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QUANTITATIVE STUDY ON THE ASSEMBLAGES OF CRETACEOUS PLANKTONIC FORAMINIFERAL GENUS *ROTALIPORA*

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ABSTRACT

Analysis of subsurface Cretaceous sediments of South India shows the presence of following six species of *Rotalipora* Brotzen: *R. balernaensis* Gandolfi, *R. appenninica* (O. Renz), *R. cushmani* (Morrow), *R. evoluta* Sigal, *R. greenhornensis* (Morrow) and *R. reicheli* (Mornod). A quantitative study carried out on the 310 specimens of *Rotalipora* indicates that the six species seem to have evolved along two lineages and certain extreme variants appear to be transitional forms between two species evolving in a single lineage. Progressive increase in the spiroconvexity and widening of the umbilicus are characteristic of *R. balernaensis-appenninica cushmani* lineage, whereas, progressive decrease in spiroconvexity and widening of the umbilicus are diagnostic of *R. balernaensis-evoluta-greenhornensis-reicheli* lineage. Rapid evolutionary changes within these six species help to recognise the presence of five *Rotalipora* zones. They are: *R. balernaensis* zone (Late Albian), *R. evoluta* zone (Early Cenomanian), *R. greenhornensis* zone (Early-Middle Cenomanian), *R. reicheli* zone (Middle-Late Cenomanian) and *R. cushmani* zone (Late Cenomanian).

INTRODUCTION

The value of the Cretaceous planktonic foraminiferal genus *Rotalipora* is well known as a tool for worldwide correlation of Cenomanian strata. Studies related to the biostratigraphic succession of different species of *Rotalipora* include those of Gandolfi (1955) Bolli (1957, 1959), Marks (1967), Douglas (1969), Eicher (1969), Moorkens (1969), Porthault (1969) Raju (1970), Petters (1976) and Narayanan (1977). Other important papers concerning the *Rotalipora* faunas include the comprehensive taxonomic study by Loeblich and Tappan (1961), form analysis by Pessagno (1967) and phylogenetic analysis by Bandy (1967).

Although different species of *Rotalipora* have been reported from India by Gowda (1964), Raju (1970) Banerji and Radha (1970) and Narayanan (1977) little is known about their intraspecific variation. The present study is therefore an attempt to record the biometric variation of each of the species of *Rotalipora* recovered from continuously cored shallow wells of Cauvery Basin, South India. These wells have yielded a very rich assemblage of both planktonic as well as benthonic foraminifera. Such a good faunal control has also enabled the authors to trace the evolutionary lineage of *Rotalipora* and on that basis, to establish a detailed biozonation for the stratigraphic interval ranging from Late Albian to the top of Cenomanian.

MATERIAL AND TAXONOMIC CONSIDERATIONS

The present study is based on continuous core samples obtained from two shallow wells. The locations of these and other wells together with the geology of the area are shown in figure 1. Of the five wells drilled between Karai and Kulakalnatham villages, only Karai-4 and Karai-6 wells encountered *Rotalipora* assemblages belonging to Late Albian and Cenomanian. Samples from these two wells at regular intervals of three metres were processed and all *Rotalipora* specimens from each sample were picked and mounted systematically. Associated planktic and benthic species from each sample were also sorted out separately. Altogether 310 specimens of *Rotalipora* were recovered.

The *Rotalipora* specimens recovered were assignable to six species. The criteria used to recognise the six species, *Rotalipora balernaensis* Gandolfi, *R. appenninica* (O. Renz), *R. cushmani* (Morrow), *R. evoluta* Sigal, *R. greenhornensis* (Morrow) and *R. reicheli* (Mornod) were essentially based on the earlier taxonomic works of Loeblich and Tappan (1961) and Pessagno (1967). Because of wide range of intra-specific variability of these different taxa, certain extreme variants like those of *R. evoluta* have often been confused with *R. appenninica* and *R. greenhornensis* (Loeblich & Tappan, 1961 ; Pessagno 1967). Similarly some extreme variants of *R. cushmani* are sometimes reported as *R. evoluta* (Bandy, 1967) or as *R. cushmani* var. *seevoluta* (Dalbiez, 1955). In a continuously evolving lineage, the

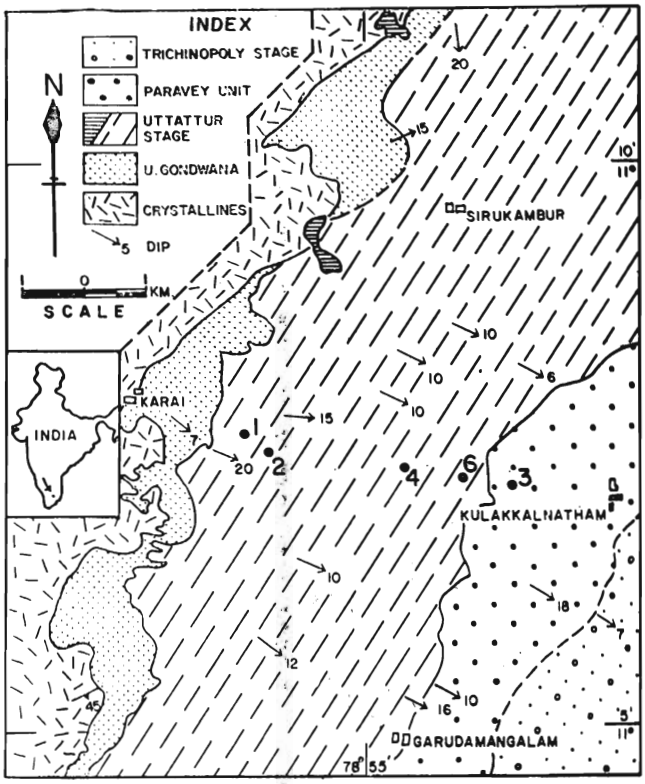

Fig. 1. Geological map of area around Karai showing locations of shallow wells, Karai-1, 2, 3, 4 and 6.

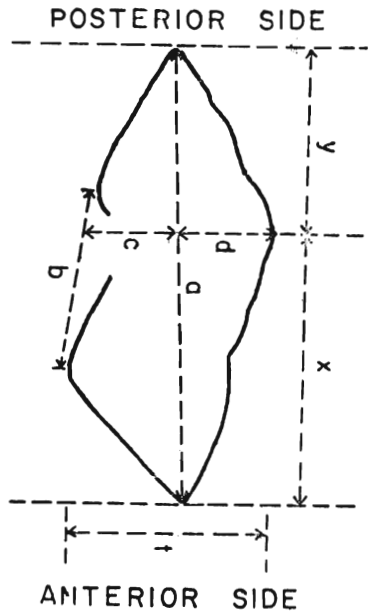

Fig. 2. Axial view of a *Rotalipora* specimen showing the disposition of various parameters.

intermediate forms between two species may often pose this type of taxonomic problem. It becomes therefore necessary to distinguish the typical forms of different taxa from the intermediate ones. An attempt is also made in the present study to define the optimum range of variability of the six species by quantifying certain morphological characteristics. The aim is to show that the extreme variants which do not fall within such ranges may have to be considered as intermediate forms. For this prupose eight biometric parameters were taken into account. The measurements were made in the axial view of the specimens as shown in figure 2, drawn with the help of camera lucida. This method enables quick recording of many specimens and also allows a close comparison of specimens from other areas figured or drawn in their axial view. The parameters taken into consideration are as follows :

1. Maximum diameter of the test....(a)
2. Distance across the umbilicus, measured along the line connecting the acute projections of the chambers as shown in figure 2....(*b*)
3. Umbilical thickness of the test as shown in figure 2....(*c*)
4. Spiral thickness of the test as shown in figure 2.... (*d*)
5. Total thickness of the test....(t)
6. Distance from the centre to the anterior margin of the test.....(x)
7. Distance from the centre to the posterior margin of the test....(y)
8. Number of chambers in the final whorl....(z)

All the *Rotalipora* specimens at the first evolutionary appearance level of each species and also at two intermittent levels in which the assemblage was rich and well preserved were taken into account for the biometric analysis. In total 310 specimens were analysed for counts and measurements and their distributions are shown in Table 1.

EVOLUTION AND PHYLOGENY

Many workers including Bandy (1967) and Cita (1963) suggested that *Ticinella* forms the link in the evolutionary lineage between *Hedbergella* and *Rotalipora*. However, Pessagno (1967) believed that *Rotalipora* might have evolved either from *Ticinella* stock by compression of test and addition of peripheral keel as noted by earlier workers or from *Praeglobotruncana* stock by acquisition of secondary sutural apertures on the umbilical side.

