SECTION 4
SECTION 4
CRETACEOUS-TERTIARY BOUNDARY

In the Pangadi area of Andhra Pradesh, good exposures of Cretaceous and Paleocene rocks containing fascinating suites of fossils are found and an attempt was made to demarcate the Cretaceous-Tertiary boundary in this region.

In the above area, the topmost stratigraphic unit belonging to the Mesozoic is the Tirupati sandstone which constitutes the uppermost formation of the East Coast Gondwana. On fossil evidence and stratigraphic considerations, the Tirupati sandstone is dated as Aptian or Alban (Bhalla, 1972) (Table 1).

The age of the overlying infra-trappean beds has been a matter of controversy. This is mainly because of the fact that characteristic genera and/or species which can place these beds precisely in the stratigraphic column are not found in them. The foraminiferal assemblage described by the author (Bhalla, 1966), however, includes certain well-known species which have been recorded either from the Paleocene or Eocene of the different parts of the world. The mega- as well as microfaunal assemblage, on the whole, favours a Paleocene age for these strata which represent the beginning of the Tertiary Era in this part of India.

Structurally, Pangadi area is practically undisturbed and the beds show low dips towards east and southeast. The contact between the Tirupati sandstone and the overlying infra-trappean beds is concealed below a vast stretch of alluvium and is nowhere seen in the area. However, on the basis of sedimentological studies, an unconformity between the two has been suggested and the fossil records of both corroborate this contention.
It is, therefore, evident that the Tirupati sandstone is of Aptian or Albian age whereas the overlying Infra-trappean beds are of Paleocene age; and the unconformity between the two marks the Cretaceous-Tertiary boundary in the area (Bhalla, 1968).

REFERENCES

BHALLA, S. N.


FORAMINIFERA FROM THE INFRA-TRAPPEAN BEDS OF THE PANGADI AREA, INDIA

S. N. BHALLA
Aligarh Muslim University, Aligarh, India

Abstract—The infra-trappean beds of the Pangadi area have yielded eight species of foraminifera, including two new species, *Paradiplostephanus deccanpalliense* and *Planulina bhatiai*. The foraminiferan assemblage suggests a shallow marine, inner-shelfic environment of deposition. The balance of foraminiferan evidence points to a Paleocene age for these beds.

Introduction

The nature of the Cretaceous-Eocene sequence has been one of the most controversial problems of geology and has engaged the attention of geologists almost all over the world. In India, the Cretaceous-Eocene rocks are widely distributed and are found associated together at several places. An interesting area of the Cretaceous-Eocene succession is found in the vicinity of Pangadi, Andhra Pradesh. In this locality, outcrops of Upper Gondwana rocks, infra-trappean beds, and inter-trappean rocks are found in a small circumscribed area, and their association with the Deccan Traps make them even more interesting.

The marine infra-trappean beds of the Pangadi area (Text-fig. 1) occupy an important place in Indian stratigraphy. Their age has been a subject of great controversy since they were first scientifically described (King, 1880). Although some megafossils from these beds have been described, their identifications need revision. The microfossils from these beds have been recorded by Rao & Rao (1935), but the present work deals for the first time with the foraminifera in detail.

Detailed sampling was done at different localities of the exposed infra-trappean beds in this area with a view to make a comprehensive study of their microfauna, especially foraminifera.

In the present work, the reclassification proposed by Reiss (1963) has been followed for the perforate species of foraminifera, but Pokorny's (1963) classification has been adopted for porelaneous foraminifera.

Synonymies are reduced to a minimum, arranged chronologically, and indicate only important shifts in the generic names. Further, in order to avoid repetition, the words *et al.*, follow those references in which complete or satisfactory synonymies have already appeared.

Holotypes and paratypes of the new species have been deposited in the Museum of the Geology Department, Panjab University, Chandigarh, and their references are designated by a PUGD catalogue number in the text. Hypotypes of previously described species are also housed in the Geology Department of Panjab University.

Laboratory Procedure and Techniques

The samples were crushed, boiled in detergents, disaggregated, and finally screened through a set of standard sieves. Microfossils were picked up from the picking tray with the help of a fine...
The immersed specimen was examined under cross nicois. The black brushes in the keeled forms having a radially built wall were best seen at the periphery by rotating the stage of the microscope. However, in forms having globular chambers, as Vaginulina d'Orbigny, the black brushes can well be seen in the centre of the chambers. Where conclusive results could not be obtained with the above-mentioned methods, thin sections were prepared.
The pores in the walls were studied by immersing the specimen in xylene for about two days in order to remove the air bubbles in the specimen and then crushing it in Canada balsam under a cover slip (Wood, personal communication, 1964).

In order to make the surface features distinct, specimens were stained following the silver nitrate method described by Levinson (1951).

**PREVIOUS WORK**

The Infra-trappean beds near Pangadi were first reported by King (1874, p. 159), who followed the silver nitrate method described by Levinson (1951).

The Infra-trappean beds near Pangadi were first reported by King (1874, p. 159), who (ibid., King 1880, p. 231) gave a check-list of the fossils so far recorded from the Infra-trappean beds of this area, observed, "Although the whole facies is tertiary there is a remarkable absence of characteristic genera, and the chief distinctions from the cretaceous fauna of the upper beds in South India is simply the want of any marked cretaceous form. The fauna is distinctly marine." Discussing the evidence concerning the age of the Infra-trappean rocks of this region, these authors (ibid.) considered them to belong to "... cretaceous times than to tertiury. They may be of intermediate age." Their views were supported by Oldham (1893).

Das Gupta (1933) collected *Cardita beaumonti* d'Archiac from the Infra-trappean rocks of Pangadi and suggested that these beds were of late Cretaceous age.

Rao & Rao (1935) reported for the first time foraminifera, *Rastella* Lamarck, *Discorbina* Parker & Jones, *P adulinea*, *Brady*, *Glabergerina* d'Orbigny and some miliolids and radiolarians, from the Infra-trappean rocks of this region. They correlated these beds with the Uttartor (Cenomanian) of Trichinopoly on foraminiferal evidence. However, they did not give specific identifications, descriptions, or illustrations of these fossils. Except for some unidentifiable miliolid molds, the author did not find any specimens which could be referred to any of the above-mentioned genera. Reliance cannot be placed on identifications made by Rao & Rao (1935).

Rao and others (1936), while discussing the age of the Decan Traps near Rajahmundry, concluded that the Infra-trappean beds are of very late Cretaceous age.

