other rock types of mainly calcareous facies.

Apart from the Foraminifera, the micro-fauna is represented by ostracods, fish frag-

TABLE 2

DISTRIBUTION OF FORAMINIFERA IN THE LOWER ARIYALUR STAGE OF VRIDHACHALAM .

VRIDHACHALAM SPECIES	BIOSTRATIGRAPHIC ZONES				
	<i>G. l. coronata</i> Zone	<i>G. concavata</i> Zone	<i>G. marginata</i> sub-Zone	<i>G. ventricosa</i> sub-Zone	<i>G. l. tricarinata</i> Zone
1	2	3	4	5	6
<i>Anomalina complanata</i> Reuss	C	C			
<i>Anomalina henbesti</i> Plummer					C
<i>Anomalina madraszi</i> Banerji				C	F
<i>Anomalina submadraszi</i> Banerji					C
<i>Anomalina vridhachalensis</i> Banerji		C			
<i>Anomalinoides pinguis</i> (Jennings)			R	R	C
<i>Apiopterina cylindroides</i> (Roemer)			R	F	
<i>Bolivina cretosa</i> Cushman			F	F	
<i>Bolivina incrassata</i> Reuss	R				
<i>Cibicides ammonoides</i> (Reuss)	A	?	R		
<i>Cibicides beaumontianus</i> (D'Orbigny)	C	?	?	?	C
<i>Cibicides blanfordi</i> Banerji	?	R	C	C	F
<i>Cibicides harperi</i> (Sandidge)					C
<i>Cibicides purobi</i> Banerji	C	A	C	C	C
<i>Cibicides stephensoni</i> Cushman	R	C	A	C	F
<i>Cibicides subcarinatus</i> Cushman & Deaderick	C	A	C	C	F

1	2	3	4	5	6
<i>Dorotha oxycona</i> (Reuss)		C			
<i>Dentalina catenula</i> Reuss				F	F
<i>Dentalina gracilis</i> D'Orbigny			R	F	
<i>Dentalina megapolitana</i> Reuss	R				
<i>Fronicularia goldfussi</i> Reuss			F	F	
<i>Gaudryina faujasi</i> (Reuss)	C	?	R	R	
<i>Gaudryina quadrangularis</i> Bagg		F			
<i>Gaudryina quadrans</i> Cushman			F	F	
<i>Glandulina manifesta</i> Reuss			C	C	
<i>Glandulina elongata</i> Banerji				F	
<i>Glandulina pygmea</i> Reuss		C			
<i>Globotruncana concavata</i> (Brotzen)		C			
<i>Globotruncana globigerinoides</i> Brotzen			C	C	
<i>Globotruncana</i> cf. <i>G. inornata</i> Bolli	F	F			
<i>Globotruncana linneiana coronata</i> (Bolli)	C	R			
<i>Globotruncana linneiana tricarinata</i> (Quereau)					C
<i>Globotruncana marginata</i> (Reuss)			C	R	
<i>Globotruncana renzi</i> Gandolfi	C	C			
<i>Globotruncana rugosa</i> (Marie)					C
<i>Globotruncana ventricosa</i> White				C	
<i>Globotruncana vridhachalensis</i> Banerji		C	F		
<i>Guttulina adhaerens</i> (Olszewski)			R		R
<i>Gyroidina depressa</i> (Alth)	F	A	A	A	A
<i>Gyroidina girardana</i> (Reuss)	C	F	F	F	
<i>Gyroidina globosa</i> (Hagenow)		C			

1	2	3	4	5	6
<i>Gyroidina imitata</i> (Olsson)	F				
<i>Gyroidina subangulata</i> (Plummer)				R	
<i>Heterohelix carinata</i> (Cushman)				R	F
<i>Heterohelix globulosa</i> (Ehrenberg)					C
<i>Heterohelix moremani</i> (Cushman)	F				
<i>Heterohelix striata</i> (Ehrenberg)			C	C	C
<i>Heterolepa pondi</i> Banerji	C	A	R	R	C
<i>Hoeglundina supracretacea</i> (Ten Dam)	C	A	C	A	A
<i>Lagena acuticosta</i> Reuss	R	R			
<i>Lenticulina macrodiscus</i> (Reuss)	F	C	C	F	
<i>Lenticulina münsteri</i> (Roemer)	V	C	C	C	F
<i>Lenticulina navarroensis</i> (Plummer)					C
<i>Lenticulina pondi</i> (Cushman)			C	C	
<i>Lenticulina spisso-costatus</i> (Cushman)					C
<i>Loxostomum clavatum</i> (Cushman)			R	F	
<i>Marginulina bullata</i> Reuss			R	F	
<i>Marginulina cretacea</i> Cushman			F	F	
<i>Marginulina navarroana</i> Cushman					F
<i>Marginulina obliquinodes</i> (Bandy)		R			
<i>Marginulina trilobata</i> D'Orbigny		F			
<i>Nodosaria affinis</i> Reuss		F	F	F	
<i>Planulina multipunctata</i> Bandy		F			
<i>Planulina spissocostata</i> Cushman					F
<i>Pleurostomella subnodosa</i> Reuss		F	C		
? <i>Pseudotextularia</i> cf. <i>P. elegans</i> Rzehak					C

