RECENT CONTRIBUTIONS TO OUR KNOWLEDGE OF THE CRETACEOUS ROCKS OF SOUTH INDIA

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1. INTRODUCTION

IT is now well known that the Cretaceous is one of the most interesting and important periods in the geological history of India*; this is because of the variety of rock formations representing different facies of deposition during this period found in many parts of this country which enable us to reconstruct a more or less complete picture of the geological, geographical, and biological conditions which prevailed during that period. Of these formations, the marine fossiliferous rocks have of course the greatest value and naturally receive the largest amount of attention. For purposes of this paper we will therefore confine our attention only to these marine beds, especially those found in South India and indicate the recent advances in our knowledge of these rocks and their importance.

Before proceeding further it is necessary to have a general idea of the present distribution of the marine Cretaceous rocks in India as a whole. These may be broadly divided into two regional groups: (1) those found in the extra-Peninsula covering the main Himalayan region with its extensions into Baluchistan, Sind, Cutch and Narbada Valley—all these having been deposited either in the main sea of Tethys or its transgressional extensions; (2) the second including those of the Peninsular region found along the East coast of India along a narrow strip of country from Trichinopoly in the south to Assam in the north, and representing the deposits due to a transgression of the Southern Sea as distinct from the Northern Tethys. Peninsular India which had normally stood out as a stable land mass for long periods before, had thus during the Cretaceous period, the unique experience of being locally invaded by the adjacent seas both from the north and from the south, the main land mass, however, serving as a barrier between the two seas and keeping them separate and distinct. We have thus the remarkable position in Peninsular India of having deposits of both these seas lying almost side by side,—those of the Narbada Valley representing the northern facies, and the east coast deposits belonging to the southern,—thus

* Throughout this paper, the term India has been used to indicate the country as it stood before the 'partition' in 1947.

providing an excellent opportunity for comparative studies. The following map (Fig. 1) gives an idea of the current view regarding the distribution of land and sea in India during this period after the two transgressions came into existence. As a result of recent studies, however, it would appear that this picture of the palaeogeographical conditions which we have been adopting all along needs revision and modification in certain respects; this question will be taken up in the later part of this paper after reviewing the results of recent investigations and the data furnished by them in the elucidation of this problem.

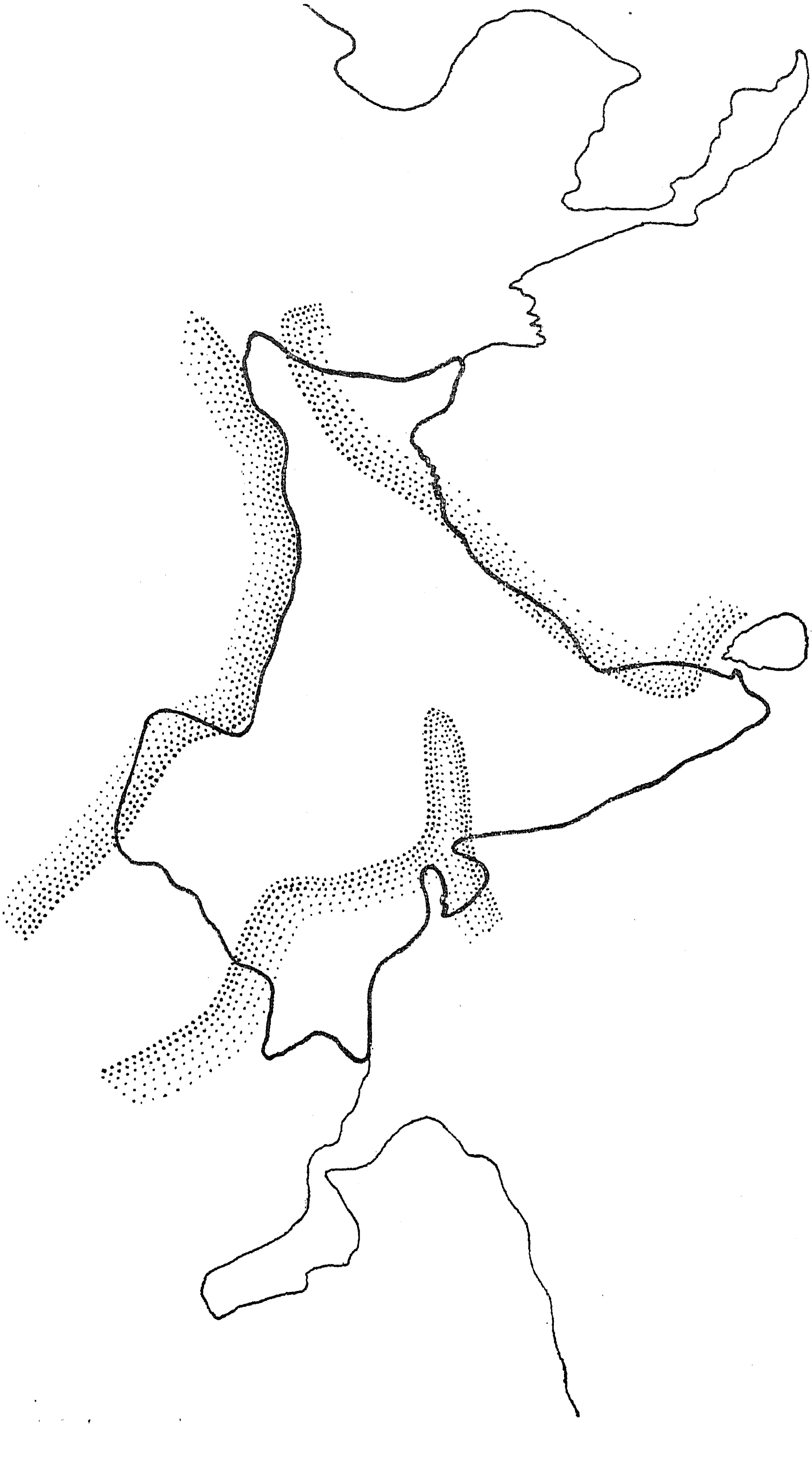
2. PRESENT PAPER

The present paper deals only with the Cretaceous rocks found along the East coast of India and formed as a result of the transgression of the southern sea in this area. These are now found in several disconnected patches in this region although there is no doubt that at the time immediately following their formation these beds must have been more extensive and continuous. The present small and discontinuous distribution of these rocks is due largely to the effects of denudation on the one hand and their being frequently covered over by later deposits on the other. Of these Cretaceous rocks as they are now seen, the following five areas may be recognised: (1) Trichinopoly District, (2) Vridhachalam, (3) Pondicherry, (4) Rajahmundry and (5) Assam. The first three of these which occur close together may be considered as forming one unit and the following map (Fig. 2) shows the general disposition of these three areas and their relationship to the other adjacent rocks of the area. We will now proceed to deal with these areas one by one and draw special attention in each case to the results of recent researches and their importance in the study of the Cretaceous system of India as a whole.