L. Rama Rao (1950, 1964), while discussing the problems pertaining to the Cretaceous—Eocene boundary, discouraged drawing a sharp boundary between the Cretaceous and the Eocene and suggested instead the use of the term "Creocene" for the transitional horizons separating the Cretaceous from the Eocene.

L. Rama Rao (1953) reviewed the problem of "Danian" with special reference to India, and on the evidence of *Cardita beaumonti* considered the Infra-trappean beds to be of "Danian" age. He observed (ibid., p. 361) that "... the Rajahmundry Cretaceous beds below the Traps are of "Danian" age ...", thus by implication including the "Danian" in the Cretaceous. This is apparently in contradiction with his earlier view (L. Rama Rao, 1953).

Pascoe (1959, p. 1262) has given a comprehensive list of the fossils so far recorded from Infra-trappean rocks. The list includes the following:


**GEOLOGY OF THE AREA**

Pangadi (Survey of India, Toposheet No. 65G/12, 1°7'18"N 79°01'390"E) is a small village in the West Godavari district of Andhra Pradesh. The Pangadi area is of great geological interest because it is here that the trap rocks rest directly on the marine, fossiliferous Infra-trappean beds. The stratigraphic position of the Infra-trappean beds in this area follows.

<table>
<thead>
<tr>
<th>Rock unit</th>
<th>Rock type</th>
<th>Geologic age</th>
</tr>
</thead>
<tbody>
<tr>
<td>Decan Traps</td>
<td>Volcanic</td>
<td>Early Eocene</td>
</tr>
<tr>
<td>Erosional unconformity</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Infra-Trappean Marine beds</td>
<td>Palaeocene</td>
<td></td>
</tr>
<tr>
<td>Tirupati Sandstone</td>
<td>Fresh-water</td>
<td>Late Gondwana (Early Cretaceous)</td>
</tr>
</tbody>
</table>

The Infra-trappean beds overlie the Tirupati sandstones and are in turn overlain by the Decan Traps. However, the exact contact of the...
Tirupati sandstones and the Infra-trappean beds is not exposed in the area. Two good exposures of the Infra-trappean beds were noticed in the area: one, is about 0.5 mile southeast of Devarapalle in a small nala cutting near a pond on the Devarapalle-Lakhimpuram footpath (Locality P), and the other is 0.5 mile south of Duddukuru (Locality Q). The outcrop at Devarapalle is small; the base of the section is not seen; and the succession at Locality P follows.

Sample number

Bed Number 3 varies greatly in thickness. In places it is totally absent and thus allows the trap to overlie directly bed Number 2. This probably indicates an erosional unconformity between the Infra-trappean beds and the traps. The following sequence of Infra-trappean rocks was observed about 0.5 mile south of Duddukuru (Locality Q), where the base of the section was not seen.

Sample number

The basal sandstone (bed Number 1) can be seen extending from near the village Duddukuru to the junction between the traps and the limestone 0.5 mile south of the village. A short note reporting new species of foraminifera from these Infra-trappean beds has been sent for publication, but the detailed description of each species is given below.

**SYSTEMATIC PALEONTOLOGY**

Order Foraminifera d'Orbigny, 1826
Superfamily Milolidae Ehrenberg, 1839
Family Milolidae Ehrenberg, 1839
Genus Quinqueloculina d'Orbigny, 1826

**Quinqueloculina sp. A**

*Pl. 40, fig. 1*

*Description.—* Mold small, nearly oval, more or less triangular in end view, having a broadly rounded periphery; sutures more or less well marked, depressed; chambers distinct, slightly inflated; peripheral chambers nearly cylindrical; apertural end not protruded but somewhat truncated. Dimensions in mm.: length, 0.37; breadth, 0.30; and maximum thickness, 0.30.

*Discussion.—* A single internal mold, which may be questionably referred to *Quinqueloculina brevidentata* Le Calvez, 1947 from the Middle Eocene (Lutetian) of France, was found.

*Occurrence.—* Sample P/3.

**Quinqueloculina sp. B**

*Pl. 40, fig. 2*

*Description.—* Mold elongate, nearly twice as long as broad, more or less oval in end view; chambers distinct, inflated, four visible on one side and three on the other side, peripheral chambers cylindrical; sutures distinct, somewhat depressed; apertural end slightly projecting; periphery broadly rounded. Dimensions in mm.: length, 0.48; breadth, 0.25; and maximum thickness, 0.25.

*Discussion.—* The solitary internal mold could not be assigned to any known species of *Quinqueloculina*.

*Occurrence.—* Sample Q/3.

Superfamily Nodosariidae Ehrenberg, 1839
Family Nodosariidae Ehrenberg, 1839
Subfamily Nodosarininae Ehrenberg, 1839
Genus Vaginulina d'Orbigny, 1826
emend. Marie, 1941

**Vaginulina cf. V. ctenomana**

*Perner, 1892, Pl. 1, no. 1, p. 62 (Bohmanian text, p. 37), Pl. 5, fig. 18, Cushman, 1944, Pl. 18, fig. 17 (type redrawn)*

*Description.—* Test free, elongate, flattened; dorsal margin more or less straight; ventral
Holotype of *Fseudopolymorpha devarapalleensis* n. sp. showing arrangement of chambers in a megalospheric form. lc, lb, Side views; lc, basal view. X125.

Margin gently convex; periphery smooth and rounded; chambers five, proloculus spherical; sutures indistinct, slightly curved, somewhat thick; aperture small, radiate, at the dorsal angle. Dimensions in mm.: length, 0.47; maximum breadth, 0.20; and maximum thickness, 0.12.

Discussion.—Only one specimen was found in the material which strongly resembles *Vaginula cenomanana* that was first described by Perner (1892) from the Cenomanian of Bohem (Czechoslovakia). The Indian form differs, however, in being smaller and in having fewer chambers. It may represent a megalospheric generation of this species.

Occurrence.—Sample P/3.

Family POLYMORPHINIDAE d'Orbigny, 1839

Subfamily POLYMORPHINAE d'Orbigny, 1839

Genus *GUTTULINA* d'Orbigny, 1826

*Guttulina lactea* (Walker & Jacob)

Pl. 40 fig. 6

Serpula laevis oralis Walker & Boys, 1784, p. 2, Pl. 1, fig. 3.

Serpula lactea Walker & Jacob, 1798, p. 637, Pl. 14, fig. 2.

Gallulinia lactea Cushman & Ozawa, 1930, p. 43, Pl. 10, figs. 1-4; *cf.* Brozzen, 1948, p. 49, Figs. 8, 10; Puri, 1953, p. 107, Pl. 9, figs. 11, 12, Haque, 1956, p. 196, 107, Pl. 28, figs. 6a-c; Haynes, 1958, p. 45, Pl. 3, figs. 1-12.