1	2	3	4	5	6
<i>Quinqueloculina antiqua</i> Franke					C
<i>Ramulina</i> cf. <i>R. abscissa</i> Loeblich & Tappan	F				
<i>Raphunulina exerta</i> (Berthelin)				F	
<i>Raphanulina lacrima</i> (Reuss)					F
<i>Rugoglobigerina</i> cf. <i>R. rugosa</i> (Plummer)					F
<i>Saraceneria traingularis</i> (D'Orbigny)	A	R	R	F	
<i>Spiroplectammina semicomplanata</i> (Carsey)	C	F			
<i>Textularia ariyalurensis</i> Banerji	C	R	R		
<i>Textularia ripleyensis</i> W. Berry			F	F	
<i>Textularia subconica</i> (Franke)		R	R	F	
<i>Tritaxia</i> cf. <i>T. dubia</i> (Reuss)			R	F	
<i>Tritaxia jarvisi</i> Cushman		R			
<i>Tritaxia tricarinata</i> (Reuss)	A	C			
<i>Valvulineria</i> cf. <i>V. allomorhinoides</i> (Reuss)		R			
<i>Valvulineria plummerae</i> Loetterle	F				
<i>Verneuilina cretosa</i> Cushman		R			

ments (teeth and ? otoliths), echinoid spines, fragments of coral colonies and molluscan shells.

STRATIGRAPHICAL ANALYSIS

Of the 110 species of Foraminifera encountered in the Lower Ariyalur Stage, the few important and diagnostic ones are listed under their respective biostratigraphic Zones and sub-Zones. The quantitative results of their distribution are obtained by counting the number of specimens of each species in a fixed quantity of samples. Frequency of distribution thus obtained is expressed as follows:

Very Abundant (V)	more than 50 specimens of a species
Abundent (A)	30 - 49 " " "
Common (C)	10 - 29 " " "
Few (F)	4 - 9 " " "
and Rare (R)	1 - 3 " " "

Although many additional samples were examined for supplementary information, only 48 received quantitative analysis for the tabulation showing the approximate abundance of different faunal elements. The distribution of these samples zone-wise are 9 in *Globotruncana linneiana coronata* Zone, 12 in *Globotruncana*

concovata Zone, 14 in *Globotruncana globigerinoides* Zone and 13 in *Globotruncana linneiana tricarinata* Zone. The number of samples from each Zone does not indicate a like ratio of stratigraphic thickness, but rather reflects the adequacy of exposures.

The restricted and more characteristic species which help in defining a Zone, are listed under *Index species*. The other species from a Zone are grouped into three main categories based on their frequency of distribution. These are :

- (i) *Dominant Species*—which constitute 5% or above of the entire assemblage and which can help in distinguishing a Zone from another.
- (ii) *Subsidiary Species*—between 5-2% of the entire assemblage.
- (iii) *Accessory Species*—less than 2% of the entire assemblage.

This kind of quantitative analysis is one of the very useful parameter for the ecological study apart from its biostratigraphic implications.

The faunal elements in various biostratigraphic Zones and Sub-Zones except the lowermost unfossiliferous sandstone Zone are described in their group order. The criterion of listing the different genera and species in their respective Zones is their alphabetical order.

GLOBO TRUNCANA LINNEIANA CORONATA ZONE (CONIACIAN)

The foraminiferal fauna in general is represented in the Zone by 10% of planktons and little less than 10% of arenaceous forms; rest is calcareous benthos mostly of perforate type. In one sample the percentage of arenaceous forms is recorded as high as 35%. A total of 23 genera and 37 species are determined. The lower part of the Zone is characterized by the relative abundance of arenaceous forms like

Gaudryina, *Hyperammina*, *Spiroplectammina*, *Textularia* and *Tritaxia*. The upper part of the Zone differs from the lower in marked increase in the percentage occurrence of members of the family Anomalinidae. However, it may be observed that this variation in the relative abundance of faunal elements from the lower to upper parts of the Zone is almost gradual and no well defined sub-divisions of the Zone is possible.

INDEX SPECIES

Globotruncana linneiana coronata (Bolli),
Heterohelix moremani (Cushman).

DOMINANT SPECIES

Cibicides ammonoides (Reuss), *Hoeglundina supracretacea* (Ten Dam), *Lenticulina münsteri* (Roemer), *Saracenaria triangularis* (D'Orbigny), *Tritaxia tricarinata* (Reuss).

SUBSIDIARY SPECIES

Anomalina complanata Reuss, *Cibicides beaumontianus* (D'Orbigny), *Cibicides purobi* Banerji, *Cibicides subcarinatus* Cushman & Deaderick, *Gaudryina faujasi* (Reuss), *Globotruncana renzi* Gandolfi, *Gyroidina girardana* (Reuss), *Heterolepa pondi* Banerji, *Textularia ariyalurensis* Banerji.

ACCESSORY SPECIES

In all 21 species, and many *indet.* forms belonging to genera—*Anomalina*, *Astacolus*, *Bolivina*, *Cibicides*, *Clavulinoides*, *Dentalina*, *Gyroidina*, *Hyperammina*, *Lenticulina*, *Nodosaria*, *Quinqueloculina*, *Ramulina*, *Saracenaria*, *Siphogenerinoides*, *Spiroplectammina*, *Textularia*, *Tritaxia* and *Valvulineria* are recorded under this category. There are very few records of the occurrence of *Siphogenerinoides* in beds older than Campanian. Redmond (1955) has recored *S. bentonstonei* Redmond from the Coniacian of Colombia.