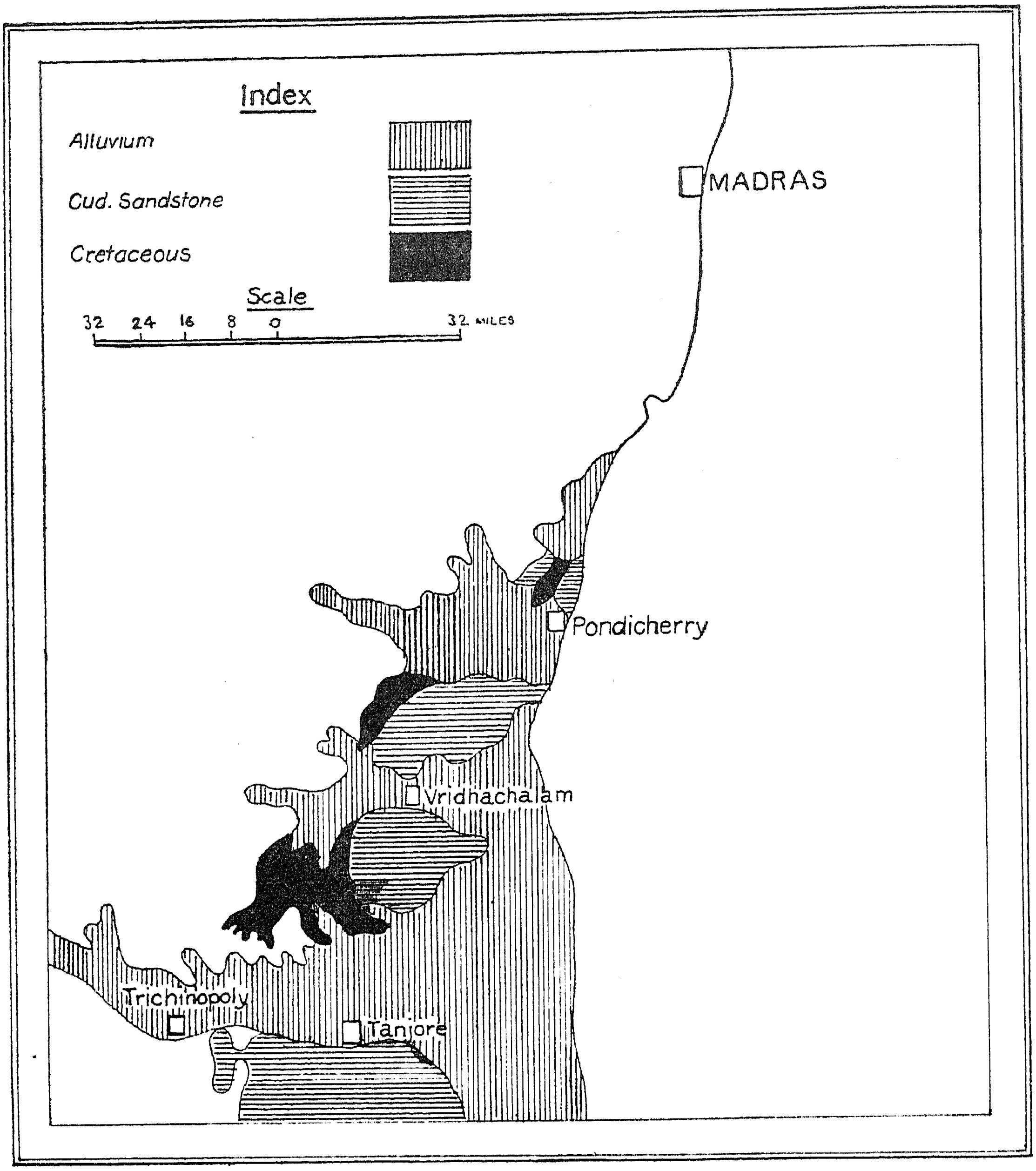
3. TRICHINOPOLY DISTRICT

Of all the areas mentioned above, that in the Trichinopoly District is easily the most important; for here we have not only the biggest patch (about 300 sq. miles) but also one in which we get a much fuller upper Cretaceous succession than in any of the other areas. A detailed study of this area is therefore important not only in itself but also as furnishing a standard succession with which the rocks of the other areas could be compared and correlated; and hence the Trichinopoly area will naturally figure prominently in the course of this paper.

Our starting point in this study of the Trichinopoly Cretaceous is the memoir published so far back as 1865 by H. F. Blanford[1] giving the first elaborate account of the nature and disposition of these Cretaceous beds together



TEXT-FIG. 1. Map of India showing the probable distribution of land and sea during the Cretaceous period, according to the current view. Dotted areas represent the Sea.



TEXT-FIG. 2. Map showing the Cretaceous of the Trichinopoly, Vridhachalam and Pondicherry areas, and their relationship to the adjacent rocks.

with a record of the important fossils noticed at the different stratigraphical levels; based on these observations he also prepared a geological map of the area which was published along with his memoir. The very large collection of fossils made by Blanford in the course of his field-work were soon studied in great detail by Stoliczka and the results published in four volumes of the *Palæontologia Indica.*[47] Of the four volumes published by Stoliczka, three deal with the mollusca which are the most common fossils throughout the succession including more than 600 species; in addition to these, we have all the other groups of invertebrates also well represented including the foraminifers, corals, annelids, bryozoans, brachiopods and echinoderms. Apart from these invertebrates, some vertebrate fossils were also found by Blanford represented by fragmentary remains of fishes and reptiles. All these have been described in volume four of the *Palæontologia Indica.* Even a general perusal of these four volumes is sufficient to impress one with the abundance and variety of the fossils occurring here, especially when we remember that they are all concentrated in a comparatively small area of about 300 square miles; no wonder then that Sir Thomas Holland referred to this area as " a veritable field museum of upper Cretaceous palaeozoology". These palaeontological studies form an important supplement to the stratigraphical observations made by Blanford; and the two together give us a complete picture of the pioneer work dealing with these formations.