Description.—Test elongate, compressed, oval in end view; greatest width towards the base, apertural end slightly tapering; chambers five, not very distinct, elongate, embracing, reaching back to the base, arranged in a clockwise quinqueloculine series; sutures distinct, very slightly depressed; wall thick, calcareous; aperture terminal, radiate, surface smooth. Dimensions in mm.: length, 0.43; breadth, 0.23.

Discussion.—The specimens show close resemblance to the forms described and figured by Haynes (1958). It is a well-known cosmopolitan species and ranges from Paleocene to Recent. From the Paleocene it has been recorded by Haynes (1958), Brozzen (1948), Haque (1956), and others. This is its first record from India.

Occurrence.—Abundant in sample P/3.

Genus *PSEUDOPOLYMORPHA* Cushman & Ozawa, 1928

*Pseudopolymorpha devarapalleensis* n. sp.

Pl. 40, figs. 4, 5; Text-figs. 2, 3

Description.—Test elongate, somewhat compressed, ovate having blunt ends; periphery rounded; chambers seven, elongate, fairly well marked, slightly embracing, earlier chambers arranged in a quinqueloculine series, later be-
TEXT-FIG. 5—Paratype A of *Pseudopolymorpha devarapallemsis* n. sp., showing arrangement of chambers in a microspheric form. 1a, 1b, Side views; 1c, basal view. X 125.

coming biserial, last chamber occupying nearly half of the test, sutures slightly impressed; aperture terminal, radiate; wall smooth and thick.

**Dimorphism and variation.**—This species is apparently represented by two generations; the microspheric individuals have a small proloculus and as many as nine chambers (Text-figs. 3a–c), and megalospheric individuals have comparatively larger proloculus and as many as seven chambers (Text-figs. 2a–c). The chambers of the microspheric forms are more embracing, and the quinqueloculine portion of the test is comparatively well developed compared with the megalospheric individuals. Tests belonging to the two generations do not differ markedly in size.

Variation has been observed in the size of the test as shown by the following measurements in millimeters.

<table>
<thead>
<tr>
<th>Dimension</th>
<th>Holotype</th>
<th>Paratype A</th>
<th>Other paratypes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Length</td>
<td>0.73</td>
<td>0.67</td>
<td>0.45 to 0.72</td>
</tr>
<tr>
<td>Breadth</td>
<td>0.34</td>
<td>0.33</td>
<td>0.28 to 0.33</td>
</tr>
<tr>
<td>Thickness</td>
<td>0.33</td>
<td>0.33</td>
<td>0.28 to 0.33</td>
</tr>
</tbody>
</table>

**Discussion.**—This new species of *Pseudopolymorpha* shows some resemblance to *Pseudopolymorpha decorata* (Reuss) [= *Polymerophina decorata* Reuss, 1863] figured by Cushman and Ozawa (1930, Pl. 24, figs. 6, 8a,b), but differs from it in having an oval shape, comparatively more embracing chambers, a less developed biserial portion, and blunt apertural and basal ends.

**Type horizon.**—Infra-trappean beds; sample No. F/3; pale sandy limestone.

**Type locality.**—Infra-trappean beds exposed along the Devarapalle-Lakshmipuram footpath, about 0.5 mile southeast of the Devarapalle village, West Godavari District, Andhra Pradesh, India.

**Geological age.**—Paleocene.

**Repository of type material.**—Holotype, PUGD F1218; paratype A, PUGD F1219.

**Etymology of trivial name.**—This species is named after the village Devarapalle near which the Infra-trappean beds are exposed.
FORAMINIFERA FROM PANGADI AREA, INDIA

Granulate group, but later Wood & Haynes (1957, p. 46) modified the earlier views of Wood (1949) and stated: "The results appear to show that both radial and granular species are included in Cibicides as at present understood." However, they (Wood & Haynes, 1957) considered that the microstructure of the wall, as well as pore character, are of value in classification.

Hofker (1951, p. 10) placed great stress on the "... small, embedded umbilical plug," and considered this character to be "... of high systematic importance."

Reise (1959, p. 355) has also recorded "granular-calcareous structure" in some species of Cibicides.

Loeblich & Tappan (1961, p. 284) considered, "test wall composition and structure" as the criteria for the separation of superfamilies and included the family Cibicididae in the superfamily Cibicidoidea, which has a granular wall. In a later publication, Loeblich & Tappan (1962, p. 71) restricted the genus Cibicides to include "radially built bilamellid wall."

Cifelli (1962, p. 125) in his studies on Cibicides, has shown that in some species the test wall is radial but the septa are of granular microstructure and concluded, "Clearly, the nature of the wall at least as it is presently understood, cannot alone provide a natural basis for classifying the hyaline Foraminifera."

A similar opinion was expressed by Wood and Haynes (1957), "The evidence as to the value of the wall structure in classification is yet inconclusive."

Although all species of Cibicides in the present work have a radial wall, the author, in view of the foregoing discussion, believes that the genus Cibicides should include forms that may have either a radial or a granular wall.

Cibicides mensilla (Schwager)

Pl. 40, fig. 10

Description: Trochospiral, plano-convex, nearly circular in outline; dorsal side evolute, flat, ventral side convex having moderately developed umbilical plug; some specimens also having an umbilical boss of clear shell material on dorsal side; chambers noninflated, distinct, increasing gradually in size with growth, 7 to 10 in last coil; sutures clearly marked, pore-less, backward curving, limitate; dorsal sutures flush with surface, ventral sutures in some specimens very slightly depressed in last two or three chambers, spiral suture clearly visible; dorsal pores coarse having very fine ones in between, ventral pores very fine having a few coarse ones scattered on the last three or four chambers; peripheral subacute showing poreless keel, very slightly lobulate in last three or four chambers, in some forms entire; aperture intermargin, peripheral, extending a short distance along the spiral suture on the dorsal side; wall calcareous displaying radial microstructure of the pores.