Ticinella which is generally regarded as the link between *Hedbergella* and *Rotalipora* has not been reported so far from Cauvery Basin, India. The earliest species of *Praeglobotruncana* known from Cauvery Basin

Table 1

STAGES	CORE POSITION AND DEPTH		STRATIGRAPHIC LEVEL OF SAMPLING	TOTAL NUMBER OF SPECIMENS	FREQUENCY OF ROTALIPORA SPECIES					
	KARAI-4 WELL	KARAI-6 WELL			*R. balernaensis*	*R. evoluta*	*R. appenninica*	*R. greenhornensis*	*R. reicheli*	*R. cushmani*
CENOMANIAN		Core-22 69-72 m	First Appearance Level of *R. cushmani*	92	..	..	..	19	63	10
	Core-8 23-26m	Core-27 84-87m	First Appearance Level of *R. reicheli*	32	..	3	1	18	10	..
	Core-12 35-38m		Intermittent Sample	69	..	33	14	22	.	..
	Core-18 53-56m		First Appearance Level of *R. greenhornensis*	45	..	22	13	10	..	..
	Core-28 83-86m		First Appearance Level of *R. appenninica*	21	11	6	4	..	..	..
ALBIANI	Core-39 116-119m		First Appearance Level of *R. evoluta*	30	18	12	..	..	..	..
	Core-40 119-121m		Intermittent Sample	21	21			..	.	.
			TOTAL	310	50	76	32	69	73	10

is *P. delrioensis* Carsey (Raju, 1970 ; Narayanan, 1977 ; Ramanathan and Rao, 1982). Ramanathan and Rao (1982) reported widely varying individuals within the assemblage of *P. delrioensis* from upper part of *Hedbergella planispira* zone (?Aptian to Middle Albian) of Cauvery Basin. According to them, this species includes a range of variations from forms with globular chambers having a weak peripheral keel to specimens with a relatively compressed test possessing a sharp angled periphery. In the present study, *Rotalipora balernaensis* Gondolfi, the earliest species of the genus is believed to have descended directly from the compressed and sharply angled variants of *P. delrioensis* Carsey during Late Albian.

The beginning of Cenomanian has often been recognised by many workers based on the first evolutionary appearance of *R. evoluta*. Typical specimens of *R. evoluta* were recovered from core 39 (116-119m) of Karai-4 well. Of the thirty specimens recorded from this interval, eighteen belong to *R. balernaensis* and twelve to *R. evoluta* including their respective extreme variants. Figure 3 shows the relationship between a/b and c/d, x and y, and a and t of the individuals of *Rotalipora* from core 40 and core 39 of Karai-4 well. From this figure, it may be noted that none of the above morphological characteristics is helpful in distinguishing *R. evoluta* from *R. balernaensis*, and as such these species seem to be closely related to one another. *R. evoluta* appears to have derived from *R. balernaensis* by the development of umbilical shoulders, highly arched and semicircular primary aperture and almost straight sutures on the umbilical side.

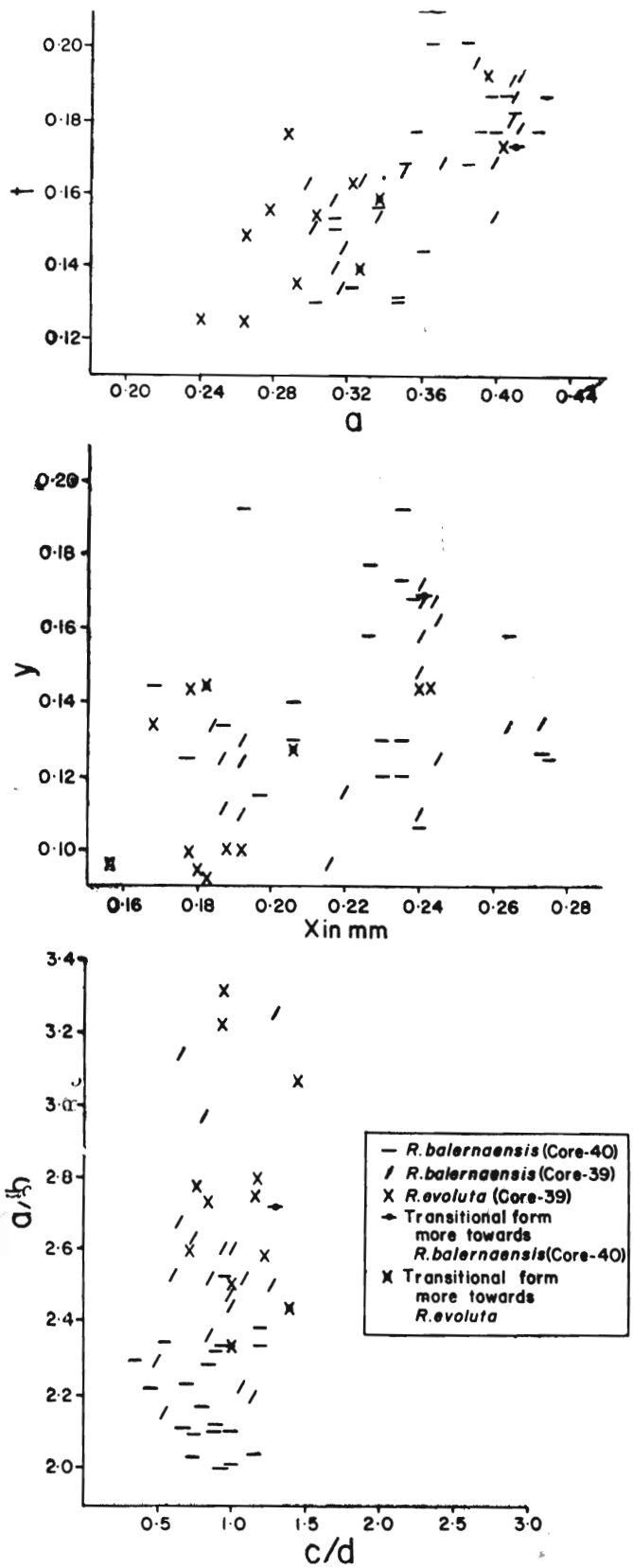

Fig. 3. Relationship between a/b and c/d, x and y, and a and t of *Rotalipora* specimens from cores 40 and 39 of Karai-4 well.

The first appearance of *R. appenninica* is further higher up in the section in core 28 (83-86 m) of Karai-4 well. Of the twenty one specimens from this sample eleven are assignable to *R. balernaensis*, six to *R. evoluta* and four to *R. appenninica*. The relationship between a/b and c/d, x and y and a and t of these specimens is shown in figure. 4. In this figure also it may be observed that all the specimens are nearly grouped into a single cluster. It is possible that *R. appenninica* might have evolved either from *R. evoluta* or directly from *R. balernaensis* stock. The latter seems to be more acceptable for the following reasons : (i) *R. appenninica* has a low arched aperture and curved sutures on umbilical side as in *R. balernaensis* and lacks distinct umbilical shoulders unlike in *R. evoluta*, (ii) *R. appenninica* is restricted to the field with c/d values less than 1, showing its distinct trend of evolution towards spiroconvexity, whereas *R. evoluta* continues to include both spiroconvex and umbilico-convex individuals as in *R. balernaensis* and (iii) the development of somewhat thicker test with prominent secondary sutural apertures can give rise to *R. appenninica* from *R. balernaensis*. Furthermore close morphological affinities between these two species often led many workers to describe *R. balernaensis* as a subspecies of *R. appenninica* (Gandolfi, 1957 ; Bandy, 1967).

Specimens of *R. greenhornensis*, *R. reicheli* and *R. cushmani* have their first appearance at successive higher stratigraphic levels at 56 m in Karai-4, 26m in Karai-4 and 72 m in karai-6 wells respectively. The relationships between a/b and c/d, x and y and a and t of these specimens are shown in figures 5, 6 and 7. It may be noted from the above figures that specimens of *R. greenhornensis*, *R. reicheli* and *R. cushmani* form separate clusters particularly in a/b to c/d graph, whereas, those of *R. appenninica* and *R. evoluta* continue to fall in a single cluster. This clearly indicates that the early species of *Rotalipora* show a certain amount of overlap in the morphological characteristics taken into consideration in the present study, whereas, the later species seem to exhibit some distinctions. The important morphological characters responsible for such differences appear to be the progressive change in the convexity of the test and widening of the umbilicus. The values of c/d recorded for the different assemblages from samples at successive stratigraphic levels are shown in figure 8. This figure shows that there are possibly two lineages along which the species of *Rotalipora* might have evolved during Cenomanian. The other important features of these two lineages are summarised in Table 2 and the possible phylogeny and stratigraphic ranges of *Rotalipora* species are shown in figure 9.