Based on his palaeontological studies, together with the stratigraphical observations made by Blanford, Stoliczka suggested the following broad classification and correlation of the Cretaceous rocks of this area:

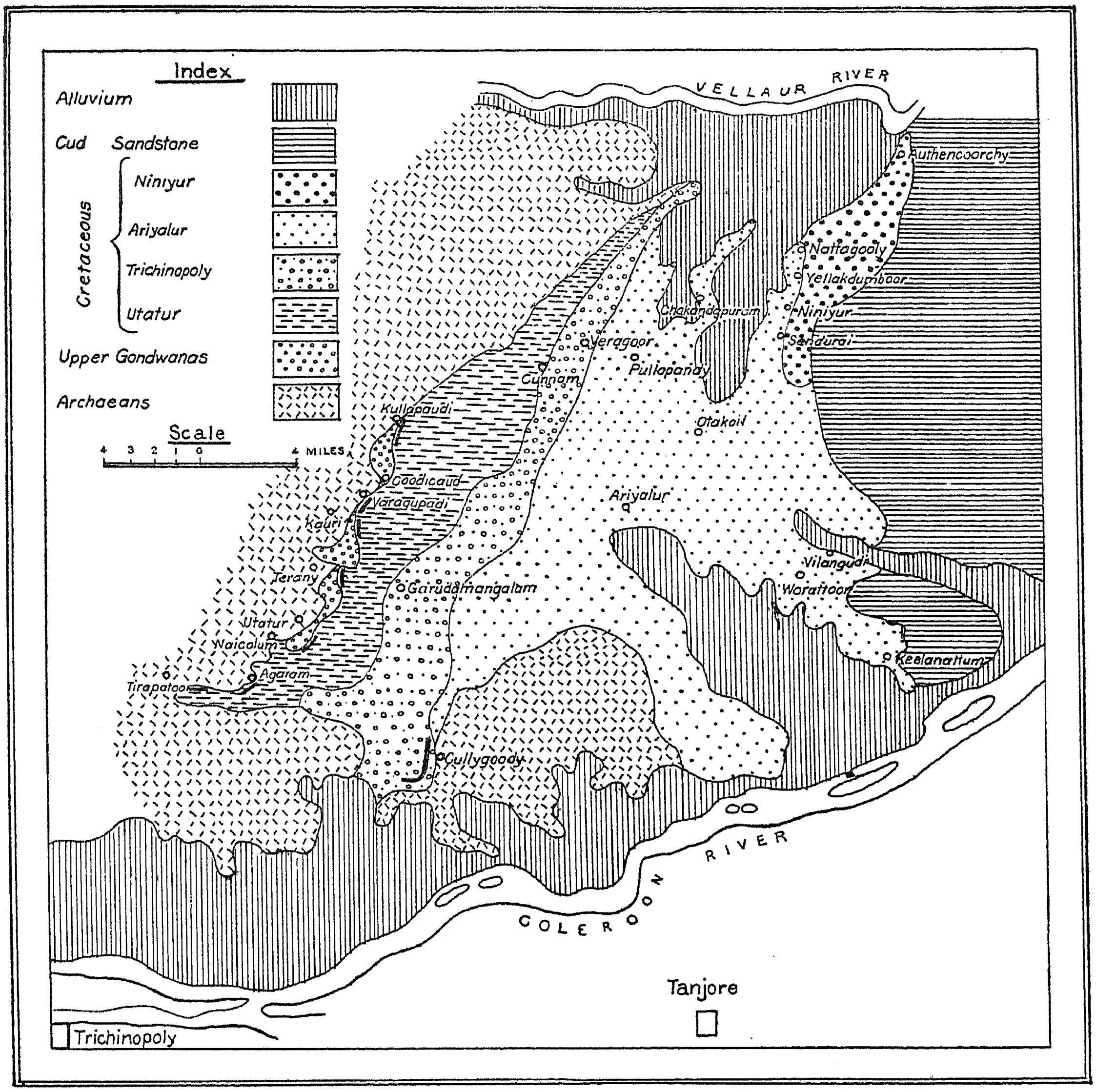
		England	*France*
Ariyalur group	..	Upper chalk	Senonian
Trichinopoly group	..	Lower chalk	Turonian
Utatur group ..	..	Upper green sand and chalk marl	Cenomanian

In his memoir Blanford has given a full description of the beds constituting each of these subdivisions, drawing special attention to their lithological and palaeontological variations from place to place; and whenever a doubt or difficulty arose regarding the comparison and correlation of these beds due to their constantly varying lithology and irregular disposition in the different parts of the area, he has discussed all aspects of the question and justified the conclusions which he finally adopted. On the basis of his studies, he also indicated the boundaries of each of these subdivisions on the map pointing out at the same time that these cannot be taken as strictly correct since " the boundaries between the adjacent groups could not in all cases be so carefully ascertained as might be desired "; in the absence however of any later mapping of the area as a whole side by side with palaeontological zoning, the views of Blanford regarding the boundaries are still current. The following map of the area (Fig. 3) according to Blanford gives an idea of the extent and disposition of these groups.

We will now proceed to deal with each of these groups in the Trichinopoly Cretaceous succession, with special reference to the recent advances in our knowledge of these strata. It was nearly 30 years ago that the present writer started a re-examination of these rocks on modern lines; and as a result of repeated visits to the different parts of the area, we have been able to make several interesting observations, both stratigraphical and palaeontological, which have been embodied in a series of papers published from time to time by the present author and his collaborators, a connected account of which was published in the year 1942.[28] The main results of these and later investigations will be specially referred to in the course of this paper in their appropriate places.

(i) Utatur group

The rocks of this group naturally occur along the western part of the area where they overlie unconformably the Archaeans, with small patches of the upper Gondwanas intervening here and there between the two formations. The Utatur beds are composed of rocks like conglomerates, sandstones and gritty limestones, clays, and silts, showing all the features characteristic of shallow water and littoral deposition. The rocks are highly fossiliferous, the molluscs being the most abundant. The study of these fossils, especially from the basal members of the group, would be of the greatest interest not only in determining the lower age limit of this Cretaceous succession but also in thus fixing the age of the marine transgression. Of the rocks found at the base of the Utaturs special mention must be made of a typical limestone which now occurs in isolated bands and ridges at a number of places along the western margin (Fig. 3). Blanford examined them and pointed out that they are of the nature of ' coral-reef limestones '; the different bands according to him are evidently remnants of old coral-reefs of the 'fringing' type which must have grown here and there along the shore line of the Cretaceous sea soon after the transgression. As is well known even from the days of Blanford, such coral-reef limestones in a marine succession are of great value in the interpretation of many aspects of Historical Geology and have an