Few important identified species are : *Bolivina incrassata* Reuss, *Cibicides stephensoni* Cushman, *Dentalina megapolitana* Reuss, *Gyroidina*

depressa (Alth), *Gyroidina imitata* (Olsson), *Lagena acuticosta* Reuss, *Valvulineria plummerae* Loetterle, *Globotruncana* cf. *G. inornata* Bolli and *Ramulina* cf. *R. abscissa* Loeblich & Tappan.

The Foraminifera present in the lower part of this Zone are in general characteristically silicified, or tests composed of quartz grains cemented together with silica and are mostly ill-preserved. In the upper part, there is no indication of such preservation of forms; on the other hand a considerably well preserved fauna is recorded.

Calcareous planktons occur sparsely in the lower part of the Zone, indicating that the basin of deposition was physically connected to an open sea which contributed the marine faunal elements to this basin. However, the nature of the basin was not suitable for the prolific growth of the planktonic forms.

The upper part of the Zone, characterized by the abundance of Anomalinidae, indicates the deposition in shelf waters of shallow to moderate depths. According to Lowman (1949), an abundance of *Cibicides* and related forms is characteristic of mid-continental shelf (40-80 metres depth) of the Gulf of Mexico.

The arenaceous group is as a whole abundant in the lowermost part of the Zone, however, it must be remembered that this is a relative abundance in comparison with the other fauna, otherwise it also is rare in relation to the total volume of sediments and no way it can be considered as prolific fauna.

GLOBOTRUNCANA CONCAVATA ZONE (SANTONIAN)

The faunal elements comprise about 15-25% of planktonic types, percentage increasing from the lower to upper part of the Zone, and little more than 10% of arenaceous types. The family Nodosariidae increases in the percentage

of occurrence from about 10% at the bottom to as high as 25% at the top of the Zone, whereas a reduction from about 28% to 15% respectively is noticed in case of Rotaliidae. There is also a marked fluctuation of percentage distribution of Anomalinidae, but no regularity in distribution is noticed. This Zone is witnessed by the first appearance of many genera like *Dorothia*, *Fronicularia*, *Glandulina*, *Marginulina*, *Pleurostomella* and *Verneulina*.

INDEX SPECIES

Anomalina vridhachalensis Banerji, *Glandulina pygmaea* Reuss, *Globotruncana concavata* (Brotzen), *Planulina multipunctata* Bandy.

DOMINANT SPECIES

Cibicides purobi Banerji, *Cibicides subcarinatus* Cushman & Deaderick, *Globotruncana renzi* Gandolfi, *Globotruncana vridhachalensis* Banerji, *Gyroidina depressa* (Alth), *Heterolepa pondi* Banerji, *Hoeglundina supracretacea* (Ten Dam), *Lenticulina macrodiscus* (Reuss).

SUBSIDIARY SPECIES

Anomalina complanata Reuss, *Cibicides stephensoni* Cushman, *Dorothia oxycona* (Reuss), *Gaudryina quadrangularis* Bagg, *Gyroidina globosa* (Hagenow), *Lenticulina münsteri* (Roemer), *Marginulina trilobata* D'Orbigny, *Nodosaria affinis* Reuss, *Pleurostomella subnodosa* Reuss, *Tritaxia tricarinata* (Reuss).

ACCESSORY SPECIES

A total of 42 species of very low frequency of occurrence, belonging to most of the genera mentioned above, are recorded. Few diagnostic species identified under this category are: *Cibicides blanfordi* Banerji, *Globotruncana linneiana coronata* (Bolli), *Lagena acuticosta* Reuss, *Marginulina obliquinodus* (Bandy), *Saracenaria*

triangularis (D'Orbigny), *Textularia ariyalurensis* Banerji, *Textularia subconica* Franke, *Tritaxia jarvisi* Cushman, *Valvulinera* cf. *V. allomorphinoides* (Reuss), *Verneuilina cretosa* Cushman.

In general high degree of variations in morphological characters of the tests among the above listed species are noticed, such as in their diameter, thickness and their ratios, number of whorls, total number of chambers, number of the chambers in the last whorl, shape and size of the last chamber, wall characters, sutural modifications etc. The arenaceous species dominating in the lower part of the preceding Zone have been largely replaced by calcareous perforate types. In this Zone, the family Nodosariidae comprises of comparatively large number of species but each species is represented by smaller number of specimens. According to Norton (1930), these species are often common at depths of 10-20 metres, but persist to a greater depth usually in smaller numbers. The development of a rich planktonic assemblage indicates a normal marine environment and it may also point out that the marine transgression during the Santonian times was one of the most extensive Cretaceous transgression in this area. This transgression also witnessed in further south, around Ariyalur (about 54 kms. south of Vridhachalam). It may be worth mentioning here that the presence of Coniacian and Santonian strata in Vridhachalam and Santonian in adjoining areas of Pondicherry was reported for the first time by the author in 1964 (in Micropal., news reports, p. 507-8). The foraminiferal assemblage reported from these two horizons as listed above will have considerable stratigraphic value for further work in southern sedimentary regions of India.

GLOBOTRUNCANA GLOBIGERINODES ZONE (CAMPANIAN)

This Zone on the basis of two stratigraphically restricted species of *Globotruncana* and few others is subdivided into two sub-Zones. The variations in the percentage distribution and in intra-specific characters of few benthonic species also help in distinguishing these two sub-Zones from each other (Banerji, 1966 c). These sub-Zones are described in their ascending order.

1. *Globotruncana marginata* sub-Zone (Lower Campanian).

