SECTION 2
SECTION 2

EAST COAST GONDWANA

The Gondwana Supergroup has attracted a great deal of attention since it was first described by Feistmantel in India in 1876 mainly due to vast reserves of coal and prolific flora and fauna preserved in this thick pile of sediments, mostly fresh-water but in some places marine, and ranging in age from Upper Carboniferous to Lower Cretaceous. The study of this Supergroup is interesting and of great significance because of its relation to the theory of continental drift, phenomenon of ancient glaciation, nature and origin of coal, fossil flora and fauna, and a variety of other aspects of scientific value.

The Gondwana rocks are widely distributed in India and those found on the east coast are commonly referred to as East Coast Gondwana. Although work on these rocks commenced nearly a century ago, they have not received much attention because they were not of economic significance. They are of considerable scientific interest, however, due to the presence of marine fauna, including ammonites, in addition to characteristic Upper Gondwana land flora in them. These rocks are especially attractive because occasionally the marine fauna and land flora are found preserved in a single bed, sometimes even in a single hand specimen. Within a sequence of fresh-water strata to the extent of the Gondwana, attaining a thickness of several thousand metres, intercalations of fossiliferous marine sediments are of tremendous value and, therefore, the east coast beds have a special status in the Gondwana stratigraphy of India. A study of these rocks and their flora and fauna illuminates the distribution of ancient land and sea, paleoenvironment, stratigraphic correlations, and the polemical upper age limit of the sequence.
<table>
<thead>
<tr>
<th>Formation</th>
<th>Cuttuck</th>
<th>Eluru</th>
<th>Gingee</th>
<th>Madras</th>
<th>Tiruchirappalli</th>
<th>Lithology</th>
<th>Fossils</th>
<th>Environment</th>
<th>Age</th>
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</thead>
<tbody>
<tr>
<td>Upper</td>
<td>-</td>
<td>Tirupati</td>
<td>Pavulur</td>
<td>Sattawedu</td>
<td>-</td>
<td>Sandstones</td>
<td>Fragmentary plants and a few animals</td>
<td>Fresh-water</td>
<td>Astian or Santian</td>
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<tr>
<td>Middle</td>
<td>-</td>
<td>Raghavapura</td>
<td>Vamavaram</td>
<td>Sripurumbudur</td>
<td>7Uttur Plant beds</td>
<td>Shales</td>
<td>Animals including Early Cretaceous ammonites and foraminifers with an admixture of Rajmahal and Jabalpur plants</td>
<td>Truly marine to Fresh</td>
<td>Meccocian</td>
</tr>
<tr>
<td>Lower</td>
<td>Athgarh</td>
<td>Colapilli</td>
<td>Budawada</td>
<td>-</td>
<td>7Uttur Plant beds</td>
<td>Sandstones</td>
<td>Rajmahal plants</td>
<td>Fresh-water</td>
<td>Middle Jurassic</td>
</tr>
</tbody>
</table>

Table 2: Upper Condawana sequence on the east coast of India.
The Upper Gondwana rocks on the east coast occur in a chain of isolated outliers from near Cuttack to Tiruchchirappalli (Figure 1), approximately following the eastern coast-line of the Indian Peninsula. These beds dip at low angles towards east or southeast and are mostly covered by laterite or alluvium. However, exposures are well seen in three sectors, eg., Eluru, Ongole, and Madras. Of these, exposures in the Eluru sector of Andhra Pradesh are best developed and have been most thoroughly studied.

The stratigraphic nomenclature of the Gondwana Supergroup is in a state of flux in India. Different subdivisions have been named differently and there is no consistency in the usage of stratigraphic terminology. Sometimes they have been given chronostratigraphic rank terms while at others, lithostratigraphic terminology has been used for them. However, with the publication of the Code of Stratigraphic Nomenclature of India (1971), efforts are now being made to standardise the stratigraphic nomenclature of the Gondwana sequence but the final picture has not yet emerged. In view of this, the well-established stratigraphic terminology, though erroneous in the modern sense, has been adhered to in the present work.

The Upper Gondwana sequence on the east coast has been broadly divided into three formations - Lower, Middle, and Upper - mainly on the basis of fossil evidence and stratigraphic considerations (Table 1). The Middle formation is the centre of attraction because unlike the Lower and the Upper fresh-water formations, it is marine in nature (Table 2). The fossil assemblage of this formation contains a marine fauna as well as land flora which is of considerable value in dating it and also in the interpretation of its environment of deposition.
In the Eluru sector, the Middle formation of the Upper Gondwana is named as Raghavapuram shale. About 26 sq. km of the area was geologically mapped and detailed sampling was done for micropaleontological investigation by the author. From the type-section of the Raghavapuram shale, a fairly rich assemblage of foraminifera consisting entirely of arenaceous species was discovered and described for the first time in detail by the author (Bhalla, 1965, 1968a, 1969a). The microfauna is dominated by Haplophragmoides and Ammobaculites. Emphasis was placed on tracing the range of variation of different species belonging to these highly variable genera of foraminifera and also in working out their dimorphism. A total of fifteen species, including six new species, were described in detail.

**Paleoecology:** The interpretation of paleoecology of the Raghavapuram shale was attempted, also for the first time by the author (Bhalla, 1968b, 1968c).

A characteristic feature of the fossil assemblage of the Raghavapuram shale is that it contains an admixture of land flora and marine fauna. The fossil fauna includes a rather meagre ammonite assemblage, Tellinga, Pectin, Solon, etc., and is restricted to the lower 18 to 21 m of the sequence whereas the microfauna comprise a rich assemblage of exclusively arenaceous foraminifera having simple interiors with Ammobaculites and Haplophragmoides as the dominant genera and is confined to the upper 30 m of the succession (Bhalla, 1968c). The megafossils indicate a rather shallow, truly marine environment whereas the predominance of arenaceous species of foraminifera having simple interior is generally attributed to a near-shore, shallow-water, marsh environment.
On the basis of fossil evidence, it was inferred that the deposition of the Raghavapuram shale commenced in a near-shore, shallow-water environment which had open sea connection, thus allowing the free but sporadic movements of a few ammonites and other megafauna to the site of deposition. This was truly marine environment marking the transgressive phase of the sea in which the lower 18 to 21 m of the sediments were laid down. Thereafter, the sea gradually regressed towards the east and southeast and the basin became land-locked resulting in the development of a near-shore, shallow, marsh environment having low oxygen, low $p^H$, and low salinity values and under these conditions, the upper 30 m of the Raghavapuram sequence was deposited (Bhalla, 1968c). The change-over from truly marine to marsh environment is marked by the change of fauna and synchronous appearance of a fairly thick band of glauconite-bearing mudstone at a level 18 to 21 m from the base of the shale sequence (Bhalla, 1969b). With the further regression of the sea, fresh-water conditions again prevailed in the basin resulting in the accumulation of the Upper formation, i.e., Tirupati sandstone. Thus, in the Eluru sector and, perhaps, in other sectors also, the Lower and Upper formations are of fresh-water origin while the Middle formation is of marine nature.

Like other coastal marine deposits, the Raghavapuram shale is the result of marine transgression which took place on the east coast of India from east and southeast. The trend of its outcrop suggests that the Raghavapuram basin was, perhaps, crescentic in outline surrounded by land on three sides - north, northwest and west - in which deposition of fresh-water Golapilli sandstone was already in progress. Although the Raghavapuram shale is found exposed about 100 km west of the present shore-line of the east coast, it has been pointed out by the author (Bhalla, 1970) that these beds extend towards the Godavari delta and even beyond into the Bay of Bengal but lie concealed below the younger formations.
Although in Ongole sector, a meagre foraminiferal assemblage from the topmost bed of the Budavada sandstone (homotaxial with the Raghavapuram shale) was also discovered by the author (Bhalla, 1969; except Eluru, fossils are not prolific in the Middle formation at other sectors. A total of only six specimens belonging to five genera of foraminifera were recovered and it was suggested that the accumulation of the sandstone took place in a tranquil, open marine basin near to the shore-line.

Upper Age Limit: The upper age limit of the East Coast Gondwana has long been a controversial problem in Indian geology. This was mainly due to the fact that both marine fauna and land flora occur in these sediments and a discrepancy exists between the chronological testimony of the two fossil groups.

The plant assemblage of the Upper Gondwana on the east coast was compared with that of the Upper Gondwana type-section in Rajmahal range where it is extensively developed and, consequently, its assemblage is termed as "Rajmahal flora" or "Upper Gondwana flora" — both these terms being synonyms in Indian geological literature. The Rajmahal flora has been studied in great detail and was considered to be of Jurassic age. The overall predominance of the elements of the Rajmahal flora in the plant assemblage of the East Coast Gondwana led workers to consider Jurassic as the upper age limit of the east coast sequence.

As against the floral testimony, the ammonites and other megafossils restricted to the Middle formation only, indicate Upper Neocomian age. The Lower Cretaceous age is supported by foraminifera also.
The above account reveals that while the plant fossils indicate a Jurassic age for the Upper Gondwana of the east coast, the ammonites and other marine fossils suggest that the beds are not older than the Neocomian. The only course then left is to scrutinise the reliability of floral and faunal evidences.

It is difficult to doubt the testimony of ammonites because firstly, they are not reworked, and secondly, the ammonites are excellent age-markers during the Mesozoic. Moreover, the evidence from ammonites is corroborated by micro- as well as other megafossils also.

The Gondwana rocks containing prolific flora are extensively developed in the vicinity of the east coast of India. It is possible that the plant fossils now entombed in the Middle formation were reworked from pre-existing Gondwana sediments for a short distance or had fallen as blocks of plant-bearing Jurassic rocks from low cliffs into coastal basins during Lower Cretaceous times and got intimately mixed up with the ammonite-bearing marine Cretaceous sediments (Bhalla, 1972). The sedimentological studies of the Lower and the Upper Gondwana of the Eluru sector indicate that the sediments of the Lower formation of the Upper Gondwana were derived from the pre-existing Lower Gondwana rocks. The assumption of the derived nature of the flora settles the controversy regarding the upper age limit of the East Coast Gondwana (Bhalla, op. cit.).

The Neocomian age is assigned to the Middle formation only which would, in turn, necessitate that the Upper formation should be taken further up in the column and Aptian or Albian should be considered as the upper age limit of the East Coast Gondwana (Bhalla, 1972).
Paleogeography: The foraminiferal assemblage of the Raghavapuram shale shows very close affinity with those described from the Lower Cretaceous of Australia. Several species are common to Raghavapuram shale and the Lower Cretaceous of the Great Artesian Basin of Australia described by different authors.

It has been suggested by a few workers on continental drift that during Tithonian—heocomic times, some parts of the east coast of India, including Raghavapuram area, were connected with the Great Artesian Basin of Australia by a mixed environment. The present study supports the view regarding close India—Australia association during Lower Cretaceous.

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NEW SPECIES OF FORAMINIFERA FROM THE RAGHAVAPURAM SHALES (LOWER CRETACEOUS), ANDHRA PRADESH, INDIA

S. N. BHALLA*

Introduction: During the course of micropalaeontological investigations of the East Coast Gondwanas, a rich assemblage of arenaceous Foraminifera, including six new species, was obtained from the type section of the Raghavapuram shales (Lower Cretaceous) exposed on the northern slope of hill A 512', about one and a half miles east of Raghavapuram village (17°00'02": 81°15'30") in Andhra Pradesh.

The Raghavapuram shales form the middle division of the East Coast Gondwanas and constitute an important marine, fossiliferous horizon. Lithologically, this horizon consists chiefly of shales with occasional sandy beds and is about 160' thick at the type section.
King (1880) has given a detailed account of the geology of the area. Except Sastri et al. (1961) who have reported three species of Foraminifera—Haplophragmoides concava (Chapman), H. chapmani Crespin, and Ammobaculites fisheri var. tirupathiensis var. nov. from these beds, no work on the Foraminifera of the Raghavapuram shales has yet appeared. These authors have assigned a Lower Cretaceous age to this stage.

The foraminiferal fauna now under study suggests a shallow, brackish water, rather marshy, environment of deposition and confirms the Lower Cretaceous age of the beds. The present paper gives only the diagrams and descriptions of the holotypes of the new species of Foraminifera obtained from the Raghavapuram shales at the type section; detailed descriptions will be published later.

Systematic Descriptions:

Genus Haplophragmoides Cushman, 1910

Haplophragmoides hagni Bhalla, sp. nov.
(Fig. 1, No. 2a-b)
Test planispiral, slightly evolute, inflated, medium sized, final evolution consists of eleven, fairly well marked, chambers which increase very gradually in size with growth; only two chambers of inner whorl visible from outside; sutures straight, distinct, strongly limbate, almost flush with the surface; periphery entire, faintly lobulate, if at all, in the later chambers, broadly rounded; aperture an arched slit at the base of the apertural face (interio-marginal); umbilical area depressed; wall finely arenaceous, consisting of fine grains of quartz with little cement; surface smooth somewhat shining.

Dimensions (in mm.):
Major diameter 0.63
Minor diameter 0.53
Thickness 0.33

Genus Ammobaculites Cushman, 1910

Ammobaculites crespinae Bhalla, sp. nov.
(Fig. 1, No. 3)
Test of medium size, elongate, free, rounded in end view; early portion involutely coiled, consisting of four chambers, uniserial portion of five chambers, last formed chamber dome-shaped; chambers inflated, increase gradually in size with growth; aperture central, rounded with a very short neck; sutures well marked, straight, depressed; periphery lobulate; wall moderately thick, arenaceous, composed of quartz grains with much siliceous cement; surface smoothly finished.

Dimensions (in mm.):
Length of the test 1.03
Length of the uncoiled portion 0.80
Maximum width of the uncoiled portion 0.43
Maximum diameter of the coiled portion 0.43
Diameter of the last chamber 0.40

Ammobaculites kofkeri Bhalla, sp. nov.
(Fig. 1, No. 1)

Figure 1. Foraminifera from Raghavapuram Shales

Test free, large, flattened, and elongate; early portion planispirally coiled, somewhat evolute with gradually enlarging four chambers,
uniserial part with five imbricate and compressed chambers, increasing gradually in size with growth; last formed chamber has maximum height but penultimate chamber has maximum width; sutures of coiled portion not well marked, of uniserial portion distinct, depressed, more or less straight; periphery lobulate; wall thick rather coarsely arenaceous, composed of quartz grains of moderate size with normal amount of cement, insoluble in acid; aperture rounded, central.

**Dimensions (in mm.):**
- Length of the test: 1.36
- Length of the uncoiled portion: 1.00
- Maximum width of the uncoiled portion: 0.73
- Maximum diameter of the coiled portion: 0.50
- Diameter of the last chamber: 0.67

*Ammobaculites indicus* Bhalla, sp. nov. (Fig. 1, No. 4)

Test free, narrow, cylindrical; coiled portion slightly evolute with four chambers, uniserial portion rectilinear with six chambers; chambers, especially of uniserial portion, inflated, rounded in cross-section, nearly all of the same size, higher than broad; sutures straight, depressed, well marked in uncoiled portion, less so in coiled portion; periphery lobulate; aperture terminal, simple, small, and rounded; wall thin, arenaceous, of quartz grains with fair amount of silica as cementing material; surface fairly smooth.

**Dimensions (in mm.):**
- Length of the test: 0.73
- Length of the uncoiled portion: 0.60
- Maximum width of the uncoiled portion: 0.13
- Maximum diameter of the coiled portion: 0.18
- Diameter of the last chamber: 0.13

*Ammobaculites raghavapuramensis* Bhalla sp. nov. (Fig. 1, No. 5)

Test free, large, compressed; early portion planispirally coiled with fourteen chambers, uncoiled portion with four chambers in a rectilinear series; chambers increase very gradually in size with growth; sutures well marked, limbate in coiled as well as in uncoiled portion, straight to gently curved, depressed; periphery entire in early portion, slightly lobulate in uncoiled portion; aperture an elongate slit, terminal; wall finely arenaceous, of minute quartz grains with moderate amount of siliceous cement; surface smoothly finished; colour white.

**Dimensions (in mm.):**
- Length of the test: 1.60
Ammobaculites sahnii Bhalla sp. nov.  
(Fig. 1, No. 6)

Test free, large, elongate, nearly circular in end view; early portion streptospirally coiled, consisting of four chambers, uniserial portion of six imbricate, inflated chambers, in a rectilinear series, increasing rapidly in diameter with growth giving the test a flaring appearance; last chamber 'cap'-shaped, oblique to the axis of rectilinear series; sutures distinct, slightly curved, depressed; periphery lobulate; aperture circular, terminal; wall thick, arenaceous, composed of quartz grains of moderate size with siliceous cement; exterior rough.

Dimensions (in mm.)
Length of the test 1.47
Length of the uncoiled portion 1.10
Maximum width of the uncoiled portion 0.90
Maximum diameter of the coiled portion 0.37
Diameter of the last chamber 0.90

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A NOTE OF THE VALIDITY OF *HAPLOPHRAGMOIDES HAGNI* BHALLA, 1965

S N BHALLA

Aligarh Muslim University, Aligarh, India

A few new species of Foraminifera, including *Haplophragmoides hagni*, were described and illustrated by Bhalla (1965) from the type section of the Raghavapuram shales, Andhra Pradesh, India.

In a recent publication, Baksi (1966) placed *Haplophragmoides hagni* Bhalla, 1965, under the genus *Trochammina* Parker & Jones, 1859, and gave a new combination to the species *Trochammina hagni* (Bhalla) comb. The main argument of Baksi (1966, p. 8) for this taxonomic shift is that the photograph of *Haplophragmoides hagni* in apertural view is given by Bhalla (1965, fig. 2b) clearly shows the trochospiral nature of the coiling. A careful look at the above mentioned photograph, however, shows a slight distortion in the apertural view of the holotype of *Haplophragmoides hagni* which Baksi (loc. cit.) erroneously interpreted as the trochospiral nature of the coiling. A slight distortion in a planispiral test does not necessarily make it trochospiral. However, apart from the photograph, Bhalla (1965, p. 40), while describing the holotype of *Haplophragmoides hagni*, clearly mentioned that the test is “planispiral,” an important diagnostic feature probably overlooked by Baksi.