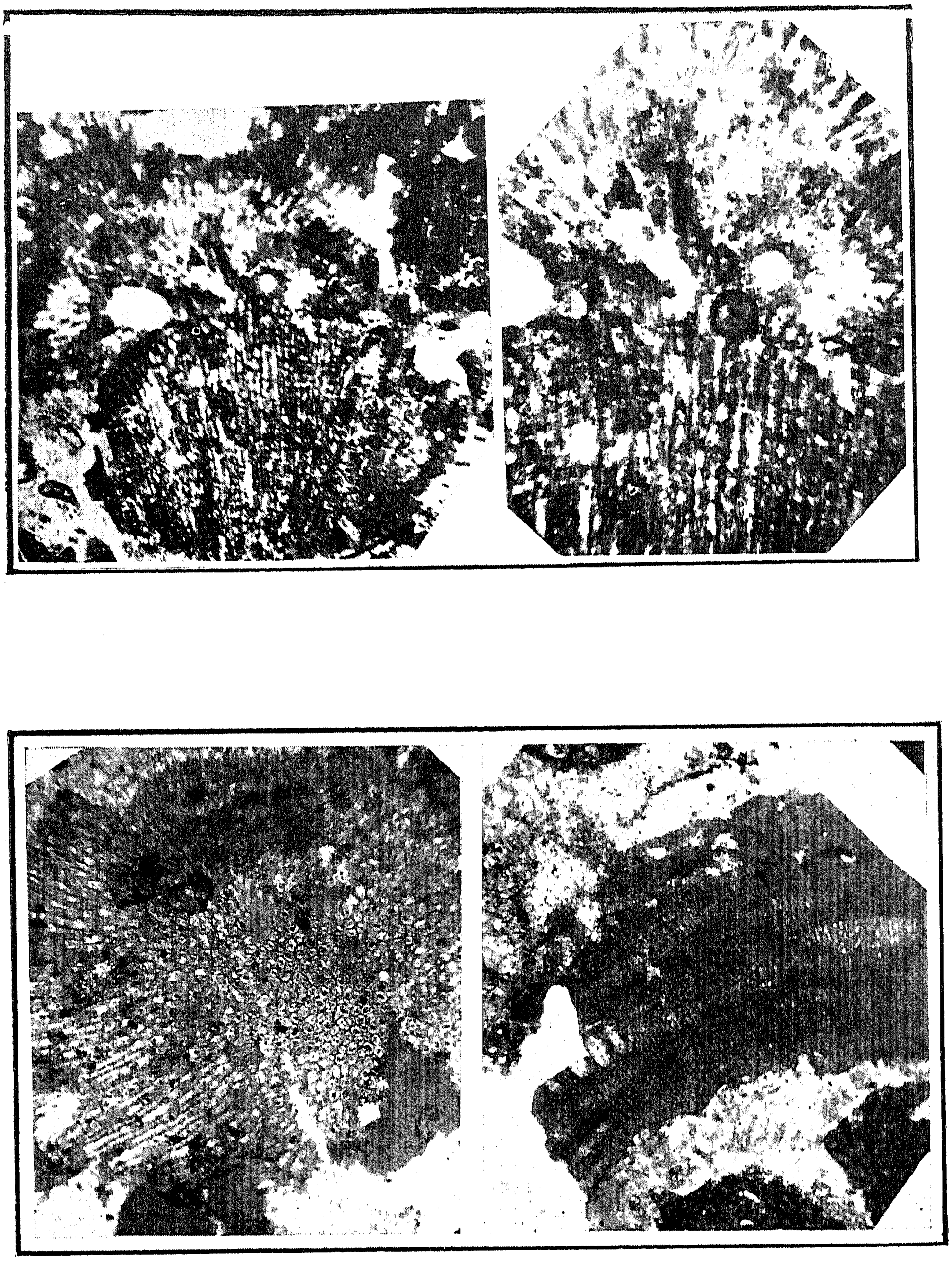


TEXT-FIG. 3. Map of the Trichinopoly Cretaceous area (adapted from Blanford's map).

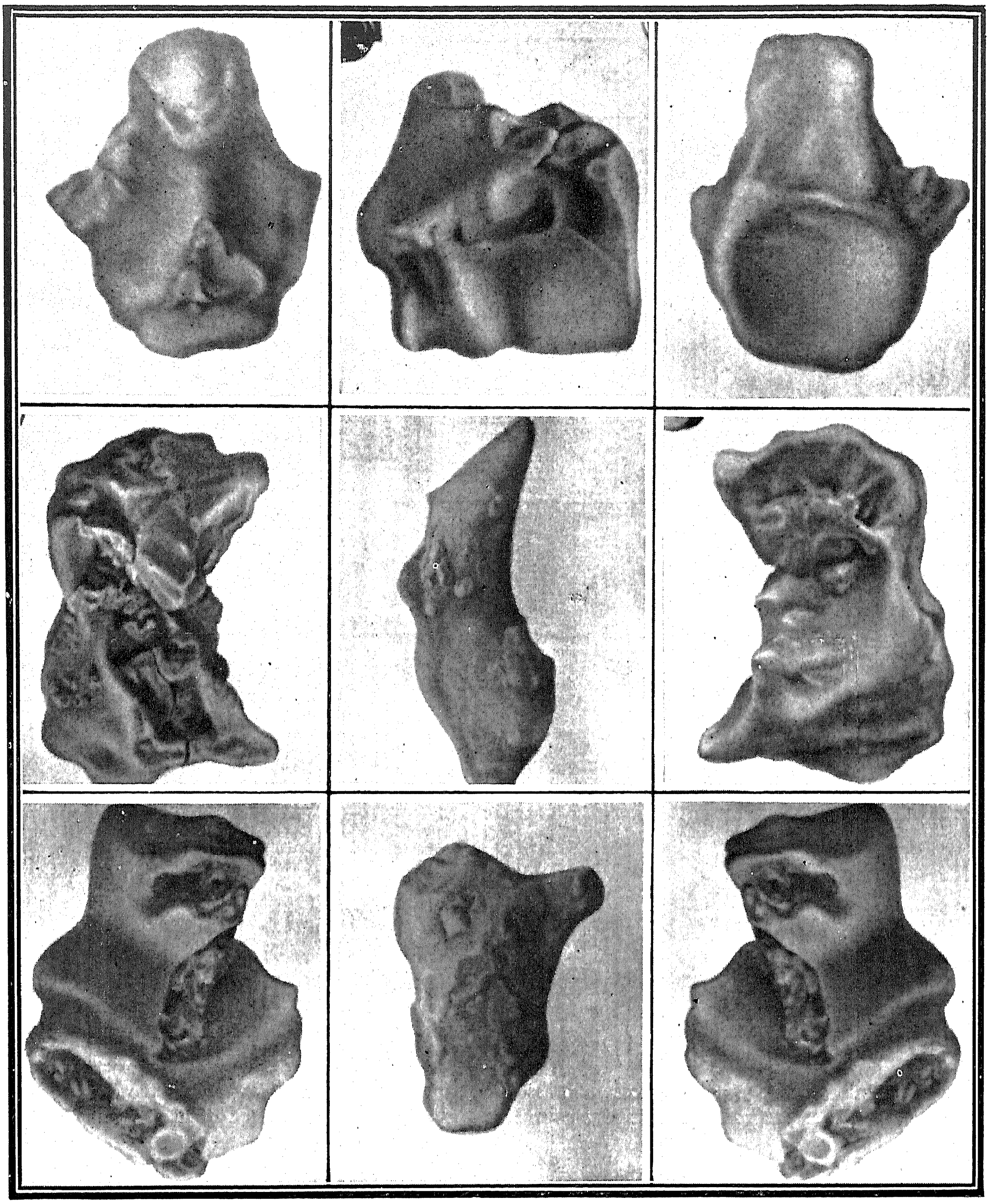
important part to play in the study of palaeogeographical and palaeo-ecological conditions during the period of their formation; and here we have in the Trichinopoly area a beautiful example of such an occurrence which must naturally therefore receive our fullest attention.