The planktonic elements in the fauna range in their occurrence from 20 to 35%. A slight increase from the preceding Zones is noticed in case of arenaceous forms. Calcareous forms comprise Nodosariidae 20-25%, Anomalinidae 10-15% and Rotaliidae 10-12%. This sub-Zone can be distinguished on the basis of sudden increase in the distribution percentage of the planktonic forms and decrease in case of the members of the family Rotaliidae.

INDEX SPECIES

Globotruncana marginata (Reuss)

DOMINANT SPECIES

Cibicides stephensoni Cushman, *Glandulina manifesta* Reuss, *Globotruncana globigerinoides* Brotzen, *Gyroidina depressa* (Alth), *Lenticulina pondi* (Cushman).

SUBSIDIARY SPECIES

Bolivina cretosa Cushman, *Cibicides blanfordi* Banerji, *Cibicides purobi* Banerji, *Cibicides subcarinatus* Cushman & Deaderick, *Frondicularia goldfussi* Reuss, *Gaudryina quadrans* Cushman, *Globotruncana vridhachalensis* Banerji,

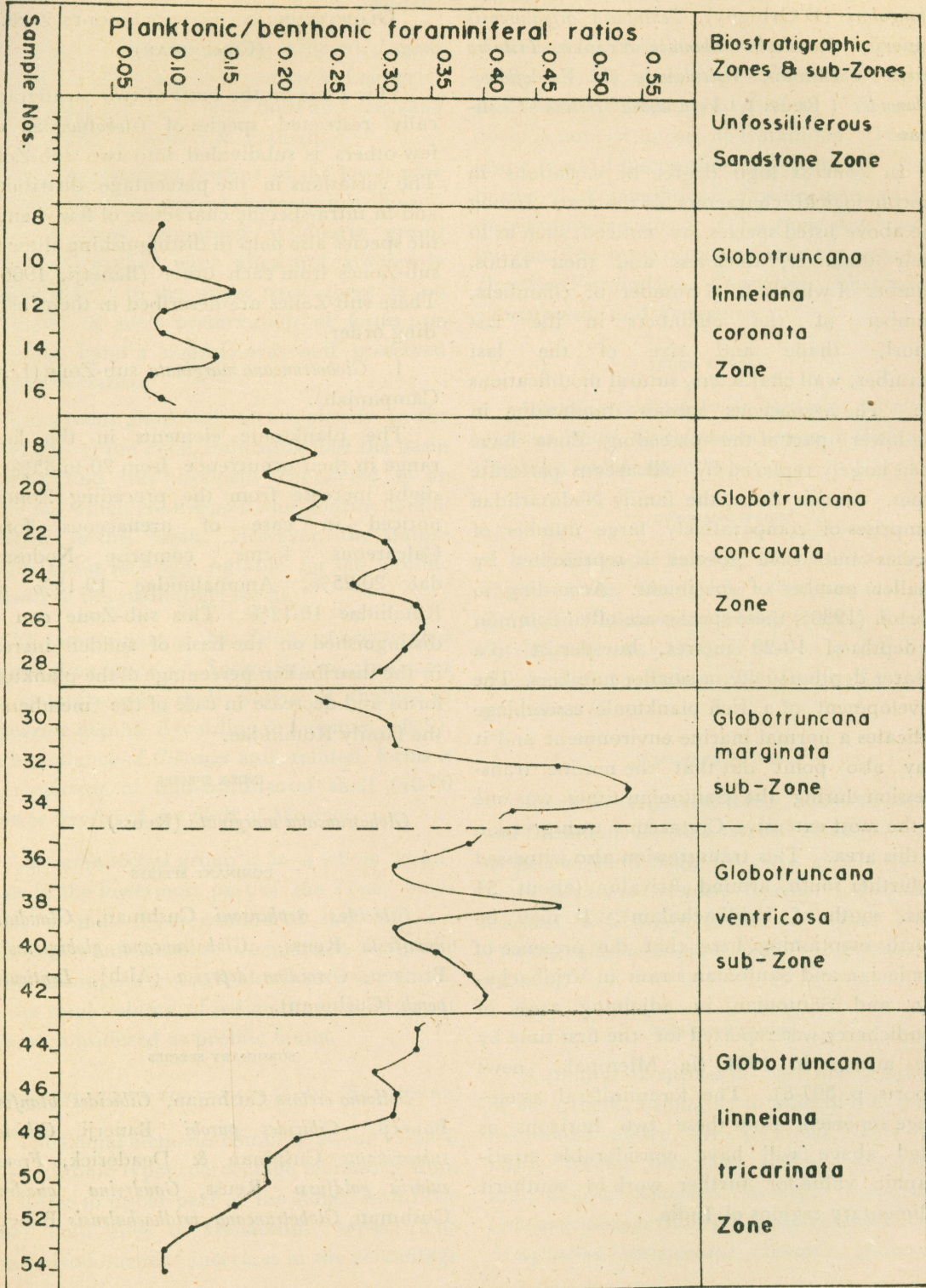


Figure 2

Heterohelix striata (Ehrenberg), *Hoeglundina supracretacea* (Ten Dam), *Lenticulina münsteri* (Roemer), *Marginulina cretacea* Cushman, *Nodosaria affinis* Reuss, *Pleurostomella subnodosa* Reuss, *Textularia ripleysensis* W. Berry.

