The Palaeobotanist **35**(1) : 22-31, 1986.

Stratigraphy, age and palaeoecology of Upper Gondwana equivalents of the Krishna-Godavari Basin, India

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ABSTRACT

Venkatachala, B. S. & Sinha, R. N. (1986). Stratigraphy, age and palaeoecology of Upper Gondwana equivalents of the Krishna-Godavari Basin, India. *Palaeobotanist* **35**(2) : 22-31.

Age equivalents of the Upper Gondwana sediments are exposed in the Krishna-Godavari Basin which comprises three depressions separated from one another by basement ridges. The sequence exposed in the West Godavari Depression is classified into the Golapalli Sandstone (oldest), Raghavapuram Shale and Tirupati Sandstone (youngest) on the basis of lithologic characteristics. Likewise, in the Krishna Depression, towards the south, this sequence is classified into the Budavada Sandstone (oldest), Vemavaram Shale and Pavalur Sandstone. A number of shallow wells have been drilled on the outcrops. The dominantly arenaceous units, the Golapalli, Tirupati, Budavada and Pavalur sandstones, of the outcrop are represented by shales in the subsurface. The Raghavapuram and Vemavaram shales, however, continue to have the same lithology in the subsurface. It is concluded that the tripartite classification in the outcrops is not tenable in the subsurface and the respective units are probably lithofacial variants of a major argillaceous sequence.

The exposed sequence is devoid of palynofossils. Plant megafossils, though scarce, are considered referable to the Late Jurassic. The sequence met in the shallow wells contains abundant palynofossils of non-marine and transitional environments. The assemblages recorded from the dominantly argillaceous beds contain numerous taxa characteristic of an Early Cretaceous age. Hence, the sequences in the two depressions are homotaxial and of Early Cretaceous age as is also inferred from microfaunal assemblages. An inter-relationship between the gymnosperm and phytoplankton populations has enabled to delineate some of the major environmental regimes which vary from non-marine in the west to shallow marine in the east through transitional swampy environments. The upland floral elements are predominant at the basin margin. The bulk of the terrigenous matter was derived from areas located westwards. It is significant to note that the phytoplankton progressively increase due east and southeast. It could be as high as 20 per cent near about the western margin of the basin. If the sequences remain to be dominantly shaly in the subsurface of the present day coastal areas they are likely to possess good characters of source rocks of hydrocarbons especially in view of the progressive increase in phytoplankton percentages and favourable depths of burial and palaeotemperatures which are evidenced by geophysical data and occurrence of extrusives in the outcrop area respectively.

Key-words—Palynostratigraphy, Palaeoecology, Megafossils, Upper Gondwana, Krishna-Godavari Basin (India).

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सारांश

कृष्णा-गोदावरी द्रोणी (भारत) के समतुल्य उपरि गोंडवाना का स्तरविन्यास, इसकी आयु एवं पुरापारिस्थितिकी

बेंगलूर श्रीनिवासा वेंकटाचाला एवं रवीन्द्रनाथ सिन्हा

कृष्णा-गोदावरी द्रोणी में उपरि गोंडवाना अवसादों के समकालीन समतुल्य विगोपित हैं जिनमें एक दूसरे से आधार-कटकों द्वारा पृथक्कृत तीन अवनमन विद्यमान हैं। पश्चिम गोदावरी अवनमन में विगोपित अनुक्रम शैलिकीय लक्षणों के आधार पर गोलापल्ली बालुकाश्म (पुरातनतम्), राघवपुरम शैल एवं तिरुपति बालुकाश्म (अल्पतम् आयु का) में विभक्त किया गया है। इसी भाँति कृष्णा अवनमन में दक्षिण की ओर यह अनुक्रम बुडवाड़ा बालुकाश्म (पुरातनतम्), वेमावरम् शैल एवं पावालूर बालुकाश्म में विभक्त किया गया है। दृश्याँशों पर कई उथले कूएँ वेधित किये गये हैं। इन दृश्याँशों की प्रभावी बालुकामय इकाईयाँ—गोलापल्ली, तिरुपति, बुडवाड़ा एवं पावलूर बालुकाश्म—उपसतह में शैलों से निरूपित हैं। तथापि राघवपुरम् एवं वेमावरम् शैलों का स्तर-विन्यास उपसतह में वैसा ही है। यह निष्कर्ष निकाला गया है कि दृश्याँशों में किया गया त्रिपक्षीय वर्गीकरण उपसतह में मान्य नहीं है तथा सम्बद्ध इकाईयाँ एक मुख्य मृण्मय अनुक्रम के सम्भवतया शैल-संलक्षणीय रूपान्तर हैं।

विगोपित अनुक्रम परागकणविहीन है। गुरुपादपाश्म, यद्यपि कम हैं, अन्तिम जूराई युग के माने गये हैं। उथले कुओं में विद्यमान अनुक्रम में असमुद्री एवं परिवर्तनशील वातावरणों के परागकण आदि प्रचुर मात्रा में मिलते हैं। प्रभावी मृण्मय संस्तरों से अभिलिखित समुच्चयों में प्रारम्भिक क्रीटेश्यस युग के अनेक

लाक्षणिक वर्गक मिलते हैं, अतएव इन दोनों अवनमनों के अनुक्रम समवर्गकी हैं तथा प्रारम्भिक क्रीटेश्यस आयु के हैं जैसा कि सूक्ष्मजन्तु-जातीय समुच्चयों से भी इंगित होता है। अनावृतबीजीयों एवं पादप-प्लवकों के मध्य अन्तरबन्धुता से कुछ वातावरणीय प्रवृत्तियों को चित्रित करने में सहायता मिली है। ये प्रवृत्तियाँ परिवर्तनशील दलदली वातावरणों के फलस्वरूप पश्चिम में असमुद्री से पूर्व में उथली समुद्री तक विस्तृत हैं। द्रोणी तट पर भूमीय वनस्पतिजातीय अवयवों की पूर्व बाहुल्यता है। स्थलजात पदार्थ का पुंज पश्चिम की ओर के क्षेत्रों से व्युत्पादित था। यह उल्लेखनीय है कि पादपप्लवकों की प्रतिशततायें पूर्व एवं दक्षिण-पूर्व में क्रमिक रूप से बढ़ती हैं। द्रोणी के पश्चिम किनारे के आस-पास यह 20 प्रतिशत तक भी प्रेक्षित की गई है। वर्तमान तटीय क्षेत्रों की उपसतह में यदि अनुक्रम प्रधान रूप से शैलवत् हों तो उनमें हाइड्रोकार्बनों की स्रोत चट्टानों, विशेषतया पादपप्लवकों की प्रतिशतता में क्रमिक वृद्धि तथा पुरातापक्रमों एवं शवाधान की अनुकूल गहराईयों जो कि क्रमशः भूभौतिक आँकड़ों एवं दृश्याँश क्षेत्र में अन्तर्वेधीयों की उपस्थिति से प्रमाणित हैं, के विशिष्ट लक्षण विद्यमान हो सकते हैं।