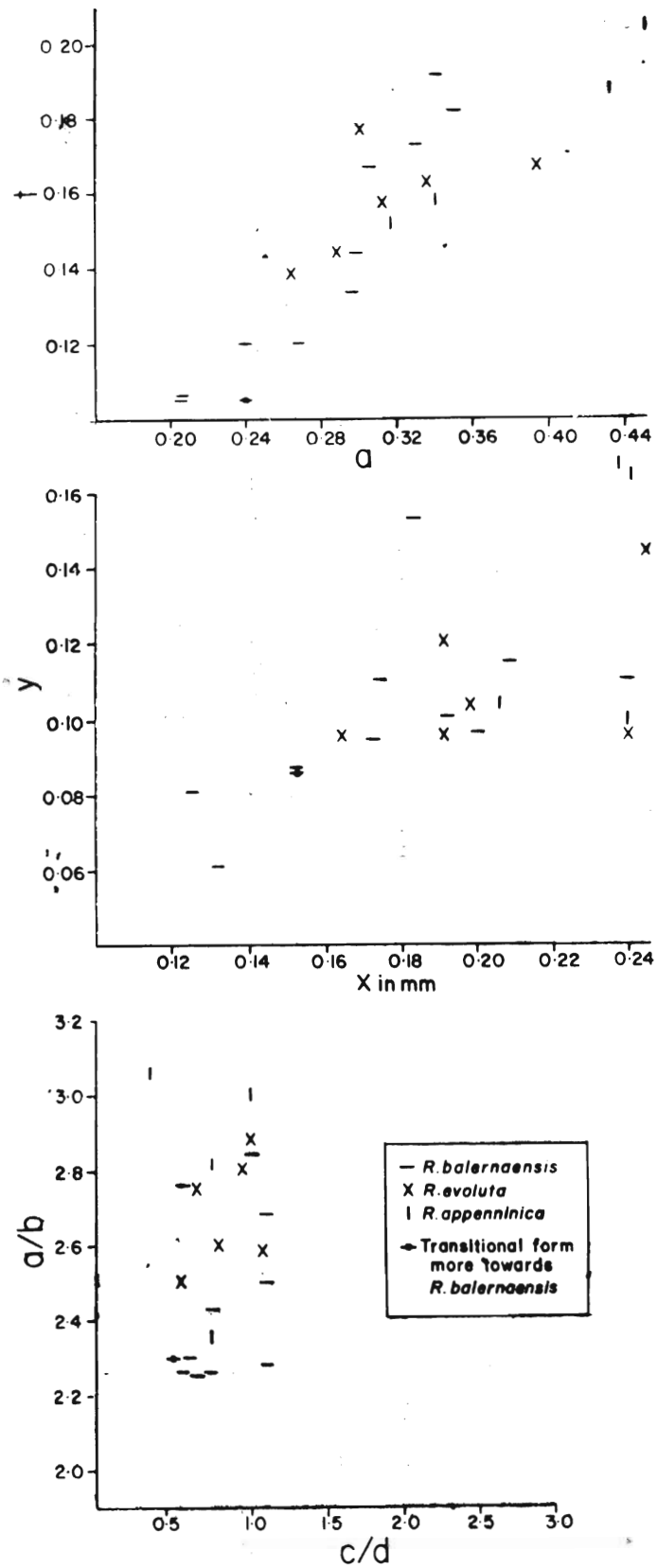

Fig. 4. Relationship between a/b and c/d, x and y, and a and t of *Rotalipora* specimens from core 28 of Karai-4 well.

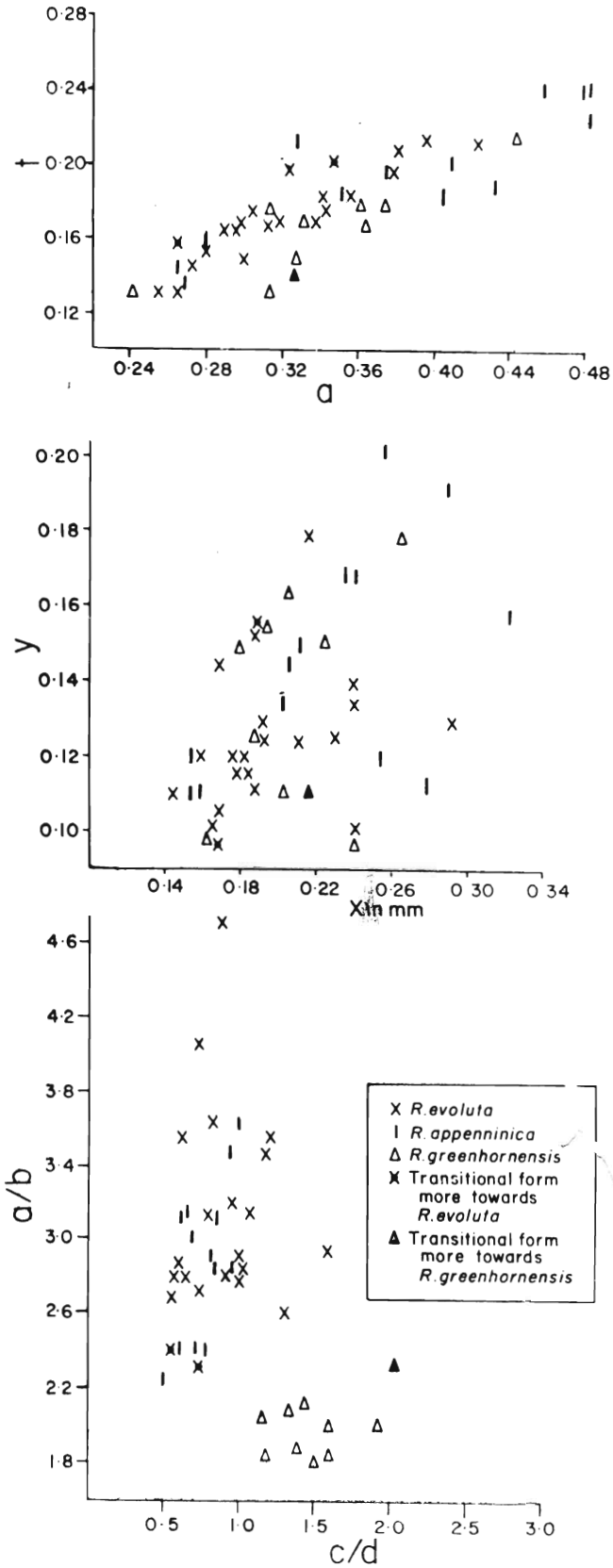

Fig. 5. Relationship between a/b and c/d, x and y, and a and t of *Rotalipora* specimens from core 18 of Karai-4 well