ACCESSORY SPECIES

Almost all genera reported from Vridhachalam are represented in this sub-Zone by various species. *Anomalinoidea*, *Apiopterina*, *Guttulina*, *Loxostomum* and *Raphanulina* have not been observed from the preceding Zones. In all more than 40 species are recorded, out of which a few important are :

Anomalinoidea cf. *A. pinguis* (Jennings), *Apiopterina cylindroides* (Roemer), *Cibicides ammonoides* (Reuss), *Dentalina gracilis* D'Orbigny, *Gaudryina faujasi* (Reuss), *Guttulina adhaerens* (Olszewski), *Heterolepa pondi* Banerji, *Loxostomum clavatum* (Cushman), *Marginulina bullata* Reuss, *Saracenaria triangularis* (D'Orbigny), *Textularia ariyalurensis* Banerji, *Textularia subconica* (Franke), *Tritaxia* cf. *T. dubia* (Reuss).

2. *Globotruncana ventricosa* sub-Zone (Middle to Upper Campanian).

There is no appreciable change in the percentage distribution of most of the species except few as mentioned below as compared to the preceding sub-Zone. Almost all the families and genera present in *Globotruncana marginata* sub-Zone are also represented here.

INDEX SPECIES

Globotruncana ventricosa White, *Glandulina elongata* Banerji.

Remarks—*Globotruncana globigerinoides* Brotzen occurs here as a dominant species. *G. marginata* (Reuss) is also identified from a few samples of this sub-Zone as an accessory species. The base of this sub-Zone is taken

as the datum line of *Globotruncana ventricosa* White, i.e., its first appearance in the section.

Among other species, almost all of them have retained their respective categories of distribution as in the preceding sub-Zone. However, following distinctions can be made :

(i) the absence of *Globotruncana vridhachalensis* Banerji and *Cibicides ammonoides* (Reuss).

(ii) the presence of *Anomalina madraszi* Banerji as a dominant species. It is also recorded from the succeeding zone.

(iii) the marked increase in the percentage distribution of *Hoeglundina supracretacea* (Ten Dam) and reduction in case of *Cibicides stephensoni* Cushman.

(iv) Species like—*Dentalina catenula* Reuss, *Gyroldina subangulata* (Plummer), *Heterohelix carinata* (Cushman), and *Raphanulina exerta* (Berthelin) occurring in this sub-Zone as accessory species are not identified from the preceding sub-Zone.

(v) the variation in the intra-specific characters like diameter thickness and their ratios of the tests of some critical species from these two sub-Zones are discussed elsewhere (Banerji 1966 c).

The increase in percentage of planktonic Foraminifera indicates a progressive deepening of the basin and perhaps it reached to a maximum depth during the Lower Campanian times when the planktonic/benthonic ratio was highest (see fig. 2). Considering the entire assemblage, the deepest benthic environment appears to be of central zone type. The increase in percentage of planktons was not marked with further corresponding increase in speciation, on the other hand a number of them observed in the preceding Zones are not present in this sub-Zone. This may imply that the basin in the later stage was no longer

an open sea which would have brought in many other planktons of Upper Campanian times. The increase in percentage distribution of the members of the family Nodosariidae during this period may indicate their favour for the deeper basin.

GLOBOTRUNCANA LINNEIANA TRICARINATA ZONE

(Upper Campanian to Lower Maestrichtian)

This is the uppermost biostratigraphic unit in this sequence at Vridhachalam; its uppermost time limit is assigned to the Lower Maestrichtian. No characteristic Middle—Upper Maestrichtian species is observed here.

The percentage distribution of the faunal elements vary largely in lower and upper parts of this Zone as expressed below (figures average) :

	Lower part	Upper part
Planktonic forms	25	10 per cent
Arenaceous forms	20	10 " "
Family Nodosariidae	30	10 " "
Family Anomalinidae	15	35 " "
and others	10	35 " "

Among other includes many rotalids, biserial and triserial calcareous forms and miliolids; the latter increases appreciably in the upper part of this Zone.

This Zone is not further subdivided into sub-Zones as there is no such contrast with the index species between lower and upper parts. The total foraminiferal frequency per sample is considerably reduced in the upper part.

INDEX SPECIES

The most important feature is that as many as seven diagnostic species are found to be restricted to this Zone.

Anomalina henbesti Plummer, *Anomalina sub-madraszi* Banerji, *Cibicides harperi* (Sandidge), *Globotruncana linneiana tricarinata* (Quereau), *Globotruncana rugosa* (Marie), *Lenticulina spissocostata* (Cushman), *Marginulina navarroana* Cushman.

DOMINANT SPECIES

Anomalinoides pinguis Jennings, *Cibicides beaumontianus* (D'Orbigny), *Cibicides purobi* Banerji, *Gyroïdina depressa* (Alth), *Heterohelix globulosa* (Ehrenberg), *Heterohelix striata* (Ehrenberg), *Heterolepa pondi* Banerji, *Hoeglundina supracretacea* (Ten Dam), *Lenticulina navarroensis* (Plummer), ?*Pseudotextularia* cf. *P. elegans* (Rzehak), *Quinqueloculina antiqua* Franke.

SUBSIDIARY SPECIES

Anomalina madraszi Banerji, *Cibicides blanfordi* Banerji, *Cibicides stephensoni* Cushman, *Cibicides subcarinatus* Cushman & Deaderick, *Guttulina adhaerens* (Olszewski), *Planulina spissocostata* Cushman, *Raphanulina lacrima* (Reuss), *Rugoglobigerina* cf. *R. rugosa* (Plummer).