With a view to get a detailed knowledge of these limestones and the possible correlation of the different bands, we undertook sometime back an elaborate study of these rocks based on a representative collection of samples from the different localities; these were examined both in hand specimens and in micro-sections and the rocks of the different bands compared with one another. From these studies which were pursued in collaboration with C. Prasanna Kumar and K. Y. S. Iyengar, it would appear that these bands may be broadly classified into two groups representing two distinct facies. (i) The northern, including the bands of Kullapaudy, Varagupady, and Kaury and (ii) the southern, including those of Terany, Naicolum, Agaram and Tirapattoor; the rocks of the former facies contain as a rule purer but less crystalline types of limestone, while those of the latter are more crystalline but with a larger proportion of siliceous and ferruginous impurities constituting about 10–12% of the rock. It may thus be concluded that the different disconnected bands as now seen along the western border really represent the denuded remnants of two main reefs—one including the three bands of the northern facies, and the other including the four of the southern.

Special attention may be drawn to an important fact which emerged from a detailed microscopic examination of these limestones, *viz.*, the abundant occurrence of fossil algae in many of them. These belong to the family Corallinaceae of which the genus *Archaeolithothamnium* is the one present most commonly; several other types of algae are also noticed here and there; and these have yet to be studied in detail. One thing, however, is clear, and that is, that along with the corals the algae also flourished in these reefs and played quite an important part in building up these limestones. In this connection, particular attention may be drawn to our recent find of a *Solenopora* in the limestone band near Kullapaudy, which we have described as a new species *S. sahnii*.[40] The most remarkable feature of this occurrence is that the very rock section which contains this form also contains a fine section of *Archaeolithothamnium lugeoni* belonging to the Corallinaceae (Plate XIV). Such an association which we have also noticed in some of the other Cretaceous rocks of this area is of special significance in showing that the current view that the Corallinaceae made their appearance in the Cretaceous only *after* the Solenoporaceae died out in the Jurassic, is no longer tenable. In addition to the algae, numerous small foraminifers are also noticed in many



Some of the Solenoporaceae and associated algae from the Trichinopoly Cretaceous rocks. (Reproduced from *Current Science*, 1954, by kind permission of its Editor.)



Some of the Reptilian bones from the 'Middle Ariyalur' beds.

of these limestone sections, the common forms being *Nodosaria*, *Rotalia*, *Discorbina*, *Textularia*, *Orbulina*, *Globigerina*, and *Planorbulina*. Quite recently S. Sambe Gowda has recorded[42] the occurrence also of certain Holuthurian remains in some of these coral-reef limestones. These microfossils represent the calcareous skeletal elements of the Holothuroidea; and on the basis of their studies, he has provisionally identified the following genera: *Ancistrum*, *Lactophasma*, *Mesothuria*, *Zygothuria* and *Myriotrochus*. It may be noted that this is the first record of fossil Holothuroidea in India and in view of the fact that this rather obscure group of fossils is now being increasingly recognised as of great stratigraphical value as a result of investigations outside India, their occurrence in the Trichinopoly area is of special importance. A close examination will undoubtedly reveal many more fossil remains of this group in the South Indian Cretaceous rocks, the study of which may be expected to yield interesting results.

Apart from these bands along the western border, and at some distance away from them, there is another prominent limestone band occurring near the village of Cullygoody (Fig. 3). Blanford gave quite an elaborate description of this also and specially discussed the question of its relationship to the other bands along the western margin. After considering all aspects, he came to the conclusion that the Cullygoody limestone is essentially similar to the others in all respects and must therefore be considered also as part of the 'coral-reef limestone series' occurring at the base of the Utatur group. In connection with our recent work on the coral-reef limestones, we devoted special attention to the problem of the Cullygoody limestones and their relation to the bands along the western border. The limestones of Cullygoody show a greater lithological and textural variation; but there is no doubt that, as a whole, they are also of the nature of a true 'coral-reef limestone' like those of the western margin. Sections of the Cullygoody limestone also reveal the presence of numerous algae and small foraminifers like those of the latter. Regarding the exact age of the Cullygoody limestone, however, it appears to the present writer that the view expressed by Blanford that it is contemporaneous with the other coral-reef limestones found along the western margin at the base of the Utatur group, is still open to doubt. The stratigraphical position of the Cullygoody limestone and its relation to the associated Cretaceous beds of the area are still rather obscure; the exact age of the immediately adjacent Cretaceous rocks has also yet to be satisfactorily determined; this is particularly necessary, since in the neighbourhood of Cullygoody, we see in close proximity, exposures of all the three groups—Utatur, Trichinopoly and Ariyalur—occurring side by side. From the few recent observations made in the field it seems that the Cullygoody limestone overlies certain conglomerates and sandstones of Utatur (or Trichinopoly ?) age, and is itself overlaid by other sandstones and gritty limestones of the Trichinopoly (or Ariyalur ?) division. This would indicate that the Cullygoody limestone, though similar in nature and mode of origin, is younger than those found at the base of the Utatur group. This view which the present writer put forward sometime back derives some support from the fact that small bands of coral limestones like those of the basal Utaturs have also been since noticed at undoubtedly higher stratigraphical levels elsewhere in the area.

On the other hand, quite a contrary view has been put forward recently by S. R. Narayana Rao[19] on the basis of certain *Solenopora* found in these limestones. He has described two species of this interesting and important alga here *S. jurassica* and *S. coromandalensis*; and on the basis of these fossils, especially the former, he concludes that the Cullygoody limestone is really Jurassic in age and not Cretaceous. He actually considers them as stratigraphically equivalent to the upper Gondwana 'plant beds' found below the Utaturs along their western border. As has already been mentioned above, we have now noticed several examples of *Solenopora* occurring in some of the other undoubted Cretaceous rocks of this area, and there is no reason to believe that there is anything inconsistent in the occurrence of this genus in the Cullygoody limestone which is being considered on all evidences as Cretaceous in age.