The basic difference between *Haplophragmoides Cushman, 1910*, and *Trochammina Parker & Jones, 1859*, is that, although the former is planispiral and has a partly or completely involute test, the latter is strictly trochospiral. Because *Haplophragmoides hagni* Bhalla, 1965, has a planispiral test, the present author does not find Baksi’s justification valid in transferring it to the genus *Trochammina*. Thus, according to Article 61(b) of the International Code of Zoological Nomenclature of 1961, *Trochammina hagni* (Bhalla) Baksi, 1966, becomes a subjective synonym of *Haplophragmoides hagni* Bhalla, 1965. Also, the selection of holotype and paratypes by Baksi (1966, p. 18) for his *Trochammina hagni* (Bhalla) does not conform with the recommendations of the International Commission on Zoological Nomenclature.

A careful comparison of *Haplophragmoides hagni* Bhalla, 1965, with the figures and descriptions of *Trochammina hagni* (Bhalla) as given by Baksi (1966) further reveals that the latter is not the same as *H. hagni* Bhalla, 1965. *H. hagni* differs from the forms described and illustrated by Baksi (1966) in having a planispiral and inflated test, strongly limbate sutures, entire and broadly rounded periphery, and in showing no compressional effect.

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A NOTE ON THE DEPOSITIONAL HISTORY OF
RAGHAVAPURAM SHALES, EAST COAST
GONDWANAS, INDIA

S. N. BHALLA

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A NOTE ON THE DEPOSITIONAL HISTORY OF RAGHAVAPURAM SHALES, EAST COAST GONDWANAS, INDIA

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During the course of micropaleontological studies of the East Coast Gondwanas of India, the author recovered a prolific assemblage of foraminifera from the Raghavapuram shales—a middle member of the Upper Gondwanas of east coast. The nature of the foraminiferal assemblage deserves careful attention since it lends credence to the paleoecological studies of the Raghavapuram shales. A few papers which deal, though cursorily, with the depositional history of these shales, are by Bhalla (1965) and Baksi (1966). The present note gives a brief account of the author's main findings regarding the paleoecology of the beds.

The foraminiferal assemblage of the Raghavapuram shales contains exclusively of arenaceous species which are few in number but have large population and sometimes have robust forms. The species are:—

The occurrences of exclusively arenaceous assemblage of foraminifera have been subjected to intensive studies in fossil as well as in living state. The studies of different workers reveal that the arenaceous foraminiferans generally flourish under shallow, brackish-water, rather marshy conditions where the oxygen content and pH value are low. A majority of calcareous foraminiferans are unable to thrive in such an environment and as a consequence, are generally not found in ancient sediments which were deposited under these conditions. A few calcareous species which tolerate the rigours of such an ecological niche, are rare and there is every possibility that after the death of the animal, the test may be dissolved by the toxic substances generated in the water-body by organic decay. The occurrence of arenaceous assemblage of foraminifera, therefore, indicates certain set of environmental conditions and helps in deducing the paleoecology of the beds.

The type-section of the Raghavapuram shales, from where the collection for the present study was made, is exposed near Raghavapuram village (17° 00' 02" : 81° 15' 30") in the West Godavari district of Andhra Pradesh and is about 160 feet thick. On the basis of fossil assemblage, the entire sequence can be divided into two main parts; (1) Lower.—The lower 60 to 70 feet of the shales are devoid of foraminifera but contain a few megafossils, eg., Pecten, Solon, Tellina, some ammonites, and plant remains. (2) Upper.—The upper part is about 100 feet thick and contains a large population of arenaceous foraminifera which continue up to the top of the succession. In this portion, no megafossils has been observed.

From the foregoing discussion, it is suggested that there were two distinct episodes during the life span of the Raghavapuram basin: (1) Transgressive.—During this phase, the basin was established and it had open sea connections which allowed the occasional movement of a few megafossils in it. The presence of plant remains indicates that the basin was near to the shore-line. Under these conditions, the lower 60 to 70 feet of the shale sequence was deposited. (2) Regressive.—After the first
phase, the Early Cretaceous sea gradually regressed and the basin became land-locked. It was also influenced by fresh-water due to its proximity with the land area. The water-body, thus, became brackish and marshy conditions developed resulting in the decrease of oxygen content and pH value. The upper 100 feet of the shales were laid under these conditions. This is indicated by the presence of abundant arenaceous foraminifera in this part of the shale sequence.
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PALEOECOLOGY OF THE RAGHAVAPURAM SHALES (EARLY CRETACEOUS), EAST COAST GONDWANAS, INDIA

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(Received August 9, 1968)

SUMMARY

The Raghavapuram stage, a middle division of the East Coast Gondwanas and of Early Cretaceous age, has yielded a fairly rich foraminiferal assemblage comprising entirely of arenaceous species. The dominant genera are Ammobaculites and Haplophragmoides. The foraminiferal fauna indicates that out of about 160 ft. of the sequence at the type-section of the Raghavapuram Shales, the lower 60–70 ft. of the sediments were deposited in a basin having open-sea connection. Later on, the basin gradually became land-locked and the rest of the column was deposited in a shallow, brackish-water, near-shore, rather marshy environment having low oxygen, low pH, and low salinity values.

INTRODUCTION

The Raghavapuram stage is the middle division of the East Coast Gondwanas of India. It occupies an important place in the Gondwana stratigraphy because unlike other fresh-water stages of the East Coast Gondwanas, it is marine in nature. It contains mega- as well as micro-fossils which are interesting and significant from the point of view of age determination and also in interpreting the environment of deposition. During the course of a micropaleontological investigation of the East Coast Gondwanas, the author (BHALLA, 1965, 1969) recorded a fairly rich assemblage of Foraminifera from the type-section of the Raghavapuram Shales consisting exclusively of arenaceous species. In all, fifteen species of Foraminifera were found. The species are: Saccammina lagenoides (Crespin), Ammopemphix sp., Ammodiscus cf. A. cretaceus (Reuss), Haplophragmoides concavus (Chapman), H. cf. H. dickinsoni Crespin, H. hagni Bhalla, H. kirki Wickenden, H. wilguyensis Crespin, Ammobaculites crespinae Bhalla, A. indicus Bhalla, A. irregulariformis Bartenstein and Brand, A. cf. A. polythalamus Loeblich, A. raghavapuramensis Bhalla, A. hoferi Bhalla, and A. sahni Bhalla. Although a few papers have been published on the Foraminifera
Fig. 1. Localities of the Raghavapuram Shales. A. Type-locality of the Raghavapuram Shales, on the northern side of the 512 ft. hill (view looking southeast). B. Photograph showing a typical exposure of the Raghavapuram Shales (Bed B.12) at the type-section.
of the Raghavapuram Shales, no significant study of the paleoecology of these beds has yet been made. It is BAKSI (1966) who dealt with the environment of deposition of the Raghavapuram Shales in some detail.

The sequence of various stages in the area is given in Table I.

Table I

THE SEQUENCE OF VARIOUS STAGES IN THE UPPER GONDWANAS OF THE EAST COAST

<table>
<thead>
<tr>
<th>Stage</th>
<th>Fossils</th>
<th>Lithology</th>
<th>Environment</th>
<th>Age</th>
</tr>
</thead>
<tbody>
<tr>
<td>Upper Gondwanas</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tirupati</td>
<td>plants and a few animals</td>
<td>sandstones</td>
<td>fresh-water</td>
<td>Middle Cretaceous</td>
</tr>
<tr>
<td>Raghavapuram</td>
<td>animals, including Lower-Cretaceous ammonites and Foraminifera, and a few plants</td>
<td>shales</td>
<td>marine to marsh</td>
<td>Lower Cretaceous</td>
</tr>
<tr>
<td>Golapilli</td>
<td>plants</td>
<td>sandstones</td>
<td>fresh-water</td>
<td>Jurassic</td>
</tr>
</tbody>
</table>

Detailed sampling of the Raghavapuram Shales at the type-section (Fig.1A–B), exposed on the northern slope of 512 ft. hill, about one and half mile east of the Raghavapuram village 17°N 81°E in Andhra Pradesh (Fig.2), was done for micropaleontological studies.

_Palaeeoalogy, Palaeolimol., Palaeocool.,_ 5 (1968) 345-357
HISTORICAL RECAPITULATION

Very little work has been done on the paleoecology of the Raghavapuram Shales.

BHALLA (1965) described six new species of Foraminifera from the type-section of the Raghavapuram Shales and, on foraminiferal evidence, surmised that the shales were deposited in a shallow, brackish-water, rather marshy environment.

BAKSI (1966) described Foraminifera from the Raghavapuram Shales and also dealt with the paleoecology of the beds. On the basis of Foraminifera, he suggested that the lower and middle members of the Raghavapuram Shales were deposited in a near-shore, brackish-water, lagoonal environment while the sediments of the upper member were laid down in a slightly different environment marked by the establishment of open-sea connections.

The present work is the first comprehensive study of the paleoecology of the Raghavapuram Shales. The results, however, do not support the contentions of BAKSI (1966), mentioned above.

PALEOECOLOGY

The paleoecological studies of sediments older than Tertiary can only be made in a generalised way. Many workers, including NATLAND (1957), SKOLINCK (1958), PHLEGER (1960), BURNABY (1962), AGER (1963) have cautioned against comparing Cretaceous and other pre-Tertiary fossil assemblages with Recent ones. However, the Raghavapuram faunal assemblage (both micro and mega) shows certain characteristics and peculiarities and on the basis of these, the following generalised conclusions regarding the paleoecology of the beds may be made.

A characteristic feature of the fossils of Raghavapuram Shales is that the assemblage contains an admixture of fossil fauna and flora. The fossil fauna includes micro- as well as mega-fossils. The former comprise only the arenaceous Foraminifera predominantly belonging to the genera Ammobaculites and Haplophragmoides which occasionally have robust specimens. The fauna includes seven species of Ammobaculites, five species of Haplophragmoides, and one each of Saccammina, Ammodiscus, and ?Ammopemphix. None of the species recorded, however, survives to Recent times. The foraminiferal tests are usually much contorted and deflated in the upper beds (B/16). The calcareous and/or planktonic forms are completely absent. All the arenaceous forms have simple internal structure and no form like Cyclammina with labyrinthic or alveolar structure was found in these sediments. The megafossils, e.g., Solen, Tellina, Pecten, various ammonites, etc., are restricted to the lower beds (B/1–10) while the Foraminifera are found only in the upper beds (B/11-16), (Fig.3).

Foraminiferal assemblages, exclusively arenaceous, have been recorded by many workers from the Cretaceous of different parts of the world, e.g., HEDBERG

*Palaeogeography, Palaeoclimatol., Palaeoecol.*, 5 (1968) 345-357
### PALEOECOLOGY OF THE RAGHAVAPURAM SHALES

<table>
<thead>
<tr>
<th>STAGE</th>
<th>THICKNESS</th>
<th>COLUMN NUMBER</th>
<th>FORAMINIFERA</th>
<th>MARINE LITHOSTATOS</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Legend for Foraminifera**
- Slageninae
- Ammobaculites cf. A. irregulariformis
- Foraminifera absent

**Lithology**
- Vesicular sandstones
- Soft, later itaid, sandstones
- Clays with clay-ironstone concretion
- Sandy beds
- Sandy shales
- Soft shales
- Hard shales

**Color Symbols**
- Brown yellow
- White
- Ferruginous: dark browned & yellow
- Light colored with purple & yellow blotches
- Pale with purple spots & blotches
- Brownish yellow
- Pale green to buff
- Yellowish brown to buff
- Brown to buff with yellow blotches
- Buff

Fig.3. Stages in the evolution of Raghavapuram Basin. A. Near-shore, shallow-water, open-sea environment. B. Regression of the sea and the development of marshy conditions.

*Palaeogeography, Palaeoclimatol., Palaeoecol.*, 5 (1968) 345-357

Explanation of figs. 3 to 4 have got reversed in printing.
(1934) from Venezuela, BOLIN (1956) from Minnesota (U.S.A.), SKOLNICK (1958) from the Black Hills area (U.S.A.), EICHER (1960) from Wyoming (U.S.A.); GEROCH (1960) from Lagota Beds of Silesian Carpathians, TAPPAN (1962) from Alaska, and CRESPIN (1963) and LUDBROOK (1966) from Australia, among others. CRESPIN (1963) and LUDBROOK (1966) obtained a rich arenaceous foraminiferal assemblage from certain Lower-Cretaceous beds of Australia. Many of the Australian forms are common or closely related to those from the Raghavapuram area.

In the present-day seas, similar arenaceous assemblages have been recorded and studied, among others, by LOWMAN (1949), PHLEGER and WALTON (1950), ELLISON (1951) STAINFORTH (1952), PARKER (1952), PARKER and AHERAN (1959), WALTON (1955, 1964), LANKFORD (1959), BANDY (1956, 1960, 1963), BANDY and ARNAL (1960), PHLEGER (1960), and PHLEGER and BRADSHAW (1966). A survey of the literature referred to above shows that in the majority of cases the maximum population of arenaceous species of Foraminifera is restricted to a near-shore, brackish-water, marsh or lagoonal environment where the basin of deposition is rather land-locked with little or no open-sea connection.

The predominance of arenaceous species in an assemblage (almost to the exclusion of calcareous forms) is attributed to different ecological factors by different workers. However, a majority including HEDBERG (1934), LOWMAN (1949), LOEBLICH and TAPPAN (1950), BANDY (1956), TAPPAN (1962), and POKorny (1963), consider salinity to be an important controlling factor for such assemblages. WALTON (1955) attributes this to lack of calcium carbonate content in the seawater. STAINFORTH (1952), LAUGHBAUM (1960), and CRESPIN (1963), consider turbidity to be an important controlling factor for such arenaceous assemblage of Foraminifera that have large and robust forms. PHLEGER (1960), however, is of the opinion that turbidity is not directly responsible for the distribution of arenaceous Foraminifera. According to BOLIN (1956) and WALTON (1964), a predominantly arenaceous assemblage of Foraminifera indicates a near-shore, brackish-water environment. Similar assemblage of Foraminifera with Ammobaculites, Haplophragmoides, Trochammina, and Trochamminoides as dominant genera, have been recorded from the Lower Therrill member of the Gulf Coast Eocene (U.S.A.), which are considered to have been deposited in swamp or coastal marsh (fide BURST, 1958). BHATIA and SINGH (1959) recorded a prolific, exclusively arenaceous, assemblage of Foraminifera from the Upper Carboniferous of central India and attributed it to shallow, rather brackish-water, environment.

The majority of foraminiferal species cannot survive wide range salinity fluctuations which is a common feature in marsh or brackish-water environment. In marsh environment, there is a great variation in salinity values and this is mainly related to the tidal flushing (PHLEGER and BRADSHAW, 1966). The abundant plant remains and organic decay generally found in these environments, reduce the oxygen-content of the water-body thus precluding the growth of many for-
mineral genera. The few arenaceous genera which can tolerate such an environment include Ammobaculites, Haplophragmoides, and Trochammina. The Ammobaculites–Trochammina assemblage is reportedly characteristic of low-salinity, brackish-water near-shore environment e.g., Lowman (1949), Phleger and Walton (1950), Bandy (1956, 1960), and Walton (1964). Phleger (1960), while discussing the marsh fauna observed that the foraminiferal assemblage of this environment is characterized by mostly or exclusively arenaceous, benthonic forms representing 5-8 species and 3-8 genera. The occurrence of limited number of species in marshes is attributed by Walton (1955, 1964) to considerable variation in temperature and salinity. Lankford (1959), while describing the foraminiferal fauna of a marsh environment, observed that the fauna was predominantly arenaceous, represented by a few species and large populations with poorly cemented tests. Tappan (1962) and Pokorny (1963) are of the view that because of little competition in such environment, a limited number of foraminiferal species are able to thrive freely and, as a consequence, large populations of these species are found. Bandy (1956) and Behm and Grekulinski (1958) consider that there is an interrelationship between Foraminifera and marsh flora. This may be one of the reasons for large populations of some species of Foraminifera in such an environment. It is also possible that the provenance was an almost peneplained area resulting in the slow rate of sedimentation. This might have allowed the development of high frequency of foraminiferal species in Raghavapuram Shales.

An important feature of shallow brackish-water environment is that the calcareous species of Foraminifera are usually rare. This feature has been observed both in fossil as well as in Recent assemblages. Studies on Recent fauna indicate that under such environments, the organic decay results in reducing conditions and that toxic substances, including acids, are produced which result in the dissolution of calcareous tests. Under such ecological conditions it is the arenaceous group which will be preserved. This is, perhaps, one of the reasons why in ancient sediments that were deposited under marsh environments the calcareous forms are extremely rare (Parker and Atlehorn, 1959). According to Walton (1955) the dominance of arenaceous foraminifers in marshes may be due to poor percentage of calcium carbonate in marsh water. Bolin (1956) observed that almost the total absence of calcareous species indicates either low temperature or low pH or a combination of these two factors. However, Bandy and Arnal (1960) are of the view that one of the causes for the absence of calcareous species in fossil assemblages may be the post-depositional changes which dissolve the calcareous tests leaving behind the agglutinated forms. Phleger (1960) attributes low pH value to be the cause for low percentage of calcareous species in such environments. Phleger and Bradshaw (1966) while working on the sedimentary environment in a marine marsh, Mission Bay, Calif, observed that low pH value is an important characteristic of marine marshes and it has got direct control over the occurrence of organisms in such an environment. Bandy (1963) also noted.
that there is considerable fluctuation in the pH values (5.7–6.9) of marshes and, under these conditions, only arenaceous and siliceous species of Foraminifera escape dissolution forming the dominant elements of the foraminiferal population of marshes. Bandy’s idea gets credence from lab studies of Murray (1967). Murray studied the effects of lowered pH on foraminiferal tests in lab cultures. He observed that at pH 7 or below, the tests of calcareous foraminifera became etched and weak within a short span of time. In the light of Murray’s experiments, it is reasonable to infer that in environments having low pH value, there will be dissolution of calcareous foraminifers and the sediments which were deposited under such conditions will be devoid of calcareous tests of Foraminifera.

