RECORD OF EARLY TERTIARY DEPOSITS IN KERALA, INDIA AND ITS PALAEOGEOGRAPHIC SIGNIFICANCE

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Abstract

The Tertiary formations on the coastal plains of Kerala, India, which was so long known to be of only Early Miocene age have yielded Early Tertiary planktonic foraminifera as well as palynofossils ranging in age from Early Eocene onwards in a 600 metres deep bore-hole. A pre-Tertiary ferruginous sandstone with arkoses and clays has been identified below the Tertiary sequence. Based on these finds and detailed examination of the various sedimentary facies of this coastal basin and their correlation with the off-shore drill data and DSDP Site 219 on Chagos-Lakshadweep Ridge, a reinterpretation of the formation of the western continental margin of India has been suggested. Rifting between India and Chagos-Lakshadweep Ridge was initiated with the formation intra-continental graben type structure with terrigenous sedimentation in the Late Mesozoic (? Cretaceous) time. Transition to marine conditions slowly followed in the Early Eocene with sinking of the basin and drifting apart till India collided with the Eurasian plate in the Oligocene.

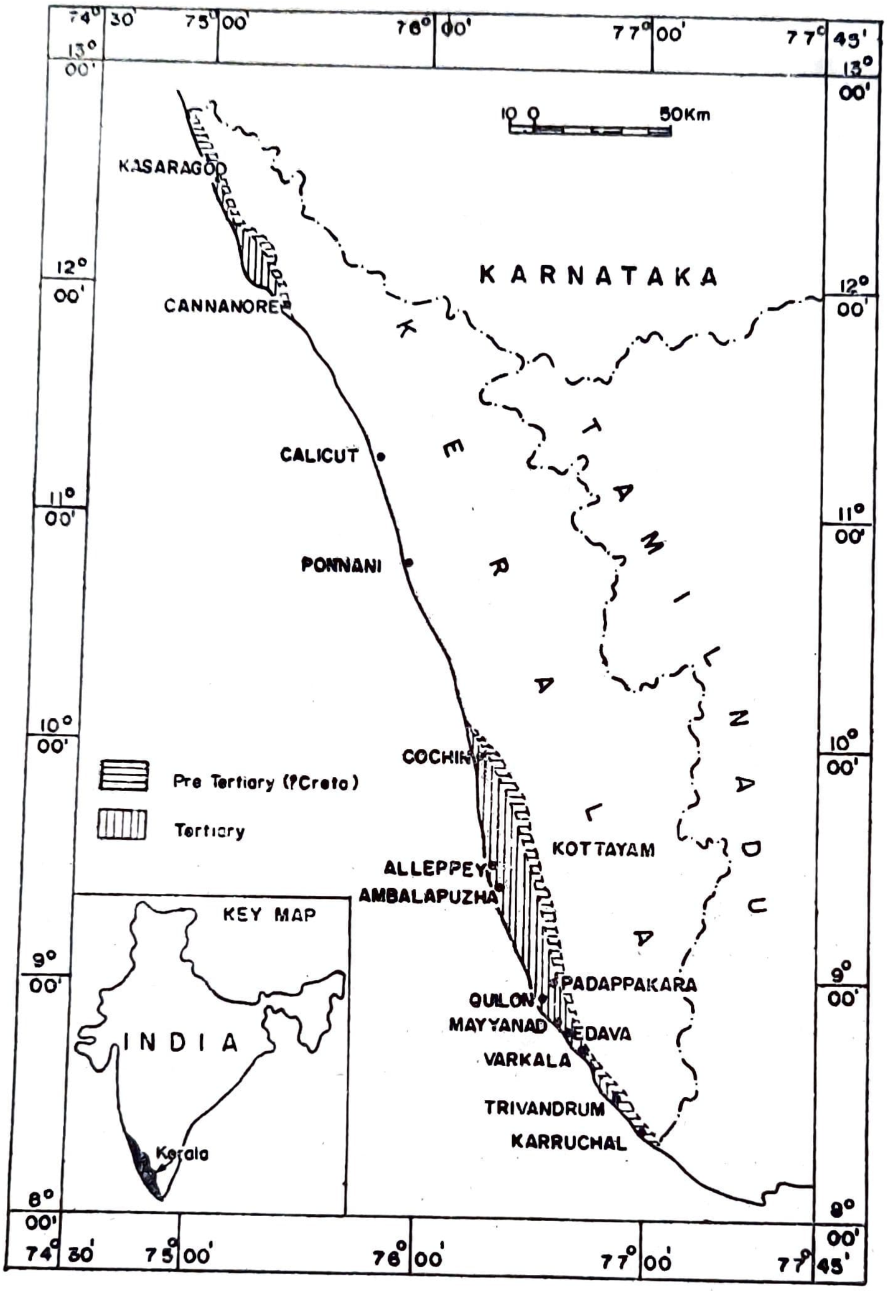
Introduction

The sedimentary formations on the coastal plains of Kerala in South-western India, were described as "Warkalli beds" and "Quilon beds" (King, 1882; Foote, 1883) corresponding to terrigenous and marine sediments respectively. The "Quilon beds" were considered to unconformably overlie the Precambrian gneisses and in turn being overlain by the "Warkalli beds" (Paulose & Narayanaswamy, 1968). These formations were assigned an Early Miocene to Pliocene age (Rasheed & Ramachandran, 1978 ; Rao & Dutta, 1976).