Dimension

<table>
<thead>
<tr>
<th>Adult specimens</th>
<th>Juvenile specimens</th>
</tr>
</thead>
<tbody>
<tr>
<td>Major diameter</td>
<td>0.18 to 0.33</td>
</tr>
<tr>
<td>Minor diameter</td>
<td>0.17 to 0.28</td>
</tr>
<tr>
<td>Thickness</td>
<td>0.10 to 0.15</td>
</tr>
<tr>
<td>Diameter of proloculus</td>
<td>16a to 33a</td>
</tr>
</tbody>
</table>

Discussion — The specimens strongly resemble Cibicides mensilla (Schwager), first described from the "Eocene" of the Libyan desert. Recently, Haque (1956) recorded it from the lowermost Laki beds (upper Paleocene) of Nannal gorge, West Pakistan. The Indian specimens are apparently similar to those described by Haque (1956) from Pakistan and probably come within the range of variation of the species. In the present forms, however, the dorsal sutures are not depressed, and the dorsal convexity is not developed as shown in Haque's figure (1956, Pl. 20, fig. 11c). The degree of convexity, however, is not considered to be of much significance in Cibicides because it is generally an attached form and shows considerable range of variation (Bhatia, 1956; Nyholm, 1961).
In text, 5:

**Planulina bhallai n. sp.**

- **Description:** Test discoidal, trochospiral, bi-evolute, dorsal side more so than the ventral; test consisting of two whorls, the first having ten chambers (including the proloculus), the second having seven chambers; chambers distinct, increasing fairly rapidly in size; sutures well marked, limbate, slightly depressed, curved, especially in the second volution, nonperforate; periphery entire, except for slight lobation in the last two chambers; keel faint, imperforate; umbilical side slightly depressed; aperture equatorial, interiomarginal, and arch-shaped having slight lip, extending on to the umbilical side; wall calcareous, moderately perforate on both sides, radial, smooth.

**Dimorphism and variation:** About one hundred specimens of this new species were examined to trace out the dimorphic generations. The average diameter of megalospheric proloculus is 28μ, but the average diameter of the proloculus in microspheric forms is 12μ. The periphery is generally entire in microspheric forms but in megalospheric individuals it is lobulate.

Slight variation has been observed in the lobulation of the periphery and the prominence of the keel. The periphery of the last two or three chambers is generally lobulate, and the poreless keel is normally not very well marked. Average diameter of the pores is 2μ. Other dimensions in millimeters are given below.

<table>
<thead>
<tr>
<th>Dimension</th>
<th>Holotype</th>
<th>Paratype</th>
<th>A specimen</th>
</tr>
</thead>
<tbody>
<tr>
<td>Major diameter</td>
<td>0.30</td>
<td>0.31</td>
<td>0.18 to 0.37</td>
</tr>
<tr>
<td>Minor diameter</td>
<td>0.25</td>
<td>0.25</td>
<td>0.13 to 0.29</td>
</tr>
<tr>
<td>Thickness</td>
<td>0.10</td>
<td>0.10</td>
<td>0.07 to 0.12</td>
</tr>
<tr>
<td>Diameter of proloculus</td>
<td>32μ</td>
<td>28μ</td>
<td></td>
</tr>
</tbody>
</table>

**Discussion:** This distinctive new species of Planulina shows some resemblance to Planulina caribana described by Cushman (1931) from the Montego Bay, Jamaica, West Indies but differs in being smaller, less compressed, and having moderately sized perforations on both the sides. From Planulina heteropora Ehrenberg, 1854, described from the Cretaceous of Egypt, this new species differs in having gently curved sutures and comparatively coarsely punctate test. Definite comparisons cannot be made with P.
clearly, as the type description has not been given and topotypes were not available for comparison.

**Type horizon.**—Infra-trappean beds; sample number P/3; pale, sandy limestone: found abundantly; also in the Infra-trappean sample Q/3.

**Type locality.**—Infra-trappean beds exposed along the Devanapalle-Lakshmipuram footpath, about 0.5 mile southeast of Devanapalle village, West Godavari District, Andhra Pradesh, India.

**Geologic age.**—Paleocene.

**Repository of type material.**—Holotype, PUGD F1220; paratype A, PUGD F1221.

**Etymology of trivial name.**—The species is named in honour of S. B. Bhatia, Reader in Geology, Panjab University, Chandigarh.

**PALEOECOLOGY**

The Infra-trappean beds contain a meagre microfossil fauna comprised of molds of miliolids, *Vaginulina, Guttulina, Pseudopolymorpha, Cibicides, Planulina, and ophiuroid ossicles*. In this assemblage, only *Planulina* is abundant, and the other forms are either rare or common. Of these, two species, *Pseudopolymorpha denarii*, and *Planulina bhatiai*, are new, and the others, except *Guttulina lactea* (Walker & Jacob), are extinct. The microfossil assemblage is associated with *Turrilella* (abundant), *Denisium*, *Vaginulina*, chelae of crabs, and other megafossils. Because of the limited number of species and the lack of forms having definite ecological significance, environment under which these beds were deposited cannot be deduced precisely. The new species cannot be taken into consideration for paleoecological deductions. Some broad generalizations, however, regarding the paleoecology of these sediments can be made. In modern seas, miliolids are found in warm marine environments of the inner neritic zone and can tolerate a salinity range of 18(7) to 36°. They have also been recorded from the brackish water environments (Lowman, 1949). Ecological data on the family Polymorphini-dae indicate that the family, on the whole, is characteristic of a warm, shallow neritic environment, although it includes certain species which can tolerate variations in depth. *Guttulina lactea*, the only species in this fauna living in modern seas, has been recorded from depths of 15 to 900 fathoms from different parts of the world.

Ecological information pertaining to *Cibicides* shows that this genus is commonly represented in a shallow water (82 to 91 m) marine environment (Hedberg, 1934; Lowman, 1949), although some species of *Cibicides*, like the polymorphini-dae, tolerate wide range of depth variation.

Data on *Planulina* suggest that the genus is common at depths of 150 to 500 feet (Lowman, 1949).

Although no systematic work on the ophiuroid ossicles from the Infra-trappean beds could be carried out, the presence of these ossicles apparently have ecological significance. The ophiuroids are characteristically marine organisms, and majority of living species inhabit a zone lying between the low tide mark and 180 feet.

Among the megafossils, *Turrilella* is the most abundant. It is an exclusively marine genus (Gardner, 1957) and represents a near-shore, sandy bottom environment (Plummer, 1933). Similarly, *Denisium* is also a shallow water form and was found in abundance by Ladd and others (1957) at a depth of 7.5 feet in the Gulf of Mexico.

The occurrence of chelae of crab is interesting. The Recent marine crabs are found in shallow (10 to 30 m.), rather turbulent water zone on a seafloor consisting of loose sand.

On the basis of the faunal evidences, the author infers that the Infra-trappean beds were deposited in a shallow marine, rather warm and turbulent, inner neritic environment which had open sea connections.