It is highly unlikely that post-depositional changes were responsible for the complete absence of calcareous Foraminifera in the assemblage from the Raghavapuram Shales as no fragmentary remains or casts, etc., of calcareous Foraminifera have been observed in the present material. It appears more probable that factors like reducing conditions presence of toxic substances and low pH values characteristic of brackish and marshy environments, were the dominant controlling factors which inhibited the growth of calcareous Foraminifera in these sediments.

Another important feature of the foraminiferal fauna of brackish-water near-shore environments is that the tests are usually much compressed and distorted. Bhalla and Singh (1959) while commenting on the work of Arnold (1954) on the laboratory cultures of Discorinopsis aquarum (Bermudes) considered variation in salinity to be the main cause for contortion in the foraminiferal tests. Bhalla (1969) discussed the causes of compression in Ammobaculites and pointed that it may be either due to the growth of a heavy network of algae on the test or the position of the animal with respect to the substratum at the time of its growth, besides other factors. Similar assemblages, containing distorted tests of arenaceous foraminifers, have been obtained by various workers including Bolin (1956) from the Upper Cretaceous of Minnesota, Tappan (1962) from the Cretaceous of Alaska, Crespin (1963) and Ludbrook (1966) from the Lower Cretaceous of Australia, and many others. A considerable range of variation has been observed in certain species of Ammobaculites and Haplophragmoides in the present material e.g. Ammobaculites irregulariformis, A. hoffkeri, A. cespinae, A. raghavapuramensis Haplophragmoides wilgumacum, etc. In the upper beds (B/16), deflated tests of Haplophragmoides concavus occur in great abundance. The ecological factor or factors chiefly responsible for contortion and deflation of tests in Lituolidae are not clearly understood but salinity, postmortal compression, and pH value have been considered to be responsible for such deflations in the tests. However, this requires careful studies in laboratory cultures before any definite conclusions can be drawn.

In recent years, Bandy (1960) and Bandy and Arnal (1960) have made an attempt to correlate foraminiferal structures with the environment. These authors are of the opinion that the arenaceous forms with simple interiors e.g. Am-
molasculites, *Haplophragmoides*, *Trochammina*, etc., are predominant in near-shore, bay, lagoonal, or estuarine environment and such forms are very abundant under low pH and low salinity conditions of some estuaries. On the other hand, forms with complicated interiors, e.g., *Cyclammina*, etc., are characteristic of deep waters. In a recent publication, BANDY (1963) observed that the dominant members of the

**TABLE II**

**DISTRIBUTION AND FREQUENCY OF FORAMINIFERA IN THE RAGHAVAPURAM SHALES (TYPE-SECTION)**

<table>
<thead>
<tr>
<th>Sample numbers</th>
<th><em>Foraminifera</em></th>
<th>DISTRIBUTION</th>
<th>FREQUENCY</th>
</tr>
</thead>
<tbody>
<tr>
<td>B 13-1</td>
<td><em>Haplophragmoides concavus</em> (Chapman)</td>
<td>A</td>
<td>A</td>
</tr>
<tr>
<td>B 12-7</td>
<td><em>Haplophragmoides? liai</em> BHALLA</td>
<td>A</td>
<td>A</td>
</tr>
<tr>
<td>B 12-6</td>
<td><em>Haplophragmoides? smalli</em> BHALLA</td>
<td>A</td>
<td>A</td>
</tr>
<tr>
<td>B 12-5</td>
<td><em>Ammonia? indicus</em> BHALLA</td>
<td>A</td>
<td>A</td>
</tr>
<tr>
<td>B 12-4</td>
<td><em>Ammonia? regulariformis</em> BARTELS and BHALLA</td>
<td>A</td>
<td>A</td>
</tr>
<tr>
<td>B 12-3</td>
<td><em>Ammonia</em> sp.</td>
<td>A</td>
<td>A</td>
</tr>
<tr>
<td>B 12-2</td>
<td><em>Ammonia</em> sp.</td>
<td>A</td>
<td>A</td>
</tr>
<tr>
<td>B 11-4</td>
<td><em>Ammonia</em> sp.</td>
<td>A</td>
<td>A</td>
</tr>
<tr>
<td>B 11-3</td>
<td><em>Ammonia</em> sp.</td>
<td>A</td>
<td>A</td>
</tr>
<tr>
<td>B 11-2</td>
<td><em>Ammonia</em> sp.</td>
<td>A</td>
<td>A</td>
</tr>
<tr>
<td>B 11-1</td>
<td><em>Ammonia</em> sp.</td>
<td>A</td>
<td>A</td>
</tr>
<tr>
<td>B 10*</td>
<td><em>Ammonia</em> sp.</td>
<td>A</td>
<td>A</td>
</tr>
</tbody>
</table>

*A* = abundant; *F* = frequent; *R* = rare; *£* = Foraminifera absent

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marsh foraminiferal fauna include arenaceous forms having simple interiors. In
the Raghavapuram Shales, all the forms are with simple interiors. If the above
mentioned surmise is correct, then, it is likely that these shales were deposited in a
near-shore, shallow-water, rather marshy environment having low pH and low
salinity conditions.

The meagre megafossil fauna comprising Tellina, Pecten, Solen, etc., is
restricted to the lower beds (B/1-10) which are completely devoid of foraminifers
(Table II). PLUMMER (1933), who recorded Tellina from the Jackson-group (Upper
Eocene) in Texas, considered it to be indicative of a near-shore, sandy-bottom
environment. In the present-day seas, Tellina has been found by LADD et al. (1957)
in near-shore environments at a depth of 21/2 ft. Similarly, Pecten is also a near-
shore form (Adkins, 1918) BANDY (1958), while working on the mollusks of the
San Pedro Basin, California, found Tellina, Pecten, and Solon to be dominant in
the shallow waters of the basin

A number of plant fossils have also been found associated with marine fauna
in these Cretaceous beds. Whether these plant fossils are indigenous or exotic is a
matter of controversy and beyond the scope of the present work However,
PASCOE (1959, p.1007) had the following interesting comments to make with
regard to this peculiar admixture of plant-remains with marine fauna: “It seems
possible for blocks of plant-bearing Jurassic rocks to have fallen, in Early-Creta-
ceous times, from low cliffs into some protected delta or coastal lake... and to
have become intimately mixed with ammonite-bearing Cretaceous sediments”. If
Pascoe’s contention is correct, then, it is likely that the basin in which the Raghava-
apuram Shales were deposited was close to the shore-line, possibly cut off from the
main sea.

CONCLUSION

From the foregoing discussion, it may be concluded that the deposition of
the Raghavapuram Shales commenced in a near-shore, shallow-water environment
which had open-sea connection, thus allowing the free but sporadic movement
of a few ammonite and other megafossils to the site of deposition (Fig.4A).
Thereafter, the sea regressed and the basin gradually became land-locked. The
salinity of the water-body also decreased appreciably due to intake of fresh-water
from the adjacent land-area resulting in the development of marshy conditions
(Fig.4B) This is evident from the exclusive occurrence of arenaceous Foraminifera
in the upper beds (B/11-16) of the Raghavapuram Shales (Table II). Foraminiferal
assemblage similar to that of the Raghavapuram Shales containing exclusively of
arenaceous forms in the present-day seas, are found in shallow, brackish-water,
near-shore, marsh-environment, having low oxygen, low pH, and low salinity
values.

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ACKNOWLEDGEMENTS

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*Palaeogeography, Palaeoclimatol., Palaeoecol.*, 5 (1968) 345-357
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PALEOECOLOGY OF THE RAGHAVAPURAM SHALES


*Palaeogeography, Palaeoclimatol., Palaeoecol.*, 5 (1968) 345-357
ABSTRACT
A systematic study of the foraminiferal fauna from the type section of the Raghavapuram Shales has revealed the presence of a fairly rich assemblage consisting entirely of arenaceous forms. Fifteen species of foraminifera are described and illustrated. The dominant genera are *Haplophragmoides* and *Ammobaculites*. The foraminifera suggest a Lower Cretaceous age for the Raghavapuram Shales. The assemblage shows close affinity with those described from the Lower Cretaceous of the Great Artesian Basin, Australia.

INTRODUCTION
The rocks of the Gondwana System have attracted a great deal of attention since they were first described by Feistmantel in 1876, mainly because of the vast reserves of coal and the prolific fossil flora and fauna preserved in this thick pile of sediments, mostly fresh-water but in some places marine, and ranging in age from Upper Carboniferous to Lower Cretaceous. The study of this system is interesting and of great scientific value because of its relation to the theory of continental drift.

In India, although a lot of paleobotanical work has been done on the Gondwanas, no significant study of its fossil microfauna has yet been made. Of the various marine exposures of the Peninsular Gondwanas, those found on the east coast of India are by far the best developed and most interesting, and are commonly designated as "East Coast Gondwanas". The rocks are especially interesting because occasionally the marine fauna and the land flora are found preserved in a single bed, sometimes even "together in the same hand specimen", to quote Pascoe (1959, p. 1004).

The Upper Gondwana rocks of the east coast occur in a chain of isolated outliers from near Cuttack to Trichinopoly, approximately parallel to the eastern coast line of the Indian Peninsula. The beds dip at low angles towards the east or southeast, and are mostly covered by laterite and alluvium.

The present work was primarily undertaken to study the little-known microfaunal assemblages in the marine beds of the East Coast Gondwanas. It was felt that this study might be very useful in fixing the controversial upper age limit of the Gondwanas of the east coast.

Nearly all of the type localities of the marine beds of the East Coast Gondwanas, except those of the Siperumbudur area, were visited (text-figure 1), and bed-by-bed samples were collected from each locality for micropaleontological study.

The Raghavapuram Shales, a middle division of the Upper Gondwanas of the east coast and of Lower Cretaceous age, have yielded a fairly rich assemblage of arenaceous foraminifera consisting of fifteen species, whereas the homotaxial beds of the Vammevaram area, as well as the marine equivalents of the Tirupati Sandstones at Ayaparaz-Kotapilli, are devoid of microfauna. The foraminifera of the Raghavapuram Shales at the type section are quite rich in number of specimens but not in number of species and genera. In the present material calcareous forms were not observed.
TEXT-FIGURE 1
Location map of the areas visited

he Raghavapuram Shales were named by King (1877, p 56) after the village of Raghavapuram (Survey of India topographical sheet no 65 G/8, lat 17° 00' 02" N, long 81° 15' 30" E) in the West Godavn District, Andhra Pradesh (text-figure 1), near which the type section of these shales is exposed. It is one of the important and well-studied localities of the Upper Gondwanas of the Ellore region and is of particular interest because, in a small area of about 8 sq miles, nearly all of the three stages of the Upper Gondwanas of the east coast are exposed. About 10 sq miles of the area were geologically mapped (text-figure 2), and a detailed sampling of the Raghavapuram Shales at the type section was carried out.

PAST WORK
Little work has been done on the foraminifera from the East Coast Gondwanas.

King (1880, p 221), in his monumental work on the East Coast Gondwanas, drew attention to the presence of foraminifera in the Raghavapuram Shales, although no identifications were given.

Bhalla (1965) described and illustrated six new species of foraminifera from the type section of the Raghavapuram Shales. These were Haplophragmoides hagni sp nov, Ammobaculites crespinae sp nov, Ammobaculites hofkeri sp nov, Ammobaculites indicus sp nov, and Ammobaculites sahnu sp nov. On foraminiferal evidence, he suggested a shallow, brackish-water, rather marshy environment of deposition and supported the Lower Cretaceous age assigned to the beds by the earlier workers.

Sastri, Chandra and Pant (1961, 1963) reported foraminifera from the Raghavapuram Shales exposed near Tirupati village in Andhra Pradesh. These authors have recorded an exclusively arenaceous fauna with Ammobaculites and Haplophragmoides as dominant genera. They described Ammobaculites fisheri var tirupatimensis var nov, Haplophragmoides concava (Chapman) and H chapmani Crespin in their work, and assigned a Lower Cretaceous age to the Raghavapuram Shales on the basis of the foraminiferal evidence.

Murthy and Sastri (1960, 1962), recorded and described the foraminiferal fauna from the Siperumbudur Beds (homotaxial with the Raghavapuram Shales) near Madras. They identified Bathysiphon cf taunnensis Sacco, Pelosina complanata Franke, Ammodiscus cretaceus (sic) (Reuss), Litotuba sp, Haplophragmoides dickinsonii (sic) Crespin, H concava (Chapman), H footei sp nov, H indicus sp nov, Ammobaculites sp and Spiroplectammnina indica sp nov, and described two indeterminate genera from these beds. On the basis of the foraminifera, they concluded that these sediments were deposited in a shallow brackish-water environment and are of Lower Cretaceous age.

Baksi (1966) described foraminifera from the Raghavapuram Shales exposed near Barakonda and Darasani-padu villages. Twelve species of foraminifera were described and calcareous foraminifera, represented by the genus Nonion Montfort, were reported. Baksi (op cit) identified the following species of foraminifera from the Raghavapuram Shales: Ammobaculites funiculans n sp, A phlegen n sp, A globosa n sp, A crespinae Bhalla, A hofkeni Bhalla, A indicus Bhalla, A sahnu Bhalla, Trochammnina hagni (Bhalla) comb nov, T stellifera n sp, T sp cf T whittingtoni Tappan, Nonion presublaeve n sp and N barakondai n sp. According to Baksi (op cit), the Raghavapuram Shales, on the whole, were deposited in a near-shore, brackish-water environment. He suggested a post-Jurassic but pre-Upper Cretaceous age for the Raghavapuram Shales.
STRATIGRAPHY
King (1880) recognized the following sequence in the area under review:

Upper Gondwanas — Tirupati Sandstones
Raghavapuram Shales
Golapilli Sandstones

Lower Gondwanas — Chintalpudi Sandstones and conglomerates

A good section of the Raghavapuram Shales is exposed on the steep northern slope of the hill with an altitude of 512 feet situated about one and a half miles east of Raghavapuram village. King designated this as the 'type section' of the Raghavapuram Shales, which occupy the major part of the area under investigation. The type section is well exposed and almost complete, and it is here that the detailed sampling was done. The shales are white, buff and purple, and include a few sandstone intercalations. The beds dip at low angles (5° to 10°) in a southeast direction. The succession, as interpreted by the author at the type locality of the Raghavapuram Shales, is in general the same as that described by King (1880), but differs in some minor details. The succession, in descending order, is as follows:

<table>
<thead>
<tr>
<th>Sample no</th>
<th>Lithology</th>
<th>Thickness (in feet)</th>
</tr>
</thead>
<tbody>
<tr>
<td>B/T</td>
<td>Tirupati sandstones — hard, dark coarse and gritty</td>
<td>5</td>
</tr>
<tr>
<td>B/17</td>
<td>Vesicular brown and yellow sandstones</td>
<td>3</td>
</tr>
<tr>
<td>B/16-1 to B/16-2</td>
<td>Soft white shales</td>
<td>6</td>
</tr>
</tbody>
</table>
BHALLA

B/15  15 Soft, irregularly vesicular latentoid sandstones.
B/14-1 to B/14-3  14 White shales.
B/13-1 to B/13-5  13 Ferruginous dark brown red yellow and purple clays with two or three seams of clay ironstone concretions (up to 1/2 feet in width and 2 feet in length) having very hard cores.
B/12-1 to B/12-7  12 Light-colored sandy shales with purple and yellow blotches and with about 6 feet of whitish shales towards the top. At 15 feet from the base they become more purple and at 20 feet to 25 feet more yellowish. Junction between the yellow and purple shales is well marked.
B/11-1 to B/11-4  11 Pale finely sandy shales, rough to the touch, with purple spots and blotches and tubiform bodies.
B/10  10 Soft buff shales.
B/9  9 Brownish-yellow sandy shales.
B/8  8 Soft buff shales covered by talus.
B/7  7 Pale green to buff shales.
B/6  6 Soft buff shales.
B/5  5 Yellowish-brown to buff sandy shales.
B/4  4 Soft buff shales.
B/3  3 Brown to buff shales with yellow blotches.
B/2  2 Buff shales, rather hard.
B/1  1 Buff shales splintery, mostly covered by talus.

Golapilli sandstones and conglomerates

The hard, dark, ferruginous Golapilli sandstones and conglomerates crop out a short distance north of the type section of the Raghavapuram Shales and are separated from the hill by a slight depression at its base. This depression is filled up by the talus derived from the Raghavapuram Shales, and covers the junction between the Golapilli and the Raghavapuram, which is not clearly seen in the area.

At the foot of the hill, the buff shales (Bed 1 of the succession) makes its first appearance from below the talus and from there the whole succession of the Raghavapuram Shales stretches towards the top of the hill. At the top, the Tirupati Sandstones conformably overlie the whole succession.

Both plant and animal remains have been found in the Raghavapuram Shales by earlier investigators. Feistmantel (1879) identified plant and some animal fossils from these beds. Pascoe (1959, p. 1001) has given a list of the fossil fauna. The most frequently found fossil is the cast of a species of *Leda* Schumacher. Other pelecypod genera, including *Gervillia* Defrance, *Mytilus* Linnaeus, *Trigonia* Bruguière, *Pecten* Muller and *Tellina* Linnaeus, ammonites, and fish scales have also been recovered from these shales. The ammonites are not well preserved.

**METHODS**

The usual procedure of crushing the samples, boiling them in detergents and screening them through a set of standard sieves has been followed in the present work. The foraminifera were picked out with a fine sable-hair brush and arranged in squared slides for identification and study.

The foraminifera from the Raghavapuram Shales are exclusively arenaceous in nature and show considerable variation, which often makes the identification difficult. Great emphasis has been laid in the present study on working out the range of variation shown by different species. Likewise, dimorphism is also considered to be an important feature and, wherever possible, the dimorphic generations are described and illustrated.

In order to study the internal structure (including the proloculus) of the arenaceous foraminifers, the specimens were first thoroughly cleaned and then kept immersed for about two days in xylene contained in a glass cavity slab. The cavity slab was then placed on the stage of a stereoscopic binocular microscope. The reflecting mirror was so adjusted that a contrast was developed between the specimen and the xylene. Natural light was found more suitable than artificial light. However, in some cases where this method was not found workable, thin sections were prepared in order to study the internal structure, size of the proloculus, etc.