Authors took up a detailed litho-and bio-stratigraphic study of the sedimentary sequence based on subsurface study through a number of deep bore-holes. In one such bore-hole near Ambalapuzha (9°23′30″ : 76°21′30″) in south Kerala, Late Eocene-Oligocene planktonic foraminifera were observed below the Miocene (Raha & Rajendran, 1984). A detailed palynological study of the entire sequence that contains carbonacoeus clays, grey clays, lignites and sandstones was subsequently carried out. This confirmed the presence of Early Eocene and possibly in part Paleocene palynofossils in the lower part of the sequence (Raha et al., 1984). The DSDP site 219 on the Chagos-Lakshadweep Ridge has also recorded a sediment sequence of 411 m extending in age from Palaeocene to Pleistocene (Whitmarsh *et al.*, 1976). These finds along with other observations have led the authors to reconsider the evolutionary history of the western continetal margin of India.

Geological set-up

The Cenozoic basin occurs as a narrow linear belt along the coastal plains of Kerala (Fig. 1). Initially the calcareous Quilom Formation of around 1.50 m thickness was observed by various workers around Quilon (King, 1882; Foote 1883; Pichamuthu &



Map 1— Showing sedimentry (Tertiary and Pre-Tertiary) distribution in Kerala.

Kumar, 1933 ; Dey, 1962). Some shallow borewells were studied in the same area by Rao and Dutta (1976) and Rasheed and Ramachandran (1978). A terrigenous facies named Warkalli 'beds' containing sandstones, clays and lignites were located in a cliff section near Varkala (8°44′ : 76°43′). Some workers considered these to be a horizon above the Quilon Formation which was thought to be the basal member of the Tertiary sequence (Paulose & Narayanaswamy, 1968). Through the recent study of a number of borehole logs and outcrops, a revised lithostratigraphy of the sequence was established by Raha *et al.* (1983) and Raha and Rajendran (1984a) as given in Table 1. The Quilon Formation, which is the calcareous unit in the sedimentary sequence pinches out eastward whereby the terrigenous sediments of Ambalapuzha and Mayyanad Formations become indistinguishable and the sequence attains the status of a formation.

The ferruginous hard and compact sandstone that occurs at the base of the sedimentary sequence was earlier considered as part of the Warkalli (bed) Formation. A facies analysis along with lithological studies indicate that this is distinctly an older sedimentary formation occuring unconformably below the Tertiary sequences and outcropping only on the fringes of the Tertiary basin (Raha & Rajendran, 1984).

Palaeontological observations

The Quilom Formation (see Table 1) comprises limestones, marls, calcareous clays, calcareous sandstones and bio-calcarenites. Massive compact biomicrites are well developed in the various subcrop sections at Mayyanad (8°50′ : 76°39′) and Ambalapuzha. The bio-calcarenites with reefal fossil assemblage containing corals, bryozoans, and echinoids with shallow water foraminifera, the miliolids and operculinids in abundance, has been recoreed at Padapakkara (8°58′ : 76°38′), Edava (8°46′ : 76°41′30″) and in the upper part of the Quilon Formation in the sub-surface near Ambalapuzha and Mayyanad. Fossiliferous soft marls occur at Edava. Hard compact bio-micrites have been observed at Padappakara and in bore-hole samples from Ambalapuzha, Mayyanad and Chavara. Planktonic forminifera have been recorded at various depths. Though their frequency is very low compared to the benthonic forms, it is well established that such planktonic foraminifera are of great use of deciphering stratigraphic position of the containing formations (Posthuma, 1971 ; Stainforth *et al.*, 1975).

Table 1—A revised lithostratigraphic classification of sedimentary sequence in Kerala

Period	Super group	Group	Formation	Lithology
Quaternary	MALABAR SUPER GROUP		Vembanad Fm.	Beach sands, alluvium, red ('teri') sands, peat beds with semi-carbonised wood, calcareous clays, etc.
			Unconformity (marked by laterite)	
Tertiary		WARKALLI GROUP	Ambalapuzha Fm.	Sandstones, clays, lignites
			Quilon Fm.	Limestones, marls, calcareous clays and sands
			Mayyanad Fm.	Sandstones, coarse gravelly sands, clays, lignites.
			Unconformity	
? Late Mesozoic			Karuchal Fm.	Hard, compact, ferruginous gritty sandstones with clay interbeds
			Unconformity	
Archaean			Gneisses, granulites and schists	

The occurrence of *Miogypsina globulina, Nephrolepidina sumatrensis, Trybliolepidina* and *Taberina malabarica*, were noted in the outcrops of Quilon Formation (Chatterjee & Pant, 1971). Rasheed and Ramachandran (1978) have identified a lower *Globigerinatella insueta-Globigerinoides quadrilobatus trilobus/Miogypsina globulina-Lepidocyclina sumatrensis* Assemblage Zone and in upper part, *Globigerinoides quadrilobatus trilobus/Miogypsina globu-*

lina-Archaias malabaricus Assemblage Zone indicating lower and middle Burdigalian age respectively.