INTRODUCTION

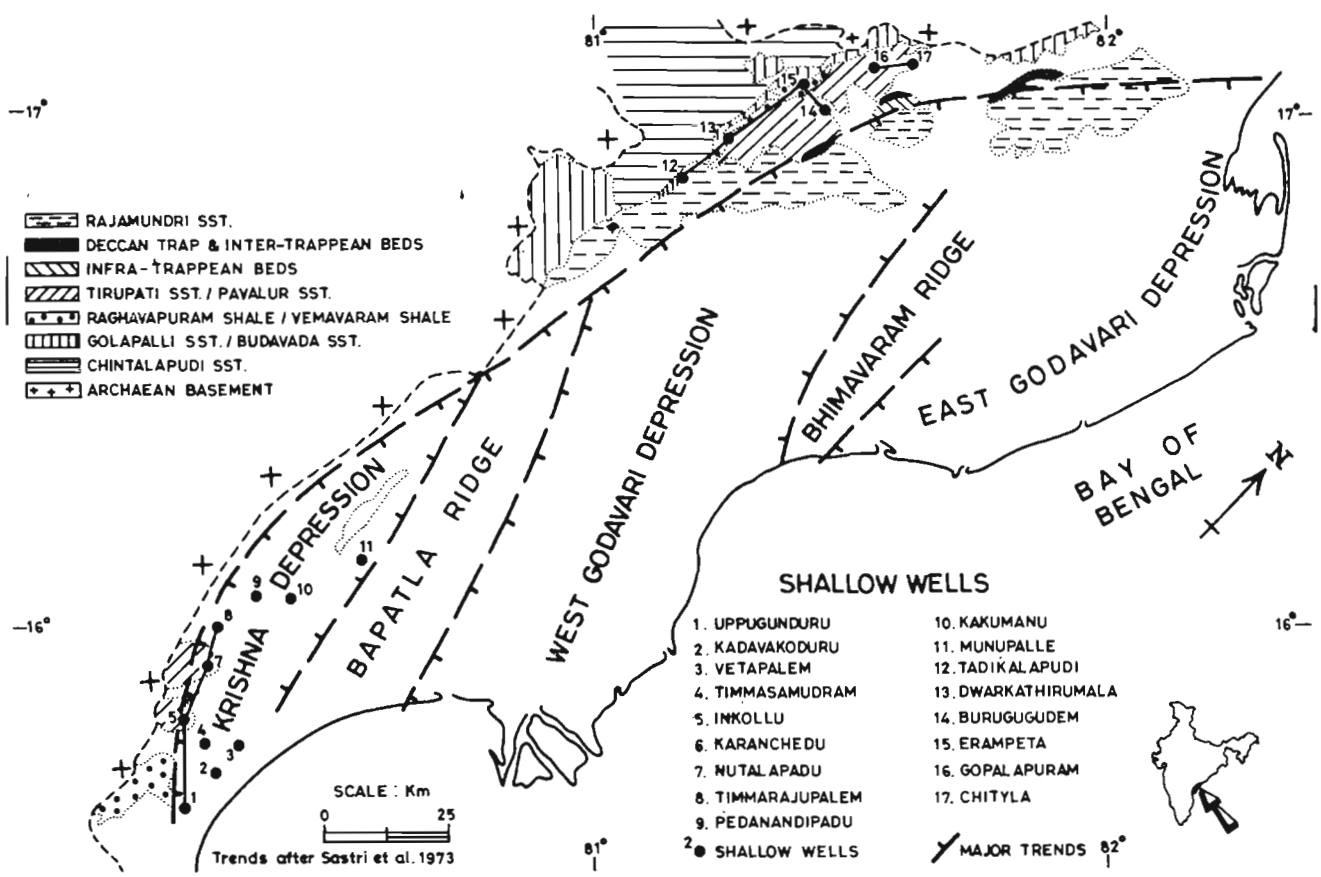
THE Krishna-Godavari Basin, situated on the eastern coast of India (Text-fig. 1, inset), is divided into several depressions separated from one another by subsurface ridges (Text-fig. 1) on the basis of geophysical data (Sastri *et al.*, 1973). The ridges are aligned similar to the north-east-southwest striking Eastern Ghats and so is also true of the axis of depressions.

Sediments correlatable to those of Upper Gondwana are exposed near the western fringes of the Krishna and West Godavari depressions (Text-fig. 1). These do not contain adequate fossil fauna and megaflora as well as palynological assemblages and those that are present, do not assist in precise dating, stratigraphical correlation or palaeoecological reconstructions.

A number of shallow wells (200 m depth) have been drilled by the Oil and Natural Gas Commission, for near-surface stratigraphic information (Text-fig. 1). A few of these wells, penetrated sediments equivalent to Upper Gondwana which, though almost devoid of microfauna and megaflora, contain rich palynological assemblages.

This paper discusses the available data with a view to date and correlate the surface and subsurface sediments which are Upper Gondwana equivalents. An attempt has been made to trace marine influences during their deposition and discuss their status. A few remarks on the development of source rocks of hydrocarbons are also offered.

The samples studied are from shallow wells located at Inkollu, Uppugunduru, Timmasamudram, Nutalapadu, Kadavakoduru, Timmarajapalem, Vetapalem, Karanchedu,



Text-fig. 1—Geological map of Godavari-Krishna Basin, India.

Peddanadipadu, Kakumanu, Munupalle, Tadikalapudi, Errampeta, Burugugudem, Gopalapuram and Chityala (Text-fig. 1, after Sharma *et al.*, 1977).

LITHOLOGY AND STRATIGRAPHY

The term 'Gondwana' first published by Feistmantel (1876) was originally introduced by Medlicott in 1872 in an unpublished report. It includes Permo-Carboniferous-Jurassic sediments deposited under non-marine environments in the Peninsular India (Fox, 1931). These sediments contain abundant plant megafossils and palynofossils. Thin beds included into the Upper Gondwana sediments (Vemavaram Shale, Raghavapuram Shale, Sriperumbudur Beds & Budavada Sandstone) and containing paralic-marine fossils were regarded as marine intercalations. The sequence, however, continued to be designated as Gondwana although, this term included strictly non-marine sediments. It may therefore be suggested that these sediments containing paralic-marine fossils should be identified separately as has been the Jurassic of Kutch (Pascoe, 1968) and earlier opined by Rao and Venkatachala (1971).

The Upper Gondwana sediments are exposed towards the western and northwestern fringes of the basin (Text-fig. 1). The Gondwana sediments exposed around Ellore (16°43′N : 81°07′E) in the West Godavari Depression are classified into three lithologic units. The Golapalli Sandstone, the oldest, named after the type area around the village Golapalli (16°43′30″N : 80°55′E; King, 1880), comprises nearly 50 m thick highly micaceous and dark purplish coarse grits and ferruginous and partly lateritized sandstones interbedded with light grey medium to coarse grained sandstones. Buff-coloured nodular limestones at places underlain by light grey soft clay are also present. The Raghavapuram Shale (King, 1880) named after the village Raghavapuram (17°00′02″N : 81°15′30″E) is poorly exposed and overlies the Golapalli Sandstone unconformably (Pascoe, 1968). It is nearly 75 m thick (Subrahmaniyam, 1960) and consists of brittle shales and soft clays both of which are at times sandy and also contain thin lenses of light buff to greyish white medium grained sandstones. The Tirupati Sandstone, the youngest and named after the type area around Dwarkatirumalai (10°57′15″N : 81°35′45″E) is 350 m thick and comprises light grey to pale buff, friable, current-bedded, partly lateritized, medium to coarse grained, occasionally gritty, micaceous and clayey sandstone containing a few bands of grey coloured clays.