**DISPOSITION OF TYPES**

The holotypes and paratypes of the species erected by the author have been housed in the museum of the Geology Department, Punjab University, Chandigarh, and their references are designated by a PUGD Catalogue number in the text. As mentioned earlier, the author (Bhalla, 1965) in an advance note reported the occurrence of six new species of foraminifera from the type section of the Raghavapuram Shales, but the detailed description of each species, including those erected by the author (Bhalla, 1965), is given in the present paper. In the following pages, the classification of foraminifera proposed by Loeblich and Tappan (1964) has been followed. The different species within a single genus are arranged alphabetically. Figures for the plates have been drawn by the author from his original camera lucida sketches.
**SYSTEMATIC PALEONTOLOGY**
Order FORAMINIFERIDA Eichwald, 1830
Suborder TEXTULARIINA Delage and Hérouard, 1896
Superfamily AMMODISCIDAE Reuss, 1862
Family SACCAMMINIDAE Brady, 1884
Genus SACCAMMINA Sars in Carpenter, 1869

*Saccammina lagenoides* (Crepin)
Plate 1 figure 1

*Pelosina lagenoides* Crepin, 1953, p 28, pl 5, fig 1
*Saccammina lagenoides* (Crepin) — Ludbrook, 1966, p 81, pl 1, fig 9

**Description**
Test free, deflated, elongate, flask-shaped, wall composed of very fine quartz grains, aperture simple, oval due to compression, terminal with a very short neck

**Dimensions**
Length 0.53 mm, maximum breadth 0.27 mm, thickness 0.10 mm

**Discussion**
Only a single specimen was found in our material. It shows very close resemblance to *Saccammina lagenoides*, described by Crepin (1953) from the Lower Cretaceous of the Great Artesian Basin, Australia. Dr Nell H. Ludbrook, of the Geological Survey of South Australia, who checked the identification of the Indian specimen of *S. lagenoides*, was of the opinion that the Indian and Australian forms are similar. The author agrees with Ludbrook (1966, p 81) in transferring this species from *Pelosina* to *Saccammina*.

**Occurrence**
Rare in sample B/16-2

Subfamily HEMISPHAERAMMININAE Loeblich and Tappan, 1961
Genus AMMOPEMPHIX Loeblich, 1952

*?Ammopemphix* sp
Plate 1, figure 2

**Description**
Test plano-convex, more or less circular in outline, with four chambers, chambers somewhat polygonal in outline and well marked, aperture visible in only one chamber, obscure in the rest; wall thin, composed of fine sand grains, smoothly finished

**Dimensions**
Diameter 0.33 mm.

**Discussion**
A solitary, broken, poorly preserved specimen which may be compared with *Ammodicus cretaceus* (Reuss) was found in our material. The types of this species are from the Bohemian Planermergel (Turonian). This species was recorded by Cushman (1944, 1946, 1949) from the Upper Cretaceous of the USA. Crepin (1955, 1963) and Ludbrook (1966) reported it from the Lower Cretaceous of the Great Artesian Basin, Australia. Recently, Murthy and Sastri (1960, 1962) have described this species from the Sriperumbudur Beds (Lower Cretaceous) near Madras.

**Occurrence**
Rare in sample B/16-2

Superfamily LITUOLACEA de Blainville, 1825
Family LITUOLIDAE de Blainville 1825
Subfamily HAPLOPHRAGMOIDINAE Maync, 1952
Genus HAPLOPHRAGMOIDES Cushman, 1910

*Haplophragmoides concavus* (Chapman)
Plate 1, figure 4

*Trochammina concava* Chapman, 1892, p 327, pl 6, fig 14a–b
*Haplophragmoides concava* (Chapman) — Tappan, 1940, p 95, pl 14 fig 7a–c, 1943 p 481, pl 77, fig 7a–b — Murthy and Sastri, 1960, p 215, 1962 p 450, pl 12, figs 9–10 — Sastri, ChandrA and PANT, 1961, p 81, 1963 p 312 pl 36, figs 6–8

**Description**
Test thin, compressed, planispirally coiled, involute, four or five chambers in the last whorl, gradually increasing in size with growth, usually not

Family AMMODISCIDAE Reuss, 1862
Subfamily AMMODISCINAE Reuss, 1862
Genus AMMODISCUS Reuss, 1862

*Ammodicus* sp cf *A. cretaceus* (Reuss)
Plate 1, figure 3

*Cf. Operculina cretacea* Reuss, 1845, p 35, pl 13, figs 64–65
*Cf. Cornutspira cretacea* (Reuss) — Reuss, 1860, p 177, pl 1, fig 1
*Cf. Ammodiscus cretaceous* (Reuss) — Cushman, 1944, p 2, pl 1, fig 2, 1946, p 17, pl 1, fig 35, 1949, p 2, pl 1, fig 3 — Crepin, 1955, p 82, 1963, p 26 pl 2, figs 6–7 — Ludbrook, 1966 p 82, pl 4, fig 23

**Description**
Test free, discoidal, compressed, slightly distorted, nearly circular in outline, initial chamber followed by a second chamber in the form of a long, planispiral, coiled tube, gradually increasing in size, forming about four coils, spiral suture fairly clear, periphery somewhat rounded, sides depressed due to compression, aperture obscure, formed by the open end of the tube, wall thin, finely arenaceous

**Dimensions**
Maximum diameter 0.43 mm, maximum thickness 0.07 mm

**Discussion**
A solitary, broken, poorly preserved specimen which may be compared with *Ammodicus cretaceus* (Reuss) was found in our material. The types of this species are from the Bohemian Planermergel (Turonian). This species was recorded by Cushman (1944, 1946, 1949) from the Upper Cretaceous of the USA. Crepin (1955, 1963) and Ludbrook (1966) reported it from the Lower Cretaceous of the Great Artesian Basin, Australia. Recently, Murthy and Sastri (1960, 1962) have described this species from the Sriperumbudur Beds (Lower Cretaceous) near Madras.

**Occurrence**
Rare in sample B/16-2
BHALLA

well marked, "collapsed", concave, triangular in outline; sutures straight, slightly depressed; periphery lobulate, subacute; umbilicus depressed; aperture indistinct; wall thin, finely arenaceous, smoothly finished.

Dimensions: Maximum diameter 0.30 to 0.50 mm., minimum diameter 0.23 to 0.37 mm., thickness 0.07 to 0.13 mm.

Discussion: The type of Haplophragmoides concavus is from the Gault of Folkstone. The species is cosmopolitan and has been recorded from the Lower Cretaceous of America, middle and upper Valanginian of north Germany, Albian of France and England; Infra-Valanginian, Valanginian, and Hauterivian of central Poland; Lower Cretaceous of Australia, etc. In India, this species has been recorded by Murthy and Sastri (1960, 1962) from the Sripurumbudur Beds (Lower Cretaceous) near Madras. Sastri, Chandra and Pent (1961, 1963) have reported it from the Raghavapuram Shales near Tirupati, Andhra Pradesh.

Although our specimens differ from those figured by Chapman in having rather obscure sutures, a very small umbilicus, and smaller size of the test, they apparently come within the range of variation. However, from the Sripurumbudur forms described by Murthy and Sastri (loc. cit.), the present specimens differ in having fewer chambers in the final whorl and not so well-marked sutures.

Occurrence: Frequent in sample B/16–2.

Haplophragmoides sp. cf. H. dickinsoni Crespin
Plate 1, figure 5
Cf. Haplophragmoides dickinsoni CRESPIN, 1953, p. 29, pl. 5, fig. 6. - LUDBROOK, 1966, p. 88, pl. 2, figs. 5–6.

Description: Test small, planispiral, involute; final coil with five to six inflated well-marked, gradually enlarging chambers; sutures generally distinct, slightly depressed, straight; periphery broadly rounded, lobulate; aperture a small arched opening at the base of the last-formed chamber (interiomarginal); wall finely to moderately arenaceous, consisting of quartz grains with a fair amount of silica as the cement; surface smooth.

Dimensions: Maximum diameter 0.28 to 0.52 mm., minimum diameter 0.23 to 0.40 mm., thickness 0.18 to 0.30 mm., diameter of proloculus 49 μ.

Discussion: Our specimens can be compared with Haplophragmoides dickinsoni Crespin, described from the Lower Cretaceous of Australia. Dr. L. C. Noakes of the Bureau of Mineral Resources, Canberra, through whom the author had the Indian specimens compared with the types of H. dickinsoni deposited there, made the following comments (personal communication, 1964): "Your specimens appear to have less chambers, and the sutures between the chambers are much deeper. The outer surface of this type is smoother." Dr. Nell H. Ludbrook, of the Geological Survey of South Australia, who checked the specimens from the Raghavapuram Shales, was of the view that the Indian specimens were similar to those described by her (Ludbrook, 1966) from the Lower Cretaceous of South Australia.


Haplophragmoides hagni Bhalla
Plate 1, figures 6–7; text-figure 3
Haplophragmoides hagni Bhalla, showing the variation in the shape of the test. 1a, 2–8, side views; 1b, peripheral view.

Diagnosis: Test planispiral, slightly evolute, inflated, medium-sized; final volution consisting of eleven fairly well-marked chambers, which increase very gradually in size with growth; only two chambers of the inner whorl visible from outside; sutures straight, distinct, strongly limbate, almost flush with the surface; periphery usually entire, faintly lobulate, if at all, in the later chambers, broadly rounded; aperture an arched slit at the base of the apertural face (interiomarginal); umbilical area depressed; wall finely arenaceous, consisting of fine grains of quartz with little cement; surface smooth, somewhat shining.

Dimorphism and variation: No evidence of dimorphism was noted in Haplophragmoides hagni. It shows very little variation. The number of chambers in the last whorl varies from nine to eleven. The periphery is gener-
ally entire (text-figure 3, figures 7–8), but in a few cases it may be slightly lobulate (text-figure 3, figures 1, 3, 5). The umbilicus is generally depressed. Usually two chambers of the inner whorl are visible from outside, but in one case (text-figure 3, figure 5) three chambers have been noticed. The tests have undergone very slight distortion but apparently no compression.

**Dimensions**

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<th>Holotype</th>
<th>Paratype</th>
<th>Adult specimens</th>
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<td>Minimum diameter (mm)</td>
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<td>Thickness (mm)</td>
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<td>0.32</td>
<td>0.20 to 0.40</td>
</tr>
</tbody>
</table>

**Illustration (pl 1)**

- fig. 6a–b
- fig. 7

**Discussion**

*Haplophragmoides nigra* shows resemblance to *Haplophragmoides atahuallpai* described by Frizzell in 1943 from the Upper Cretaceous of northwestern Peru, but differs from it in having strongly limbate sutures, a broadly rounded periphery, and a slightly evolute test.

Baksi (1966) transferred *H. nigra* Bhalla, 1965, to the genus *Trochammina* Parker and Jones, 1859, and produced the new combination *Trochammina nigra* (Bhalla) Baksi. Baksi's main ground for this taxonomic shift was that the figure of *H. nigra* in apertural view (Bhalla, 1965, fig. 2b) shows the trochospiral nature of the test. The above mentioned figure, in fact, shows a slight distortion in the test which Baksi interpreted as the trochospiral coiling. A slight distortion would not transform a planispiral test into a trochospiral one. Moreover, Bhalla (1965, p. 40) clearly mentioned that the test was "planispiral", a point which Baksi probably overlooked.

The specimens figured and described by Baksi (1966, pl 1, figs 11a–b, 12a–b; pl 2, figs 2a–b, 3) as the paratype and holotype of *Trochammina nigra* (Bhalla) are not the paratype and holotype of *Haplophragmoides nigra* Bhalla, 1965. These specimens have not been seen by the author but probably belong to some other species of *Haplophragmoides*. The author does not find Baksi's justification for putting *H. nigra* Bhalla under the genus *Trochammina* valid, and therefore *T. nigra*
(Bhalla) Baksii is treated here as a synonym of *H. hagni* Bhalla

**Type horizon** Sample B/12-4, purple sandy shales

**Type locality** Type section of the Raghavapuram Shales, exposed on the northern side of the hill with an altitude of 512 feet about one and a half miles east of Raghavapuram village, West Godavari District, Andhra Pradesh, India

**Geologic age** Lower Cretaceous

**Repository of type material** Holotype, PUGD Cat no F1199, paratype, PUGD Cat no F1200

**Etymology** This species has been named in honour of Dr Herbert Hagn of the Institute of Palaeontology and Historical Geology, Munich, West Germany

*Haplophragmoides kirkii* Wickenden

Plate 1 figure 14

*Haplophragmoides kirkii* WICKENDEN 1932 p 85 pl 1 fig 1a-c – CUSHMAN, 1946 pp 21-22 pl 2 fig 23a-c

**Description** Test free, small, planispiral, closely coiled, four inflated chambers in last whorl, last chamber usually occupying nearly half of test, sutures well marked, slightly depressed, moderately curved, periphery broadly rounded, lobulate, aperture arched, interomarginal, wall finely to moderately arenaceous, consisting of quartz grains with silica as cementing material, exterior smoothly finished.

**Dimensions** Maximum diameter 0.30 to 0.43 mm, minimum diameter 0.23 to 0.37 mm, thickness 0.17 to 0.34 mm, diameter of proloculus 49 μ

**Discussion** The present form, with four chambers in its final whorl and its small size, is very similar to *Haplophragmoides kirkii* Wickenden 1932, and also to the specimens figured by Cushman (1946).

**Occurrence** Frequent to abundant in almost all of the samples.

*Haplophragmoides wilgunyaensis* Crespin

Plate 1 figure 8 - text-figure 4

*Haplophragmoides wilgunyaensis* CRESPIN, 1963 pp 32-33 pl 7, figs 1-10 – LUDBROOK, 1966, pp 89-90, pl 2 fig 8

**Description** Test free, umbilicate, planispiral, involute, generally distorted, final volution consisting of nine to twelve inflated chambers, sutures straight, slightly depressed, not very well marked, umbilical small, depressed, forming a small pit on each side, periphery lobulate, broadly rounded, apertural face with slight depression around the aperture, aperture a low arched slit, interomarginal, wall thick, arenaceous, composed of fine quartz grains with siliceous cement. Exterior surface smooth.

**Variation** A survey of the literature on the various species of the genus *Haplophragmoides* reveals that a majority of the species belonging to this genus shows great variation, apparently due to distortion and compression of the test. Some authors have even suggested that the compression of the test is of specific importance. For example, Marks (1961, p. 35), while describing the new species *Haplophragmoides obliquicameratus*, stated, "The test at first sight has the appearance of a normal trochoid test which has been subjected to a lateral shearing stress. Although it first appeared to be a pathological case, numerous similar paratype specimens have been found". Later, Haynes (1958, p. 60) expressed doubts about the views expressed by Marks, and suggested, "that the sheared form of *H. obliquicameratus* is also due to deformation" (Lozo 1944), in describing the new species *Haplophragmoides globosa*, has made an effort to study the variation in this species in some detail. Similarly, Tappan (1957) has also showed the variation exhibited by *Haplophragmoides toparorukensis* Tappan.

*Haplophragmoides wilgunyaensis* Crespin exhibits a wide range of variation, especially in the degree and mode of compression and distortion. An attempt has been made to show on the basis of three imaginary axes (a-a', b-b' and c-c', text-figure 4, figure 1a-c) that variously distorted and compressed specimens belong to a single species, and that a broad understanding of the nature of variation is required when erecting a new species, at least in *Haplophragmoides*.

The three axes are a-a', extending from front to back and coinciding with the axis of coiling, b-b', running from right to left along the minimum diameter of the test, lying in the plane of coiling and at 90° to the a-a' axis, and c-c', passing from top to bottom, also lying in the plane of coiling but at 90° to both a-a' and b-b' axes. The distortion in the test has been shown by the curved ends of the relevant axes.

The use of axes for demonstrating the variation in the tests of foraminifera was first suggested by Arnold (1954) in his study of variation in *Discornopsis aquayori* (Bermúdez) in laboratory cultures. In the present study, a slight modification has been made in the axes shown by Arnold, viz., the direction of compressive forces has been shown by broken lines and arrows.

The tests in *H. wilgunyaensis* do not follow any fixed pattern of distortion, and various peculiarly shaped tests have been found. Tests compressed along the a-a' axis grade into those compressed along the b-b' axis ('vide...
The number of chambers in the final whorl varies from nine to twelve. The sutures are usually well marked and can be best seen when the specimens are moistened. They are generally straight, but curved ones, mainly due to distortion, have also been observed. The umbilical depression is nearly always present, though having various shapes and sizes due to compression, but, in a few cases where the tests have suffered a great degree of distortion, it becomes obscure (text-figure 4, figures 3–4, 8–9). The periphery is lobulate and may be broadly rounded (text-figure 4, figures 3–5, 11) or subacute (text-figure 4, figures 2, 6, 9–10, 14). The test is always involutely coiled.

Discussion

Crespin (1963) described *H. wilgunyaensis*, a distinctive species of *Haplophragmoides*, from the Lower Cretaceous of Australia. It has also been recorded by Ludbrook (1966) from the Lower Cretaceous of South Australia. Our specimens come well within the range of variation and are identical with the types of *H. wilgunyaensis* (fide Noakes, personal communication, 1964). Dr Nell H. Ludbrook, who also examined the Indian specimens of *H. wilgunyaensis*, was of the opinion that they were similar to those in the Lower Cretaceous of Australia, except that in the Indian specimens the number of chambers in the last coil might sometimes be less.

Occurrence

This species occurs abundantly in nearly all samples of the Raghavapuram Shales (Lower Cretaceous) at Raghavapuram.
Maync (1954a, b) revised his earlier work (1952) in the light of the papers published by Bartenstein (1952) and Loeblich and Tappan (1953). Taking into consideration Bartenstein's view (1952), Maync (1954a, p 52) remarked: "If this idea should actually prove to be true, the genus Bulbophragmium, and possibly also Bulbobaculites, would thus be invalid as such." Furthermore, Maync (1954b, p 142) tentatively supported Bartenstein's concept (1952) and observed: "If Bartenstein's view should prove to be correct, the genera Bulbophragmium Maync, 1952, for streptospirally coiled forms of Lituola and Bulbobaculites Maync, 1952, for the irregularly twisted representatives of Ammobaculites, would only indicate different generations."