Recent sub-surface explorations in connection with ground water investigations in the coastal tract of central Kerala have revealed that the calcareous Quilon Formation has a thickness of 100-130 metres on the western margin of the coastal plains with a longer sedimentary history of chiefly inner shelf carbonate facies. In the bore-hole near Ambalapuzha the Quilon Formation extends between 200 metres to 356 metres. The calcareous Quilon Formation contains at its base a 25 metres thick zone of black carbonaceous clay with foraminifera and ostracodes. Below this, the sequence contains predominantly sandstones with clays and lignites. An analysis of the foraminifera of the samples from this bore-hole revealed the presence of some Oligocene zone fossils viz., *Globigerina sellii*, *Globorotalia opima opima*, *Globigerina ampliapertura* in the depth zones from 288 metres to 356 metres (Plate 3). *Globigerina binaiensis* has been noted at a detph of 258 metres. Fragmentary specimens of *Assilina* sp. have been observed in thin sections of the limestone cuttings from the depth of 288 metres to 289 metres.

The upper part of the Quilon Formation (201 to 250 metres) is characterised by *Globigerina praebulloides*, *Globorotalia obesa*, *Globigerinoides altiaperture*, *Globigerina quadrilobatus tiloba* and *G. sicanus* Assemblage Zone which characterise the Lower Miocene (N. 6—N.8). At the depth of 250 metres to 258 metres, occurs *Globigerina binaiensis* (N.3-N.6) which marks the Early Miocene period. *Globorotalia opima opima* and *Globigerina ampliapertura* occur between depths of 330 metres and 356 metres which marks the Early Oligocene (N. 1—N.2). Other larger foraminifera include *Lepidocyclina* sp. and *Operculina* sp. The characteristic Early Miocene forms so far referred to from the Quilon Formation like *Archaias malabaricus* and *Austrotrillina howchini* are restricted to the upperpart of the Quilon Formation.

The sedimentary sequences below the depth zone of 356 metres contain mostly terrigenous sandstones, clays and lignites. Thus to work out their age a detailed palynological study was found to be essential.

Palynological observations

The palynological investigation on the surface sediments of Kerala was initiated by Rao (1959) who described the fungal remains from the various Tertiary deposits of India. Ramanujam and Rao (1973) recorded the occurrence of *Ctenolophonidites* from the Warkalli deposits of Kerala with a geological history of genus *Ctenolophon*. Rao and Ramanujam (1975) and Ramanujam and Srisailam (1978) observed a large number of hysterichospharids, arcritarchs, pteridophytic spores, angiospermic pollen and fungal elements from Quilon and Warkalli deposits. Jain and Kar (1970) described 17 genera and 19 species of fungal remains from the Neogene sediments around Quilon and Varkala. Kar and Jain (1981) also reported 44 genera and 56 species of pteridophytic spores and angiospermic pollen from the same material.

For the present study, 166 samples were macerated covering the entire sequence of 600 m deep bore-hole near Ambalapuzha, out of which 89 samples yielded spores, pollen grains, microplanktons and some fungal bodies. The samples from depths of 506 metres to 509 metres and 461 metres to 464 metres were found to contain *Palmaepollenites*, *Couperipollis*, *Proxapertites*, *Polycolpites*, *Meliapollis*, *Verrutricolporits*, *Retitribrevicolporites*, *Paleosantalaceaepites*, *Striatocolporites* and *Proteacidites* in appreciable numbers and some of them have been illustrated to (Pl. 1, figs. 1-12). It is a well known phenomenon in India that palm pollen generally represented by *Palmaepollenites*, *Palmidites*, *Couperipollis* and *Spinizonocol-*

pites, mostly restricted to Paleocene-Eocene. Of the four genera, *Spinizonocolpites* stands for the *Nypa* type of pollen which being a mangrove has a special environmental requirement and is not found in all the other Lower Tertiary formations in India. So presence of *Palmaepollenites* and *Couperipollis* in these sediments generally points towards a Paleocene-Eocene age. However, typical Paleocene index species like *Dandotiaspora dilata*, *Dandotiaspora telonata*, *Dandotiaspora auriculata* and *Dandotiaspora densicorpa* which are invariably found in all the Paleocene sediments of India have not been recorded in this area. Moreover, the presence of *Proxapertites*, *Polycolpites*, *Meliapollis*, *Verrutricolporites*, *Proteacidites*, *Retitribrevicolporites*, *Paleosantalaceaepites* and *Striacolporites* together with palm pollen indicate Eocene age.

From 443 to 446 m and 276 to 288 m *Crassoretitriletes*, *Trisyncolpites* and *Bombacacidites* together with *Deltoidospora*, *Cyathidites*, *Lygodiumsporites*, *Cheilanthoidspora*, *Polypodiaceaesporites*, *Tricolpites*, *Margocolporites*. *Ctenolophonidites*, *Paleosantalaceaepites*, *Meliapollis* and some microplanktons are found. Some of these palynological taxa have been figured (Pl. 1, figs. 13-23).

The commencement of *Crassoretitriletes* in these sediments is significant. Germeraad, Hopping and Muller (1966) studied in detail the occurrence and behaviour of this genus in pantropical areas. They noted that this genus generally occurs in Lower Oligocene and continues into the Miocene. *Trisyncolpites* is an important palynological taxon in Oligocene of Kachchh, western India, and a cenozone *Trisyncolpites ramanujamii* has been designated after it. *Bombacacidites* generally makes its appearance in India in Oligocene and is also found in Miocene. So the presence of *Crassoretitriletes*, *Trisyncolpites* and *Bombacacidites* demarcate Oligocene in this bore core.