The Upper Gondwana sediments exposed around Ongole (15°30′N : 80°03′E) in the Krishna Depression are also divided into three lithologic units, the Budavada Sandstone (oldest), Vemavaram Shale and the Pavalur Sandstone (youngest). Desikachary and Ramachandra (1962), however, do not favour such a tripartite division. According to them the Budavada Sandstone exposes a nearly 500 m thick succession of shales (80%) and sandstones (20%). These sandstones are locally designated as Budavada Sandstone and are similar to those included in the Golapalli Sandstone. The Budavada Sandstone is overlain by the Vemavaram Shale which lithologically resembles the Raghavapuram Shale. Likewise, the Pavalur Sandstone appears similar to the Tirupati Sandstone in lithologic characters.

The Golapalli sandstone is considered older to the Budavada Sandstone (Pascoe, 1959). The Raghavapuram Shale is correlated to the Vamavaram Shale and Tirupati Sandstone to Pavalur Sandstone.

Subsurface Lithology—A number of shallow wells (200 m deep) are drilled on the outcrops of Budavada Sandstone, Raghavapuram Shale and Tirupati Sandstone for near-surface stratigraphic information. The lithologic data (Text-figs 2, 3) from these wells are significant and are outlined below:

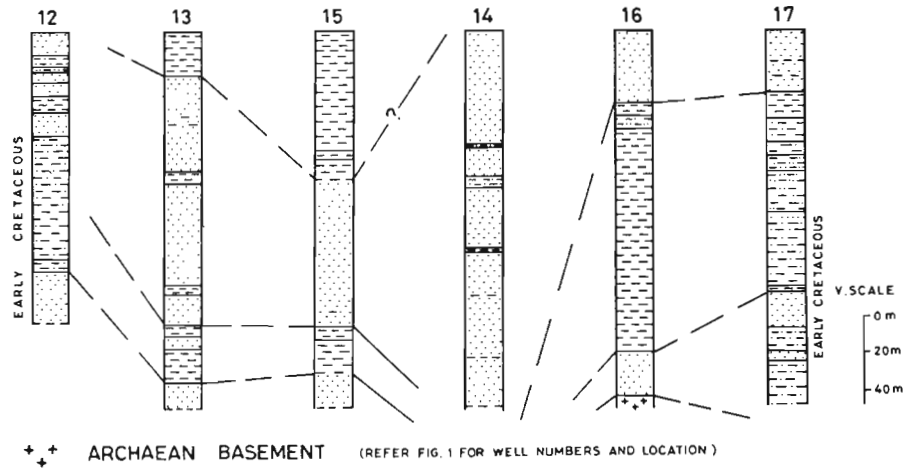
1. The section in Errampeta well (No. 15, Text-fig. 2) drilled on the outcrops of Raghavapuram Shale (Text-fig. 1) comprises only a small thickness (80 cm) of shales that overlie thick sandstones which resemble the sandstones included into the Golapalli Sandstone.

2. Five shallow wells drilled on the outcrops of Tirupati Sandstone offer interesting data. More than 50 per cent of the drilled section at Tadikalapudi (No. 12, Text-fig. 2) comprises shales which diminish to only 25 per cent at Dwarkathirumala (No. 13, Text-fig. 2) nearly 12 km due northeast. Further 20 km to the northeast at Burugugudem (No. 14, Text-fig. 2), the sequence comprises sandstones and these also change to mainly shales at Gopalapuram (No. 16, Text-fig. 2) located 12 km northeast of Burugugudem.

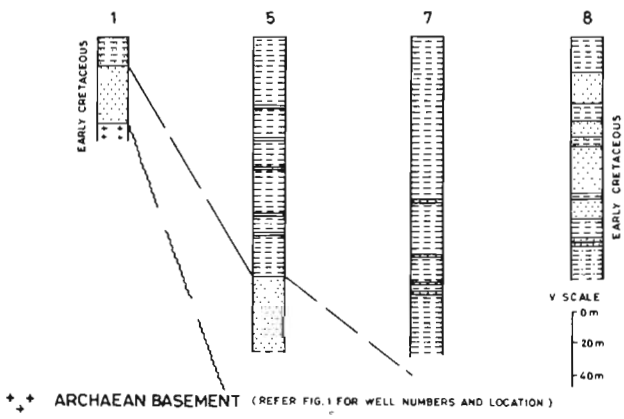
3. The Nutalapadu (No. 7, Text-fig. 3) well, though drilled on the outcrops of Budavada Sandstone penetrates an almost monotonous shale section. Likewise, the Inkollu well (No. 5, Text-fig. 3) drilled very close to the outcrops of Budavada Sandstones penetrates a thick shale section.

4. The Uppugunduru well (No. 1, Text-fig. 3) drilled up to the Archaean basement (top at 115 m) penetrated 55 m of Upper Gondwana sequence comprising 34 m thick sandstones overlain by 21 m thick silty shales even though the well is located very close to the type locality of the Vemavaram Shale.

The lithologic data enumerated above establish that a sequence mapped in the outcrop area as dominantly sandstone or shale and therefore identified as a sandstone or shale unit, viz., Golapalli Sandstone/Raghavapuram Shale, ceases to be so in the subsurface. It is significant that this change occurs within very short distance as is evident from wells drilled on the respective outcrops. Hence, the subsurface data from shallow wells suggests that the lithologic units mapped in the outcrops are represented in the subsurface by a



Text-fig. 2—Stratigraphic section through shallow wells.



Text-fig. 3—Stratigraphic section through shallow wells.

dominantly shale sequence. The tripartite classification of the exposed Upper Gondwana sediments, therefore, does not seem tenable.

REMARKS ON THE AGE

Palaeobotanical evidences—Feistmantel (1879), Seward and Sahni (1920) and Sahni (1928, 1931) have described a number of plant megafossils from the Vemavaram area. These include—*Pseudoctenis footeana, Otozamites bunbaryanus zigno* var. *indica, Ptilophyllum acutifolium, Araucarites cutchensis, Retinosporites indica, Torreyites constricta, Elatocladus jabalpurensis, Elatocladus* sp., *Brachyphyllum feistmantelii, B. expansum, Conites sessilis,* and *C. rajmahalensis. Ginkgoites lobata, Brachyphyllum expansum, Desmiophyllum indicum* and *Elatocladus plana* are recorded from the Raghavapuram area. Equisetalean stem compressions were reported by Sarma (1958) from the Golapalli Sandstone. Suryanarayana (1954) described fragmentary plant remains (*Sphenopteris* sp., *Pterophyllum bifurcatum*—an unidentified cycadophytic stem) from Vemavaram. Rao (1959) recorded *Dicroidium feistmantelii* from the Vemavaram shales. On the basis of flora, a Jurassic age was assigned by Bose (1966). Baksi (1967) described a rich plant megafossil assemblage comprising *Cladophlebis* sp., *Dicroidium* sp., *Taeniopteris spathulata, Ptilophyllum acutifolium, P. cutchense, P. tennerrimum, Otozamites rarinervis, O. abbreviatus, Dictyozamites falcatus, Williamsonia blanfordi, Cycadolepis indica, Ginkgoites feistmantelii, Ginkgoites* sp., *Elatocladus plana, Brachyphyllum rhombicum, B. feistmantelii, Pagiophyllum* sp. cf. *P. peregrinum, Araucarites cutchensis* and *Conites* sp. from Raghavapuram Shale which according to him is of Early Cretaceous age. However, Shah *et al.* (1971) assign a doubtful Jurassic age to the entire Upper Gondwana Sequence exposed on the east coast of India on the basis of plant megafossils.