The present material contains well-preserved specimens of two species of Ammobaculites, A. hofkeni Bhalla, 1965, and A. sahni Bhalla, 1965. In both of these species tests with planispiral and streptospiral initial portions are present, and, at least in our material, there appears to be no definite relationship between the mode of coiling and the dimorphism. Microspheric and megalospheric generations have been found to have both types of coiling (vide A. hofkeni, text-figure 6, figures 4, 8 (microspheric), figures 9, 13 (megalospheric) and A. sahni, text-figure 9, figures 3, 5 (microspheric), figures 6, 12 (megalospheric)). Therefore, the mode of initial coiling appears to be simply an individual morphological feature. It is neither "a fundamental taxonomic feature" as emphasized by Maync (1952, p 40), nor is it a morphological feature connected with dimorphism as suggested by Bartenstein (1952)

**Ammobaculites crespinae** Bhalla

Plate 2, figures 1–3 text figure 5

**Ammobaculites crespinae** BHALLA 1966, pp 40–41, text-fig 1, no 3 – BAKSI, 1966 p 7 pi 1 fig 1

**Diagnosis** Test of medium size, elongate, free, rounded in end view, early portion involutely coiled, consisting of four chambers, uniserial portion consisting of five chambers, last-formed chamber dome-shaped, chambers inflated, increasing gradually in size with growth, aperture central, rounded, with a very short neck, sutures well marked, straight, depressed, periphery lobulate, wall moderately thick, composed of quartz grains with much siliceous cement, surface smoothly finished

**Dimorphism and variation** Both the microspheric and megalospheric generations have been found in the present material. The microspheric forms are elongate and cylindrical having a small coiled portion (text-figure 5, figures 3, 5, 7), whereas the megalospheric individuals are comparatively short and stout, and have a larger coiled portion (text-figure 5, figures 4, 6, 12).
The number of chambers in the coiled portion varies from three to six and in the uniserial portion from three to seven. The sutures are distinct, depressed and usually straight, but may be sometimes curved. In a great majority of cases the last-formed chamber is dome-shaped, but this is not always the case. Generally, the aperture has a very short neck.

The juvenile forms have three to four chambers in the coiled portion and one to three in the uncoiled portion. *Ammobaculites hofkeri* has more or less distinct morphological characters, and it was therefore possible to work out the complete growth stages from the juvenile to the adult. About two hundred specimens were examined.

### Dimensions

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<th>Holotype</th>
<th>Paratype A</th>
<th>Paratype B</th>
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<td>Length of uncoiled portion (mm)</td>
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<td>Maximum diameter of coiled portion (mm)</td>
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<tr>
<td>Diameter of last chamber (mm)</td>
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<td>0.40</td>
<td>0.40</td>
</tr>
<tr>
<td>Illustration (plate 2)</td>
<td>fig 1</td>
<td>fig 2</td>
<td>fig 3</td>
</tr>
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</table>

**Adult specimens**. Length of the test 0.50 to 1.50 mm, width of the uncoiled portion 0.23 to 0.66 mm.

**Juvenile specimens**. Minimum length of the test 0.30 mm, minimum width of the uncoiled portion 0.17 mm.
Microspheric forms. Average diameter of the coiled portion 0.30 mm, diameter of the proloculus 16 μ.

Megalospheric forms. Average diameter of the coiled portion 0.43 mm, diameter of the proloculus 33 μ.

Discussion Ammobaculites crespiniae closely resembles Ammobaculites fishen Crespin, 1953, described by Crespin from the Lower Cretaceous of New South Wales, Australia. However, it differs from A. fishen in being larger in size, and in having inflated chambers in the coiled portion, a dome-shaped last-formed chamber, and a rounded aperture which generally has a very short neck. Through the courtesy of Dr. L.C. Noakes of the Bureau of Mineral Resources, Canberra, it was possible to have our specimens compared with the types of A. fishen deposited there. He (personal communication, 1964) made the following comments regarding the Indian forms. "Your specimens appear to be quite different from our type. The shape of the test of the type is very slender, while the earlier and the younger chambers of the uncoiled part of the test are all of the same diameter. Your specimens show an increase in the diameter of the chambers of the uncoiled part of the test from the earlier to the younger chambers of the tests and are much stouter."

A. crespiniae Bhalla shows some resemblance to Ammobaculites mcnspicuus Cushman and Waters, 1928, described from the Pennsylvanian of Texas, but differs from the earlier to the younger chambers of the tests.

Type horizon Sample B/11–4, pale-colored sandy shale with purple blotches.

Type locality Type section of the Raghavapuram Shales exposed on the northern side of the hill with an altitude of 512 feet about one and a half miles east of Raghavapuram village, West Godavari District, Andhra Pradesh, India.

Geologic age Lower Cretaceous.

Repository of type material Holotype, PUGD Cat no. F1201, paratype A, PUGD Cat no. F1202, paratype B, PUGD Cat no. F1203.

Etymology This species has been named in honour of Dr. Irene Crespin, formerly of the Bureau of Mineral Resources, Canberra, Australia.

Ammobaculites hofkeri Bhalla Plate 1, figures 15–18, text-figure 6

Ammobaculites hofkeri, BHALLA, 1965, pp. 41–42, text-fig. 1, no. 1—BAKSI, 1966, p. 7, pl. 1, figs. 7–8

Diagnosis Test free, large, flattened, elongate, early portion planispirally coiled, somewhat evolve with three to eight gradually enlarging chambers, uniserial part with three to eight imbricate and compressed chambers, increasing gradually in size with growth, last-formed chamber has maximum height but penultimate chamber has maximum width, sutures of coiled portion not well marked, of uniserial portion distinct, depressed, more or less straight, periphery lobulate, wall thick, rather coarsely arenaceous, composed of quartz grains of moderate size with normal amount of cement, aperture rounded, central.

Dimorphism and variation Dimorphic generations have been recognized in A. hofkeri. The microospheric tests have a small initial coil followed by a large, flaring uniserial portion (plate 1, figure 17, text-figure 6, figures 4, 6), whereas the megalospheric tests have a fairly large initial coil and a short uniserial portion with more or less parallel sides (plate 1, figures 16, 18, text-figure 6, figures 2, 9, 13). In comparison with the microospheric tests, the megalospheric tests are short and stout, and have a greater width.

A. hofkeri exhibits a wide range of variation (text-figure 6, figures 1–28). About six hundred specimens were examined to study the range of variation in this species. The chambers of the coiled portion are not much compressed and vary from three to eight in number. The size of the initial coil also varies much. The mode of coiling may be planispiral or streptospiral. The chambers in the initial portion can be best seen when the specimen is immersed in glycerin. In the uniserial portion, the chambers are compressed, well marked, and vary from three to eight in number. The increase in the width and height of the chambers is gradual and regular. The sutures are distinct, depressed, and generally straight, but sometimes may be curved. The last chamber reaches the maximum height and terminates in the simple, oval or rounded aperture, usually situated in the middle.

The juvenile forms have three to five chambers in the coiled portion and one to two in the uniserial portion. The aperture is simple, rounded and terminal.

Dimensions

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<th>Description</th>
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<th>Paratype A</th>
<th>Paratype B</th>
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<td>1.73</td>
<td>1.80</td>
<td>1.43</td>
</tr>
<tr>
<td>Length of uncoiled portion (mm)</td>
<td>1.00</td>
<td>1.50</td>
<td>1.40</td>
<td>1.03</td>
</tr>
<tr>
<td>Maximum width of uncoiled portion (mm)</td>
<td>0.73</td>
<td>0.73</td>
<td>0.67</td>
<td>0.90</td>
</tr>
<tr>
<td>Maximum diameter of coiled portion (mm)</td>
<td>0.50</td>
<td>0.33</td>
<td>0.60</td>
<td>0.86</td>
</tr>
<tr>
<td>Diameter of last chamber (mm)</td>
<td>0.67</td>
<td>0.70</td>
<td>0.70</td>
<td>0.50</td>
</tr>
<tr>
<td>Illustration (plate 1)</td>
<td>fig. 15</td>
<td>fig. 17</td>
<td>fig. 18</td>
<td>fig. 38</td>
</tr>
</tbody>
</table>

Adult specimens: Length of test 0.90 to 2.17 mm, width of uncoiled portion 0.50 to 1.00 mm.
Juvenile specimens: Minimum length of test 0.33 mm, minimum width of uncoiled portion 0.23 mm.

Microspheric forms: Average diameter of coiled portion 0.23 mm, diameter of proloculus 33 μ.

Megalospheric forms: Average diameter of coiled portion 0.60 mm, diameter of proloculus 66 μ.

Discussion: A. hofkeri is somewhat similar to Ammobaculites cuyleri Tappan, 1940, described from the Lower Cretaceous of Texas, but differs from it in having a less compressed test, a coarsely arenaceous wall, larger size, a rounded or oval aperture, faint sutures in the coiled portion, and comparatively rapid increase in the width of the chambers in the uniserial portion.

From Ammobaculites torosus Loeblich and Tappan, 1949, described from the Lower Cretaceous of Texas, A. hofkeri Bhalla differs in having less inflated chambers, a smooth exterior, and a rather definite shape of the last chamber, and in the absence of a neck and a slight lip around the aperture. The aperture is not always rounded as in A. torosus.

A. hofkeri differs from Ammobaculites sahnu Bhalla in the much compressed test, the rather regular chambers in the coiled portions, and the absence of the characteristic "cap-shaped" last chamber of A. sahnu.

Recently, Crespin (1963) reported A. fragmentarius Cushman, 1927, from the Lower Cretaceous of Australia. Some of the variants of A. hofkeri show some resemblance to A. fragmentarius, but differ from it in the absence of the flaky structure of the wall, which is an important feature of A. fragmentarius, and in having both streptospirally and planispirally coiled initial portions, and a greater number of chambers, both in the coiled and in the uncoiled portions.

Type horizon: Sample B/11-1, fine white sandy shale with purple blotches.

Type locality: Type section of the Raghavapuram Shales exposed on the northern side of the hill with an altitude of 512 feet about one and a half miles east of Raghavapuram village, West Godavari District, Andhra Pradesh, India.

Geologic age: Lower Cretaceous.


Etymology: The species has been named in honour of Dr. J. Hofker, The Hague, Netherlands.

Ammobaculites indicus Bhalla Plate 1, figures 9-11 text-figure 7

Ammobaculites indicus BHALLA, 1965, p. 42, text-fig 1, no. 4 – BAKSI 1966 pp. 6–7 pl. 1 fig. 5

Diagnosis: Test free, narrow, cylindrical, coiled portion slightly evolute, with four to six chambers, uniserial portion rectilinear with two to six chambers, chambers, especially of uniserial portion, inflated, rounded in cross section, nearly all of the same size, higher than broad, sutures straight, depressed, well marked in uncoiled portion, less so in coiled portion, periphery lobulate, aperture terminal, simple, small and rounded, wall thin, composed of quartz grains with a fair amount of silica as cementing material, surface fairly smooth.

Dimorphism and variation: No evidence of dimorphism was noted in A. indicus. The only variation observed is in the shape and size of the test (text-figure 7, figures 1–6). The number of chambers in the coiled portion varies from four to six, and in the uncoiled portion from two to six. The sutures are usually straight. The test is generally cylindrical with inflated chambers.

Dimensions:

<table>
<thead>
<tr>
<th>Length of test (mm)</th>
<th>Holotype</th>
<th>Paratype A</th>
<th>Paratype B</th>
</tr>
</thead>
<tbody>
<tr>
<td>Length of uncoiled portion (mm)</td>
<td>0.60</td>
<td>0.50</td>
<td>0.43</td>
</tr>
<tr>
<td>Maximum width of uncoiled portion (mm)</td>
<td>0.13</td>
<td>0.15</td>
<td>0.15</td>
</tr>
<tr>
<td>Maximum diameter of coiled portion (mm)</td>
<td>0.16</td>
<td>0.16</td>
<td>0.20</td>
</tr>
<tr>
<td>Diameter of last chamber (mm)</td>
<td>0.13</td>
<td>0.13</td>
<td>0.13</td>
</tr>
<tr>
<td>Illustration (plate 1)</td>
<td>fig 9</td>
<td>fig 10</td>
<td>fig 11</td>
</tr>
</tbody>
</table>

Adult specimens: Length of test 0.37 to 0.73 mm, width of uncoiled portion 0.12 to 0.17 mm.
Discussion A indicus somewhat resembles Ammobaculites inconspicuous Cushman and Waters, 1928, described from the Pennsylvanian of Texas, but differs from it in having an open umbilicus and a lesser number of chambers in the uniserial portion, and in the shape of the uniserial chambers, which usually have more height than width and do not increase in size with growth, whereas those of A. inconspicuous are broader than high and increase in size with growth. From Ammobaculites parallelus Ireland, 1956, described from the Pennsylvanian of Kansas, A. indicus differs in having fewer chambers, a rather open initial coil, longer-than-broad chambers in the uniserial portion, and a fairly smooth surface. Harlton (1927) described the somewhat similar species Ammobaculites rectus (H B Brady) [Haplophragmium rectum Brady, 1876] from the Pennsylvanian of southern Oklahoma, but A. indicus differs from it in having an open umbilicus.

Type horizon Sample B/11–4 pale fine sandy shales with purple blotches

Type locality Type section of the Raghavapuram Shales, exposed on the northern side of the hill with an altitude of 512 feet about one and a half miles east of Raghavapuram village, West Godavari District, Andhra Pradesh, India

Geologic age Lower Cretaceous

Repository of type material Holotype, PUGD Cat no F1208, paratype A, PUGD Cat no F1209, paratype B, PUGD Cat no F1210

Etymology The trivial name indicus means Indian in Latin

Ammobaculites irregulariformis Bartenstein and Brand
Plate 1, figure 12


Description Test free, elongate, compressed, initial portion irregularly coiled, with four to nine chambers, uniserial portion with three to five chambers, chambers generally compressed, broader than high and irregular in outline, last-formed chamber largest of all, aperture terminal, small, irregularly elliptical, sutures irregular, somewhat straight, generally well marked and fairly deep in uniserial portion, less so in coiled portion, periphery very irregular in outline, wall coarsely arenaceous, consisting of fairly large quartz grains with siliceous cement, surface rather smooth

Dimensions Length of test 0.43 mm, length of uncoiled portion 0.27 mm, maximum width of uncoiled portion 0.17 mm, maximum diameter of coiled portion 0.25 mm, diameter of last chamber 0.13 mm

Discussion The present species may be compared with A. polythalamus Loeblich, 1946, which was originally described from the Upper Cretaceous of Texas. Our specimens differ from the Texas forms in having fewer chambers and a comparatively rounded periphery.

Occurrence This species is restricted to sample B/11–1

Ammobaculites sp cf A. polythalamus Loeblich
Plate 1 figure 13

Cf Ammobaculites polythalamus LOEBLICH, 1946 p 135 pl 22, fig 7a–b text fig 2

Description Test free, small, slightly compressed, coiled portion of five chambers, followed by a uniserial portion of three chambers, chambers somewhat inflated, arranged in a rectilinear series, ultimate chamber more or less tapering narrower than the penultimate, sutures faint and radial in coiled portion, well marked, straight and slightly depressed in uniserial portion, periphery faintly lobulate, aperture small, rounded, central, wall finely arenaceous, consisting of quartz grains with siliceous cement, surface rather smooth

Dimensions Length of test 0.43 mm, length of uncoiled portion 0.27 mm, maximum width of uncoiled portion 0.17 mm, maximum diameter of coiled portion 0.25 mm, diameter of last chamber 0.13 mm

Discussion The present species may be compared with A. polythalamus Loeblich, 1946, which was originally described from the Upper Cretaceous of Texas. Our specimens differ from the Texas forms in having fewer chambers and a comparatively rounded periphery.

Occurrence This species is restricted to sample B/11–1

Ammobaculites raghavapuramensis Bhalla
Plate 2, figures 8–10 text figure 8

Ammobaculites raghavapuramensis BHALLA 1965 pp 42–43 text-fig 1, no 5

Diagnosis Test free, large, compressed, early portion planispirally coiled with twelve to fifteen chambers, uncoiled portion with four to seven chambers in a rectilinear series, chambers increasing very gradually in size
with growth, sutures well marked, limbate in coiled as well as in uncoiled portion, straight to gently curved, depressed, periphery entire in early portion, slightly lobulate in uncoiled portion, aperture varying from oval to an elongate slit, terminal, wall finely arenaceous, composed of minute quartz grains with a moderate amount of siliceous cement, surface smoothly finished, color white.

**Dimorphism and variation** No evidence of dimorphism was noticed in *Ammobaculites raghavapuramensis*. A wide range of variation, however, may be observed in this species, especially in the coiled portion and also in the degree and nature of the compression of the test (text-figure 8, figures 1-12).

The early coiled portion may be involute (text-figure 8, figures 1, 5), or the inner whorls may be variously exposed, depending upon the nature and degree of compression and contortion (text-figure 8, figures 2-3, 7). The number of chambers in the final coil varies from twelve to fifteen, in the uncoiled portion from four to seven.

The coiled portion in the holotype is strongly compressed but undistorted. It may, however, be twisted in many specimens with respect to the long axis of the uniserial portion (text-figure 8, figures 2-3, 7). In the majority of cases, the sutures are straight, but curved sutures may also occur (text-figure 8, figures 3, 5). The curvature in some sutures may possibly be due to the strong twisting and distortion of the test (text-figure 8, figure 5). A complete gradation exists between forms figured 1-2-3-8-7-6 in text-figure 8. This is also reflected in the shape of the aperture, which varies from a rounded opening (text-figure 8, figure 1) to an elongate slitlike opening (text-figure 8, figure 6). The tests are nonflaring with the uniserial portion of nearly uniform width throughout. The juvenile forms are planispirally coiled and evolute. Their inner whorls are variously exposed, depending upon the nature of the compression and contortion (text-figure 8, figures 9-12).
Arnold observed that the growth of a heavy network of Allogromia laticollare in laboratory cultures show that the flattening of the test is induced by environment factors. The causes of compression in Ammobaculites need not be recognized. The variation study shows that the noncompressed forms grade into the compressed ones. These observations are in harmony with the views expressed by Barnard (1949). The genus Ammomarginulina Wiesner, 1931, is actually a compressed variant of Ammobaculites and therefore should be suppressed as a junior synonym of the genus Ammobaculites Cushman, 1910.