Occurrence of *Malvacearumpollis*, *Hibisceaepollenites*, *Psiloschizosporis* and *Quilonipollenites* mostly delineate Lower Miocene in the bore core from the depth of 278-279 m. It may be mentioned here that in Khari Nadi Formation (Lower Miocene) in Kachchh western India (Kar, 1985) also recovered *Malvacearumpollis*, *Hibisceaepollenites* and *Psiloschizosporis* and considred them as marker fossils for Lower Miocene. This genus is rather poorly represented in Kerala though in Oligocene-Miocene sediments of Kachchh, Meghalaya and Assam it is found as one of the most dominant elements. *Striatrilets*—the dispersed sporses of *Ceratopteris* (family—Parkeriaceae) favours fresh water coastal plain and perhaps in Kerala during Oligocene-Miocene it was not prevalent. Miocene palynological assemblage is richest in the bore-core and the following genera are frequently found : *Cyathidites*, *Lygodiumsporites*, *Todisporites*, *Deltoidospora*, *Cheilanthoidspora*, *Polypodiaceaesporites*, *Tricolpites* *Retitrescolpites*, *Lakiapollis*, *Ctenolophonidites*, *Triporopollenites*, *Polyporites*, *Ericipites*, *Phragmothyrites*, *Parmathyrites*, *Notothyrites*, *Lirasporis* and microplanktons. Some of the significant taxa have been figured in Plate 2.

To sum up, of the total thickness of 600 m analysed in this deep borehole, Eocene is represented between depths 443 m down to 509 m. Possibly Early Eocene is marked by the sediments ranging in depth from 509 m to 594 m, part of which and underlying sediments may represent Paleocene, though typical Paleocene Zone fossils were not found in them. Based on palynological evidences the Oligocene base appears to be at around 443 m depth with an upward vertical extent upto 279 m. Oligocene planktonic foraminifera are noticed between depths of 228 m and 356m. The Miocene-Oligocene boundary may lie between 258 m and 278 m represented by *Globigerina binaiensis* Zone (N.3-N.6).

Sedimentation history

The oldest sedimentary formation in this basin comprises coarse gritty sandstones, conglomeratic at places, intercalated and orvelain by arkoses and clay beds (Text-fig. 2). These hard and compact sandstones and conglomerates with the associated arkoses and clay beds underlie the Tertiary sediments (Raha & Rajendran, 1984). The earliest Tertiary sediments are coarse sandstones followed by dark carbonaceous clays that have yielded Early Eocene palynofossils. The Tertiary sediments range in age from Early Eocene through Oligocene to Miocene. The Oligocene started with the deposition of coarser sandstones suggesting a rejuvenation of the provenance followed by clay and sandstone alternations. The Early Oligocene is marked by calcareous clays and fossiliferous limestones with planktonic foraminifera indicating connection with the open sea and a change over from deltaic continental through lagoonal to marine environment of deposition. Transgresssion of the sea continued till Early Miocene culminating in reefal and inner shelf deposits containing corals, pteropods, lamellibranches, echinoids and foraminifera in abundance. Continental facies with coarse sandstones, clays and lignites interfingered with the marine facies within the basin with culmination in regression of the sea that exposed the top of the sedimentary sequences to processes of weathering and lateritisation. Gradual sinking of the central part of the basin with lagoonal to deltaic environment in the Quaternary times is noted around the Vembanad Lake (estuary) where black steaky clays of peat-bogs and swampy environment preceded alluvial and beach sand deposits. All these reflect that the coastal plains between Cochin and Varkala formed a major basin with continued sinking till sub-Recent times. These must have been associated with major basin marginal fault as well as transverse faults that might have controlled the sedimentation in the off-shore region of the basin as well.

Palaeogeographic significance

The sedimentary formations of the coastal plains of Kerala were so far known to be of Early Miocene (Burdigalian) age. Based on this data, various hypotheses were framed to explain the evolution of the western continental margin of India. Sinha and Roy (1982) suggested that the separation of Chagos-Lakshadweep Ridge from the Indian sub-continent was in Mio-Pliocene times. McKenzie and Sclater (1971) have explained their palaeomagnetic data on the Indian Ocean floor by indicating various positions of the Indian plate since Late Cretaceous times. Howev, knowledge on the geology of this part, i.e. between the coastal plains of Kerala and the Chagos-Lakshadweep Ridge was very limited.

Present study suggests an initial continental sedimentation in the Late Mesozoic period followed by the lagoonal to deltaic sedimentation in the Early Tertiary (Early Eocene), and gradual transformation to marine conditions in the Late Eocene-Early Oligocene. Marine transgression with inner-shelf and reefal facies till Early Miocene times was recorded on-land about 16 km east of present coast line.

These observations bear great significance on the evolution of the western continental margin of India with reference to reconstruction of Gondwanaland and plate tectonics theory. Ben Avraham and Bunce (1977) reported the occurrence of a sedimentary sequence up to 5 km thick of mainly Jurassic and Cretaceous age on the Maldive Islands (South of Lakshadweep Islands). The pre-Tertiary sandstones, conglomerates and arkoses recorded on the coastal plains of Kerala and also in a bore-hole off Cochin by Oil and Natural Gas Commission (Mitra *et al.*, 1983) are probable equivalents of the same.