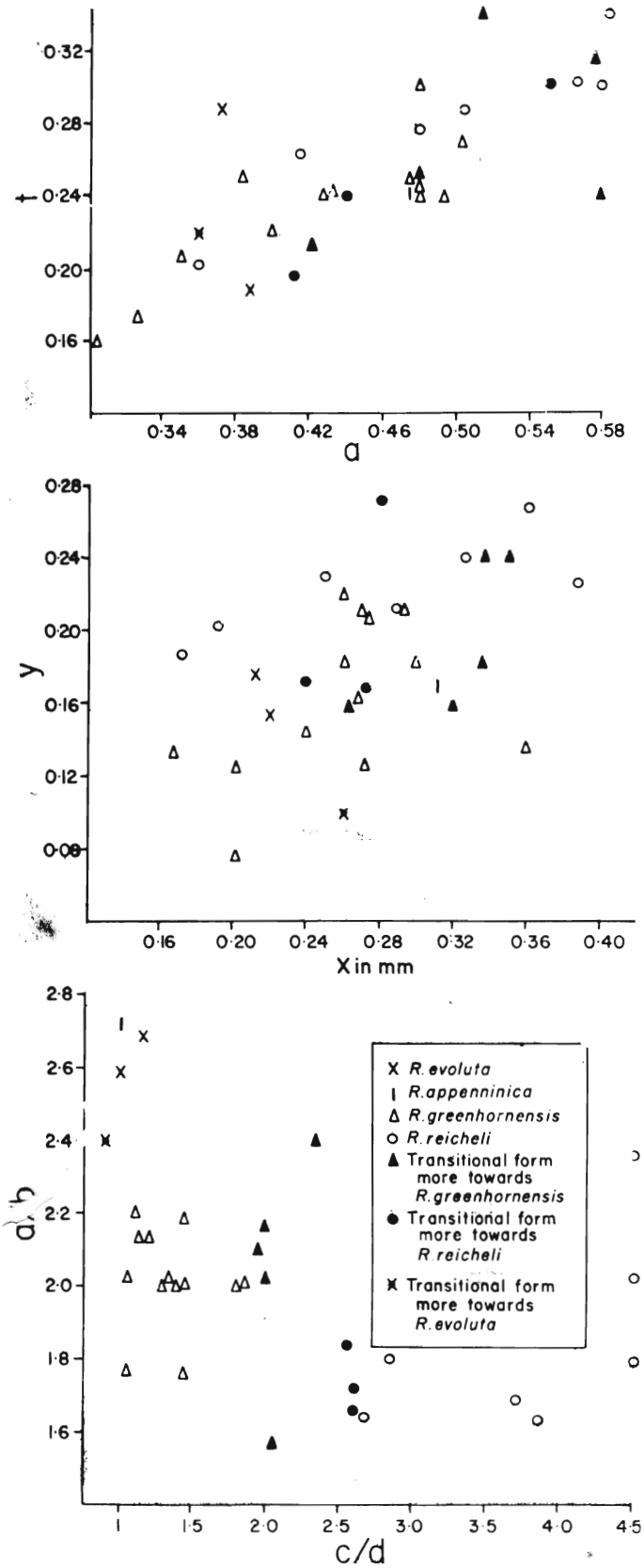

Fig. 6. Relationship between a/b and c/d, x and y, and a and t of *Rotalipora* specimens from core 27 of Karai-6 well.

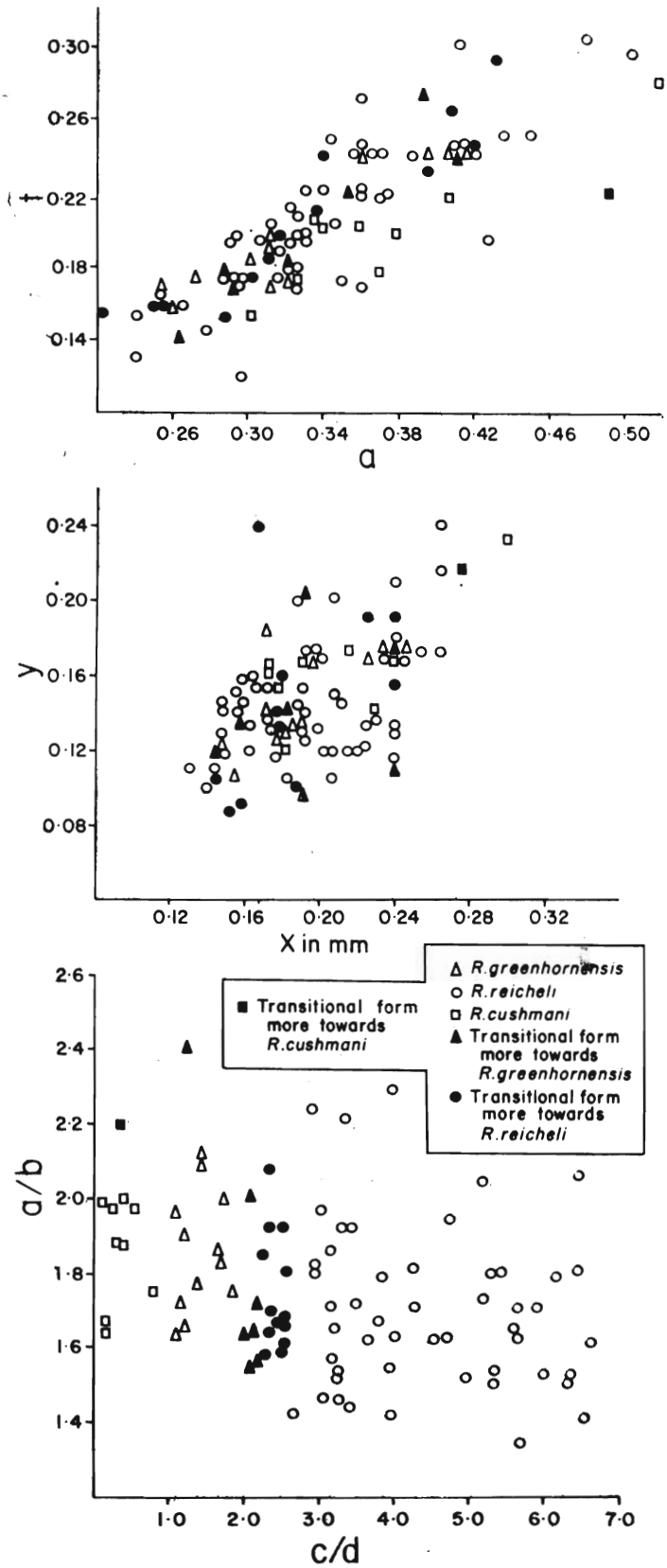

Fig. 7. Relationship between a/b and c/d, x and y, and a and t of *Rotalipora* specimens from core 22 of Karai-6 well.

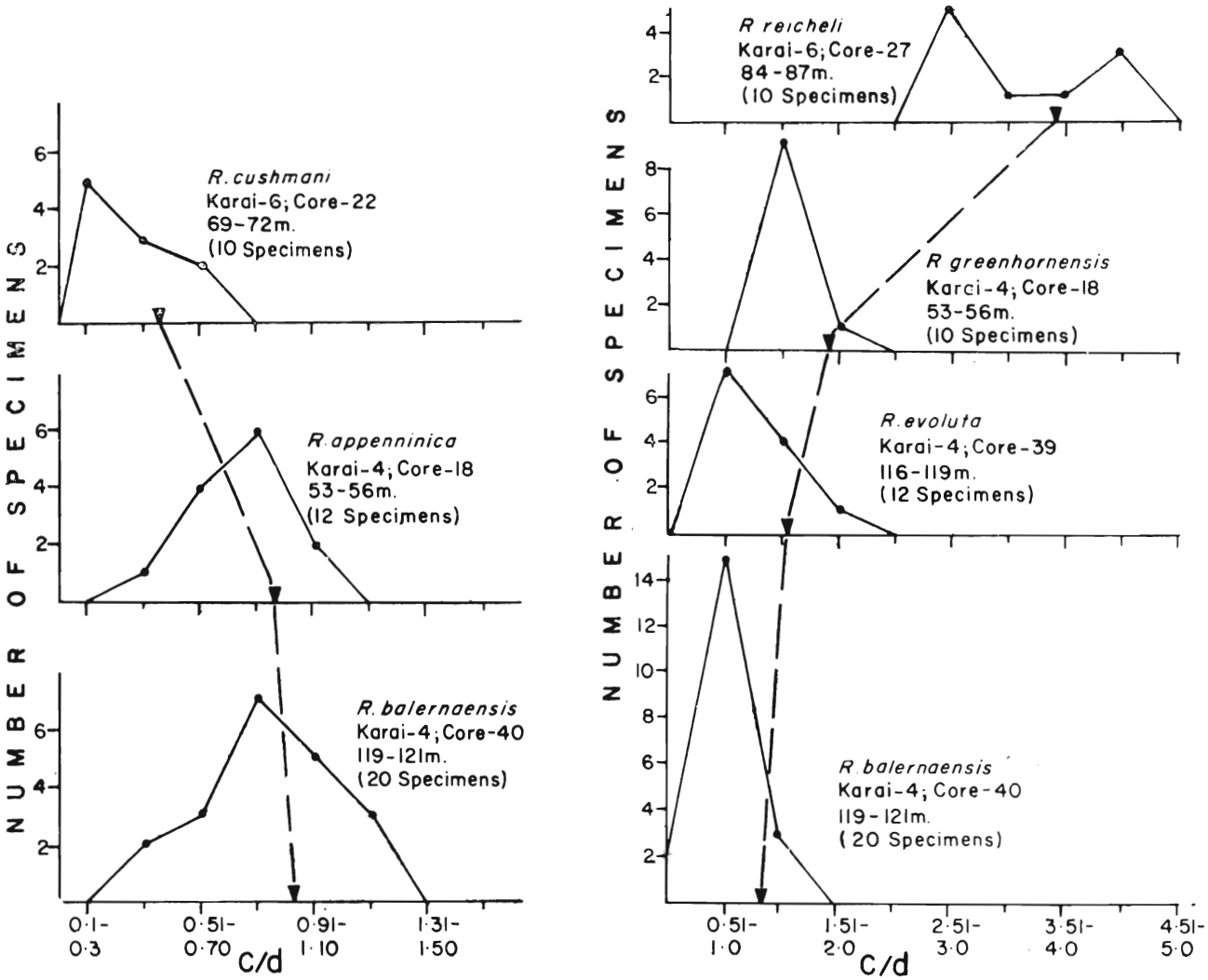

Fig. 8. Diagram showing gradual decrease in c/d ratios from *R. balernaensis* to *R. cushmani* and gradual increase in c/d ratios from *R. balernaensis* to *R. reicheli*.