The assemblage of plant megafossils from the Golapalli Sandstone is fairly similar to that from the Raghavapuram Shale except that it lacks *Elatocladus plana, Araucarites cutchensis, Ginkgo* sp., *Conites* sp., *Mesembrioxylon* and *Dadoxylon* besides *Pachypteris* (*Dichopteris*) *ellorensis.* Fossils that distinguish Golapalli Sandstone and are not recorded from the Raghavapuram shales include *Nilssonia* sp., *Retinosporites* sp., *Marattiopsis* sp., *Taeniopteris ensis, Williamsonia indica, Elatocladus conferta, Brachyphyllum expansum* and *Araucarites macropterus.* The Tirupati Sandstone is poorly fossiliferous and contains only *Ptilophyllum acutifolium, P. cutchense* and *Williamsonia blanfordii* besides unidentified fossil woods (Baksi, 1967). The difference in the megafloral composition in Golapalli Sandstone, Raghavapuram Shale and Tirupati Sandstone is ascribed to preservational variations and limited palaeobotanical findings and not vegetational differentiation.

The plant megafossil assemblage lacks the characteristic early Cretaceous fronds, *Weichselia* and

Onychiopsis. These fronds are reported from Umia, Jabalpur and Himmatnagar sandstones which are conclusively dated as Early Cretaceous. The absence of these two Early Cretaceous forms, therefore, could be ascribed to lack of preservation in the Upper Gondwanas of the Krishna-Godavari Basin.

The Golapalli and Budavada sandstones are correlated with the Rajmahal Sandstone in Bihar and Athgarh sandstones in Mahanadi Basin. The Raghavapuram and Sivaganga beds and also the Kota Stage which is dated as middle-late Jurassic in age are correlated with Golapalli and Budavada sandstones (Bose, 1966). The Rajmahals are considered as Jurassic in age. The Tirupati and Pavalur sandstones and the Satyavedu Bed are correlated with the Jabalpur Series which is regarded as Early Cretaceous in age. Thus, it may be seen from the foregoing discussion that the Upper Gondwana equivalent of the Krishna-Godavari Basin are considered as Upper Jurassic-? Lower Cretaceous in age on the basis of plant megafossil evidences.

Faunal evidences—Faunal assemblages, especially those diagnostic of marine habitat, are restricted to the upper part (Vemavaram & Raghavapuram shales and Tirupati Sandstone) of the exposed Gondwana Sequence. The lower part of the shale sequence included into the Raghavapuram Shale contains ammonites, foraminifera and fish scales (Bhalla, 1972).

Sastri *et al.* (1961, 1963) record arenaceous forms consisting of *Ammobaculites fisheri* var. *tirupathiensis*, *Haplophragmoides concava* and *H. chapmani* from the Raghavapuram shales and assign an Early Cretaceous age. Bhalla (1965) described *Haplophragmoides bagni*, *Ammobaculites crespinae*, *A. hofkeri*, *A. indicus*, *A. raghavapuramensis* and *A. sahnii*, from the type section of Raghavapuram shales and assigns an Early Cretaceous age. Bhalla (1968, 1969) compares the arenaceous foraminiferal assemblage with those recovered from the Early Cretaceous of the Great Artesian Basin, Australia. Baksi (1966) in a study of the Raghavapuram Shale records *Ammobaculites funicularis*, *A. phlegeri*, *A. globosa*, *A. crespinae*, *A. hifkeri*, *A. indicus*, *A. sahnii*, *Trochammina bagni*, *T. stellifera*, *T.* sp. cf. *T. whittingtoni*, *Nonion presublaeva* and *N. barakondai* which are referable to a Post-Jurassic but pre-Late Cretaceous age.

Mitra *et al.* (1971) consider the entire east coast Gondwana sediments as younger to the Rajmahals (Jurassic) and assign them an Early Cretaceous age. This is in agreement with the age deduced from foraminiferal assemblages (Sastri *et al.*, 1963; Baksi, 1966; Bhalla, 1969).

Sastri and Mamgain (1971, table 2) assign a Neocomian-Aptian age to the East Coast Gondwana sediments, i.e. Golapalli Sandstone, Raghavapuram Shale, Tirupati Sandstone and Budavada Sandstone and Vemavaram Shale and correlated them with the Sriperumbudur and Satyavedu beds.

Palynological evidences—The palynological assemblages in the subsurface sequences met in shallow well are well diversified. A total of 57 genera and 78 species of spores and pollen and 9 types of phytoplankton (hystrichosphaerids & dinoflagellates) are recorded (Sharma *et al.*, 1977). The preservation of fossils is usually good and affords a detailed morphological study and precise taxonomic evaluation. In general, the assemblages are relatively richer in dominantly argillaceous sequences. The diagnostic palynofossils are also present in the arenaceous sequences.

Species spectrum curves as recommended by Wilson (1959) are used to determine the number of fossils counted in each sample. Quantitative assessments are based on 200 fossil counts per sample. The distribution pattern of the various taxa is fairly uniform in the Krishna and West Godavari depressions and also in Bapatla-Vellupucherla Ridge.

The palynoflora from the continental Upper Gondwana and equivalent sediments are reviewed by Bharadwaj (1969) and Venkatachala (1970). The earliest Jurassic assemblage from the subsurface in the Jaisalmer Basin is distinguished by *Cosmosporites*, *Gliscopollis* and *Exesipollenites*. A comparable assemblage is recorded in the Early Jurassic sediments from Nommal Gorge, Salt range. The assemblage in the Krishna-Godavari Basin, however, is distinct and not comparable as the distinguishing genera enumerated above are conspicuously absent.