The Cullygoody limestone is a very important formation and further work, both stratigraphical and palaeontological, is necessary to clarify its exact position *vis-a-vis* the other coral-reef limestones on the one hand and the adjacent marine Cretaceous beds on the other. Quite recently an important contribution to the study of these limestones from an altogether different approach has been made by C. Gundu Rao[5] and that is from the point of view of their Heavy Mineral analysis. The three limestone units mentioned above, *viz.*, (1) those of the northern facies, (2) those of the southern facies and (3) the Cullygoody limestones have been separately treated and the Heavy Mineral assemblages of these have been compared not only amongst themselves but also with those of the adjacent Upper Gondwana beds in the area which have also been similarly studied. A full paper dealing with this work will be shortly published; suffice it to say that this investigation has yielded several interesting results which will be of value for consideration along with the findings of the later stratigraphical and palaeontological researches in solving the problem of these coral-reef limestones and their mutual relationships.

Overlying these coral-reef limestones along the western border, we get the regular sedimentary beds of the Utatur group chiefly composed of gypseous shales and sandy clays with intercalated bands of impure limestone. The rocks are frequently concretionary; the concretions are sometimes two to three feet in diameter and often enclose a big-sized and well-preserved fossil in their core. The Utatur beds are highly fossiliferous including practically all the important groups of invertebrates; of these the Ammonites are of course the most important for purposes of age determination and correlation, and it is chiefly on their evidence that Blanford assigned a Cenomanian age for these beds. Species of *Nautilus* are also quite common; and it is specially interesting to note that some of these shells like those of *N. huxleyanus*, *N. pseudoelegans* and *N. kayeanus* show a distinct lateral eccentricity, a feature which according to Zittel, indicates that these are 'phylogerontic' forms. In addition to the numerous invertebrate fossils, Blanford had also found a few vertebrate remains here and there represented by "the vertebra, and teeth of a fish (a shark) and a few bones of doubtful nature"; more recently C. A. Matley collected some reptilian remains from the Utatur beds near Naicolum consisting according to him of "about 650 fragments of dermal armour, accompanied by a few spine-like objects and some bones". Of these he thought that "some of the small bones are chelonian and that many of the 'scutes' may be smashed fragments of a carapace".

Another remarkable feature of the Utatur group is the abundant occurrence of phosphatic nodules associated with the silts and clays. These nodules occur scattered over large areas here and there; sometimes they may be seen *in situ* with a tendency to occur in distinct clusters or bunches with several hundreds of them forming a bunch. When broken across, these nodules are seen to be composed of a homogeneous material varying in colour from light brown to dark brown to dark in the different nodules, the colour in any particular specimen being uniform. In some cases the well-known septarian structure is noticed; in most of the nodules, however, the inside material is quite compact and shows numerous minute acicular crystals (of calcite and gypsum) scattered all over. An interesting problem connected with these phosphatic nodules is that regarding their exact mode of origin. It is obvious that these phosphatic nodules did not grow as a result of accretion of phosphatic material round about a distinct nucleus. According to the present author who went into this question some years ago[22] these nodules appear to have originated in the following manner: "In the calcareous silts and clays of the Utatur beds, the ordinary argillo-calcareous nodules so commonly met with in fine-grained shallow water sediments were first formed. The waters of the sea in which these nodules were formed would, by means of the carbon dioxide present, take up large quantities of the available phosphatic material in solution especially in regions round about decaying organic matter. As these carbonated waters holding the phosphates in solution percolated through the interior of these nodules and was there allowed to stand, the phosphate was redeposited in the presence of the calcium carbonate inside the nodules; and the carbonate thus replaced was removed in solution by the same carbonated water. The degree of phosphatisation naturally varied from place to place depending upon the availability of the phosphatic material and the conditions, favourable or otherwise, for its transference into the nodules. Where the conditions were *not* favourable, the argillo-calcareous nodules merely continued as such, as they are seen even at the present day with little or no phosphatic matter in them; in other places where the conditions were quite favourable, these nodules were impregnated with phosphatic material. Thus we get nodules showing varying amounts of phosphatic material in accordance with all gradations from favourable to unfavourable conditions for phosphatisation."

In connection with his work on these phosphatic nodules, the present writer also examined a large number of sections of these nodules in search of the possible occurrence of micro-fossils in their material. This study revealed the presence of numerous small foraminifers in almost all the sections, the forms commonly seen being *Nodosaria*, *Globigerina*, *Textularia*, *Rotalia*, *Pulvinulina*, *Planorbulina* and *Discorbina*. Numerous rounded grains of glauconite are also frequently noticed, and from a close examination of these it is clear that most of them are casts of foraminiferal shells; in some cases this mineral is actually seen infilling the chambers of a foraminiferal shell with the shell wall also preserved. It is also possible that some of these grains are of a coproglauconitic nature arising from the glauconisation of grains of coprolite.

It may be pointed out that along with these foraminifers, some radiolarian remains are also noticed in many of these nodules.[25] In several of these sections, these minute fossil structures are so poorly preserved and are so fragmentary in character that it is hardly possible to say anything more definite about them than that they are referable to the group Radiolaria; but now and then we come across sections where these remains are fairly complete and show enough of their structure and characters to help us in a more definite identification. Among such well preserved forms the following genera have been recognised: *Cenosphaera*, *Staurosphaera* (or *Spongostaurus*?), *Odontosphaera*, *Xiphostylus*, *Rhopalastrum*, *Carposphaera*? and *Lithocampe*. Though our knowledge of Cretaceous radiolaria from other parts of the world is fairly extensive, so little is known regarding this group from the

Cretaceous rocks of India; the present find of their occurrence in these phosphatic nodules is therefore of special interest and indicates the possibility of finding more of these remains on a fuller examination of the fine grained sedimentary rocks of the area.

More foraminifera have been recently found in the Utatur beds by Dr. K. Jacob and M. V. A. Sastri[7] who have recognised the following genera: *Robulus*, *Lenticulina*, *Nodosaria*, *Saracenaria*, *Vaginulina*, *Frondicularia*, *Lagena*, *Bolivinita*, *Gyroidina*, *Globigerina* and *Anomalina*. Of special interest is the occurrence also recorded by these authors here of *Globotruncana* represented by two species *G. appenninica* and *G. indica*, of which the former more or less fixes the age of the containing beds as Cenomanian. A reference is also made in their paper to the reported find by Thalmann of *G. arca*, together with *Lepidorbitoides* in thin sections of a limestone from Kallakudy (Cullygoody); but as the authors have pointed out, this requires critical re-examination since neither of these two forms mentioned by Thalmann fit in with the Cenomanian age now being assigned to the containing rock. The other possibility would be that if Thalmann's identifications are correct, (as they are likely to be) the particular limestone near Kallakudy which contains these forms is *not* a Cenomanian bed but is much younger—probably Maestrichtian. This question will be referred to again later in this paper while dealing with the Ariyalur group where we have recently noticed a distinct and well represented Maestrichtian horizon.