Beloussov (1984), while discussing the evolution of the transition zones between continents and oceans described three important stages—continental, lagoonal and marine. The first stage appears in the rift regime when the coast is divided by steep faults into conglomeratic at places, intercalated and orvelain by arkoses and clay beds (Text-fig. 2). These hard and compact sandstones and conglomerates with the associated arkoses and clay beds underlie the Tertiary sediments (Raha & Rajendran, 1984). The earliest Tertiary sediments are coarse sandstones followed by dark carbonaceous clays that have yielded Early Eocene palynofossils. The Tertiary sediments range in age from Early Eocene through Oligocene to Miocene. The Oligocene started with the deposition of coarser sandstones suggesting a rejuvenation of the provenance followed by clay and sandstone alternations. The Early Oligocene is marked by calcareous clays and fossiliferous limestones with planktonic foraminifera indicating connection with the open sea and a change over from deltaic continental through lagoonal to marine environment of deposition. Transgresssion of the sea continued till Early Miocene culminating in reefal and inner shelf deposits containing corals, pteropods, lamellibranches, echinoids and foraminifera in abundance. Continental facies with coarse sandstones, clays and lignites interfingered with the marine facies within the basin with culmination in regression of the sea that exposed the top of the sedimentary sequences to processes of weathering and lateritisation. Gradual sinking of the central part of the basin with lagoonal to deltaic environment in the Quaternary times is noted around the Vembanad Lake (estuary) where black steaky clays of peat-bogs and swampy environment preceded alluvial and beach sand deposits. All these reflect that the coastal plains between Cochin and Varkala formed a major basin with continued sinking till sub-Recent times. These must have been associated with major basin marginal fault as well as transverse faults that might have controlled the sedimentation in the off-shore region of the basin as well.

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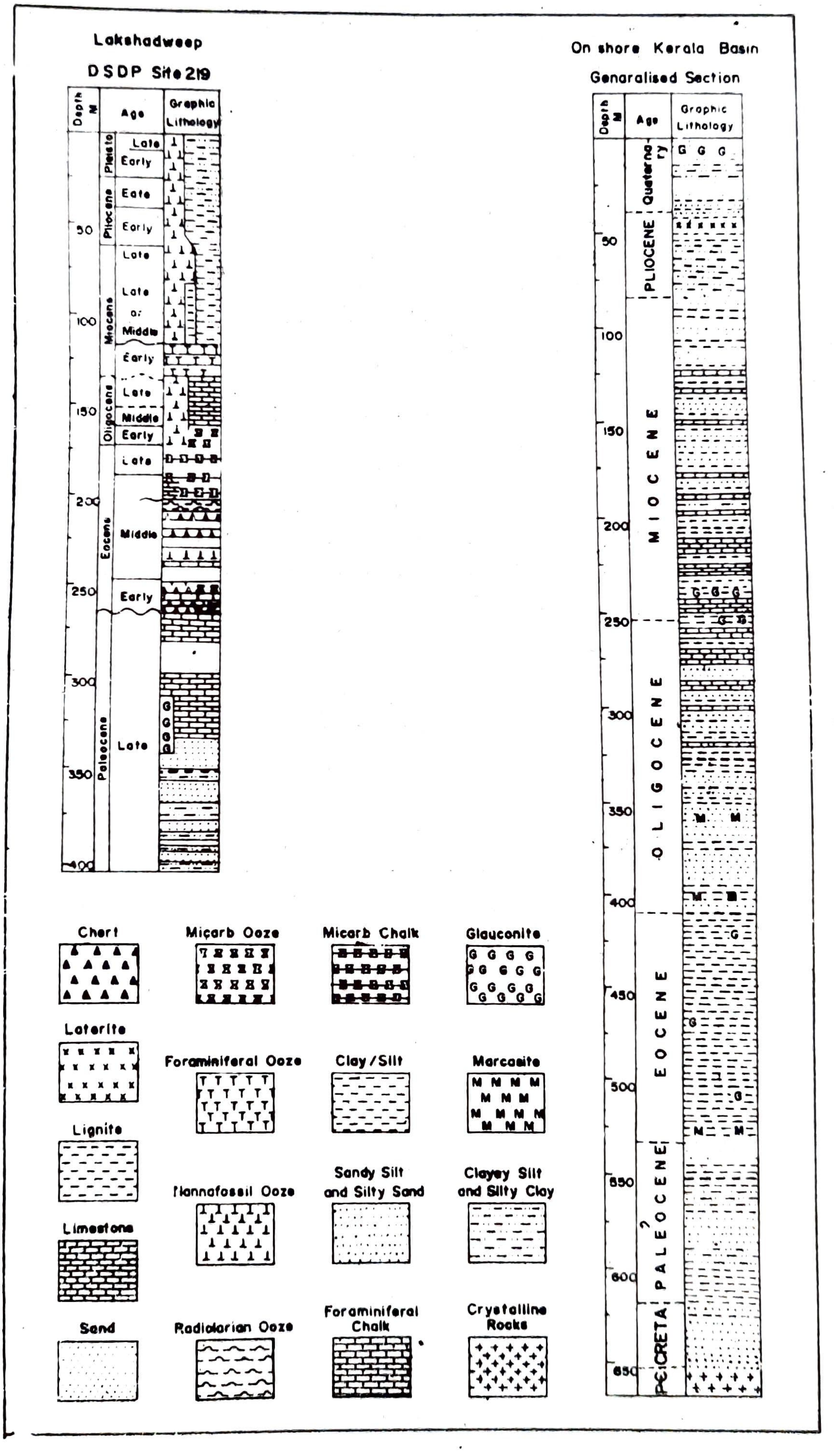