Considerable variation in the degree of inflation was encountered in Ammobaculites raghavapuramensis Bhalla, and a full spectrum of variation from one extreme to the other was observed. The variation study shows that the noncompressed forms grade into the compressed ones. This is evident from the figures (text-figures 8, figures 1–3, 6), wherein the shape of the aperture may be seen to vary from oval to narrow and linear, depending upon whether the test is noncompressed or compressed. These observations are in harmony with the views expressed by Barnard (1949). The genus Ammomarginulina Wiesner, 1931, is actually a compressed variant of Ammobaculites and therefore should be suppressed as a junior synonym of the genus Ammobaculites Cushman, 1910. John H Wall of the Research Council of Alberta, Canada, also agrees (personal communication, 1963) mentioned that in laboratory cultures the chambers of Nubeculana lucifuga and Calcituba polymorpha are often more inflated when the animal grows perpendicular to the bottom of a dish than when it grows attached to the bottom throughout its test length. Baksi (1986) attributed the compression mainly to the diagenesis of the sediments. It is also possible that the flattened forms of Ammobaculites lived tightly pressed into minute crevices that would prevent the full inflation of their chambers. The compressional effect in Ammobaculites may be due to either one or a combination of the above-mentioned factors. However, in order to know the real cause of compression in Ammobaculites, it is suggested that the foraminifer should be thoroughly studied in laboratory cultures. This would also help in determining the full spectrum of variation commonly found in Ammobaculites.

Ammobaculites raghavapuramensis Bhalla shows some resemblance to Ammomarginulina loncata Loeblich and Tappan, 1949, described from the Albian beds of Texas, but differs from it in having a large, slightly evolute test, more chambers in the coiled and in the uncoiled portions, fairly well-marked sutures, an elongate to rounded aperture, and a finely arenaceous wall with a lesser amount of cement. From Ammobaculites laevatus Lozo, 1944, it differs in its slightly evolute test, its rounded or elliptical cross section of its chambers in a spectrum of variation.

Type horizon: Sample B/11–3, pale fine sandy shales with purple blotches.

Type locality: Type section of the Raghavapuram Shales exposed on the northern side of the hill with an altitude of 512 feet about one and a half miles east of Raghavapuram village, West Godavari District, Andhra Pradesh, India.

Geologic age: Lower Cretaceous.


Etymology: This species has been named after the village of Raghavapuram near which the type section of the Raghavapuram Shales is exposed.

Ammobaculites sahnii Bhalla

Plate 2, figures 4–7; text-figure 9.

Ammobaculites sp. MURTHY and SASTRI, 1962, p. 451, pl. 13, fig. 3.
Ammobaculites sahnii BHALLA, 1965, p. 43, text-fig. 1, no. 6.
- BAKSI, 1966, p. 6, pl. 1, fig. 6.

**Diagnosis:** Test free, large, elongate, nearly circular in end view; early portion streptospirally coiled, consisting of three to twelve chambers; uniserial portion consisting of three to seven imbricate inflated chambers in a rectilinear series, increasing rapidly in diameter with growth giving the test a flaring appearance; last chamber "cap-shaped", oblique to the axis of the rectilinear series; sutures distinct, slightly curved, depressed; periphery lobulate; aperture circular, terminal; wall thick, composed of quartz grains of moderate size with siliceous cement; exterior rough.

**Dimorphism and variation:** Both the microspheric and megalospheric generations were recognized in Ammobaculites sahnii. The microspheric individuals have a large and flaring test with a small coiled portion composed of four to twelve chambers (plate 2, figure 7; text-figure 9, figures 3–5, 9), whereas the megalospheric forms have a short, stout, nonflaring test with a comparatively large coiled portion composed of three to four chambers (plate 2, figure 4; text-figure 9, figures 6, 10, 12).

Bartenstein (1952) found tests having streptospiral and planispiral initial coils in the same sample and suggested that the two different types of coiling represent the microspheric and the megalospheric generations of the same species. However, in the present material, there does not appear to be any marked relationship between the mode of initial coiling and dimorphism. The irregu-
TABLE 1
Distribution of foraminifera in the type section of the Raghavapuram Shales near Raghavapuram

<table>
<thead>
<tr>
<th>Sample No.</th>
<th>Holotype</th>
<th>Paratype A</th>
<th>Paratype B</th>
<th>Paratype C</th>
</tr>
</thead>
<tbody>
<tr>
<td>N114-1</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>N114-2</td>
<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>N114-3</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>N114-4</td>
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<td></td>
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</tr>
<tr>
<td>N114-5</td>
<td></td>
<td></td>
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</tr>
<tr>
<td>N114-6</td>
<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>N114-7</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>N114-8</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>N114-9</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>N114-10</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

LEGEND
A = ABSENT
B = RARE < 5 SPECIMENS
C = FREQUENT > 10 SPECIMENS
D = NORMALLY ABSENT

Streptospiral coiling may be due to other factors rather than to dimorphism. Individuals having a streptospirally coiled initial portion have been found representing the microspheric as well as the megalospheric generation and the same holds true for the forms having a planispirally coiled initial portion. The ratio of microspheric to megalospheric forms is 1 : 3.

About four hundred specimens were examined in order to study the range of variation. The coiled portion, which may be small and reach up to the middle of the uncoiled portion, consists of three to twelve inflated or compressed chambers. The chambers in the uncoiled portion vary from three to seven in number and are usually inflated. Their width may be two to three times their height. In some cases the increase in the width of a chamber is quite abrupt (text-figure 9, figure 13). The sides of the uncoiled portion may be rectilinear or curvilinear. The sutures, which are fairly well marked, depressed and straight, may be either curved or irregular. The last chamber is comparatively large and "cap-shaped", and in some specimens occupies nearly half or one-third of the uncoiled portion (text-figure 9, figures 6, 8, 13, 21-22). It may be inflated or slightly compressed, and vertial or tilted with respect to the long axis of the uniserial portion. The aperture is simple, terminal, rounded to irregular, and usually situated in a slight depression. The color of the test may sometimes be reddish-brown due to iron oxide staining.

The juvenile forms of *A. sahnii* have three to five chambers in the coiled portion and one to four in the uncoiled portion.

**Dimensions:**

<table>
<thead>
<tr>
<th></th>
<th>Holotype</th>
<th>Paratype A</th>
<th>Paratype B</th>
<th>Paratype C</th>
</tr>
</thead>
<tbody>
<tr>
<td>Length of test (mm)</td>
<td>1 47</td>
<td>1 53</td>
<td>1 60</td>
<td>1 73</td>
</tr>
<tr>
<td>Length of uncoiled portion (mm)</td>
<td>1 10</td>
<td>1 23</td>
<td>1 20</td>
<td>1 17</td>
</tr>
<tr>
<td>Maximum width of uncoiled portion (mm)</td>
<td>0 90</td>
<td>0 90</td>
<td>1 00</td>
<td>0 80</td>
</tr>
<tr>
<td>Maximum diameter of coiled portion (mm)</td>
<td>0 37</td>
<td>0 57</td>
<td>0 43</td>
<td>0 77</td>
</tr>
<tr>
<td>Diameter of last chamber (mm)</td>
<td>0 80</td>
<td>0 90</td>
<td>1 00</td>
<td>0 80</td>
</tr>
<tr>
<td>Illustration (plate 2)</td>
<td>fig 5</td>
<td>fig 6</td>
<td>fig 7</td>
<td>fig 4</td>
</tr>
</tbody>
</table>

Adult specimens: Length of test 0.83 to 3.00 mm, width of test 0.43 to 1.10 mm, diameter of aperture 0.03 to 0.10 mm.

Juvenile specimens: Minimum length of test 0.33 mm, minimum width of test 0.23 mm.

Microspheric forms: Average diameter of coiled portion 0.27 mm, diameter of proloculus 20 μ.

Megalospheric forms: Average diameter of coiled portion 0.50 mm, diameter of proloculus 66 μ.

**Discussion:** *Ammobaculites sahnii* somewhat resembles *Ammobaculites imbrcatus* Skolnick, 1958, described...
from the Black Hills area, U S A , but differs from it in not having a "keel" in the last two chambers, which is a diagnostic feature of Ammobaculites imbricatus. It also differs in the size and shape of the last-formed chamber, in the nature of the coil, and in having a flaring uncoiled portion.

Ammobaculites sahnii Bhalla shows much resemblance to Haplophragmium bullatum Perner, 1897, described from the Cretaceous of Bohemia, Czechoslovakia, but differs in having a flaring test and a rough exterior, and in the shape of the test. In a majority of the cases unlike Haplophragmium bullatum the last-formed chamber is not in agreement with the trend of earlier chambers of the uniserial portion. From the description and figure of H bullatum Perner (Perner, 1897, pl. 1, fig 6c), it is evident that the species possesses a single aperture, on account of which it should be transferred to the genus Ammobaculites Cushman, 1910 from Haplophragmium Reuss, 1860. The latter is characterized by having a multiple aperture. The true relationship of Ammobaculites sahnii Bhalla and Haplophragmium bullatum Perner could not be ascertained as type-topotype specimens of the latter were not available.

Ammobaculites sahnii Bhalla is undoubtedly identical with the indeterminate Ammobaculites sp described by Murthy and Sastri (1962) from the Sniperumbudur Beds (Lower Cretaceous), India, being similar in shape, size, and nature of the test, especially the last-formed chamber. The Sniperumbudur specimen is, therefore, considered a synonym of A. sahnii Bhalla, 1965.

The present species also shows resemblance to some species of the genus Orbignyna Hagenow, 1842, but the longitudinal and transverse sections of A. sahnii do not show any radial partition in the chambers, which is a characteristic feature of the genus Orbignyna.

Type horizon Sample B/11-1, fine white sandy shales with purple blotches.

Type locality Type section of the Raghavapuram Shales exposed on the northern side of the hill with an altitude of 512 feet about one and a half miles east of Raghavapuram village, West Godavari District, Andhra Pradesh, India.

Geologic age Lower Cretaceous.

Repository of type material Holotype, PUGD Cat no F1214, paratype A, PUGD Cat no F1215, paratype B, PUGD Cat no F1216, paratype C, PUGD Cat no F 1217.

Etymology This species has been named in honour of Prof M R Sahni, Honorary Professor, Department of Geology, Punjab University, Chandigarh, India.

COMPOSITION, AFFINITIES, AGE AND CORRELATION OF FORAMINIFERAL FAUNA

The foraminiferal fauna of the Raghavapuram Shales consists of fifteen species (vide table 1), all of which are arenaceous. Of these, twelve belong to the family Lituidae, two to the Saccamminidae, and one to the Ammodiscidae. The abundant species are Haplophragmoides wilgynyansensis Crespin, Ammobaculites crespinae Bhalla, H. hofkeri Bhalla, and A. sahnii Bhalla.

The microfauna includes certain well-known cosmopolitan Cretaceous species of foraminifera, or closely comparable forms like Ammodiscus sp of A. cretaceus, Haplophragmoides concavus, H. kirki, Ammobaculites irregulanformis, and Ammobaculites sp of A. polythalamus Ammodiscus cretaceus has been recorded from the Lower Cretaceous of Australia and India and from the Upper Cretaceous of Czechoslovakia and the U S A. H. concavus has been widely reported from the Lower Cretaceous of Australia, India, Europe and the U S A. Similarly, A. irregulanformis is also a cosmopolitan species and occurs in the Lower Cretaceous of Australia, Poland and Germany.

Bhalla (1965) reported six new species of foraminifers (re-described in greater detail in the present paper) from the type section of the Raghavapuram Shales, which show Lower Cretaceous affinities. Of these, Ammobaculites crespinae Bhalla resembles Ammobaculites fisheri Crespin, described from the Lower Cretaceous of Australia. Ammobaculites hofkeri Bhalla shows resemblance to Ammobaculites cuilen Tappan and also to Ammobaculites torousus Loeblich and Tappan, both described from the Lower Cretaceous of Australia. Some variants of Ammobaculites raghavapuramensis Bhalla show resemblance to Ammobaculites marganuii loncata Loeblich and Tappan, and also to Ammobaculites laevigatus Lozo, both described from the Lower Cretaceous of Texas. It also somewhat resembles Ammobaculites fragmentarius Cushman, described from the Lower Cretaceous of Australia. Some variants of Ammobaculites hofkeri Bhalla shows similarities to Ammobaculites imbricatus Skolnick, described from the Lower Cretaceous of the Black Hills area of the U S A. It also resembles Haplophragmoides bullatum Perner, described from the Cretaceous of Bohemia, Czechoslovakia.

The foraminiferal fauna of the Raghavapuram Shales was studied by Murthy and Sastri (1962) described foraminifera from the Sniperumbudur Beds (homotaxial with the Raghavapuram Shales) near Madras and, on the foraminiferal evidence, assigned a Lower Cretaceous age to the beds. The following species are common to the Raghavapuram and the Sniperumbudur assemblages: Ammo-
Sastri, Chandra and Pant (1963) reported three species of foraminifera from the Raghavapuram Shales exposed near Tirupati, but only *H. concavus* is common to the present assemblage. On the foraminiferal evidence, these authors suggested a Lower Cretaceous age for the Raghavapuram Shales.

Baksi (1966) described twelve species of foraminifera from the Raghavapuram Shales exposed near Ramanujapuram and Darasanipadu villages, and five of these species also occur in the present assemblage. *Haplophragmoides hagni*, *Ammobaculites hofkeni*, *A. indicus* and *A. sahnii* (Baksi, op cit) assigned a post-Jurassic and pre-Upper Cretaceous age to the Raghavapuram Shales.

In the absence of marker species of foraminifera in the Raghavapuram Shales, it has not been possible to fix precisely the age of these beds, but the over-all predominance of Lower Cretaceous forms indicates that the Raghavapuram Shales were deposited during Lower Cretaceous (Neocomian) times. The present work confirms the earlier views, based on microfossils as well as megafossils, that the Raghavapuram Shales are of Lower Cretaceous age. A detailed study of the ammonites of the Raghavapuram Shales is necessary for the precise placement of these beds in the proper stage within the Lower Cretaceous.

The foraminiferal assemblage of the Raghavapuram Shales shows very close affinity with those described by Crespin (1963) and Ludbrook (1966) from the Lower Cretaceous of Australia. Out of fifteen species of foraminifera from the Raghavapuram Shales, six species are also found in Australia: *Saccammina lagenoides*, *Ammodiscus sp cf A. cretaceus*, *Haplophragmoides concavus*, *H. sp cf H. dickinsoni*, *H. wilgunyaensis* and *Ammobaculites irregulariformis*. All have been described by Crespin (1963) from the Lower Wilgunya Formation (Lower Cretaceous) or its equivalents of the Great Artesian Basin, Australia, and these species also occur in the Raghavapuram Shales. The following species of foraminifera are common to the Raghavapuram assemblage and the Marree Formation (Aptian-Albian) assemblage described by Ludbrook (1966) from the Great Artesian Basin in South Australia: *Saccammina lagenoides*, *Ammodiscus sp cf A. cretaceus*, *Haplophragmoides sp cf H. dickinsoni* and *H. wilgunyaensis*.

Ahmad (1961 pl 8) in his monumental work on the paleogeography of Gondwana land based on isopach maps, observed that, during Tithonian–Neocomian times, some portions of the East Coast of India, including the Raghavapuram area, were connected with the Great Artesian Basin of Australia by a mixed environment. As mentioned earlier, the foraminiferal fauna of the Raghavapuram Shales shows close affinity with those of the Lower Cretaceous of the Great Artesian Basin, Australia. The similarity in the mode of preservation and in variation shown by the Indian and Australian specimens is remarkable. The present study, therefore, supports the views expressed by Ahmad (1961) regarding the close India–Australia association during the Lower Cretaceous.

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**PLATE 1**

All figures X 55

1. *Saccammina lagenoides* (Crespin)
2. *Ammomopemphix* sp
3. *Ammodiscus* sp cf *A. cretaceus* (Reuss)
4. *Haplophragmoides concavus* (Chapman)
5. *Haplophragmoides* sp cf *H. dickinsoni* Crespin
6–7. *Haplophragmoides hagni* Bhalla
   6. holotype, a, side view, b, peripheral view
   7. paratype
8. *Haplophragmoides wilgunyaensis* Crespin
9–11. *Ammobaculites indicus* Bhalla
   9. holotype, side view
   10. paratype A
   11. paratype B
12. *Ammobaculites irregulariformis* Bartenstein and Brand
13. *Ammobaculites* sp cf *A. polythalamus* Loeblich
14. *Haplophragmoides kirki* Wickenden
15–18. *Ammobaculites hofkeni* Bhalla
   15. holotype, side view, megalospheric form
   16. paratype B, side view, megalospheric form
   17. paratype A, side view, microspheric form
   18. paratype C, side view, megalospheric form
ACKNOWLEDGMENTS
The author takes this opportunity to express his gratitude to the following persons and institutions who helped him in various ways: Prof Lyman D Toulmin of Florida State University, Tallahassee, Florida, and Dr V K Srivastava, Aligarh Muslim University, for their constructive criticism, to Dr (Mrs) Nell H Ludbrook of the Geological Survey of South Australia, Adelaide, for checking the species of foraminifera described in the present paper and also for making useful comments during her visit to Aligarh, to Prof Zach M Arnold, Museum of Paleontology, University of California, Berkeley, California, and Dr John H Wall, Research Council of Alberta, Canada, for their views on variation in *Ammobaculites*, to Dr L C Noakes, Bureau of Mineral Resources, Canberra, Australia, for comparing the Indian specimens of *Ammobaculites* and *Haplophragmoides* with the holotypes of Crespin’s species deposited in the Commonwealth Palaeontological Collections at Canberra, and also for his comments on *Ammobaculites crespinae* Bhalla, 1965, to Prof Herbert Hagn of the Institute of Paleontology and Historical Geology, Munich, Germany, for making available some Cretaceous material from Europe, and to the people of Andhra Pradesh who helped the author in all possible ways during the field work.