ACCESSORY SPECIES

In all about 40 species of the smaller Foraminifera are recorded. There are many unidentifiable species and they appear to be planktonic in nature. This Zone is characterized by the absence of genera like—*Saracenaria*, *Spiroplectammina*, *Valvulineria* and *Verneuilina* and the first appearance of ?*Pseudotextularia* and *Rugoglobigerina*. The lower part of the Zone is dominated by planktons whereas the upper part is represented by large number of miliolids like *Quinqueloculina Massilina* and *Triloculina* (rare). Miliolids are considered to be characteristic of intertidal zone and the inner part of the continental shelf of the

modern sea (Bandy, 1960). This may indicate that the basin of deposition, which was fairly deep in the beginning of this Zone, had become progressively shallow; this is further evidenced by the paucity of the faunal growth in the upper part of this Zone. Clusters of large shells of pelecypods observed in the samples from the upper part of the Zone may further elaborate this view.

CONCLUSIONS

The more significant observations made during this investigation are as follows.

1. The report of a hitherto mostly undescribed smaller foraminiferal fauna from the Lower Ariyalur Stage (Upper Cretaceous) of Vridhachalam.

2. The listing of more important and diagnostic foraminiferal species with the determination of their vertical range and relative abundance within this sequence of strata.

3. An exact determination of the sequence of faunules in the two stratigraphic sections studied thereby providing further evidences for the more precise correlations with other stratigraphic sections.

4. The discovery of several new and good fossil indices (grouped as "Index Species" in this report) for the biostratigraphic work.

5. The relative abundance of different types of fauna as planktons, calcareous perforate/imperforate benthos, arenaceous, etc. and their relationship with the ecological pattern of the depositional basin.

6. The calcareous perforate benthonic foraminifera are more than 12 times as abundant as other categories of Foraminifera in this succession.

7. The faunal elements are mostly of cosmopolitan in nature and are very similar to other Indo-Pacific regions. The events of such development of fauna were approximately synchronous throughout the tropical belt.

FAUNAL REFERENCE LIST

The original references of the species listed in this report are arranged alphabetically below. Trinomials represent genera, species and sub-species.

- Anomalina complanata* Reuss, 1851, Natur. Abh. Vienna, Bd. 4, Abth. 1, p. 36, pl. 4, fig. 36.
- Anomalina henbesti* Plummer, 1936, Texas Univ. Bull., 3501, p. 290, pl. 5, figs. 7-10.
- Anomalina madraszi* Banerji, 1967, Cushman Found. Foram. Res., Contr., vol. 18, pt. 4, pl. 15, figs. 3, 4, 5.
- Anomalina submadraszi* Banerji, 1967, *ibid.*, pl. 15, figs. 6, 7, 8.
- Anomalina vridhachalensis* Banerji, 1967, *ibid.*, pl. 15, figs. 9, 10, 15.
- Anomalinoides pinguis* (Jennings), *Anomalina pinguis* Jennings, 1936, Am. Paleontology, Bull., vol. 23, no. 78, p. 37, pl. 5, fig. 1.
- Apiopterina cylindroides* (Roemer) Banerji, *Polymorphina cylindroides* Roemer, 1838, Neuss Jahrb. p. 385, pl. 3, fig. 26.
- Bolivina cretosa* Cushman, 1936, Cushman Lab. Foram. Res., Spec. Publ., 6, p. 49, pl. 7, fig. 10.
- Bolivina incrassata* Reuss, 1851, Haidinger's Natur. wiss. Abh., vol. 4, p. 29, pl. 4 fig. 13.
- Cibicides ammonoides* (Reuss) Trujillo, = *Rosalina ammonoides* Reuss 1844, Geog. Skizzen Bohm., vol. 2, p. 214.
- Cibicides beaumontianus* (D'Orbigny) Brotzen, = *Truncatulina beaumontiana* D'Orbigny, 1840, Soc. Geol. France, Mem. 1st. ser., vol. 4, p. 35, pl. 3, figs. 17-19.