**COMPOSITION, AGE, AND AFFINITIES OF THE MICROFAUNA**

The Infra-trappean beds of the Pangadi area contain a meagre microfossil assemblage. In all, eight species of foraminifera (Text-fig. 6), were found, of which one belongs to the family Nodosariidae, two each to the families Polymorphini-dae and Miliolidae, and three to the family Cibicidae. The foraminifera on the whole are rare, except *Cibicides mensilla* and *Planulina bhatiai* n. sp. which are found abundantly.

The miliolids are represented only as molds. *Quinqueloculina* sp. A, may actually belong to *Q. brevidentata*, an Eocene species but, because actual foraminiferal tests were not found, no specific comments can be made on this. Only one specimen of *Vaginulina* has been found which shows some resemblance to *V. cenomana*, which was described originally from the Cenomanian of Czecho-slovakia.

The occurrence of *Guttulina lactea* and *Cibicides mensilla* is significant. The former species is cosmopolitan and ranges from Paleocene to Recent. The Indian specimens show close resemblance to the Paleocene forms figured and described by Haynes (1938) from the Thanet beds of England and by Haque (1956) from the Paleocene of West Pakistan. *Cibicides mensilla*, which is found abundantly in this material, was
first described from the "Eocene" of the Libyan desert. Bandy (1944) recorded it from the Eocene of Cape Blanco, Oregon, U.S.A. Recently, Haque (1956) reported it from the lowermost Laki beds (Upper Paleocene) of Namlal gorge, West Pakistan.

The megafossils of the Infra-trappean beds have not been studied in detail. It is not certain whether the majority of the species belong to Cretaceous or to Tertiary. Das Gupta (1933) on the basis of Cardita beaumonti from these beds, considered them to belong to the upper part of the Upper Cretaceous. Detailed investigation by Kutsch (1936, non ridi), however, on the so-called C. beaumonti from different parts of the world shows that "C. beaumonti s.l." exhibits a wide range of variation and ranges from Maestrichtian to Middle Eocene. Unless "C. beaumonti" from the Infra-trappean beds is thoroughly restudied, little reliance can be placed on this species in ascertaining the age of these sediments.

Many workers consider these beds to be of Danian age, but in recent years Danian is favoured to be included in the Paleocene rather than in the Cretaceous.

The Infra-trappean beds are separated from the Inter-trappean rocks (of definite early Eocene age) by 40 feet to 50 feet of Traps and a slight unconformity. On this basis, the Infra-trappean beds are not likely to be older than Paleocene. Although the balance of foraminiferal evidence indicates a Paleocene age for the Infra-trappean strata, the fauna is too meagre to suggest any definite age for these beds. The conclusive evidence must come from the megafossils which are abundant but need a detailed and thorough revision.

ACKNOWLEDGMENTS

The author is grateful to Professor M. R. Sahni, formerly Head of the Geology Department, Panjab University, Chandigarh, and now Honorary Professor of Geology, Panjab University, for his constant encouragement and constructive comments. I am indebted to Dr. S. B. Bhatia of the Panjab University Geology Department for his guidance and help. To Dr. V. K. Srivastava, Geology Department, Aligarh Muslim University, I am grateful for his friendly criticism and useful suggestions. I am thankful to Professor Herbert Hage of Munich, Germany, for making available for study some Cretaceous and Tertiary material from Europe and to Professor Alan Wood of Aberystwyth, Wales, for suggesting the techniques for studying the pores in foraminifera. Sincere thanks are extended to the Director General, Geological Survey of India, for providing the library facilities.

REFERENCES


FORAMINIFERA FROM PANGADI AREA, INDIA


—1944, Notes on some of the Cretaceous foraminifers described by Perner in 1892 and 1897: Cushman Found. Foraminifera Research Contr., v. 20, pt. 4, p. 107-111, Pls. 18-20.


HEINE, H. D., 1934, Some Recent and fossil brackish to fresh-water foraminifera: Jour. Paleontology, v. 8, p. 469-476, 1 text-fig.


LeROY, L. W., 1953, Biostratigraphy of the Magi Section, Egypt: Ibid., Mem. 54, 73 p., 13 pis., 4 text-figs.


Manuscript received April 21, 1965.
CRETACEOUS-TERTIARY BOUNDARY IN THE PANGADI AREA,
WEST GODAVARI DISTRICT, ANDHRA PRADESH

S. N. BHALLA
Department of Geology, Aligarh Muslim University, Aligarh

ABSTRACT
The Cretaceous-Tertiary boundary in the Pangadi area, Andhra Pradesh, is discussed in
the light of the foraminiferal evidence obtained from the infra-trappean beds exposed in the
region. The Foraminifera, though poor in number and frequency of species, indicate the
prevailing of a shallow marine, inner-neritic condition of sedimentation. The assemblage
favours a Palaeocene age for the infra-trappean beds. On this basis, the overlying flows of
the Deccan Traps are regarded to be of early Eocene age.

INTRODUCTION
The demarcation of boundaries, whether political or natural, has always been a
ticklish problem. Of all the boundaries in the geological column, the one between
the Cretaceous and the Tertiary or, to be more precise, that between the Cretaceous
and the Palaeocene, is, perhaps, the most controversial and at the same time a very
interesting problem of world stratigraphy. The problem of the Cretaceous-Tertiary
boundary has attracted the attention of not only the palaeontologists who are consi­
dered to be at the helm of the affair, but also of sedimentologists, geochronologists,
and petrologists from different parts of the world. However, it is interesting to note
that in spite of different criteria employed and detailed work done throughout the
world, no amicable agreement regarding the Cretaceous-Tertiary boundary has yet
emerged.

In southern India, a few good exposures of marine Cretaceous-Tertiary sequence
containing attractive fossil assemblages are present. In the vicinity of Pangadi in the
West Godavari district of Andhra Pradesh, an interesting set of sedimentary rocks,
underlying the Deccan Traps, is present which is commonly referred to as the infra­
trappeans. These infra-trappeans are important from the stratigraphical point of
view because a detailed study of these rocks serves a two-fold purpose: (1) it reveals
the nature of the Cretaceous-Tertiary sequence in this region, and (2) it throws con­
siderable light on the age of the Deccan Traps with which they are closely associated
in the area.

The age of the infra-trappean beds of the Pangadi area has been a subject of con­
troversy ever since these were brought to the attention of Indian geologists by
William King in 1874. The majority of workers consider it to be of topmost
Cretaceous age. The rocks contain abundant marine fossils and it is rather unfortu­
nate that except for one or two reports on the fossils from these beds, no detailed
work on the fossil fauna has yet been made.