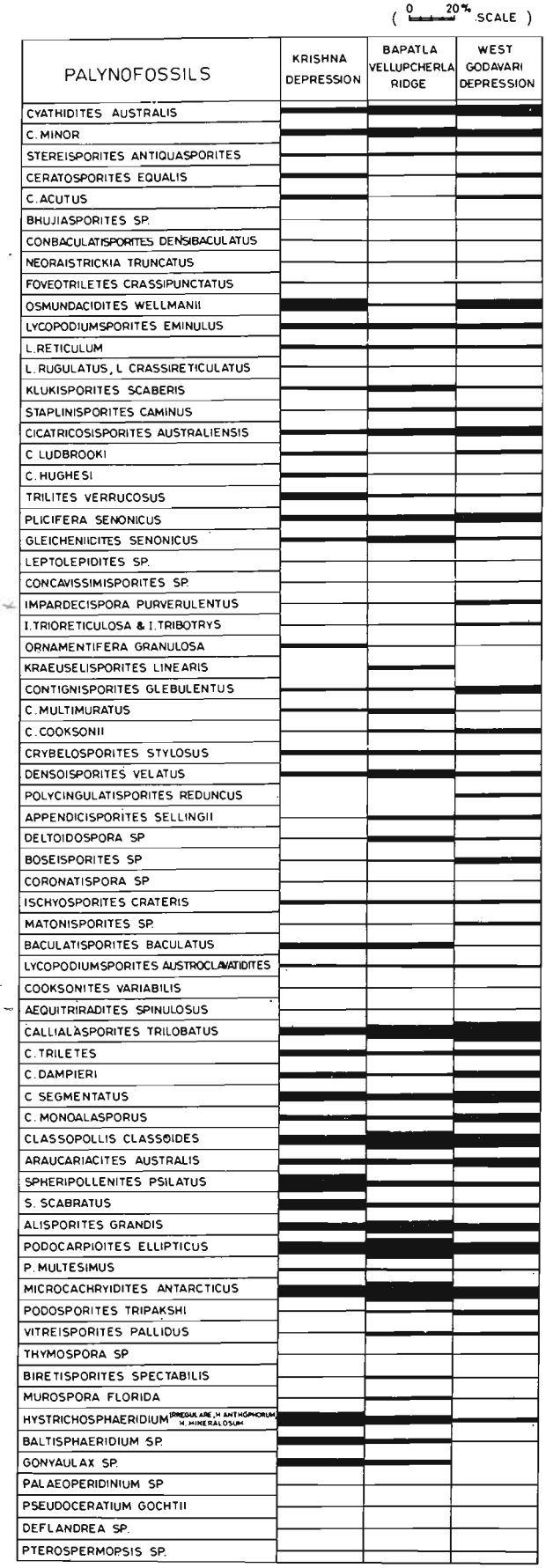
The Neocomian-Aptian assemblages from the subsurface of Cauvery Basin are closely comparable (Venkatachala, 1974; Venkatachala *et al.*, 1972). *Microcachryidites antarcticus*, *Trilites verrucosus*, *Sphaeripollenites* spp., *Leptolepidites major*, *Podosporites tripakshi*, *Klukisporites scaberis*, *Aequitriradites verrucosus*, *Kraeuselisporites majus*, *Impardecispora perverulentus*, and *Crybelosporites stylosus*, dominant in the Neocomian-Aptian assemblage of the Cauvery Basin, are significant fossils of the Krishna-Godavari Basin. The Aptian-Early Albian assemblage in the Cauvery basin is distinguished by the occurrence of *Coptospora cauveriana*, *Polypodiaceoisporites* spp. and *Appendicisporites tricornitatus*. The absence of these characteristic taxa in the assemblages under discussion precludes any comparison with those of Late Aptian-Early Albian recorded from the Cauvery Basin.

The assemblages in the Upper Gondwana sediments of Krishna-Godavari Basin are closely comparable to those of the *Crybelosporites stylosus* and the *Dictyotosporites speciosus* zones (Dettmann & Playford, 1969) in Australia. These zones, dated as Neocomian and Neocomian-Aptian, are characterised by *Aequitriradites hispidus*, *Crybelosporites stylosus*, *Murospora floriada*,

Contignisporites cooksonii, Cyclosporites hughesi, Kraeuselisporites linearis, Biretisporites spectabilis, Cicatricosisporites australiensis, C. ludbrookii, Dictyotosporites speciosus, Cooksonites variabilis and *Foraminisporis asymmetricus*, all of which are present in the Upper Gondwana sediments of Krishna-Godavari Basin.

The assemblage described by Ramanujam (1957) from presumably the Vemavaram shales is dated as Late Jurassic and the assemblage as deduced from illustrations and descriptions includes *Cyathidites* sp., *Gleicheniidites* sp. cf. *Osmundacidites, Neoraistrichia* sp., *Lycopodiumsporites* spp., *Ischyosporites* sp., *Cicatricosisporites* sp., *Callialasporites* sp., *Cycadopites* sp. cf. *Vitreisporites* sp., *Podocarpidites* sp. and *Dacrycarpites* sp. All these genera, except *Dacrycarpites*, are present in the subsurface assemblage described from the Krishna-Godavari Basin (Text-fig. 4). However, the presence of characteristic genera, e.g. *Aequitriradites, Feotriletes, Cooksonites, Murospora, Appendicisporites*, etc. in the subsurface of the Krishna-Godavari Basin renders the two assemblages incomparable. It is considered that the assemblage described by Ramanujam (1957) from Vemavaram shales is incomplete and obviously a reassessment of this material is necessary; the same is also applicable to the Vemavaram assemblage described by Kar and Sah (1970).

The rich palynological assemblages recorded from the subsurface sequences met in wells drilled on the outcrops of the Upper Gondwana sediments conclusively prove that these sediments are Neocomian-Aptian in age. There is an apparent difference of opinion on the age as deduced from the plant megafossil evidences and foraminiferal evidences, the latter substantiated by palynological evidences. As Baksi (1967, p. 213) has rightly commented ".....the presence or absence of any element in the Upper Gondwana flora is more related to chance finding than the absence of it". Thus, the plant megafossil assemblage though distinct, might not be the representative or complete. The age can not be assigned only on the negative evidences such as the absence of *Weichselia* and *Onychiopsis*. Palynological evidences discussed in detail in this paper emphasize the close comparison with Early Cretaceous assemblages of Kutch and the subsurface sediments of Cauvery Basin. Foraminiferal evidences also favour the Early Cretaceous age assignment. Thus on the available evidences it is concluded that the Upper Gondwana sequence represented by Golapalli Sandstone, Raghavapuram Shale and Tirupati Sandstone in the West Godavari Depression and their equivalents (Budavada Sandstone, Vemavaram Shale & Pavalur Sandstone) in the Krishna Depression are Early Cretaceous.



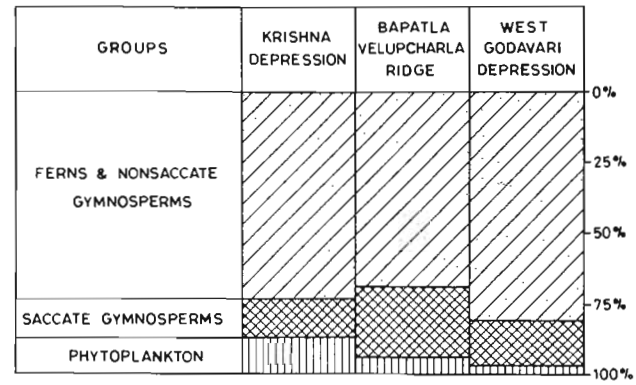
Text-fig. 4—Distribution of palynofossils.