Table 2

R. balernarensis-evoluta greenhornensis reicheli lineage	*R. balernaensis-appenninica cushmani* lineage.
1. Progressive increase in the ratio of c to d from a mean of 0.855 to 3.489.	1. Progressive decrease in the ratio of c to d from a mean of 0.855 to 0.343.
2. Progressive development of umbilical shoulders starting from *R. evoluta*	2. Lineage usually without the development of umbilical shoulders.
3. Gradual shallowing and widening of the umbilicus	3. Progressive deepening and widening of the umbilicus.
4. Lineage with gradual increase in the number of chambers in the final whorl, starting from a mean of about 5½ chambers in *R. balernaensis* to 6 in *R. evoluta* to 7 in *R. greenhornensis* and *R. reicheli*.	4. Lineage with more or or less the same number of chambers in the final whorl throughout with a range from 5½ m to 6 chambers.

BIOSTRATIGRAPHY

The biostratigraphic correlation of the two wells is shown in figure 10. Altogether five zones have been recognised for the stratigraphic interval that includes Late Albian and Cenomanian.

Rotalipora balernaensis zone

This zone is defined by the partial range of the ancestral species, *R. balernaensis*. It includes the stratigraphic interval from the first appearance of *R. balernaensis* to the first evolutionary appearance of *R. evoluta*. The base of *R. evoluta* is taken as the boundary between the Albian and Cenomanian, which is in agreement with the earlier observations of Pessagno (1967), Douglas (1969), Sigal (1969), Barr (1972) and Narayanan (1977).

Other associated planktonic foraminifera of this zone include *Hedbergella planispira* (Tappan), *H. delrioensis*

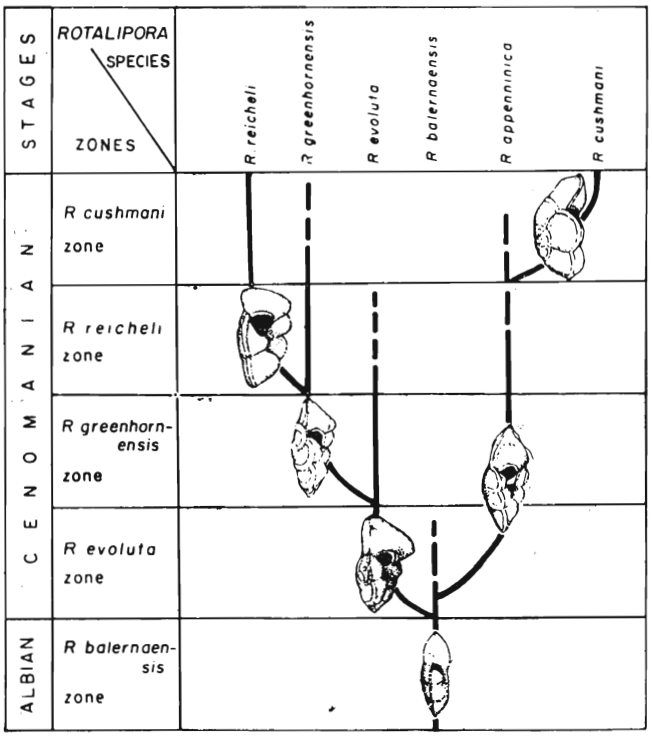

Fig. 9. Tentative phylogeny and stratigraphic ranges of different species of *Rotalipora* in Cauvery Basin, South India.

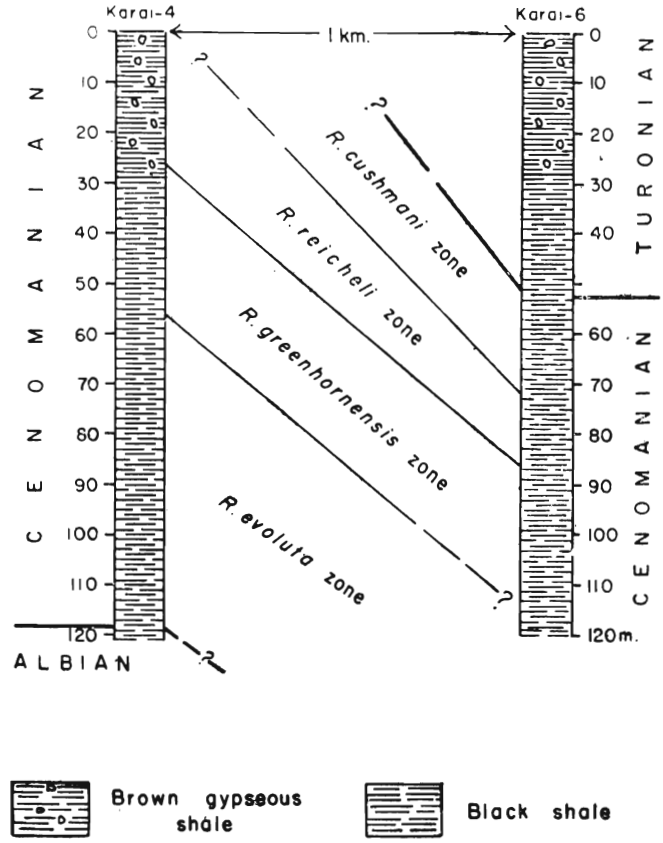

Fig. 10. Biostratigraphic correlation between Karai-4 and Karai-6-wells based on *Rotalipora* species.

(Carsey), *Praeglobotruncana delrioensis* (Plummer) and *Planomalina buxtorfi* (Gandolfi). The assemblage recorded from *R. balernaensis* zone indicates a Late Albian age.

Narayanan (1977) and Ramanathan and Rao (1982) proposed *P. buxtorfi* total range zone and *P. buxtorfi* partial range zone respectively for the Upper Albian section in the Cauvery Basin. *P. buxtorfi* (Gandolfi) has been recorded from 99 to 121 m depth in Karai-4 well and found to extend clearly into Early Cenomanian where it is associated with *R. evoluta* and *Hedbergella portsdownensis* (Williams-Mitchell).

Of the five wells drilled in this area, Karai-4 is the only well which penetrated Upper Albian sediments and that too, only two metres (119-121 m). A few metres further drilling would have solved the problem connected with the relative ranges of *P. buxtorfi* and *R. balernaensis*. Nevertheless, the range chart given by Narayanan (1977) shows that *R. balernaensis* has a first evolutionary appearance slightly at a higher stratigraphic level compared to that of *P. buxtorfi*.

Rotalipora evoluta zone

This zone is defined as the interval from the first evolutionary appearance of *R. evoluta* to that of *R. greenhornensis*. *R. appenninica* (O. Renz), *Hedbergella portsdownensis* (William-Mitchell), *H. amabilis* (Loeblich and Tappan) and *Paraeglobotruncana stephani* (Gandolfi) also make their first evolutionary appearance within this zone.

A Late Cenomanian to Early Turonian age was given to the range of *R. evoluta* by Bandy (1967). Dalbiez (1955) noted the tendency of some of the specimens of *R. cushmani* to uncoil and considered them as *R. cushmani* var. *evoluta* Sigal representing the Late Cenomanian. However, Loeblich and Tappan (1961) regarded *R. evoluta* as a valid Early Cenomanian species, not having an overlapping range with *R. cushmani*. Pessagno (1967) also considered *R. evoluta* as an Early Cenomanian species ancestral to *R. appenninica*. A similar range for *R. evoluta* has been reported from North Africa by Sigal (1969) and Barr (1972) from California by Douglas (1969) and from India by Narayanan (1977). In the Cauvery Basin a rich occurrence of *R. evoluta* has been recorded from the Early Cenomanian. However, this species is found to have an overlapping range with *R. reicheli* but disappears well before the first evolutionary appearance of *R. cushmani*. *R. evoluta* partial range zone of Cauvery Basin is equivalent to *G. washitensis* zone of Bolli (1959)

and *R. appenninica* zone of Bolli (1966), representing an Early Cenomanian age.