Text-fig. 2—Vertical section through DSDP Site 219 (Lakshadweep Island) after Whitmarsh *et al.*, 1974) and the generalised stratigraphic section of Kerala onshore basin.

grabens and horsts, the graben accommodating the first continental sediments accompanied by basalt effusions and dolerite dykes. The magnetite-bearing sandstones in the offshore well near Cochin are seen interbedded with basalts. Though such basaltic associations are not seen in the sediments of the coastal plains, there are a number of basic dykes in this region. If the Mesozoic sediments of the Maldive Islands are correlated with those of the west coast of India, the rifting stage between the two can be dated as Mesozoic, as some of the basic dykes of Kerala are dated to be around 104-127 Ma (Sinha-Roy, 1983). These dykes are thus older than the Deccan trap volcanicity that ranges between 42 Ma-84 Ma (Alexander, 1979 ; Kaneoka, 1980). The initial rift volcanism of East Africa is indicated to be around 116-128 Ma (Pallister, 1971).

Foundering of the region betwen Chagos-Lakshadweep Ridge and India thus probably started around 127 Ma, simultaneously with rifting on the eastern margin of Africa, along with the northward movement of India. Subsequently the basin developed in the area between southwestern India and the Chago-Lakshadweep Ridge with the transition from continental to marine environment. This is also corroborated by the presence of clastic sediments of Paleocene age in the DSDP Site 219 on the Chagos-Lakshadweep Ridge (Whitmarsh *et al.*, 1974). These data together with the observations on the Indian ocean region west of the Mid-Oceanic Ridge points to the need for reconsideration of the presently accepted Gondwana fit (Raha & Rajendran, 1984b).

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Explanation of Plates

(All photomicrographs are enlarged *Ca.* × 500)

Plate 1

1. *Cyathidites major* Couper
2. *Laevigatosporites lakiensis* Sah & Kar
3. *Seniasporites verrucosus* Sah & Kar
4-5. *Palmaepollenites ovatus* Venkatachala & Kar
6. *Tricolpites reticulatus* Cookson
7-8. *Meliapollis ramanujamii* Sah & Kar
9. *Retitribrevicolporites matanamadhensis* (Venkatachala & Kar) Kar
10-11. *Paleosantalaceaepites primitiva* Biswas
12. *Paleosantalaceaepites ellipticus* Sah & Kar
13. *Deltoidospora* sp.
14. *Crassoretitriletes vanraadshooveni* Germeraad, Hopping & Muller
15. *Polypodiaceaesporites chatterjii* Kar

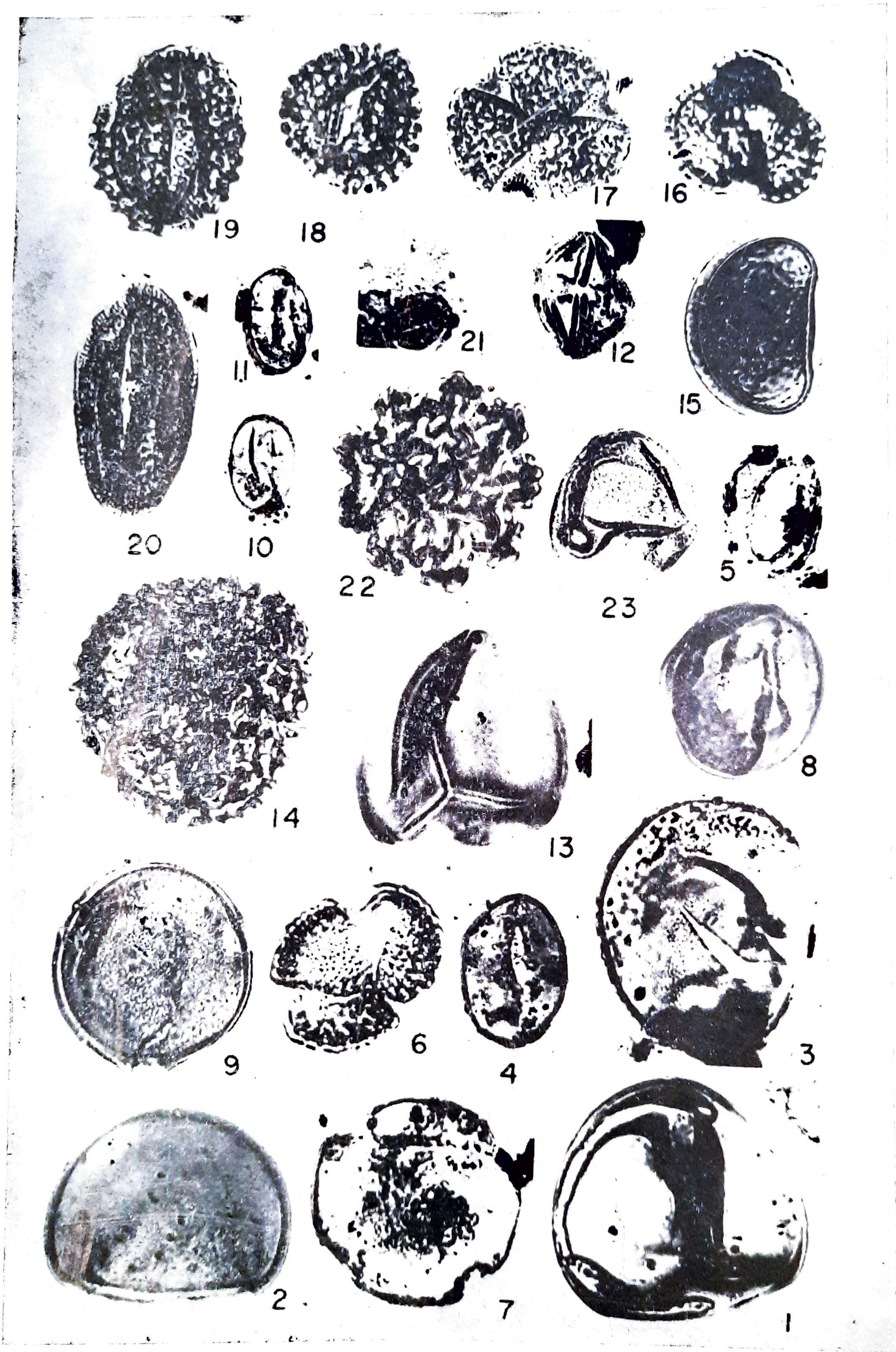
16-19.	*Margocolporites tsukadii* Ramanujam
20.	*Striacolporites ovatus* Sah & Kar
21.	*Bombacacidites triangulatus* Kar
22.	*Ctenolophonidites costatus* van Hoeken-Klinkenberg
23.	*Trilatiporites sellingi* Ramanujam