The recent advances in our knowledge of Foraminifera, especially the planktonic
group, have proved that they are the best tools in local as well as long distance
correlations. Parker (1965) pointed out certain irregularities in the distribution of
planktonic Foraminifera but, maintained that in spite of the irregularities, they are
excellent for stratigraphic correlations. Since the last decade, an intense micropalaeontological activity has been generated by the workers on Foraminifera to demarcate the Cretaceous-Tertiary boundary. The most interesting point arising out of their studies is the inclusion of the Danian in the Paleocene. Not only the Foraminifera, but other groups of microfossils also, including calcareous nannoplankton, support this view. However, it is beyond the scope of the present paper to discuss the position of Danian in the geological time scale, especially when the whole problem of the Cretaceous-Tertiary boundary, including that of the Danian, has been critically reviewed in a recent publication by Rama Rao (1964). The author agrees with the view that the Danian marks the basal stage of the Paleocene.

It was therefore, considered that a detailed study of the Foraminifera, from the infra-trappean beds of the Pangadi area would greatly advance our knowledge regarding the age and palaeoecology of these beds which, in turn, would throw light on the nature of the Cretaceous-Tertiary boundary, and also on the age of the overlying flows of the Deccan Traps in this area. With this end in view, detailed sampling of these infra-trappean beds was done to make a comprehensive study of the Foraminifera entombed in these sediments.

HISTORICAL RESUME

The infra-trappean beds of the Pangadi area occupy an important place in Indian stratigraphy. The beds were discovered by King in 1874 and their fossil content was studied by Rev. Hislop. King (1880) in his monumental work on the geology of the Rajahmundry region, dealt with the infra-trappean beds in detail and suggested an Upper Cretaceous age for them. According to him, these beds were deposited in a marine environment.

Medlicott and Blanford (1879) opined that the fauna of the Pangadi infra-trappean beds show Tertiary affinities and that they are of marine origin. However, they failed to arrive at any definite conclusion as regards the age of these beds.

Das Gupta (1933) described Cardita beaumonti d'Archiac from the Pangadi infra-trappeans and on this basis assigned these beds to the topmost Cretaceous age.

Rao & Rao (1935) discovered Foraminifera and Radiolaria from the infra-trappean beds, but neither descriptions nor illustrations were given. On the basis of the foraminiferal assemblage, they correlated the infra-trappean beds with the Uttattur (Cenomanian) rocks of Trichinopoly area.

Rao et al. (1936) while dealing with the age of the Deccan Traps of the Pangadi area, considered the infra-trappean rocks to be of Upper Cretaceous age.

Rama Rao (1950) did not consider it desirable to draw a sharp boundary between the Cretaceous and the Eocene and, therefore, suggested the use of the term 'Creocene' for the transition beds which intervene between the undisputed Cretaceous and the Eocene strata.

On the basis of Das Gupta's (1933) find of C. beaumonti from the Pangadi infra-trappeans, he (1953) considered these beds to be of Danian age. As regards the position of the Danian, he maintained his earlier views (Rama Rao, 1950). In 1956 he considered the infra-trappean rocks of Pangadi to be of Danian age and the overlying flows of the Deccan Traps, including the inter-trappean beds, to be of early Eocene age.
Sarkar (1964) revised *Venericardia beaumonti* and allied forms from the Indian sub-continent. He made some taxonomic shifts in certain forms of *V. beaumonti* but retained the form from the Pangadi infra-trappeans, described by Das Gupta (1933), as such.

Mathur & Evans (1964) considered the infra-trappean beds of the Pangadi area to be either of late Cretaceous or of Paleocene age.

Raju *et al.* (1965) suggested an unconformity between the infra-trappean and the underlying Tirupati sandstones on the basis of heavy mineral data. These authors (*op. cit.*) considered the Pangadi infra-trappean beds to be of late Cretaceous age.

Baksi (1965) while discussing the palaeoecology of the infra-trappean beds of Pangadi, considered the lower part of the sequence to be of fluvial deltaic nature, and the upper part to be of estuarine origin.

Bhalla (1966) made a comprehensive study of the Foraminifera from the infra-trappean beds of the Pangadi area and concluded that the assemblage suggested a shallow, marine, inner-neritic environment of deposition. According to him (*op. cit.*), the balance of foraminiferal evidence favoured a Paleocene age for these beds. Besides the Foraminifera, some ostracodes were also found by the author in these beds and are being reported here for the first time. However, due to imperfect state of preservation and paucity of specimens, no systematic work on these could be carried out.

**STRATIGRAPHY**

The stratigraphical succession of the infra-trappean beds of the Pangadi area was worked out by the author at two localities: Locality-A (Pl. I. fig. 1), about half a mile southeast of Devarapalle village; and Locality-B (Pl. I. fig. 2), about half a mile south of Duddukuru village. The sequence is as follows:

<table>
<thead>
<tr>
<th>Deccan Traps (Volcanic)</th>
<th>Lower Eocene</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Locality-A</strong></td>
<td></td>
</tr>
<tr>
<td>3. Compact, yellowish limestone full of <em>Turritella</em> 6&quot; to 2'</td>
<td>Unconformity</td>
</tr>
<tr>
<td>2. Sandy limestone (fossiliferous) 1' 6&quot;</td>
<td></td>
</tr>
<tr>
<td>1. Greenish sands (fossiliferous) 3'</td>
<td></td>
</tr>
<tr>
<td><strong>Locality-B</strong></td>
<td></td>
</tr>
<tr>
<td>3. Compact, yellowish limestone with abundant <em>Turritella</em> 8&quot; to 1'</td>
<td>Unconformity</td>
</tr>
<tr>
<td>2. Soft sands 2' to 3'</td>
<td></td>
</tr>
<tr>
<td>1. Calcareous sandstones 40'</td>
<td>Palaeocene</td>
</tr>
</tbody>
</table>

(After Raju *et al.*, 1965)

The top bed (Bed No. 3) of the infra-trappeans at both the localities, is a yellowish, compact limestone. It is interesting from the palaeontological point of view because it is crowded with *Turritella* and other invertebrate shells (Plate 2) and
CRETACEOUS-TERTIARY BOUNDARY IN PANGADI AREA

has yielded the maximum number of foraminiferal species (Bhalla, 1966). It varies considerably in thickness; at some places it is up to 2 feet thick whereas at others, it is completely missing with the result that the Traps come in direct contact with Bed No. 2. This feature of the limestone suggests a possible erosional unconformity between the infra-trappeans and the overlying traps.