Rotalipora greenhornensis zone

The base of this zone is placed at the first evolutionary appearance of *R. greenhornensis* which happens to be the top of *R. evoluta* zone. The upper limit of this zone is placed at the level of first evolutionary appearance of *R. reicheli*. Other associated planktonic foraminifera of this zone include *Rotalipora evoluta*, *R. appenninica*, *Praeglobotruncana delrioensis*, *P. stephani* (Gandolfi), *Hedbergella planispira*, *H. delrioensis*, *H. portsdownensis* and *H. amabilis* (Loeblich & Tappan). This zone suggests an Early to Middle Cenomanian age, equivalent to *R. appenninica* zone of Bolli (1959) and *R. brotzeni* zone of Bolli (1966).

Rotalipora reicheli zone

This zone may be defined as the interval ranging from the first evolutionary appearance of *R. reicheli* to that of *R. cushmani*. *R. evoluta* disappears near the top of this zone. Transitional forms between *R. appenninica* and *R. cushmani* start appearing in this zone. *Praeglobotruncana turbinata* (Reichel) and *Heterohelix moremani* (Cushman) having a rare distribution also make their first evolutionary appearance near the base of this zone. *R. reicheli* partial range zone of the present study precisely corresponds to the *R. reicheli* zone first proposed by Bolli (1966) and it represents Middle to Late Cenomanian age.

Rotalipora cushmani zone

This zone is characterised by the total range of the nominate taxon, *R. cushmani*, *R. greenhornensis* disappears within the upper limits, whereas, *R. reicheli* extends up to the top of this zone. A Late Cenominian to Early Toronian age was given to the range of *R. cushmani* by Dalbiez (1955), Klaus (1959), Bandy (1967) and Porthault (1969). In the present study, *R. cushmani* has been recorded from 52.5 to 72 metres in Karai-6 well. A core from 49.5 metres in this well has yielded a few forms referable to *Praeglobotruncana gigantea* (Bolli). Bolli (1966) considered *P. gigantea* as a zonal marker for an interval between the last occurrence of *R. cushmani* and the first evolutionary appearance of *Marginotruncana helvitica* (Bolli). According to him *P. gigantea* zone represents an Early Turonian age. The upper range limit of *R. cushmani* and *R. reicheli* in the Cauvery Basin is therefore considered to be restricted to the Cenomanian (See Fig. 9).

SYSTEMATIC PALAEONTOLOGY

Order *Foraminiferida*
Family *Rotaliforidae* SIGAL, 1958
Sub-family *Rotaliforinae* SIGAL, 1958
Genus *Rotalipora* BROTZEN, 1942

Rotalipora appenninica (O. RENZ) (Pl. I—4-7)

Globotruncana appenninica O. Renz, 1936, text-figs 2, 7a; pl. 6, figs. 1-11; pl. 7, fig. 1; pl. 8, fig. 4.

Rotalipora brotzeni (Sigal); Bolli, Loeblich and Tappan, 1957, p. 41, pl. 9, figs. 7a-c.

Rotalipora greenhornensis (Morrow); Loeblich and Tappan, 1961, p. 299-301, po. 7, figs. 10a-c, not 5-9.

Remarks : Specimens recorded as *R. appenninica* shows a range in a/b values from 1.98 to 3.72 with a mean value of 2.537. Out of various parameters taken into account, the ratio of the maximum diameter to the distance across the umbilicus helps to differentiate *R. appenninica* from *R. cushmani*. Specimens recorded as *R. cushmani* range in a/b values from 1.64 to 2.20 with a mean value of 1.897. On the basis of the standard deviation obtained for the above data, the upper limit of *R. cushmani* may be defined as a/b—2.055 and the lower limit of *R. appenninica* as a/b—2.112. Any extreme variant recorded as *R. cushmani* with a/b value of higher than 2.055 or *R. appenninica* with a/b value lower than 2,112 may have to be considered as only transitional form in between these two species (*See* Fig. 7). None of the parameters taken into account could help to distinguish *R. appenninica* from either *R. evoluta* or *R. balernaensis* quantitatively. However, *R. evoluta* differs from *R. appenninica* in having umbilical shoulders, straight sutures on the umbilical side, highly arched primary aperture and in showing more rapid increase in chamber size, whereas, *R. balernaensis* differs from *R. appenninica* in having a thin relatively smaller test and in possessing less prominent secondary sutural appertures.

Rotalipora balernaensis GANDOLFI (Pl. I—1-3)

Globotruncana (*Rotalipora*) *appenninica balernaensis* Gandolfi, 1957, p. 60. pl. 8, fig. 3.

Globotruncana (*Rotalipora*) *appenninica* O. Renz var. *alpha* Gandolfi; Reichel, 1950, p. 605, fig. 3.

Rotalipora balernaensis Gandolfi; Loeblich and Tappan 1961, p. 297, pl. 8, fig. 11.

Remarks : This ancestral species of *Rotalipora* shows a wide range in variation from being spiroconvex to umbilicoconvex, The recorded ratio of c to d varies from 0.33 to 1.28. This species was originally described as a subspecies of *R. appenninica* by Gandolfi (1957). However, Loeblich and Tappan (1961) considered it as a valid ancestral species of *Rotalipora*. In the present material, out of 21 specimens recorded from core 40 of Karai-4 well, 20 are assignable to *R.*

balernaensis without any ambigutiy. Only one specimen, having a relatively higher a/b value (2.72) and c/d value (1.28) shows almost straight sutures and development of weak shoulders on the umbilical side. This specimen may be considered a transitional form between *R. balernaensis* and *R. evoluta* (See Fig. 3). An extreme variant of *R. balernaensis* has been recorded from the middle part of *R. evoluta* zone (Core-28 of Karai-4 well). This specimen is typically spiroconvex, with somewhat well developed secondary sutures but the test as such is very thin with depressed sutures on both spiral as well as umbilical sides. This specimen may be considered as a transitional form between *R. balernaensis* and *R. appenninica* (see Fig. 4). The presence of transitional specimens between *R. balernaensis* and *R. evoluta* and between *R. balernaensis* and *R. appenninica* indicate that *R. balernaensis* forms the common stock, for the branching of two lineages recognised in the present study.

Rotalipora cushmani (Morrow)
(Pl. I—8-9)

Globorotalia cushmani Morrow, 1934, p. 199, pl. 31, figs. 2-4.

Globotruncana (*Rotalipora*) *montsalvensis* Mornod, 1950, p. 584, figs 4(1), 7(1, 2).

Rotalipora turonica Brotzen: Bolli, Loeblich and Tappan, 1957, p. 41, pl. 9, figs 6a-c.

Remarks : Specimens of *R. cushmani* range from being very high to low in spiroconvexity and the recorded values vary from 0.18 to 0.78 with a mean value of 0.343. Similar measurements made by Pessagno (1967, p. 293) show that out of 15 specimens, 13 have values less than 0.63 while two others which are biconvex have values of 1.00. The mean value given by him for this parameter of *R. cushmani* is 0.489 with a standard deviation of 0.292. The topotypes of *R. cushmani* from the Greenhorn limestone (Hartland shale member) illustrated by Loeblich and Tappan (1961, pl. 8, figs. 2c, 3c, 6c, and 9c) show a range in c/d values from 0.50 to 0.78. Similarly the hypotypes illustrated by these authors (Pl. 8, figs. 4c, 5c and 10c) from Georgia and California also show c/d values ranging from 0.37 to 0.58, Hence the extreme variants of *R. cushmani* recorded by Pessagno (1967) with c/d values as 1.00 may have to be considered as transitional forms. Two specimens sent as *Rotalipora montsalvensis* (Mornod) from the Cenomanian of southeastern France by Dr. B. Porthault have the c/d values 0.614 and 0.727. All other morphological features of these specimens also are not sufficiently different from *R. cushmani*. Hence the present authors agree with Pessagno (1967, p. 293) that *Globotruncana* (*Rotalipora*) *montsalvensis* Mornod should be regarded as a junior synonym of *R. cushmani*.

Some extreme variants of *R. cushmani* are sometimes reported as *R. cushmani* var. *evoluta* Sigal (Dalbiez, 1955). In the present study 76 specimens of *R. evoluta* have been recorded and they range in a/b values from 2.33 to 4.72 with a mean of 2.877. The maximum a/b values recorded for the specimens of *R. cushmani* is only 2.20 and the mean value is 1.897. The topotypes of *R. cushmani* illustrated by Loeblich and Tappan (1961, pl. 8, figs. 2c, 3c, and 9c) also show a/b values less than 2.1. The hypotypes of *R. cushmani* (four specimens) from southeastern France also range in their a/b values from 1.765 to 2.00. Hence *R. cushmani* can be differentiated from *R. evoluta* by the larger size of its umbilicus relative to its diameter.