The frequently mentioned discrepancy in age inferred from faunal and floral assemblages appears a falacy as far as the sediments on the east coast of India are concerned. From the foregoing discussion, it is clear that the incompleteness of the evidence, either faunal or floral, is a reality and should be ascribed to nonfinding of forms rather than their actual absence.

PALAEOECOLOGY

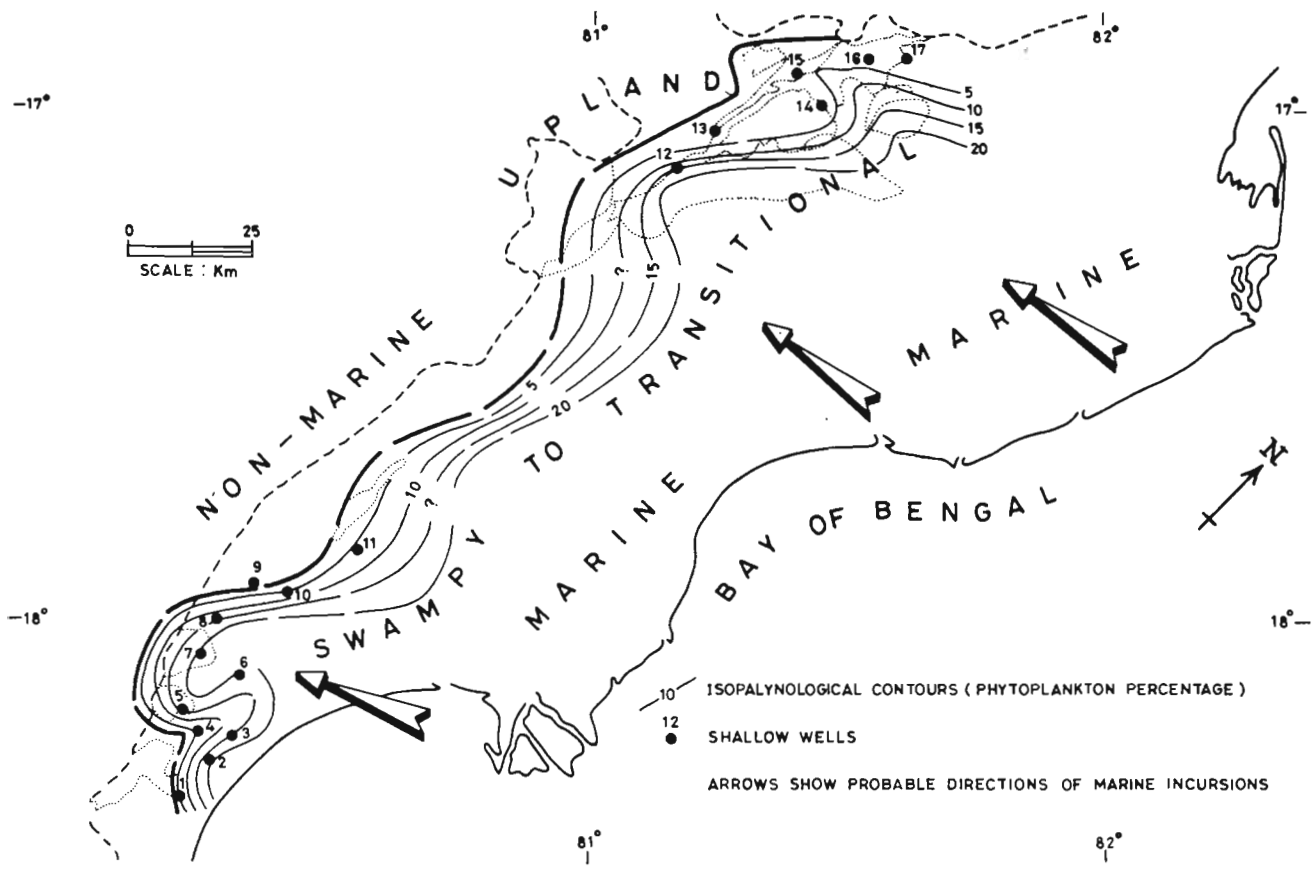
The relative abundance of saccate gymnospermous pollen, ferns as well as non-saccate gymnospermous pollen and phytoplankton (Text-fig. 5) are used for inferring the palaeoecology. The saccate gymnospermous pollen being wind pollinated are considered allochthonous and thus represent "Upland vegetation." The fern and non-saccate assemblage designate swampy environments. While the phytoplanktons designate shallow marine (mainly neritic) environments.

There is a general abundance of pteridophytic spores, phytoplankton and gymnospermous pollen are fairly well represented. The palynofloral assemblage (Text-fig. 4) is indicative of a marine swamp mainly dominated by ferns of Schizaeaceae, Osmundaceae, Cyatheaceae, Lycopodiaceae, Matoniaceae and Gleicheniaceae.



Text-fig. 5—Abundance of major floral groups.

Gymnospermous plants mainly of Araucariaceae and Cheirolepidaceae also occupied an important position in the vegetation of the neighbouring region. Cheirolepidaceae, a near shore representative represented by pollen of *Classopollis* (Venkatachala, 1966), is known to represent brackish marine sediments throughout the Mesozoic sequence. Saccate Podocarpaceous and other gymnospermous pollen including *Callialasporites* could have flown into the basin of deposition from various sources. A sizeable representation, such as 20 per cent and more of the total