Structurally, the area is practically undisturbed. The infra-trappean beds dip with an angle of 6° to 10° towards southeast and overlie the Tirupati sandstones; however, the contact between the two is concealed below the alluvium and is not seen in the area. On the basis of the heavy mineral characteristics of the two formations, Raju et al. (1965) suggested an unconformity between the Tirupati sandstones and the infra-trappean beds. A slight erosional unconformity between the infra-trappeans and overlying flows of the Deccan Traps exists and is indicated by a considerable variation in the thickness of the top bed of the infra-trappean sequence.

PALAEOECOLOGY OF THE INFRA-TRAPPEAN BEDS

The infra-trappean beds of the Pangadi area have not been subjected to detailed palaeoecological investigations in the past. Baksi (1965, p. 145) in a short note on the environment of deposition of the infra-trappean sequence mentioned, "... a definite estuarine condition (from faunal evidence) in its upper part, the lower beds being deposited under fluvial deltaic conditions. ... The nature and volume of the detritus in this formation suggest a slight uplift in the source area ... " However, no faunal evidence for the estuarine nature of the upper part of the infra-trappean beds was given in support of his conclusions.

Bhalla (1966) described eight species of Foraminifera from the Pangadi infra-trappean beds. The foraminiferal assemblage comprise abundant Planulina and Cibicides, and rare to frequent forms of Guttulina, Pseudopolymorphina, Vaginulina, and miliolid moulds. Except for Guttulina lactea (Walker & Jacob), other species are either new or do not live in the modern seas. He (Bhalla, op. cit.) suggested that these beds were deposited in a shallow, marine, rather warm, inner neritic environment having open-sea connections.

Further ecological information is furnished by the presence of abundant ophiuroid ossicles in the topmost bed of the infra-trappean sequence (Bhalla, 1966). The ophiuroids are exclusively stenohaline organisms and most of them favour a near shore, shallow water environment. Thus it corroborates the contention that these beds were deposited under truly marine conditions.

Another evidence supporting the marine nature of the beds is obtained from the work of Rao & Rao (1935) who reported the occurrence of Radiolaria besides the Foraminifera from the infra-trappean beds. The Radiolaria are exclusively marine protozoa and their presence in these beds does not, naturally, support the estuarine origin as postulated by Baksi (1965).

In association with the microfossils, megafossils are also found in the infra-trappean beds. A check-list of the megafossil fauna is given by Pascoe (1959, p. 1262). It includes Turritella, Cardita (Venericardia) beaumontii, Volutilithes, Glycimeris, Natica, Rostellaria, Lamulites, Nautilus, Dentalium, Meretrix, chela of a crab, etc. Of these Turritella is most abundant. The studies of Gardner (1957) show that Turritella is an exclusively marine genus. It is abundant in warm and shallow waters.
of modern seas (Easton, 1960) and favours a near shore, sandy bottom condition (Plummer, 1933). *Dentalium* is a marine, benthonic genus and prefers a shallow water environment (Ladd *et al.*, 1957). Similarly, *Natica* is also a marine genus but is found from neritic to abyssal depths (Clarke, 1962; Jung, 1965). The occurrence of chelae of crab suggests a shallow water environment as the modern marine crabs inhabit an approximately 10 to 30 metre depth range.

The petrography of the limestone occurring in the upper part of the infra-trappean beds provides an altogether independent palaeoecological evidence and supports the conclusions of this author drawn on faunal evidences. The limestone is a sandy, packed, biomicrodite (often passing into sandy biomicrite) in the terminology of Folk (1962). An important feature of this rock is the presence of large quantities (15% to 35%) of terrigenous material in the sand-grade size which is intimately mixed up with the organic debris (Pl. 2). The land-derived detritus comprise angular grains of quartz and fresh felspars (perthite and acid plagioclase) with minor amounts of red and colourless garnet and actinolite.

Such limestones originate essentially in calm, turbulence-free environments which could be established both in shallow, protected, basins as well as in deep waters. However, the large quantities of sand sized terrigenous material and lack of even small amounts of clay and silt in the rock and, above all, the fauna itself, rule out the possibility of deep sea sedimentation and suggests rather the proximity of land in relation to the basin of deposition. It is obvious that the rock originated in an inner neritic environment, in a somewhat protected basin having open sea connections, where the currents were not strong enough or persistent enough to winnow away the calcite ooze which subsequently got deposited with the shells of the sedentary organisms living in the basin. Estuaries and lagoons, though providing conditions similar to those in protected seas, would not yield the type of sediment described above by virtue of a large contribution of clay and silt which is unavoidable in these environments.

It is indeed possible that the large quantity of sandy material in limestone is due to uplift in the source area which must have consisted of crystalline schists and gneisses. This uplift, perhaps, was contemporaneous with limestone sedimentation or might have been slightly later and was responsible for creating conditions unfavourable to carbonate sedimentation. This, then, may explain the limited distribution of this limestone both in space and time and also the presence of such abnormally high amounts of land-derived debris in the rock.

From the foregoing discussion based on fossil as well as sedimentological evidences, it is concluded that these beds were deposited in a protected, rather warm, well illuminated, inner neritic environment which had open sea connection, like the one now existing in parts of the Gulf of Mexico.

**EXPLANATION OF PLATE I**

1. Infra-trappean beds with the overlying traps, in a *nala* cutting at locality A, about half a mile southeast of Devarapalle village.

2. Infra-trappean calcareous sandstone (Bed No. 1) at locality B, half a mile south of Duddukuru village.
BHALLA: CRETACEOUS-TERTIARY BOUNDARY IN PANGADI AREA
CRETACEOUS-TERTIARY BOUNDARY IN PANGADI AREA

In the Pangadi area both Cretaceous and Paleocene strata are present and an attempt has been made to demarcate the boundary between the two. The lowermost stratigraphic unit in the area is the Tirupati sandstones. The sandstone has been assigned an early Cretaceous age by various workers on the basis of plant fossils as well as on stratigraphic considerations.

The age of the overlying infra-trappean beds has been a matter of controversy ever since they were discovered by King in 1874. As has been stated elsewhere, the majority of workers favour a late Cretaceous age for these beds. They found support from the occurrence of *Cardita beaumonti* which was reported by Das Gupta in 1933, and, thus assigned a Danian age to these beds. In the past, palaeontologists invariably regarded *Cardita beaumonti* as a Danian marker and the Danian was considered as the topmost stage of the Cretaceous. However, the investigations of Rutsch (1936) revealed that *Cardita beaumonti* was not confined exclusively to the Danian but, was a variable form and ranged from Maestrichtian to Middle Eocene. As such, it is hardly of any value as an age marker. In recent years, a majority of foraminifero­logists consider that the Danian marks the basal stage of the Paleocene.