Rotalipora evoluta Sigal
(Pl. II—1-3)

Rotalipora cushmani Morrow var. *evoluta* Sigal, 1948, p. 100, pl. 1, fig. 3, pl. 2, fig. 2.

Rotalipora cf *appenninica* (Renz); Bolli, Loeblich and Tappan, 1957 p. 41, pl. 9. figs. 5a-c.

Rotalipora greenhornensis (Morrow); Loeblich and Tappan, 1961, p. 298-299, pl. 7, figs. 5-6c, not 7-10.

Remarks : *R. evoluta* has often been confused with *R. appenninica* and *R. greenhornensis*. The distinguishing features between *R. evoluta* and *R. appenninica* have been listed under the remarks given for the latter.

The biometric analysis of *R. evoluta* and *R. greenhornensis* indicates that the most significant measurements are their a/b values. The a/b values for *R. evoluta* range from 2.33 to 4.72 with a mean of 2.877 and a standard deviation of 0.400, whereas, for *R. greenhornensis* from 1.53 to 2.46 with a mean of 2.017 and a standard deviation of 0.248. On the basis of the above data obtained for the two species, specimens showing a/b values above 2.477 are included under *R. evoluta* and those giving a/b values below 2.265 are grouped under *R. greenhornensis*. Individuals recorded as extreme variants, but having a/b values between 2.265 tand 2.477 are considered as transitional forms between *R. evoluta* and *R. greenhornensis* in the present study (see Figs. 3, 5 and 6).

R. evoluta varies widely in its convexity from being strongly spiroconvex (c/d = 0.55) to umbilicoconvex (c/d = 1.85). According to Pessagno (1967, p. 295), the holotype of *R. evoluta* is spiroconvex form, whereas, the paratype is an umbilicoconvex specimen. The assemblage of *R. evoluta* can be distinguished in this respect also from that of *R. greenhornensis* which shows a strong tendency towards umbilicoconvexity (c/d values of 69 specimens of *R. greenhornensis* are greater than 1).

Rotalipora greenhornensis (MORROW)
(Pl. II—4-6)

Globorotalia greenhornensis Morrow, 1934, p. 199, pl. 39, fig. 1.

Globotruncana (*Rotalipora*) *appenninica appenninica* O. Renz; Gandolfi, 1957, p. 60, pl. 9, fig. 2.

Not *Rotalipora brotzeni* (Sigal); Bolli, Loeblich and Tappan, 1957, p. 41, pl. 9, figs. 7a-c.'

Remarks : *R. greenhornensis* has often been confused with *R. appenninica*. According to Pessagno (1967) the topotype of *R. greenhornensis* has a planiform spiral side with c to d ratio of 1.47, whereas, the lectotype and paralectotype of *R. appenninica* have convex spiral sides with c to d ratio of 0.66 and 0.77 respectively. Hence the nature of convexity of the spiral side appears to be a significant factor for distinugishing *R. greenhornensis* from *R. appenninica*.

The values of c/d for 69 specimens recorded as *R. greenhornensis* show a range from 1.00 to 2.33 with a mean of 1.529 and a standard deviation of 0.399 whereas those for 32 specimens recorded as *R. appenninica* indicate a range from 0.36 to 1.00 with a mean of 0.805 and a standard deviation of 0.66. On the basis of the above data, specimens showing c/d values above 1.130 and those giving c/d values below 0.971 may be safely grouped under *R. greenhornensis* and *R. appenninica* respectively. Normally specimens showing c/d values between 0.971 and 1.130 may have to be considered as transitional forms between these two specicies. However a close look into the a/b values of such transitional forms broadly show that forms recorded as *greenhornensis* have larger umbilicus relative to their diameter whereas those of *R. appenninica* have smaller umbilicus relative to their diameter as shown below :

R. appenninica		*R. greenhornensis*	
c/d	a/b	c/d	a/b
1.00	3.00	1.09	2.05
1.00	2.83	1.00	2.11
1.00	3.72	1.04	2.09
1.00	2.12	1.08	2.11
1.00	2.71	1.07	2.18
		1.11	2.33
		1.11	2.00
		1.12	2.20
		1.05	1.76
		1.05	2.08
		1.10	1.64
		1.12	1.97

In addition to the above quantitative differences *R. greenhornensis* seems to differ further from *R. appenninica* in having (i) reaised and beaded sutures on the umbilical side, (ii) well developed umbilical shoulders (iii) less lobulate periphery and (iv) closely spaced numerous chambers in the last whorl. It is further shown that *R. greenhornensis* and *R. appenninica* perhaps belong to somewhat different lineages, the latter evolving directly from *R. balernaensis* during Early Cenomanian and the other from *R. evoluta* during Middle Cenomanian.

Rotalipora reicheli (MORNOD)
(Pl. II—7-9)

Globotruncana (*Rotalipora*) *reicheli* Mornod, 1950, p. 583, fig. 5 (IV a-c); fig. 6 (Nos. 1-6); pl. 15, fig. 2a.

Globotruncana appenninica O. Renz var. & Gandolfi. 1942, p. 119, figs. 41 (1a-b); 42(1); 44(3-4); pl. 6, fig. 6; pl. 14, fig. 6.

Rotalipora marchigiana Borsetti; Porthault 1969, p. 532, pl. 1, figs 8a-c

Remarks : The strongly nodose and thickened sutures on the spiral side with a typical keel along the edge, and the highly inflated to angular truncate chambers on the umbilical side producing a more lobate periphery help to distinguish this species from its closely related ancestor *R. greenhornensis*. However, a considerable amount of difficulty was experienced in differentiating the juvelies of *R. reicheli* from those of *R. greenhornensis*. The spiral side of *R. reicheli* in many of the well developed specimens is almost flat and it is chiefly responsible for the high ratios of c to d recorded for this species. This parameter is considered as significant to determine the relationship between the extreme variants recorded as either *R. reicheli* or *R. greenhornensis*. The ratio of c to d determined for 75 specimens recorded as *R. reicheli* ranges from 2.23 to 6.58 with a mean of 3.957 and a standard deviation of 1.326, whereas, that for 69 specimens recorded as *R. greenhornensis* varies from 1.00 to 2.33 with a mean of 1.529 and a standard deviation of 0.399. Hence the upper limit of *R. greenhornensis* is defined herein as c/d=1.928 whereas the lower limit of *R. reicheli* is taken as c/d=2.631. Specimens having ratios greater than 1.928 but lesser than 2.631 are considered as transitional forms in the present study (see Figs. 6 and 7).

Porthault (1969) included *Globotruncana appenninica* var. & Gandolfi under the synonymy of *R. marchigiana* Borsetti. However, Loeblich and Tappan (1961) considered the former as synonymous to *R. reicheli*. Four specimens sent as *R. marchigiana* by Dr. B. Porthault show a range in c to d ratio from 2.66 to 4.66. Specimens closely comparable to *R. marchigiana* have been recorded from our assemblage also, but

they fall well within the range of variation recorded for *R. reicheli*. Hence *R. marchigiana* is considered as junior synonym of *R. reicheli*.

CONCLUSIONS

1. The six species of Cretaceous planktonic foraminiferal genus *Rotalipora* seem to have evolved along two lineages. The *R. balernaensis-appenninica-cushmani* lineage. is characterised by tests showing progressive increase is spiroconvexity and widening of the umbilicus, whereas, the *R. balernaensis-evoluta-greenhornensis-reicheli* lineage is typified by tests exibiting progressive decrease is spiroconvexity and widening of the umbilicus.

2. Based on the evolutionary appearance and last occurrence of different *Rotalipora* species, five zones have been recognised for the Late Albian and Cenomanian sections of the Cauvery Basin, India. Of these five zones, *R. balernaensis*, *R. evoluta*, *R. greenhornensis* and *R. reicheli* zones are partial range zones, whereas *R. cushmani* zone is a total range zone defined on the basis of respective partial and total ranges of the nominate taxa.

3. None of the parameters taken into account could help to distinguish the early species of *Rotalipora* like *R. balernaensis*, *R. evoluta* and *R. appenninica*. However, it is shown that *R. balernaensis* differs from *R. appenninica* in having thin and relatively smaller tests and in possessing less prominent secondary sutural appertures. Similarly *R. evoluta* is shown to differ from *R. balernaensis* and *R. appenninica* in having umbilical shoulders, straight sutures on the umbilical side, highly arched primary apperture and in showing more rapid increase in chamber size.