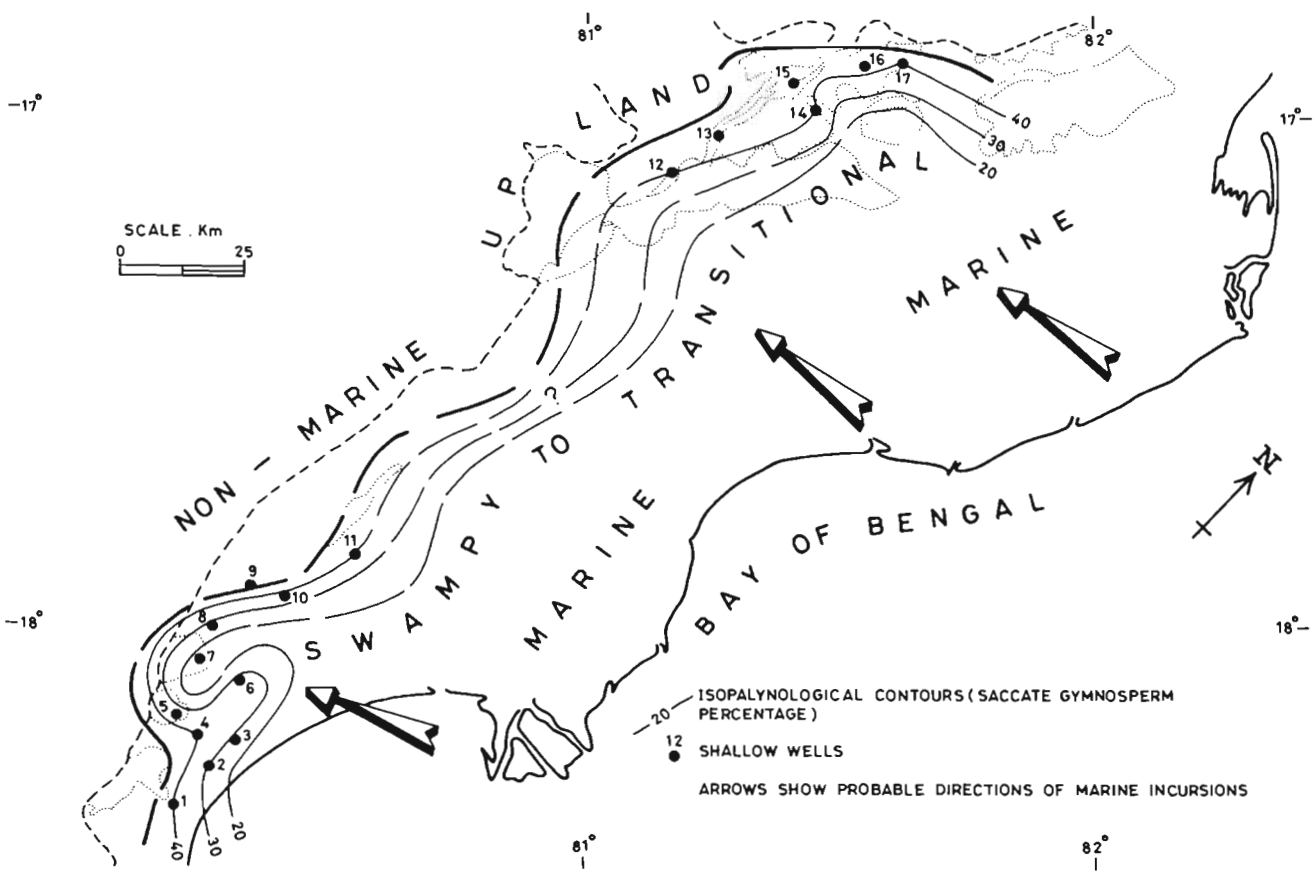
Text-fig. 6—Major environmental regimes reconstructed on the basis of phytoplankton percentage -Neocomian-?Aptian.

population of phytoplankton at a few horizons in Nutalapadu shallow well (Text-fig. 6) confirms marine influence/transgression. The saccate gymnosperms represented by *Microcachrydites, Podosporites, Podocarpidites, Alisporites, Araucariacites, Vitreisporites* and *Callialasporites* are allochthonous elements. These forms are of upland habitat and are concluded to have flown into the depositional area from areas close to the basin margins as is also suggested by their distribution (Text-fig. 7). Their relatively greater abundance in the Upper Gondwana sequence met at Tadikalapudi, in the northern part of the Bapatla-Velupcharla ridge may indicate that the southern parts of the Pranhita-Godavari graben had already been uplifted supporting an upland vegetation during the sedimentation of the coastal Gondwana sediments under study.

The fern spores are abundant and fairly uniform in their distribution (Text-fig. 5). They mostly include *Leptolepidites, Neoraistrickia, Ceratosporites, Foveotriletes, Concavissimisporites, Impardecispora, Cicatricosisporites, Klukisporites, Appendicisporites, Contignisporites, Murospora* and others which are concluded to be autochthonous; they are suggestive of warm and humid climates and swampy environments.

The phytoplankton distribution is not uniform. Their abundance at several levels indicates marine incursions in an otherwise dominantly swampy environment. The relative percentages of the major floral groups have been contoured (Text-fig. 6, 7) for inferring the special distribution of the various ecological regimes. The saccate gymnosperm pollen are most abundant in the basin margins and progressively decrease basin wards (Text-fig. 7). The phytoplankton are low nearer the basin margins and increase basin wards (Text-fig. 6). The contours for the saccate gymnospermous pollen and phytoplankton are complimentary to one another and display similar trends. These trends are suggestive of bay-like extensions in both the Krishna and West Godavari depressions. In the former, however, they were relatively in a more inland position. The progressive increase of phytoplankton was from the southwest to the northeast.

The sampling depths are limited to only 200 m and therefore do not permit a study of the entire Upper Gondwana sequence. Due to the presence of plant megafossils in the oldest exposed coastal Upper Gondwana sequence it may be surmised that the initial sedimentation took place under dominantly non-marine environments which gave place to swampy environments as is suggested by ferns, through interruptions by marine incursions which are evidenced by the occurrence of phytoplankton.



Text-fig. 7—Major environmental regimes—Neocomian-?Aptian (Reconstructed on the basis of saccate gymnosperm percentage.

Occurrence of hydrocarbons is related to source rocks which generally include argillaceous rock types. Hydrocarbons are formed in source beds from organic matter of the right kind and state when they are subjected to certain physiochemical-geologic processes over some period of time. Autochthonous living organic matter are the chief sources of the organic matter and among these, the most notable are the phytoplankton (Bordovsky, 1965). As already mentioned, the phytoplankton percentages are as high as 25 per cent and they increase towards the southwest in which direction the lithologies would be dominantly shaly. The increased percentage of phytoplankton as well as the dominance of argillaceous facies towards the southeast together with higher subsurface palaeotemperatures, as may be inferred from occurrence of Deccan trap lava flows (Text-fig. 1) in the exposed area, indicate that the coastal areas are likely to contain Early Cretaceous potential source rocks of hydrocarbons.

CONCLUSIONS

1. The tripartite classification of the exposed Upper Gondwana equivalents in the Krishna-Godavari Basin is not tenable in the subsurface. The three lithologic units identified in the outcrops give place to a major argillaceous sequence in the near subsurface.

2. The lower age limit of the exposed sequence does not see to extend into the Jurassic.

3. The discovery in age inferred from faunal and floral components is more apparent than real. Foraminiferal and palynological assemblages indicate an Early Cretaceous age.

4. The major palaeoecologic regimes vary from non-marine to paralic through swampy environments.

5. Phytoplankton percentages increase in the coastal area in which direction relatively better Early Cretaceous source rocks of hydrocarbons might develop in the subsurface.

REFERENCES

Baksi, S. K. 1966. On the Foraminiferas from Raghavapuram mudstone, West Godavari District, Andhra Pradesh, India. *Bull. geol. Min. metall. Soc. India* **37** : 1-19.

Baksi, S. K. 1967. Fossil plants from Raghavapuram mudstone, West Godavari District, Andhra Pradesh, India. *Palaeobotanist* **16**(3) : 206-216.

Bhalla, S. N. 1965. New species of Foraminifera from the Raghavapuram shales (Lower Cretaceous), Andhra Pradesh, India. *Bull. geol. Soc. India* **2** : 39-43.

Bhalla, S. N. 1969. Foraminifera from the type Raghavapuram shales, East Coast Gondwanas, India. *Micropalaeontology* **15**.: 61-84.

Bhalla, S. N. 1972. Upper age limit of the East Coast Gondwanas, India. *Lethaia* **5** : 271-280.

Bharadwaj, D. C. 1969. Palynological succession through the Mesozoic Era in India. *J. Palynol.* **5** : 85-94.

Bordovsky, O. K. 1965. Sources of organic matter in marine basin. *Marine Geology* **3** : 5-31.