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PLATE 2
All figures X55

1-3 *Ammobaculites crespinae* Bhalla
   1, holotype, side view, megalospheric form
   2, paratype A, side view, microspheric form
   3, paratype B, side view, megalospheric form

4-7 *Ammobaculites sahnu* Bhalla
   4, paratype C, side view, megalospheric form showing streptospiral coiling
   5, holotype, side view, megalospheric form showing streptospiral coiling
   6, paratype A, side view, megalospheric form
   7, paratype B, side view, microspheric form

8-10 *Ammobaculites raghavapuramensis* Bhalla
   8, paratype B, side view
   9, paratype A, side view showing rounded uniserial portion
   10, holotype, side view showing compressed uniserial portion.
ON THE OCCURRENCE OF GLAUCONITE IN THE
RAGHAVAPURAM SHALES, EAST COAST GONDWANAS, INDIA

S. N. BHALLA
ON THE OCCURRENCE OF GLAUCONITE IN
THE RAGHAVAPURAM SHALES, EAST COAST GONDWANAS, INDIA

S. N. BHALLA *

The Raghavapuram shales constitute the middle division of the Upper Gondwanas of the east coast of India. The study of these shales is interesting and of great scientific value because of their nature and unique fossil assemblage consisting of both animals and plants. A study of the fossils entombed in these sediments, not only throws light on the polemical upper age limit of the East Coast Gondwanas, but also reveals the nature of environment under which these shales were deposited.

In a recent publication, the author (Bhalla, 1969a) gave a comprehensive account of the Foraminiferida recovered from the type section of the Raghavapuram shales; and in another (Bhalla, 1969b) discussed the paleoecology of these shales mainly on the basis of foraminiferal evidence. Bhalla (1969b) observed that the lower part of the shale sequence (60-70 feet from the base) was deposited under a shallow-water, near-shore, marine environment but the basin gradually became land-locked resulting in appreciable decrease in pH, oxygen, and salinity values and developing a marsh environment in which the rest of the column of the Raghavapuram shales were laid down.

An independent evidence supporting the paleoecological conclusions of the Raghavapuram shales drawn by the author (Bhalla, 1969b) comes from the reported occurrence of glauconite in these shales by Baksi (1966). He has reported the presence of a persistent band of glauconitic mudstone, about 2 feet thick, and occurring at a level 60-70 feet from the bottom of the shale sequence. This band of glauconitic mudstone occurs at a place where the arenaceous foraminifers appear for the first time (Fig. 1, bed B/10 to B/11). Glauconite is a ‘sophisticated’ mineral and is produced under a particular set of conditions only. It is an important criterion in deducing the environment of deposition, and is therefore being discussed here in some detail.

According to Baksi (1966, p. 351), the grains of glauconite ‘are found to be embedded in the clay matrix of the coarse fraction (+ 40 mesh, A.S.T.M.) residues or to leave negative (void) impression on the mudstones’. Under the microscope, Baksi found that, ‘the periphery of the grain-aggregate is fractured’. He further observed: ‘What is striking here, in spite of the presence of micro-foraminifers, is the absence of any glauconitic mould of micro-organism, particularly microforaminifera . . .’.

Before the conditions under which the Raghavapuram glauconite was produced are visualised, it is important to know whether the mineral, as found in the Raghavapuram mudstone, is autochthonous or allochthonous. Baksi (1965) did not deal with this aspect of Raghavapuram glauconite but some indirect clues are available which indicate that the glauconite in the Raghavapuram shales is autochthonous and not ‘fossil’ glauconite.
In the provenance, no glauconite-bearing rocks older than the Raghavapuram shales, are known to occur and, therefore, it is highly unlikely that the mineral was transported to the site of deposition from somewhere else. Further support for the autochthonous origin of the Raghavapuram glauconite comes from the Foraminiferida. The foraminiferal fauna of the Raghavapuram shales is not a reworked fauna (Bhalla, 1969a). The
synchronous appearance of Foraminifera at a level where glauconite occurs, is of great paleoecological significance. The foraminiferal assemblage is typical of marsh environment (Bhalla, 1969b) and indicates conditions which are favourable for the formation of glauconite also. This would then suggest that the glauconite was not allochthonous but developed in the same ecological niche as that of Foraminifera. The shape and size of glauconite grains and their relation to mud matrix as described by Baksi (1965), also rule out the possibility of the detrital origin of the mineral. In the light of the foregoing, it is reasonable to infer that the glauconite in the Raghavapuram shales was produced at the site of deposition of the shales and was not brought into the basin from somewhere else.

An important contribution to our knowledge of glauconite formation has been made by Burst (1958a). According to him, the formation of glauconite depends upon the following four requirements:

1. Layered or degraded silicate lattice,
2. Sufficient supplies of potassium,
3. Sufficient supplies of iron, and

In the case of Raghavapuram glauconite, the silicate lattice was inherent in the clay minerals of the shale, potassium was available from the seawater, and iron was present in the environment as is indicated by the colour and composition of the sediments, and also by the occasional presence of thin intercalations of clay-ironstones. It is the establishment of a favourable semi-reducing condition which poses a problem in the present study.

The semi-reducing conditions can be developed either through organic agencies or from restricted basin conditions. Assuming that semi-reducing environment was created by organisms, especially foraminiferens, it is indeed surprising that no ‘foraminiferal’ glauconite is found in the Raghavapuram shales. Further, it is difficult to explain the restricted occurrence of this mineral although more or less the same foraminiferal assemblage occurs in the rest of the column. This lack of association of glauconite with organisms, both in space and time, goes strongly against this mode of origin. On the other hand, if the formation of glauconite is attributed to inorganic agencies, this anomaly no longer exists. The semi-reducing environment, which is so essential for the formation of glauconite, may have arisen in a ‘restricted’ or ‘barred’ basin which developed during the deposition of the upper 100 feet (Bed B/11 upwards) of the Raghavapuram shales much in the same manner as visualised by Srivastava (1966) for the Lower Vindhyan glauconites of the Son Valley. According to Burst (1958b, p. 483), semi-reducing conditions could be ‘accomplished in a depositional area of natural semi-oxidising conditions such as restricted basins or lagoons’. The existence of such condition is strongly suggested by independent foraminiferal evidence (Bhalla, 1969b). The process of glauconite formation in the Raghavapuram shales, there-
fore, appears to be dependent upon the physico-chemical environment of the basin of deposition. This mode of origin of the glauconite explains not only the absence of "foraminiferal" glauconite and the restricted occurrence of this mineral in the Raghavapuram shales, but also the abrupt faunal break in the shale sequence (Bhalla, 1969b).

From the foregoing discussion, it becomes apparent that the Raghavapuram basin had open-sea connection up to the deposition of Bed B/10 (Fig. 2). The sea, then, regressed and the basin gradually became landlocked resulting in the development of semi-reducing conditions. This event in the history of the basin is marked by the synchronous appearance of glauconite and arenaceous foraminifers in the Raghavapuram shales. When the restricted-basin conditions became accentuated, the glauconite ceased to form but the foraminiferal fauna, capable of tolerating such conditions, kept on developing in the rest of the column. These conclusions are in harmony with the environmental changes visualised by the author (Bhalla, 1969b) on foraminiferal evidence.

Acknowledgement: I am thankful to Dr. V. K. Srivastava of the Geology Department, Aligarh Muslim University, for several helpful discussions and for going through the manuscript critically.
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OCCURRENCE OF FORAMINIFERA IN THE BUDAVADA BEDS OF THE EAST COAST GONDWANAS, INDIA

S. N. BHALLA
In a thick sequence of fresh water sediments of the extent of the Gondwanas, intercalated marine beds are of great significance. Such marine beds are rather frequent in the Upper Gondwanas of the east coast of India, and the Budavada beds are one of these.

The Budavada stage is the lower member of the Upper Gondwana of the east coast. The stage receives its name from the village Budavada (15° 51' : 80° 9') in the Guntur district of Andhra Pradesh where it is very well developed. The Gondwana rocks occupy an area of about 15 square miles near Budavada and represent all the three stages of the Upper Gondwana sequence on the east coast of India, viz., Budavada, Vemavaram, and Pavalur.

The exposures of the Budavada beds are poor due to an extensive stretch of cotton soil. However, some outcrops can be seen in well sections and pits dug out in fields. Foote (1880) was the first to make a systematic and detailed geological survey of this area. He (op. cit.) recognised the following succession of the Budavada beds. The section starts slightly west of Budavada village and runs in an east-west direction.

<table>
<thead>
<tr>
<th>Vemavaram stage</th>
<th>Shales: hard and soft, mottled in parts, generally whitish or light grey in colour.</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>5. Sandstones: gritty, calcareous, full of shells, rather hard and tough when fresh.</td>
</tr>
<tr>
<td></td>
<td>unconformity</td>
</tr>
<tr>
<td></td>
<td>Gneiss</td>
</tr>
</tbody>
</table>

The beds dip at low angles (3° to 5°) towards east. Marine fauna has been recovered from beds 4 and 5. However, bed 5 contains marine fauna as well as terrestrial flora.

Detailed sampling of the entire sequence was done for foraminifer studies but foraminifers were observed only in bed 5. This bed is full of megafossils but extremely poor in foraminifera. Only two specimens of *Dentalina* Risso, and one each of *Bathyproton* Sars, *Lenticulina* Lamarck, *Frondicularia* Defrance, and *Pseudopolymorphina* Cushman and Ozawa were recovered after a thorough search of about 800 grams of washed
The preservation of foraminifera is not satisfactory and it is not possible to identify them at species level. However, the present note reports the foraminifera from the Budavada stage for the first time.

The foraminifera recovered from the Budavada stage are long ranging, and as such, of no significance in the placement of these beds in the stratigraphic column. The Budavada stage is considered to be the marine equivalent of the fresh water Golapillis of the Ellore region (Krishnan, 1968). However, the ammonites from the upper beds (Beds 4 and 5) of the Budavada stage suggest a Lower Cretaceous age while the plant fossils of the Golapillis indicate a Lower Jurassic age. The fauna, including the ammonites, of the upper two beds (beds 4 and 5) of the Budavada stage shows close affinities with those of the overlying Vemavaram stage (Lower Cretaceous) and, therefore, the two beds should be included in the Vemavaram stage. Thus, beds 1 to 3 should constitute the Budavada stage while bed 4 should mark the base of the Vemavarams. However, this needs detailed investigations before definite conclusions can be drawn. Bhalla (1969) described a rich foraminiferal assemblage from the Raghavapuram shales which overlie the Golapillis and are homotaxial with Vemavarams. He (op. cit.) considered the Raghavapurams to be of Lower Cretaceous (?Neocomian) age. Since Golapilli and Budavada stages are homotaxial, it is reasonable to infer that the Budavada stage is not younger than the Lower Cretaceous (?Neocomian).

The foraminiferal assemblage does not indicate precisely the conditions of deposition except that the bed 5 was laid under marine environment. However, the presence of abundant and complete marine shells along with a few terrestrial plant remains in it, suggests that the deposition took place in a rather tranquil, open marine basin near to the shore line. Judging from the thickness of the Raghavapuram and Vemavaram strata—both of which are marine—it appears that the marine phase in the Ongole region was of lesser duration than in the Ellore region.

Acknowledgement: Thanks are due to Dr. V. K. Srivastava, Reader in the Department of Geology, Aligarh Muslim University, for his helpful suggestions.

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ON THE POSSIBLE EXTENSION OF THE RAGHAVAPURAM SHALES
BELOW GODAVARI DELTA, ANDHRA PRADESH, INDIA

S. N. BHALLA

BANGALORE
1970
ON THE POSSIBLE EXTENSION OF THE RAGHAVAPURAM SHALES BELOW GODAVARI DELTA, ANDHRA PRADESH, INDIA

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The rocks of the Gondwana system on the east coast of India occur in a chain of isolated outliers running almost parallel to the eastern shore line of the sub-continent. One such outlier is in the Eluru region of Andhra Pradesh. Here, the Lower as well as the Upper Gondwana rocks are well developed and are exposed in a comparatively small area.

In India, as in other parts of the continents of the southern hemisphere, the sediments of the Gondwana system are generally of fresh water origin. However, the Upper Gondwanas on the east coast of India contain certain marine intercalations which are of particular interest, because a study of these beds provides clues to some unsolved problems of Gondwana stratigraphy and paleogeography.

The Upper Gondwanas of the east coast are divisible into 3 stages; and it is interesting to note that while the lower and the upper stages are of fresh-water origin, the middle stage in almost all the outliers, viz., Eluru, Ongole, and Madras, is considered to be marine. This indicates that in the Eluru region, now under consideration, the sea invaded the coastal areas of Andhra Pradesh from the east and the Gondwana basin in which fresh water conditions prevailed, turned marine. The pile of sediments which was deposited in the basin under the influence of marine conditions, now constitute the middle stage—the Raghavapuram. After a certain period, the sea regressed and fresh water conditions returned resulting in the deposition of upper stage—the Tirupati. Thus, in the Eluru region, the lower and the upper stages are of fresh water nature whereas the middle stage is marine.

Like other coastal marine deposits, the Raghavapuram stage is the result of a marine transgression which took place during early Cretaceous times on the east coast of India. The early Cretaceous sea advanced over the Golapillis from the east and southeast and resulted in the development of the Raghavapuram basin. This basin was a rather narrow, crescentic, strip of depression, not very deep and stretching for more than 16 miles in northeast-southwest direction in Andhra Pradesh.

The Raghavapuram shales are about 160 feet thick at the type section and the beds dip at low angles towards east and southeast. Bhalla (1969a) described a prolific assemblage of foraminifera from the type section of the Raghavapuram shales and on the basis of faunal evidence inferred that while the lower 60 to 70 feet of the sequence was laid under marine conditions, the upper 100 feet of the sediments accumulated in a marginal marine marsh environment (Bhalla, 1969b). This indicates that the early Cretaceous sea advanced over the Golapillis, deposited 60 to 70 feet of the Raghavapuram sediments and then regressed leaving behind a marine marsh, in which the upper 100 feet of the shale sequence was laid down. This would, then, suggest that the transgressive phase of the early Cretaceous sea prevailed for a rather short duration in the region. With the further regression of the sea, fresh water conditions advanced towards the east and southeast resulting in the deposition of sandstones of Tirupati stage.
The band of the Raghavapuram shales is exposed about 60 miles west of the present shore line of the east coast of India. This implies that the early Cretaceous sea must have invaded at least 60 miles inside the present Andhra Pradesh and covered a vast area, most of which is now occupied by the younger formations and alluvium of the Godavari river. As mentioned earlier, the upper part of the Raghavapuram shales was deposited during the regressive phase of the sea in a marginal marine marsh environment, and not under truly marine conditions. It is obvious that during this time, sedimentation must also have taken place in the deeper and truly marine parts of the basin towards east and southeast of Raghavapuram. Such truly marine contemporaries of Raghavapuram shales, though not exposed, must occur below the Godavari delta and even beyond. In all probability, they are covered by the fresh water sandstones of Tirupati stage, and further east by the infratrappean beds, traps, the intertrappean beds, Rajahmundry sandstones, and alluvium, which belong to different ages but are younger than the Raghavapuram shales.

It is the surmise of the author that if a thorough search for the marine contemporaneous beds of the Raghavapuram shales is made, there is every reason to expect some such beds, either exposed or concealed below the younger formations in the Kakinada-Rajahmundry-Masulipatam region of Andhra Pradesh. It is quite possible that a small outcrop of Raghavapuram shales recently discovered by Sarma and Ramesam (1962) near Duddukuru, may represent the truly marine facies. If such beds are found, there will be complete transition from marginal marsh conditions to truly marine environment, and this will be reflected in the nature content. These beds will eventually help in understanding not only the early Cretaceous sea and the marine life of that time flourishing along the east coast of India, but will also contribute towards the reconstruction of paleogeography and precise age determination of the Raghavapuram stage which has not yet been possible with the available data.

References


Upper age limit of the East Coast Gondwanas, India

SATYENDRA BHALLA


The controversial upper age limit of the East Coast Gondwanas is discussed. A reassessment of the evidence furnished by animal and plant fossils is made in view of recent findings. Whereas the flora points towards a Jurassic age, the ammonites and other invertebrate megafossils indicate a Neocomian age. The microfossils support the concept of an Early Cretaceous age. This conflicting evidence of flora and fauna and the probable reliability of each is discussed. Although there is some doubt about the correctness of the floral testimony, the reliability of faunal evidence seems established, and an Aptian or Alban age is favoured as the upper age limit of the East Coast Gondwana.

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The Gondwana system, the store-house of coal in India, has interested geologists all over the globe ever since it was realised that its study presented a tremendous field for research. Due to its regional appeal, the System was studied from different angles in great detail by Indian as well as by foreign geologists. These studies have involved the theory of continental drift, the phenomenon of ancient glaciation, nature and origin of coal, reconstruction of paleogeography, fossil floras and faunas, and a variety of other aspects of scientific value.

The term Gondwana originated in India. It was coined by Midhcott in an unpublished report of the Geological Survey of India in 1872 for a set of fresh-water strata in the erstwhile state of Gonds in Madhya Pradesh. The term was published by Feistmantel (1876) as the geological exploration of the country progressed, more and more Gondwana outcrops were discovered; they started to receive added attention because vast reserves of coal were found in them. In addition to coal, the Gondwana rocks yielded a fascinating suite of plant fossils not confined to India alone, but occurring in all the continents of the Southern hemisphere. This flora aroused the interest of geologists in other countries also, and led Suess to propose the idea that all the Southern continents were at one time united or closely linked together constituting a super-continent—the Gondwana-Land. Since the beginning of this century, studies made by B Sahni and his co-
workers on the extensive flora preserved in this thick sequence of sediments have brought many interesting facts to light. A major problem considered has been the upper age limit of the Gondwanas.