It has been more recently reported by the Geological Survey of India that a preliminary examination of certain core samples obtained from Odium village has also revealed the presence of a rich micro-foraminiferal fauna in beds probably of Utatur age. This material is being further examined.

In view of their economic importance, the phosphatic deposits of the Utatur area have received special attention and Dr. M. S. Krishnan[11] has recently examined this question in detail. According to him these deposits are particularly abundant in an area of about 10–12 square miles, and the quantity available is estimated at more than eight million tons. The average calcium phosphate content is only about 50–55% and is in a form "not readily available to plants due to its very low citric solubility". Various attempts have been made from time to time "to convert this rich source of phosphatic material into monocalcium phosphate as in superphosphate using sulphuric acid so as to be available to plants, but without much success as an economic proposition". Quite recently A. Mariakulandai and others[12] of the Agricultural Research Institute, Coimbatore, have investigated this problem by the application of a new process, and as a result of their experiments, they claim that "the fusion of a mixture of 10:3:3 of Trichinopoly phosphate, serpentine, and sodium sulphate, using graphite arc for fusion has rendered 95% of the phosphate available to plants".

Apart from these phosphates, the other minerals of economic value found in the Utatur beds are gypsum and celestite. The gypsum is most commonly found in the clays occurring as a network of veins traversing the rock. As pointed out by Blanford, this mineral is not of contemporaneous origin but "appears to have crystallised out subsequently to the formation and partial desiccation of the enclosing strata and has probably been introduced by waters infiltered from the surface". The presence of celestite in this area was reported only recently; and Dr. M. S. Krishnan[10] who later investigated this occurrence more fully has shown that the veins of celestite are particularly abundant in the triangular area between Utatur, Varagupady, and Kulakanattam, and estimated that if the celestite continues undiminished in richness to a depth of 100 feet throughout this area, a quantity of between half to one million tons may be expected.

Before leaving the Utatur group we may briefly consider the question of the lower age limit of the Trichinopoly Cretaceous succession; for in this study, the evidence of the basal Utatur beds would be the most important.[20] As has already been mentioned, the lowermost sedimentary beds of the Utatur group are a series of silts and shales which are highly fossiliferous; of these fossils the Ammonites would be the most valuable from the point of view of age determination. The most abundant as well as the most characteristic Ammonite of the lowermost Utatur is *Ammonites* (*Schloenbachia*) *inflatus*. Recent studies have shown that this important species had attained a great abundance and is one of the most characteristic fossils of the middle and upper Gault, corresponding to half-way down in the Albian period of Europe. The lowermost sediments from the Utaturs with the abundance of this characteristic species cannot therefore be far different from this age; and since these beds are found along the western margin of the whole Trichinopoly Cretaceous series, we find that the actual beginning of the encroachment of the sea on land, or of the marine transgression, must have been even earlier. If further we consider, as we must, the coral-reef limestone beneath the Utaturs as part of the Cretaceous series, then we have to shift the age of the transgression still backwards to allow time for the growth of all the coral-reefs whose denuded remnants alone we see at the present day. It thus follows that if we have to name the transgression after the period in which it commenced, the term "Cenomanian transgression" now generally employed for this encroachment of the sea in South India during the Cretaceous times does not faithfully represent it in point of time and must be changed so as to accord with an older (Middle Albian) age. The recent investigations by Dr. L. F. Spath and Prof. J. W. Gregory of the Cretaceous deposits of South Africa and their Ammonites have also led them to the conclusion that "a submergence of some extent took place before the widely recognised Cenomanian transgression". In parts of Australia the similar transgression goes back even into Aptian times. The evidence in the Trichinopoly area also lends additional support to the now growing belief that at least so far as the Indo-Pacific regions are concerned, "the so-called Cenomanian transgression commenced long before Cenomanian times".

(*ii*) *Garudamangalam group* (*Trichinopoly group* of Blanford)

Having given this brief review of the salient features regarding the Utatur group, we may now pass on to the next division, *viz.*, the Trichinopoly group. As has already been pointed out by all those who have worked in this area, Blanford's naming of this division has been rather 'unfortunate' since the rocks of this group are not seen anywhere near the town of Trichinopoly. It would be more appropriate to call this the 'Garudamangalam group' since the most typical rock types of this group are best developed round about the village of Garudamangalam which stands right on this formation; this would also be in conformity with the basis on which the names of the other groups in this Cretaceous succession have been selected. In view of the desirability of making this change as early as possible, the new name has been adopted in this paper, with the old name also shown in brackets to avoid any confusion till the new name is more widely recognised. This division is a much smaller unit than the Utaturs, being confined to a narrow strip of country about 25 miles long with an average width of about 1½ to 2 miles. The rocks of this group are essentially littoral deposits like conglomerates, grits and shell limestones, frequently containing numerous pebbles of the adjacent Archaean gneisses and charnockites from the denudation of which these sediments evidently derived most of their material. The shell limestone is a particularly characteristic member of this group which as the very name indicates is a limestone crowded with shells, mostly Lamellibranchs and Gastropods. Some of these limestones with a dark blue or dark fine-grained matrix in which numerous white shells are embedded present a most beautiful appearance when polished and are much appreciated as an ornamental stone being commonly known as the "Trichinopoly marble". The common fossils in this group are the molluscs; compared with the Utaturs, the Ammonites are not so numerous here, but the Lamellibranchs and Gastropods are quite abundant.

Talking of the fossils found in this group special attention may be drawn to the occurrence of plenty of fossil wood found in these beds, which is what one would expect in view of the rocks being all littoral and shallow water deposits laid down not far from land. Several of these fossil woods are quite big-sized trunks,—one of them recently found near Satanur being about 86 feet long and 4½ feet in diameter at the base. Blanford had also noticed the occurrence of abundant fossil woods in these beds and he described them as follows: " The fossil flora of the Trichinopoly beds is, like that of the associated groups, remarkable for the preponderance, if not the almost exclusive occurrence, of exogenous or cycadeous forms as indicated by the wood which is abundant in the lower beds of the group and is met with in drifted logs of many feet in length. I have not noticed a single undoubted specimen of endogenous wood among the numerous specimens noticed in the field."

To the palaeobotanist of the present day, it is evident that the study of these plant remains is sure to be of the greatest interest; but the fact remains that during all these years no attempt has been made to make a systematic collection of these and examine them on modern lines although it is clear that such a study would be most valuable from the evolutionary point of view since they all belong to the upper Cretaceous,—a period of time covering the transition as it were from the Mesozoic gymmospermic floras to the modern angiospermic types.