Bose, M. N. 1966. Fossil plant remains from Rajmahal and Jabalpur Series in the Upper Gondwana of India, pp. 143-154 in : *Symposium on Floristics and Stratigraphy.* Birbal Sahni Institute of Palaeobotany, Lucknow.

Desikachary, S. V. & Ramachandra, M. R. 1962. Progress report for the field season 1961-62, East Coast Party (unpublished report of the O. N. G. Commission).

Dettmann, M. E. & Playford, G. 1969. *Palynology of the Australian Cretaceous : A review in stratigraphy and Palaeontology.* pp. 174-210. Australian National Univ. Press, Canberra.

Feistmantel, O. 1876. Notes on the age of some fossil floras of India. *Rec. geol. Surv. India* **9**(2-3) : 28-114.

Feistmantel, O. 1879. The fossil flora of Upper Gondwanas. Outliers on the Madras Coast. *Mem. geol. Surv. India Palaeont. indica*, Ser. 2, **1**(4) : 191-224.

Fox, C. S. 1931. The Gondwana System and its related formations. *Mem. geol. Surv. India* **58** : 1-141.

Kar, R. K. & Sah, S. C. D. 1970. Palynological investigation of the Gondwana outcrop from Vemavaram with remarks on the age of the bed. *Palaeobotanist* **18**(2) : 103-117.

King, W. 1880. The Upper Gondwanas and other formations of the coastal region of the Godavari District. *Mem. geol. Surv. India* **16** : 195-252.

Mathur, Y. K. & Mathur, K. (in press). Studies in the palaeoflora of Rajasthan, India-1. Subsurface palynostratigraphy of western Rajasthan. *J. palaeont. Soc. India.*

Mitra, N. D., Rizvi, S. R. A. & Shah, S. C. 1971. Advances in the study of stratigraphy, sedimentation and structure of the Gondwana rocks of India. *Rec. geol. Surv. India* **101** : 144-161.

Pascoe, E. 1968. *Geology of India and Burma.* Vol. **11**, pp. 485-1338. Govt. of India Publication.

Ramanujam, C. G. K. 1957. Microfossils from a carbonaceous shale near Vemavaram (Jurassic) in the East Coast Gondwana of India. *J. Indian bot. Soc.* **36**(3) : 348-372.

Rao, C. N. 1959. On the occurrence of *Dicroidium* (*Thinnfeldia*) *feistmanteli* in the East Coast Upper Gondwanas of Vemavaram, Andhra Pradesh. *Proc. 46th Indian Sci. Congr., Delhi. Abst.* **3** 236.

Rao, V. R. & Venkatachala, B. S. 1971. Upper Gondwana marine intercalations in Peninsular India. *int. Gondwana. Symp.* **5** & **6** : 353-389 Geol. Dept. A. M. Univ., Aligarh.

Sah, S. C. D. & Jain, K P. 1965. Jurassic spores and pollen grains from the Rajmahal Hills, Bihar, India : with a discussion on the age of the Rajmahal Intertrappean beds. *Palaeobotanist* **13**(3) : 264-290.

Sahni, B. 1928. Revision of Indian fossil plants. Pt. 1—Coniferales (a. impressions & incrustations). *Mem. geol. Surv. India Palaeont. Indica* (n. ser.), **11** : 51-124.

Sarma, B. B. G. 1958. Equisetalean compressions from East Coast Gondwanas. *Proc. Indian Sci. Cong. Abst.* **3** : 221.

Sastri, V. V., Chandra, A. & Pant, S. C. 1961. Foraminifera from the Raghavapuram shales near Tirupati, Andhra Pradesh. *Indian Min.* **15** : 81.

Sastri, V. V., Chandra, A. & Pant, S. C. 1963. Foraminifera from the Raghavapuram shales near Tirupati, Andhra Pradesh, India. *Rec. geol. Surv. India* **92** : 311-314.

Sastri, V. V., Sinha, R. N., Singh, G. & Murty, K. V. S. 1973. Stratigraphy and tectonics of the sedimentary basins on east coast of Peninsular India. *Amer. Assoc. Petrol. geol. Bull.* **574** : 655-678.

Sastry, M. V. A. & Mamgain, V. D. 1971. The marine Mesozoic formations of India : A review. *Rec. geol. Surv. India* **101** : 162-177

Seward, A. C. & Sahni, B. 1920. Indian Gondwana plants : A revision. *Mem. geol. Surv. India Palaeont. indica* (n. ser.) **7** : 1-41.

Shah, S C., Singh, Gopal & Sastry, M. V. A. 1971. Biostratigraphic classification of Indian Gondwanas. *int. Symp. on Stratigr. min. Res. Gondwana System. Ann. Geol. Dept., A. M. Univ., Aligarh,* **5** & **6** : 306-326.

Sharma, K. D., Jain, A. K. & Venkatachala, B. S. 1977. Palynology of the Early Cretaceous sediments from the subsurface of Godavari-Krishna basin, Andhra Pradesh, South India, pp. 110-122 in : B.S.

Venkatachala & V. V. Sastri (eds) *Proc.—IV Colloq. Indian Micropalaeontol. Stratigr. Dehradun.*

Subrahmaniyam, M. 1960. Progress report on the Godavari delta : *Rept. Geol. Directorate*, O. N. G. Commission : 1-23 (unpublished report of the O. N. G. Commission).

Suryanarayana, K. 1954. Fossil plants from the Jurassic rocks of the Madras Coast, India. *Palaeobotanist* **3** : 87-90.

Venkatachala, B. S. 1966. Mesozoic operculate pollen and their morphology. *Palaeobotanist* **15** (1&2) : 98-101.

Venkatachala, B. S. 1970. Observation on some palynological contributions to Indian stratigraphy. *Palaeobotanist* **19**(3) : 284-296.

Venkatachala, B. S. 1974. Palynological zonation of the Mesozoic and Tertiary subsurface sediments in the Cauvery Basin, pp. 476-495 in : K. R. Surange *et al.* (eds)—*Aspects and Appraisal of Indian Palaeobotany.* Birbal Sahni Institute of Palaeobotany, Lucknow.

Venkatachala, B. S., Kar, R. K. & Raza, S. 1968. Palynology of the Mesozoic sediments of Kutch, western India-5. Spores and pollen from Katrol exposures near Bhuj, Kutch District, Gujarat State. *Palaeobotanist* **17** : 185-207.

Venkatachala, B. S., Sharma, K. D. & Jain, A. K. 1972. Palynological zonation of Jurassic-Lower Cretaceous sediments in the subsurface of Cauvery Basin. *Sem. Palaeopalynol.* and *Indian Stratigr., Calcutta* : 172-187.

Venkatachala, B. S., Sharma, K. D. & Jain, A. K. 1970. Palynological studies in the Tertiary and pre-Tertiary sediments in the Cauvery Basin and along the East Coast-1. Palynology of the Lower Cretaceous sediments of the subsurface sequence of Krishna-Godavari Basin. *Institute of Petroleum Exploration, ONGC* 15.022 (1270), p. 1-53 (unpublished).

Wilson, L. R. 1959. A method of determining a useful microfossil assemblage for correlation : 1; a. *Geol. Notes* **19** : 91-93.