- Cibicides blanfordi* Banerji, 1967, Cushman Found. Foram. Res., Contr., vol. 18, pt. 4, pl. 15, figs. 11, 12, 13.
- Cibicides harperi* (Sandidge) Cushman, = *Anomalina harperi* Sandidge, 1932, Am. Mid. Natur., vol. 13, p. 316, pl. 29, figs. 1, 2.
- Cibicides purobi* Banerji, 1967, Cushman Found. Foram. Res., Contr., vol. 18, pt. 4, pl. 15, figs. 16, 17, 18.
- Cibicides stephensoni* Cushman, 1938, Cushman Lab. Foram. Res. Contr., vol. 14, p. 70, pl. 12, fig. 5.
- Cibicides subcarinatus* Cushman & Deaderick 1944, Jour. Paleontology, vol. 18, p. 341.
- Dentalina catenula* Reuss, 1860, Akad. Wiss. Wien, Math.-natur., sitz., vol. 40, p. 185, pl. 3, fig. 6.
- Dentalina gracilis* D'Orbigny, 1840, Soc. Geol. France, Mem. Ist. ser., vol. 4, p. 14, pl. 1, fig. 5.
- Dentalina megapolitana* Reuss, 1855, Deutsche geol. Gessell. Zeit., vol. 7, p. 267, pl. 8, fig. 10.
- Dorothia oxycona* (Reuss) Trujillo, = *Gaudryina oxycona* Reuss, 1860, Akad. Wiss. Wien, Math.-natur., sitz. vol. 40, p. 229, pl. 12, fig. 3.
- Frondicularia goldfussi* Reuss, 1860, Akad. Wiss. Wien, Math.-natur., sitz.; vol. 40, p. 192, pl. 4, fig. 7.
- Gaudryina fajasi* (Reuss) Cushman, = *Textularia fajasi* Reuss, 1861, Akad. Wiss. Wien. Math.-natur., sitz., vol. 40, p. 320, pl. 3, figs. 9a-b.
- Gaudryina quadrangularis* Bagg, 1908, Proc., U.S. Nat. Mus., vol. 34, p. 133, pl. 5, fig. 1.
- Glandulina manifesta* Reuss 1851, Natur. Abh. (Wien), Bd. 4, Abt. 1, p. 6, pl. 1, fig. 4.
- Glandulina elongata* (Banerji) Banerji, = *Glandulina marginuliniiformis* (Frizzell) var. *elongata* Banerji, 1965, Cushman Found. Foram. Res. Contr., vol. 16 pt. 4, p. 142 pl. 23, figs. 8, 9.
- Glandulina pygmaea* Reuss, 1851, Natur. Abh. Wien. Bd. 4, Abt. 1, p. 6, pl. 1, fig. 3.
- Globotruncana concavata* (Brotzen) Bolli, = *Rotalia concavata* Brotzen, 1934, Zeit. Deutsch Ver. Palaest., vol. 57, p. 66, pl. 3, fig. b.
- Globotruncana globigerinoides* Brotzen, 1936, Svey. geol. undersok., ser. C., no. 396, p. 177, pl. 12, figs. 3a-c; pl. 13, fig. 3.
- Globotruncana inornata* Bolli, 1957, U.S. Nat. Mus. Bull. 215, p. 57, pl. 13, figs. 5, 6.
- Globotruncana linneiana coronata* Bolli, 1944, Eclogae Geol. Helv., vol. 37, no. 2, p. 223, pl. 9, figs. 14, 15, text-fig. 1, nos. 21, 22, (*G. lapparenti coronata* Bolli).
- Globotruncana linneiana tricarinata* (Quereau) Graham & Clark, = *Pulvinulina tricarinata* Quereau, 1893, Beitr. Geol. Karte Sch., no. 33, p. 89, pl. 5, figs. 3a-d.
- Globotruncana marginata* (Reuss) Thalmann, = *Rosalina marginata* Reuss, 1845, Verstein böhm. Kreide, pt. 1, p. 36, pl. 8, figs. 54-75, pl. 13, fig. 68.
- Globotruncana renzi* Gandolfi, 1942, Riv. Ital. Pal., vol. 48, sup. Mem. 4, p. 124, pl. 3, fig. 1; pl. 4, figs. 15, 16, 28, 29; pl. 10, fig. 2.
- Globotruncana rugosa* (Marie) Hagn, = *Rosalina rugosa* Marie 1941, Mem., Mus. Hist. Nat. Paris, no. 5, p. 241, pl. 35, fig. 340.
- Globotruncana ventricosa* White, = *Globotruncana canaliculata* var. *ventricosa* White, 1928, Jour. Paleontology, vol. 2, p. 284, pl. 38, figs. 5a-c.

- Globotruncana vridhachalensis* Banerji, 1966, Jour. Geol. Soc. India, vol. 7, p. 67, pl. 5, figs. 1, 2, 5.
- Guttulina adhaerens* (Olszewski) Cushman & Ozawa, = *Polymorphina adhaerens* Olszewski, 1875, Spraw. Kom. Fizyj. Akad. Umiej., Krakwie, vol. 9, p. 119, pl. 1, fig. 11.
- Gyroidina depressa* (Alth) Cushman, = *Rotalina depressa* Alth, 1850, Haidinger's Naturwiss. Abh., vol. 3, p. 266, pl. 13, figs. 21a-c.
- Gyroidina girardana* (Reuss) Cushman, = *Rotalina girardana* Reuss, 1851, Deutsch geol. Gesell. Zeit., vol. 3, p. 73, pl. 5, fig. 34.
- Gyroidina globosa* (Hagenow) Cushman, = *Nonionina globosa* Hagenow, 1842, Neuss Jahrb, p. 574.
- Gyroidina imitata* (Olsson) Banerji, = *Gyroidinoides imitata* Olsson, 1960, Jour. Paleontology, vol. 34, p. 36, pl. 6, figs. 2-4.
- Gyroidina subangulata* (Plummer) Le Roy, = *Rotalia soldanii* var. *subangulata* Plummer, 1926, Texas Univ. Bull. 2644, p. 154, pl. 12, figs. la-c.
- Heterohelix carinata* (Cushman) Gallitelli, = *Guembelina carinata* Cushman, 1938, Cushman Lab. Foram. Res. Contr., vol. 14, p. 18, pl. 3, fig. 10.
- Hetrohelix globulosa* (Ehrenberg) Gallitelli, = *Textilaria globulosa* Ehrenberg, 1838, K. Preuss. Akad. Wiss, Abh., p. 135, pl. 4, fig. 4.
- Heterohelix moremani* (Cushman) Gallitelli, = *Guembelina moremani* Cushman, 1938, Cushman Lab. Foram. Res., Contr., vol. 14, p. 10, pl. 2, figs. 1-3.
- Heterohelix striata* (Ehrenberg) Gallitelli, = *Textilaria striata* Ehrenberg, 1838, K. Preuss. Akad. Wiss. Abh. p. 135, pl. 4, figs. 1, 2, 3.
- Heterolepa pondi* Banerji, 1967, Cushman Found. Foram. Res., Contr., vol. 18, pt. 4, pl. 15, figs. 14, 19, 20.
- Hoeglundina supracretacea* (Ten Dam) Bandy, = *Epistomina supracretacea* Ten Dam, 1948, Rev. de Inst. France, vol. III, no. 6, p. 163, pl. 1, fig. 8.
- Lagena acuticosta* Reuss, 1862, Akad. Wiss. Wien. Math. natur. sitz., vol. 44, p. 185, pl. 1, fig. 4.
- Lenticulina macrodiscus* (Reuss) White, = *Cristellaria macrodisca* Reuss, 1862, *ibid.*, p. 78, pl. 9, figs. 5a-b.
- Lenticulina muensteri* (Roemer) Banerji, = *Robulina muensteri* Roemer 1899, Verst. Nord. Oolithen, Nach., p. 48, pl. 22, fig. 29.
- Lenticulina navarroensis* (Plummer) Banerji, = *Cristellaria navarroensis* Plummer, 1927, Texas Univ. Bull. 2644, p. 39.
- Lenticulina pondi* (Cushman) Banerji, = *Robulus pondi* Cushman, 1931, Tennessee Div. Geol. Bull. 41, p. 25, pl. 2, fig. 9.
- Lenticulina spisso-costatus* (Cushman) Banerji, = *Robulus spisso-costatus* Cushman, 1938, Cushman Lab. Foram. Res., Contr., vol. 14, p. 32, pl. 5, fig. 2.
- Loxostomum clavatum* (Cushman) Cushman, = *Bolivina clavata* Cushman, 1927, *ibid.*, vol. 2, pt. 4, p. 87, pl. 12, figs. 5a-b.
- Marginulina bullata* Reuss, 1845, Verst. böhm. Kreide form. pt. 1, p. 29, pl. 13, figs. 34-38.
- Marginulina cretacea* Cushman, 1937, Cushman Lab. Foram. Res., Contr., vol. 13, p. 94, pl. 13, figs. 12-15.
- Marginulina navarroana* Cushman, 1937, *ibid.*, vol. 13, p. 98, pl. 14, figs. 17, 18.
- Marginulina obliquinodus* (Bandy) Trujillo, = *Marginulina similis* var. *obliquinodus* Bandy, 1951, Jour. Paleontology, vol. 25, p. 498, pl. 73, fig. 2.