4. Biometric analysis of *Rotalipora* species shows that specimens of *R. cushmani* could be distinguished from those of *R. appenninica* and *R. evoluta* quantitatively in terms of the ratio of the diameter of the test (a) the width of the umbilicus (b). Similarly specimens of *R. greenhornensis* could be differentiated from those of *R. appenninica*, *R. evoluta* and *R. reicheli* in terms of the ratio of the umbilical thickness (c) to the spiral thickness (*d*). In addition, individuals of *R. greenhornensis* are shown to have relatively lesser ratio of (*a*) to (b) than those of *R. evoluta* and *R. appenninica*.

5. Extreme variants of different species evolving in a lineage which do not fall within the optimum range of variability of the respective species are recognised as intermediate forms in the present study. Such forms include those between *R. appenninica* and *R. cushmani* defined on the basis of optimum variability of a/b and those between *R. greenhornensis* and *E. evoluta* or *R. reicheli* defined on the basis of optimum variability of c/d.

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EXPLANATION OF PLATES

PLATE I

(Bar length 0.10 mm)

1-3. *Rotalipora balernaensis* Gandolfi, Core 40 (119-121m), Karai-4 well.
4-7. *Rotalipora appenninica* (O. Renz), Core 28 (83-86m), Karai-4 well.
8-9. *Rotalipora cushmani* (Morrow), Core 22 (69-72m), Karai-6 well.

PLATE II

(Bar length 0.10 mm)

1-3. *Rotalipora evoluta* Sigal, Core 39 (116-119m), Karai-4 well.
4-6. *Rotalipora greenhornensis* (Morrow), Core 18 (53-56m), Karai-4 well.
7-9. *Rotalipora reicheli* (Mornod), Core 8 (23-26 m), Karai-4 well.


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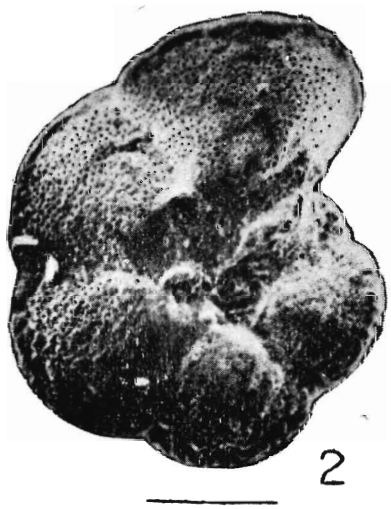
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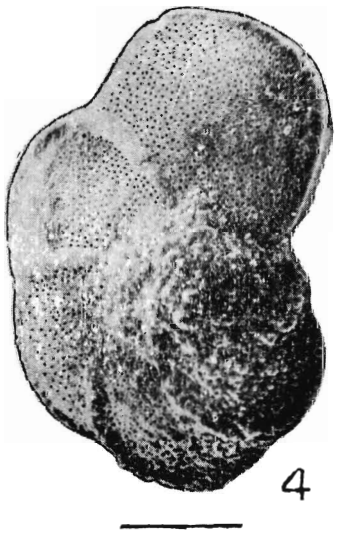
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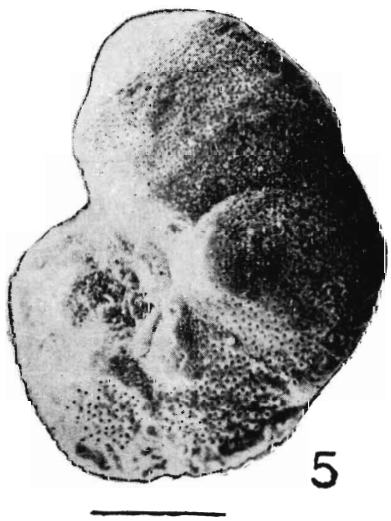
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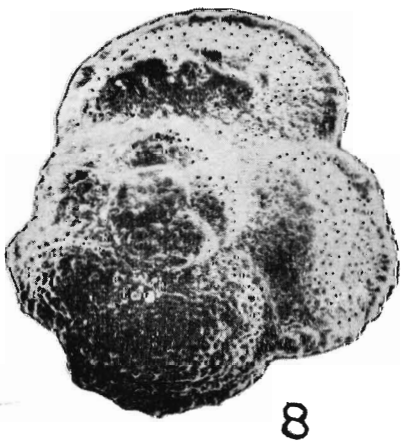
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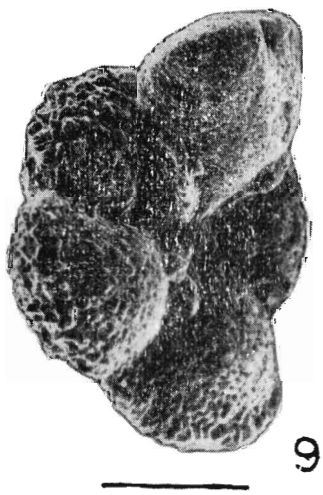
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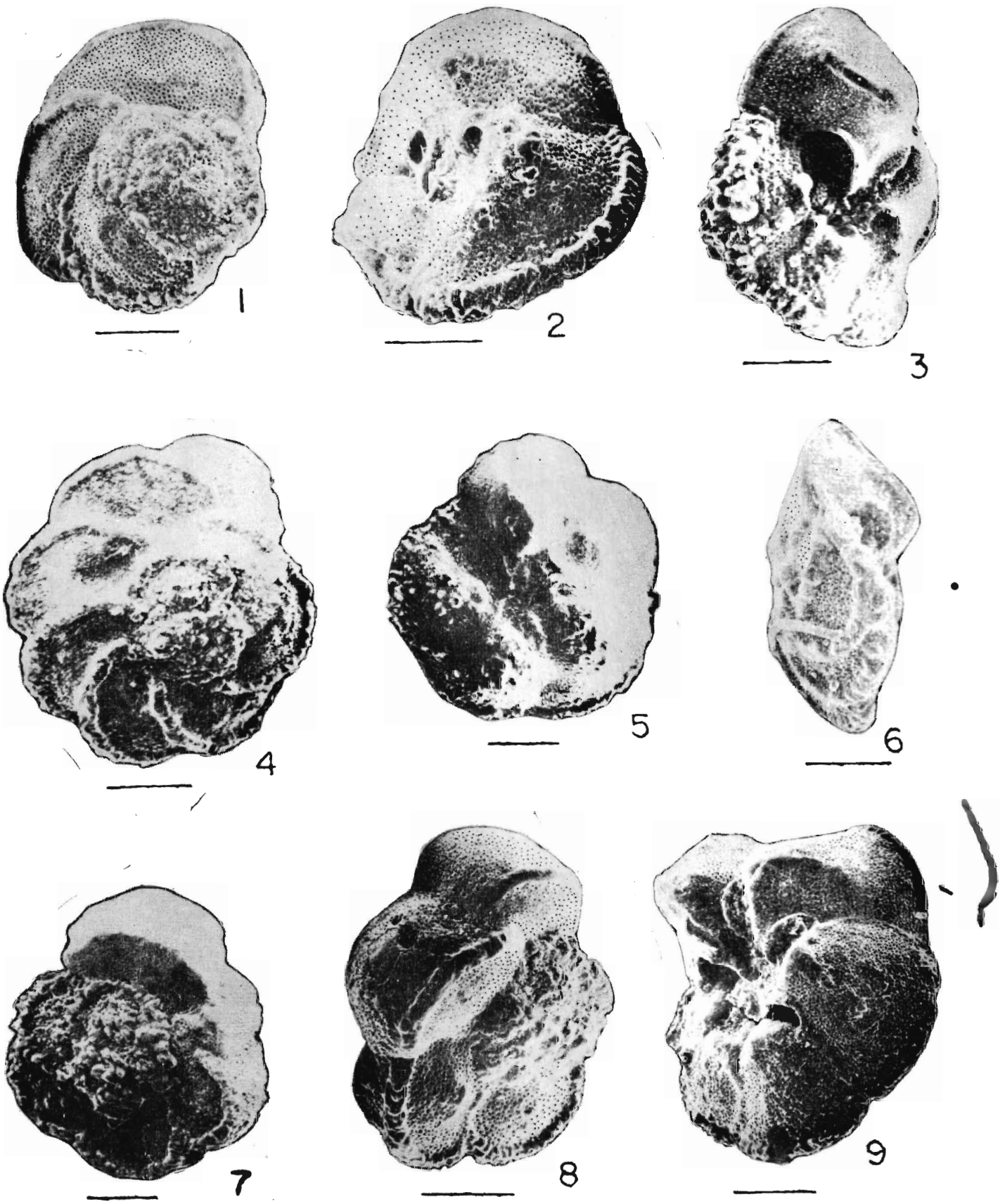

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