The Gondwana rocks are widely distributed in India. Those on the east coast are commonly designated as the East Coast Gondwanas. Although work on these strata commenced nearly a century ago, they have not received much attention, mainly because they are not of economic significance. They are of great scientific interest, however, because they contain marine animals, including ammonites, in addition to a characteristic Upper Gondwana land flora. Within a thick sequence of fresh-water sediments, intercalations of fossiliferous marine strata are of tremendous value and, therefore, the east coast beds have a special status in the Gondwana stratigraphy of India. A study of these rocks and their flora and fauna reveals data on the distribution of ancient land and sea, palaeoenvironment, stratigraphic correlations, and the upper age limit of the sequence. A discrepancy exists between the evidence furnished by plant and the evidence of animal fossils for the upper age limit of the Gondwanas. Whereas the plant fossils indicate a Jurassic age, the ammonites and other marine animals point towards an Early Cretaceous age for the beds. The age of the East Coast Gondwanas indicates the extent of Gondwana sedimentation in India, the time of development of the eastern coast-line of the sub-continent, and the time of the union and parting of the India-Australia association. It is of particular interest to students of continental drift.

Stratigraphy

The Upper Gondwanas are well-developed on the east coast of India. The exposures occur in patches extending from near Cuttack in the north to Trichur in the south (Fig. 1), almost following the eastern coast-line. In three regions of the east coast, the Upper Gondwana rocks are well-developed, viz. Eluru, Ongole, and Madras. The Eluru exposure is best developed and has been most thoroughly studied.

The Upper Gondwana sequence on the east coast of India has been broadly divided into three stages - Lower, Middle, and Upper - mainly on the basis of fossil evidences and stratigraphic considerations. These stages are the following:

**Upper Stage** (Sandstones, fragmentary plants and a few animals, fresh water) Cuttack not known Eluru Tirupati Ongole Pavulur Madras Sattavadi Trichur not known

**Middle Stage** (Shales, animals including Early Cretaceous ammonites and T. ammonites, with an admixture of Rajmahal and Jabalpur plants, marine to marshy) Cuttack not known Eluru Raghavapuram Ongole Annamalai Madras Soperumbudur Trichur not known T. tatur Plants beds

**Lower Stage** (Sandstones, Rajmahal plants, fresh water) Cuttack Atlapalli Eluru Golapalli Ongole Budavada Madras not known Trichur not known T. tatur Plants beds
The Middle Stage contains both a land flora and a marine fauna. Unfortunately no consistency is maintained in the nomenclature of the different stages. The stages derive their names from the villages where they are best developed.

The evidence for the upper age limit is treated below.

Evidence from plant fossils

The Upper Gondwana sedimentary rocks of the east coast of India contain a rich floral assemblage which has been studied for more than a century. A large volume of literature has accumulated and has provided valuable clues to certain unsolved problems connected with the East Coast Gondwanas, including their upper age limit.

Plant fossils from the Upper Gondwana rocks on the east coast were compared with those of known geological age. They were found to contain a high percentage of elements of the floral assemblage of the Upper Gondwana sediments of the Rajmahal range in West Bengal. The Upper Gondwana beds are extensively developed in the Rajmahal area where a great variety
of fossil plant material, including leaves, stems and roots occur, so it is generally considered the type-locality of the Upper Gondwana flora. 'Rajmahal flora' and 'Upper Gondwana flora' have been frequently used as synonyms. The Rajmahal flora was subjected to extensive studies by B. Sahni and his co-workers and was considered to be of Jurassic age. In India the term Rajmahal flora is commonly used to imply a Jurassic age. A majority of paleobotanists consider the Rajmahal flora to be represented in the East Coast Gondwana assemblage; consequently the age of these beds is inferred to be Jurassic.

The Lower stage of the Upper Gondwana of the east coast is well-developed in Cuttack, Eluru, and Ongole areas. The sediments of this stage, especially the Golapilli beds, have yielded an extensive assemblage of plant fossils which are characteristic of the Rajmahal flora. A check-list of some important plant fossils recovered from the Lower stage is given below:

`Taeniopteris (Angiopteridium) ensis`, `T. (A.) spatulata `, `Marattiopsis macrocarpa `, `Gleichenites gleichenoides `, `Cladophlebis denticulata `, `C. indica `, `Thuengelia sp. `, `Retinaspores indica `, `Elatoecladus indica `, `R. conferta `, `Brachyphyllum expansum `, `Retinaspores indica `, `Nilssonia morrissiana `, `Ptilophyllum acutifolium `, `P. cutchense `, `Dictyozamites falcatus `, `Williamsonia indica `, etc.

Except in the Budavada Beds of the Ongole area, the Lower stage contains plant fossils only. The upper two beds of the Budavada succession that contain ammonites and other megafossils are in the overlying Vammevarams belonging to the Middle Stage of the Upper Gondwana of the east coast.

The Middle Stage is developed in all the east coast areas except Cuttack. In the Eluru area, the Golapillis are overlain by 160 feet of strata – the Raghavapuram shales which unlike the Lower and the Upper stages contain a marine fauna, including ammonites and Foraminifera, along with rare but characteristic Upper Gondwana plant remains. The assemblage contains an admixture of several forms of the Golapillis showing Rajmahal affinities and some Jabalpur elements besides its own set of plant fossils. The Jabalpurs are at a higher level than the Rajmahals and contain a different plant assemblage. In the Ongole area, the Middle Stage is represented by Vammevaram beds, which contain a rich assemblage of animal fossils, including ammonites, and some plant remains almost identical with that of the Raghavapuram beds. In the Madras area, the Sriperumbudur beds represent the Middle Stage and contain ammonites and foraminifera besides fragmentary plant remains showing close affinities with Raghavapuram and Vammevaram assemblages. The Uttatur plant beds represent the Middle Stage in the Tiruchchirappalli area and a few fragile plant remains occur in these beds, `Ptilophyllum` being the most prominent. A check-list of the plant fossils occurring in the Middle Stage is given below:

`Cladophlebis indica `, `C. denticulata `, `Taeniopteris (Angiopteridium) spatulata `, `T. (A.) macel-landi `, `Dictyozamites indicus `, `Otocamites bengalensis `, `O. hislopii `, `Ptilophyllum acutifolium `, `P. cutchense `, `Elatoecladus plana `, `E. tenerrina `, `Retinaspores indica `, `Brachyphyllum expansum `, `Ginkgoales crassipes `, `Araucarites cutchense `, etc.
The Upper Stage is of fresh-water origin. It is missing from the Cuttack area, but from other areas it has yielded a few fragmentary and poorly preserved plant remains including *Ptilophyllum acutifolium*, *P. cutchense*, *Dictyoazamites*, *Williamsonia blanfordi*, etc.

From the foregoing information it is evident that the Lower stage contains the Rajmahal assemblage; the Middle Stage has an admixture of Rajmahal and Jabalpur floras; and the Upper Stage contains fragmentary plant remains which are generally not identifiable. Plant fossils are abundant in the Lower Stage, start declining during the Middle Stage, and become scarce in the Upper Stage. The assemblage, on the whole, suggests a Middle to Upper Jurassic age. Although, in recent years, some Wealden elements have been reported from Cutch, Rewa, and Jabalpur areas (Bose 1958; Bose & Sukh Dev 1958; Singh et al. 1963; and Roy 1967), none have so far been found in the sediments of the East Coast Gondwanas.

Evidence from animal fossils

In addition to the prolific land flora, the Upper Gondwanas of the east coast of India contain a rich marine fauna. They are found to be intimately associated with the terrestrial plant remains and throw considerable light on the palaeoenvironment, the palaeogeography, and the chronology. The age determined from the marine fauna conflicts with the traditional age deduced from floral evidence.

With the exception of the Tirupati beds at Ayaparaz-Kotapilli, the marine fossils are restricted to the Middle stage. In the Cuttack outlier, the Middle stage is missing and no record of marine life is found there. The Raghavapuram shales contain ammonites, Foraminifera, fish scales, and other marine fossils generally confined to the lower part of the shale sequence. A rich assemblage of marine fossils including brachiopods, lamellibranchs, ammonites, fish scales, Foraminifera, etc., has been recorded from the Vannavaram shales also. M. R. Sahni (1938) reported the occurrence of the Cenomanian genus *Rectithyris*—*R. expansa* and *R. recurvata*—from these beds. The Sripurumbudur beds represent the Middle Stage in the Madras area and contain ammonites, Foraminifera, and other fossils of marine nature.

A check-list of ammonites found in the Middle Stage is given below:


The Upper Stage does not contain marine fossils except at Ayaparaz-Kotapilli, where the assemblage comprises of *Lima*, *Pecten*, *Inoceramus*, *Pseudo-monadis*, and two species of *Trigonia*—*T. smeei* Sowerby and *T. ventricosa* Krauss. These two species of *Trigonia* have also been commonly recorded from the Umia beds of Cutch which have been assigned a Late Portlandian to Neocomian age. *T. ventricosa* has also been reported from the Uitenhage
series (Cretaceous) of South Africa and Early Neocomian beds of Tangan­nyika. In addition to these, the Cretaceous ammonite Helicoceras has also been recovered from Ayaparaz-Kotapilli area.

The overwhelming evidence of ammonites and other invertebrates indicates a Neocomian age to the Middle Stage. The occurrence of the Cenomanian genus Rectithyris is also a contribution towards the Cretaceous affinity of these beds.

Evidence from microfossils

The conflicting evidence of flora and fauna demanded fresh evidence in order to place precisely the upper age limit of the East Coast Gondwanas, and the testimony of Foraminifera is of considerable significance in this regard. Although King (1880) made passing reference to the presence of Foraminifera in the Raghavapuram shales, it was Sastri et al. (1961, 1963) who first described three species from these shales. This was followed by Bhalla (1965, 1969b), who made a detailed study of Foraminifera from the Raghavapuram shales. From the Ongole area, Bhalla (1969c) reported the occurrence of Foraminifera from the top bed of the Budavada sequence belonging to the Yammevarams. Murthy & Sastri (1960, 1962) described Foraminifera from the Sriperumbudur beds.

A check-list of the Foraminifera found in the Middle Stage is given below:


A striking feature which emerges from the microfaunal study is that the assemblage at Eluru, Ongole, and Madras is predominantly arenaceous and confined to the Middle Stage only. A majority of foraminiferal species occur in the Early Cretaceous of the different parts of the world, including the Lower Wilgunya Formation (Early Cretaceous) and Marree Formation (Aptian-Albian) of Australia. However, in the absence of any marker species of Foraminifera, the microfaunal evidence prohibits the assignment of precise age for these beds, but the overall predominance of the Cretaceous species further reinforces the evidence furnished by ammonites and other megafossils for the Early Cretaceous age of the Middle Stage.

Discussion

In various Gondwana exposures, the controversy of the upper age limit is mainly restricted to the east coast beds. This is perhaps because at other places there is no other evidence except floral with which it may come in conflict. The situation is chiefly due to the palaeogeographic position of the
East Coast Gondwanas

The East Coast Gondwana basin which made it possible for the sequence to include marine fauna along with the land flora. It would imply that during the Upper Gondwana times, the earth had started getting the impulses of the well-known Cenomanian transgression, and these impulses probably caused fluctuations of the shore-line of the east coast of India. By virtue of their coastal positions, the Gondwana basins in which fresh water conditions were prevailing turned marine with the advance of the sea and incorporated marine animals along with land plants, thus preserving clues for the age and the palaeoecology of the beds. Bhalla (1968) made a detailed study of the palaeoecology of the Raghavapuram shales and observed that out of 160 feet of the shale sequence, the lower 60 to 70 feet was deposited in open sea environment, allowing free but sporadic movements of ammonites and other invertebrates in the basin. Thereafter, the basin became land-locked, resulting in the development of marsh environment in which the rest of the column was laid down. This change-over is supported by the presence of a glauconite-bearing bed at 60 to 70 feet from the base (Bhalla 1969a). A palaeoecological study of the Middle Stage in other areas has not yet been made, but in view of similar assemblages found there, it may be inferred that during the deposition of this Stage a chain of isolated shallow-water marine basins developed on the east coast resulting in the incorporation of marine animals in the sediments of the Middle Stage. The association of terrestrial plants and marine animals is interesting for it is sometimes found in a single hand specimen but these fossil groups have different stories to tell.

The plant fossils are fairly abundant in the Upper Gondwanas of the east coast. The overall predominance of Rajmahal flora led workers to consider that the beds were of Jurassic age. Dettmann (1963) made a comprehensive study of spores from certain formations in South-East Australia which show plant remains similar to those found in the Rajmahals of India. On palynological evidence, she considered Australian as well as Indian formations to be of Lower Cretaceous age. Recently, Douglas (1969) gave a detailed account of megaplant remains from southern Victorian Mesozoic of Australia and made overseas correlations. Commenting on Dettmann (1963), Douglas (1969: 283) mentioned that "outright rejection of a Jurassic age for at least some of the Rajmahal Group beds does not seem justified at this juncture. He, however, compared Victorian floras with the Jurassic-Lower Cretaceous floras of other parts of the world. In view of the studies made by these workers, it is possible that the plant assemblage of the East Coast Gondwanas is also of Lower Cretaceous age but it is still premature to rely on this for two reasons: the observations made by Douglas (op. cit.), and the fact that the East Coast assemblage has not yet been thoroughly revised. The pioneering work of eminent palaeobotanists so much obsessed the thoughts of workers on the Gondwanas in India that they forgot there was other evidence the ammonites which could not be overlooked while fixing the upper age of the Gondwanas. Although the ammonites were dis-
covered as early as 1871 by Waagen, they remained in obscurity till the palaeobotanists proposed Jurassic as the upper age limit of the East Coast Gondwanas. This was in apparent contradiction to the age indicated by the ammonites and led Spath (1933) to revise the collections of ammonites made from Eluru, Ongole, and Madras areas by King, Foote, and Iyer. Spath (op. cit.) observed that the Middle stage was of Upper Neocomian age, thus making, inter alia, the Upper stage still younger.

The studies of Spath (1933) accelerated the present controversy and workers started to doubt the reliability of palaeobotanical evidence for fixing the age of the East Coast Gondwanas. Fresh evidence was sought and the discovery of *Rectithyris* by M. R. Sahni (1938) in the Vammevaram shales is of significant value. This genus is not known before Cenomanian so its presence in these beds is of considerable interest. Although it was not suggested by Sahni that the beds are so much higher up in the sequence, this find further strengthens the testimony of ammonites for the Cretaceous age of these beds. The Middle stage has yielded Foraminifera also and their evidence also favours the Cretaceous age for these east coast beds.

The above discussion reveals that while the plant fossils indicate a Jurassic age for the East Coast Gondwanas, the ammonites and other animal fossils suggest that the beds are not older than the Neocomian. This makes it difficult to bring a compromise between the two and the only course then left is to scrutinise the reliability of floral and faunal evidences.

It seems difficult to doubt the testimony of ammonites because of two reasons: firstly, the ammonites do not appear to be reworked, as no ammonite-bearing rocks older than the Middle stage are known to exist on the east coast of India, and secondly, the ammonites are very good age-markers during the Mesozoic in other parts of the world. Moreover, the evidence of ammonites is corroborated by micro- as well as mega-fossils. It is, therefore, hard to contradict the testimony of ammonites and the solution of the problem then lies in judging the evidence of plant fossils.

Pascoe (1959:1010), when dealing with the evidence of plant remains for the age of the East Coast Gondwanas, suggested that if the plants are considered to be indigenous, then, in order to bring a settlement with the ammonites, the only solution '... would seem to be that the numerous plants common to the Rajmahals and the East Coast beds are but an example of the slower evolutionary change during Upper Gondwana times as compared with those which obtained in the Lower Gondwana period'. However, Pascoe's suggestion of slow evolutionary change appears doubtful. If the rate of evolution of plants during Upper Gondwana times was slow in comparison to Lower Gondwana times, then why was it restricted to the Indian region alone? Such a phenomenon should be of a world-wide nature and not a localized one. And if such a condition was there, what were the reasons for it? No explanation to these corollaries was attempted by Pascoe.

The second possibility is that the plant fossils are reworked. The Gondwana rocks containing prolific flora are extensively developed in the vicinity
of the east coast of India. It is possible that the plant fossils now entombed in the Middle Stage were brought to the site of deposition from pre-existing Gondwana rocks and got intimately mixed up with the marine fauna during Early Cretaceous times. If the plea for the reworked nature of the floral assemblage is accepted, the discrepancy between the chronological testimony of fossil plants and animals no longer exists. The concept of a derived nature of plant fossils receives further credence from the fact that the floral assemblage of the Middle Stage contains elements of Rajmahals as well as Jabalpurs. Jabalpurs are at a higher level than the Rajmahals and contain a different plant assemblage. It is rather difficult to visualise the presence of a younger assemblage in an older strata unless the former is reworked, in which case the strata would be even younger than the assemblage. This is evidence by itself for the derived nature of the plant fossils in the East Coast Gondwanas. An additional support regarding the 'reworking' comes from the studies of Raju & Rao (1954). These authors worked on the Lower and the Upper Gondwanas of the Eluru area and, on the basis of sedimentological evidence, noted that the sediments of Golapillis were derived from the pre-existing Lower Gondwana rocks in the vicinity. It is also '... possible for blocks of plant-bearing Jurassic rocks to have fallen, in early Cretaceous times, from low cliffs into some protected delta or coastal lake ... and to have become intimately mixed with ammonite-bearing marine Cretaceous sediments', as observed by Pascoe (1959: 1007).

The assumption of the derived nature of the flora settles the controversy regarding the upper age limit of the East Coast Gondwanas and the circumstantial evidence is such to lend credence to it. This would indicate that what has so far been accepted as evidence from flora, may not be true.

Conclusion

The controversy over fixing the upper age limit of the East Coast Gondwana arises when evidence from plant and animal fossils is relied upon. As discussed above, the fauna of the east coast beds is not reworked, but it has yet to be confirmed that the plant fossils are indigenous. The floral evidence is, therefore, open to doubt. It is not safe to rely on it till the assemblage is thoroughly revised. The only course then left is to accept the testimony of ammonites and other megafossils which indicate a Neocomian age for these beds. This is further corroborated by the evidence from Foraminifera.

The ammonites and other animal fossils are present in the Middle Stage only and, therefore, the Neocomian age is assigned to this stage. This would, in turn, necessitate that the Upper Stage should be taken further up in the column and Aptian or Albian should be considered as the upper age limit of the East Coast Gondwanas.
REFERENCES