The typical genera and species of Foraminifera which have been extensively used in demarcating the Cretaceous-Tertiary boundary, are not present in the Pangadi infra-trappeans. However, the foraminiferal assemblage of these beds includes certain well known species (Bhalla, 1966) which have been recorded either from the Paleocene or from the Eocene of different parts of the world. Among these, *Cibicides mensilla* (abundant), *Guttulina lactea* (frequent), and a mould of *Quinqueloculina* closely resembling *Q. brevidentata*, are of significant value in dating the infra-trappean beds. *Cibicides mensilla* was originally described by Schwager (1883) from the Eocene of Libya and has subsequently been recorded from the Eocene of U.S.A. by Bandy (1944) and from the late Paleocene of Pakistan by Haque (1956). *Guttulina lactea* is a well known polymorphinid and has been reported from various Tertiary strata of the world. The species of *G. lactea* from the Infra-trappean beds show close similarities with the ones described and illustrated by Haque (1956) from the Paleocene of Pakistan and by Haynes (1958) from the Paleocene of England. The mould of *Quinqueloculina* closely resembles *brevidentata* Le Calvez, described from the Lutetian of France.

The megafossils, ostracodes, radiolaria, and ophiuroid ossicles also occur in the Pangadi infra-trappean beds but need detailed studies before they can be used for dating these strata.

The foraminiferal assemblage, on the whole, favours a Paleocene age for the infra-trappean beds, but due to paucity of forms having precise age records, it is not possible to assign these beds to any particular stage within the Paleocene. However,

EXPLANATION OF PLATE II

Photomicrograph of the infra-trappean limestone (Bed No. 3) showing ill sorted shell debris in calcite-mud matrix. Note the abundant quantity of terrigenous quartz grains in the sand-grade size and the articulate nature of the shells. The rock is a sandy biomicrudite.
it is certain that the infra-trappean beds represent the dawn of the Tertiary era in this part of India.

The contact between the Tirupati sandstone and the overlying infra-trappean beds is concealed below a vast stretch of alluvium and is nowhere seen in the area. However, Raju et al (1965) on the basis of heavy mineral characteristics of the Tirupati sandstones and the infra-trappean beds, suggested an unconformity between the two.

From the foregoing discussion, it is clear that the Tirupati sandstones are of early Cretaceous age whereas the overlying infra-trappean beds are Paleocene in age; and the unconformity between the two marks the Cretaceous-Tertiary boundary in the area.

The infra-trappeans are unconformably overlain by the flows of Deccan Traps which, in turn, contain the fossiliferous inter-trappean beds. As discussed earlier, the infra-trappean beds are of Paleocene age while the inter-trappeans have been assigned a definite Eocene age by various workers on the basis of fossil evidences. Thus, the flows of the Deccan Traps are sandwiched between the Paleocene infra-trappeans and the Eocene inter-trappean beds. On this basis, it is inferred that the outpouring of the lava of Deccan Traps started in early Eocene times. This conclusion is in harmony with the view expressed by Rama Rao (1956) that the traps, including the inter-trappeans, are of Lower Eocene age.

ACKNOWLEDGEMENTS

I am thankful to Professor F. Ahmed, Head of the Geology Department, Aligarh Muslim University, Aligarh, for his keen interest, constant encouragement, and valuable suggestions. I extend my grateful thanks to Dr. V. K. Srivastava, Reader in Geology, Aligarh Muslim University, for numerous discussions, constructive criticism, and for going through the manuscript, and to the Panjab University for various facilities. Thanks are also due to the authorities of the Aligarh Muslim University for sending me as a delegate to the Seminar at Bangalore.

REFERENCES


CRETACEOUS-TERTIARY BOUNDARY IN PANGADI AREA


SARKAR, S. S., (1964) A revision of the group Venericardia beaumonti d’Archia & Haime, found in India, Pakistan and Burma. XXII Int. Geol. Congr., New Delhi. Abstracts, Sec. 3, p. 34.

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 Tiruchirappalli in the south (Fig. 1), almost following the eastern coastline. 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:


**Middle Stage** (Shales; animals including Early Cretaceous ammonites and Foraminifera with an admixture of Rajmahal and Jabalpur plants; marine to marsh) Cuttack: not known. Eluru: Raghavapuram. Ongole: Vannevaruam. Madras: Srperumbudur. Tiruchirappalli:

Upper age limit of the East Coast Gondwanas, India

SATYENDRA N. 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. The 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 Albian age is favoured as the upper age limit of the East Coast Gondwanas.

S. N. Bhalla, Department of Geology, Aligarh Muslim University, Aligarh, India, March 15th, 1971; present address Geology Department, Llandinam Building, University College of Wales, Aberystwyth, Wales, U. K.

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 Midlicott 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-
Fig. 1. Sketch map of the east coast of India, showing different localities referred to in the text.

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 Gondwanas 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.

Taenopteris (Angiopteridium) ensis, T (A) spatulata, Marattia (Marattia) macrocarpa, Gleichenites gleicheniae, Cladophlebus dentculata C indica, Thunnfeldia sp, Retinosporites indica, Elatocladus indica, E conferta, Brachysphyllum expansum, Retinosporites indica, Nilssonia morrisoniana, Ptilophyllum acutifolium, P cutchense, Dictyozamites falcatarii, Williamsia 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 Vammavarams belonging to the Middle Stage of the Upper Gondwanas 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 Vammavaram 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 Srperumbudur beds represent the Middle Stage and contain ammonites and foraminifera besides fragmentary plant remains showing close affinities with Raghavapuram and Vammavaram assemblages. The Utatur plant beds represent the Middle Stage in the Tiruchirappalli 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.

Cladophlebus indica, C dentculata, Taenopteris (Angiopteridium) spatulata T (A) macel-landi, Dictyozamites indicus Otozamites bengalenicus, O hulopo, Ptilophyllum acutifolium, P cutchense, Elatocladus plana, E tenerrima Retinosporites indica, Brachysphyllum expansum, Ginkgoites 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*, *Dictyozyamites*, *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 Vammavaram shales also. M. R. Sahni (1938) reported the occurrence of the Cenomanian genus *Rectithyris* - *R. expansa* and *R. recurvata* - from these beds. The Sriperumbudur 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*, *Pseudomotis*, and two species of *Trigonia* - *T. smeii* 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 Tanganyika. 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 Vammevarams. 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 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 formation 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