Plate 2

1.	*Crassoretitriletes vanradshooveni* Germeraad, Hopping & Muller
2.	*Striatriletes susannae* van der Hammen emend. Kar
3.	*Quilonipollenites sahnii* Rao & Ramanujam
4,6.	*Proxapertites scabratus* Jain, Kar & Sah
5.	*Psiloschizosporis psilata* Kar & Saxena
7.	*Retitrescolpites typicus* Sah
8-9.	*Tribrevicolporites eocenicus* Kar
10.	*Ctenolophonidites costatus* van Hoeken-Klinkenberg
11-13.	*Hibisceaepollenites splendus* Kar (fig. 11 magnified to *ca.* × 250).

Plate 3

1.	*Globigerina binaiensis*
2.	*Globigerina sellii*
3.	*Globorotalia opima opima*
4.	*Globigerina ampliapertura*
5.	*Globorotalia opima nana*
6.	*Hantkenina* sp.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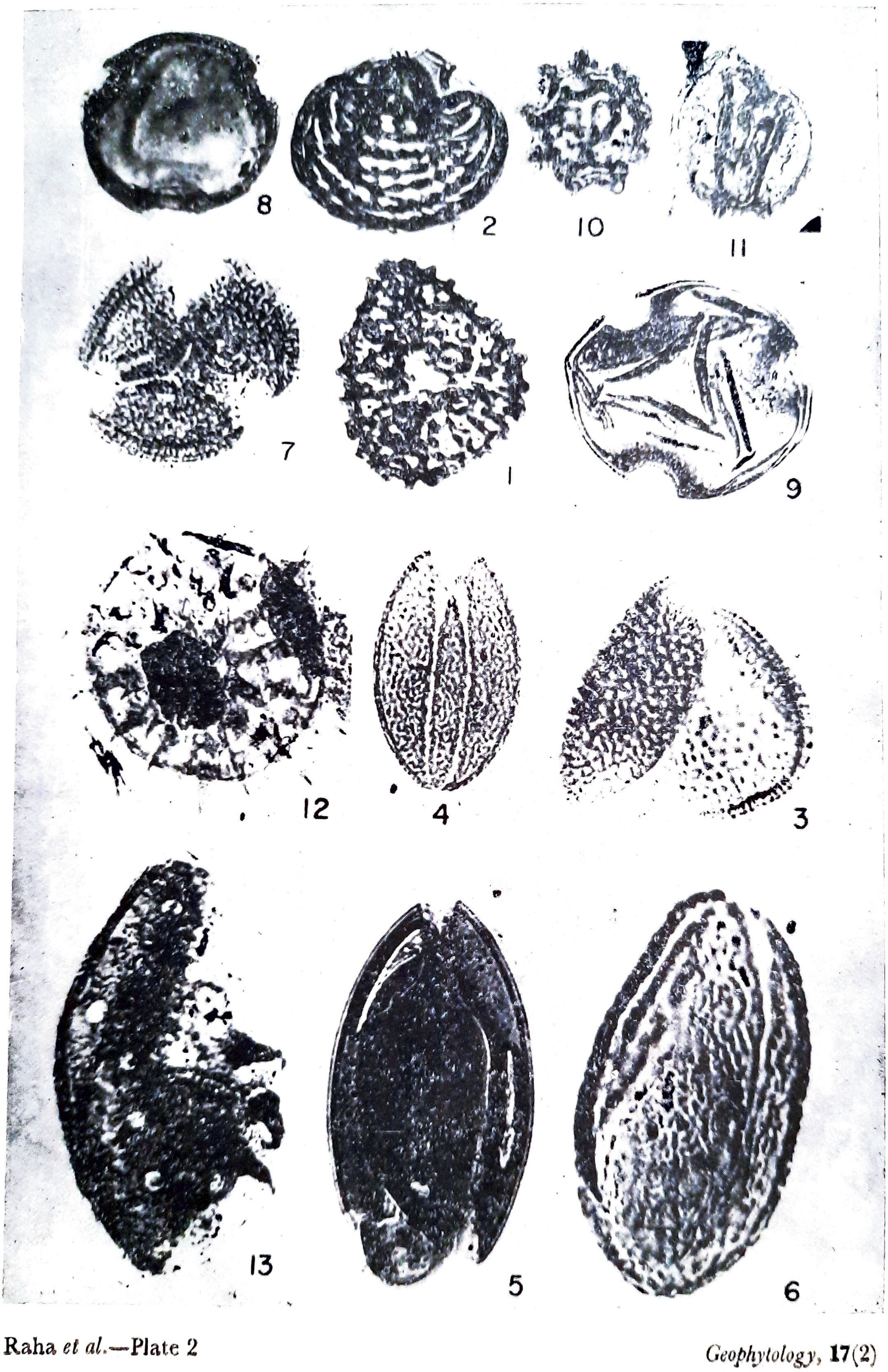
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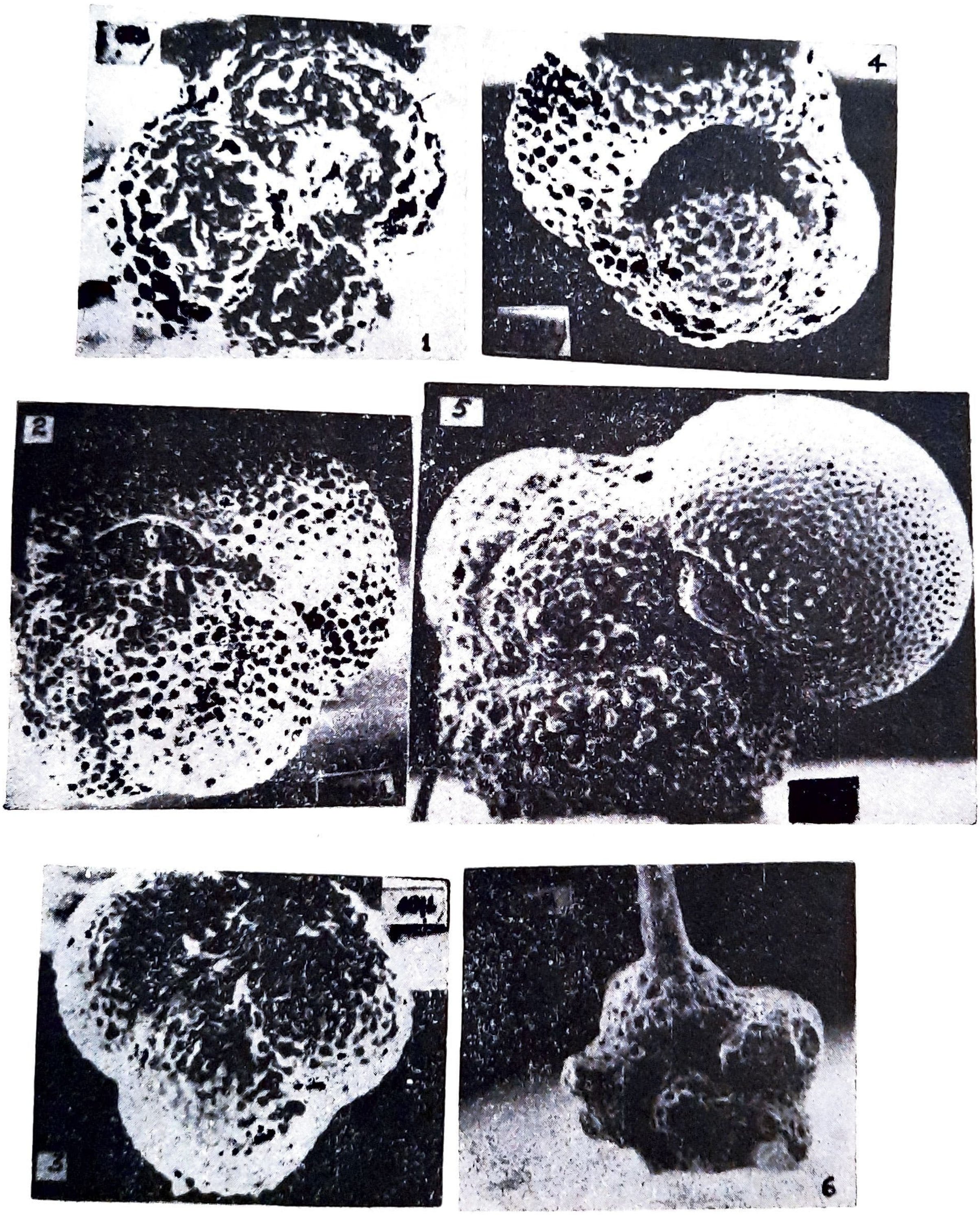
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