- Marginulina trilobata* d'Orbigny, 1840, Soc. geol. France, Mem., 1st ser., vol. 4, p. 16, pl. 1, figs. 16, 17.
- Nodosaria affinis* Reuss, 1845, Verst. böhm. Kreide, pt. 1, p. 26, pl. 13, fig. 16.
- Planulina multipunctata* Bandy, 1951, Jour. Paleontology, vol. 25, p. 506, pl. 74, figs. 9a-c.
- Planulina spissocostata* Cushman, 1938, Cushman Lab. Foram. Res., Contr., vol. 14, p. 69, pl. 12, figs. 4a-c.
- Pleurostomella subnodosa* Reuss, 1860, Akad. Wiss. Wien., Math.-natur., sitz., vol. 40, p. 204, pl. 8, fig. 2.
- Pseudotextularia elegans* (Rzehak) Frizzell, = *Cuneolina elegans* Rzehak, 1891, Natur. Hofmus. Wien. Ann., vol. 6, no. 1, pp. 2-4.
- Quinqueloculina antiqua* Franke var. *angusta* Franke, 1928, Preuss. geol. Landes., Abh., n. ser., vol. III, p. 127, pl. 11, fig. 25.
- Ramulina abscissa* Loeblich & Tappan, 1946, Jour. Paleontology, vol. 20, p. 254, pl. 37, figs. 7, 8.
- Raphanulina exerta* (Berthelin) Banerji, = *Poly-morphina exerta*, 1886, Soc. geol. France, Mem., 3rd ser., vol. 1, p. 51, pl. 4, figs. 22a-23b.
- Raphanulina lacrima* (Reuss) Zborzewski, = *Globulina lacrima* Reuss, 1851, Natur. Abh. Wien. Bd. 4, p. 27, pl. 4, fig. 9.
- Rugoglobigerina rugosa* (Plummer) Bronnemann, = *Globigerina rugosa* Plummer, 1927, Texas Univ. Bull., no. 2644, p. 38, pl. 2, figs. 10a-d.
- Saracenaria triangularis* (d'Orbigny) Cushman, = *Cristellaria triangularis* d'Orbigny, 1840, Soc. géol. France, Mém. 1st ser., vol. 4, p. 27, pl. 2, figs. 21, 22.
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- Tritaxia jarvisi* Cushman, 1936, Cushman Lab. Foram. Res., Spec. Publ. 6, p. 4.
- Tritaxia tricarinata* (Reuss) Reuss, = *Textularia tricarinata* Reuss, 1844, Verst. böhm. Kreide, pt. 1, p. 39, pt. 8, fig. 60.
- Valvulineria allomorphinoides* (Reuss) Cushman, = *Valvulina allomorphinoides* Reuss, 1860, Akad. Wiss. Wien. Math.-natur., Sitz., vol. 40, p. 223, pl. 11, figs. 6a-c.
- Valvulineria plummerae* Loetterle, 1937, Nebraska Geol. Surv. Bull., 2nd Ser., vol. 12, p. 41, pl. 6, figs. 5, 6.
- Verneuulina cretosa* Cushman, 1933, Cushman Lab. Foram. Res., Contr., vol. 9, p. 31, pl. 5, figs. 7a, b.

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