To initiate this line of work, the present author collected several years ago specimens of some of these fossil woods and prepared a number of sections for study. It was found that in most of these cases, the preservation was very bad and no structures of any diagnostic value could be recognised. In a few cases however some interesting features were indicated, but the specimens required further examination in larger sections for satisfactory identification. These preliminary studies however revealed that some of the woods are coniferous in nature, but nothing more definite could be said about them in the absence of better preserved material.

Our interest in these fossil woods was recently revived when it was reported that Dr. M. S. Krishnan and N. K. N. Iyengar of the Geological Survey of India had collected in the year 1940 a beautiful specimen of a Cycadeoid from beds of this group near Varagur, a village about 8 miles N.N.W. of Ariyalur. This fossil has since been studied in great detail by Dr. K. Jacob and N. K. N. Iyengar[6]; they say that " the specimen represents a low, unbranched somewhat vertically compressed ' trunk ', the striking feature of which is the presence of bud-like rosettes, possibly representing fertile shoots among rhomboidal or sub-rhomboidal leaf bases"; they also point out that "the discovery of this specimen in the Trichinopoly beds is important as it forms the first record of a fossil which shows the closest resemblance with the genus *Cycadeoidea*". After giving a full description of the external features of the fossil, the authors conclude: "The Trichinopoly specimen shows the closest resemblance with *Cycadeoidea*. But as the internal structure is not seen well preserved in thin sections to justify a generic identification with *Cycadeoidea*, and as a more closer comparison with any known fossils so far described is not possible, the authors prefer to create a new genus *Pseudocycadeoidea* to accommodate this interesting find from Trichinopoly."

Now that we have got *one* specimen of this most interesting Cycadeoid fossil, there is no doubt that many more of this kind—and probably much better specimens—will be found if only we look for these more thoroughly. In view of the great importance of these fossils in the study of the later stages of plant evolution, it is now up to us to take the earliest opportunity of exploring the whole area not only for more fossils of this valuable type, but also for other woods which are well preserved. Seeing that these Cretaceous beds were all deposited in a shallow sea of a transgressional nature and nowhere far off from the adjacent land, and as these land areas must have been covered by a fairly luxuriant vegetation representing the flora of the upper Cretaceous period in this region, we have every reason to expect the abundant remains of all preservable parts of these plants (and not merely the woods) entombed in these marine sediments.

We may now pass on to consider the question of the stratigraphical relationship of the Garudamangalam (Trichinopoly) group to the older Utatur division on one side and the later Ariyalur on the other. As already mentioned, the Garudamangalam (Trichinopoly) group is largely composed of very shallow water deposits overlying unconformably the rocks of the Utatur division and thus being distinct from them; on the other side, however, the exact nature of the stratigraphical boundary between this group and the succeeding Ariyalur group is by no means clear. As Blanford has pointed out it looks as though there is in many places a gradual passage from one to the other making it impossible to draw a boundary line between the two groups; he also says: "While the palaeontology of the Ariyalur group indicates a change of some magnitude at the close of the Trichinopoly period in the sudden disappearance of certain species and the first appearance of others, there is but little evidence of any corresponding interruption in the stratigraphical sequence of the deposits, nor is there any sudden change in their mineral character such as would imply important change in the physical conditions of the area...... In the south, the deposits of the two groups appear to pass into each other or at least no definite demarcation can be discovered in the almost unfossiliferous and irregularly bedded sands which lie at the junction of the two groups; and further north, where both formations become more irregularly bedded, the strike and dip of the two groups, with one exception is, so far as they can be ascertained, identical."

In the course of several E.W. traverses across both formations in the area, the present writer has also noticed that in many places the transition from the Garudamangalam (Trichinopoly) group to the Ariyalur group is so gradual that it is very difficult to find out where the one ends and the other begins; and where the succession is well developed, it is impossible to draw a line, on a stratigraphical and/or palaeontological basis demarcating the boundary between the two groups. Under these circumstances, one fails to see the identity of the Garudamangalam (Trichinopoly) group as a distinct stratigraphical unit; on the other hand, it would seem more reasonable to merge it in the Ariyalur division and consider it as forming a part of the Lower Ariyalurs. The coarse grained conglomeratic and gritty nature of the rocks of the Garudamangalam (Trichinopoly) group which are all predominantly littoral in character, and the manner in which they gradually change over eastwards to finer grained sandstones and shales with bands of limestones now considered as the Lower Ariyalurs would strongly support the idea that from the point of view of stratigraphical classification all these sediments should be considered as part of one series constituting the lower division of the Ariyalur group. The main difficulty, however, in immediately accepting this proposal is the fact that in the other areas of the South Indian Cretaceous where we get beds representing the Ariyalurs (*vide* Fig. 4), the succession starts, so far as we know, with beds equivalent to the lower Ariyalur division as defined by Blanford; and we do not get in any of these areas beds equivalent to the Garudamangalam (Trichinopoly) group which we would expect to see if it were to be merged in the Ariyalurs and treated merely as part of its lower division.

(*iii*) *Ariyalur group*

Having now dealt with the Utatur, and Garudamangalam (Trichinopoly) groups, we will now pass on to consider the next and perhaps the most important division in the Trichinopoly Cretaceous, *viz.*, the Ariyalur group. This group covers a much wider area; in fact it is more than twice the area occupied by the two older groups together (*vide* Fig. 3) and includes a variety of rock types many of which are highly fossiliferous. On the western side the contact of the Ariyalur group is with the Garudamangalam (Trichinopoly) division, while on the northern side it is covered over by the recent alluvium.

Along the southern margin the Ariyalur rocks overlie directly the Archaeans, while to the east, the group is overlapped by the Cuddalore sandstone of late tertiary age. At one time the Cuddalore sandstone must have covered a much larger part of the Ariyalur group, for we now see its outliers so far west as Husain Nagaram and Munakal; and it is evidently by their later removal by denudation that the underlying Cretaceous rocks have come to be exposed as they are seen to-day. Generally speaking the Ariyalur group is also composed of shallow water deposits like conglomeratic gritty sandstones, and nodular clays with bands of impure limestones. According to Blanford the Ariyalur group is divided into three subdivisions—the Lower, the Middle, and the Upper—of which the lower and upper are highly fossiliferous while the middle zone is practically unfossiliferous. Blanford has also given an account of the distribution of these three subdivisions in the field and indicated approximately the boundary lines between them. Recent studies have added considerably to our knowledge of these Ariyalur rocks and necessitated a revision of many of Blanford's ideas as will be seen in the sequel; for purposes of our present description, however, we may follow Blanford's classification and deal with each one of these subdivisions.

(*a*) *Lower Ariyalurs.*—The beds forming the lower division of the Ariyalur group are quite extensive covering nearly half the area of the entire group. They are well seen in the country within a radius of about four to five miles to the west and south-west of the town of Ariyalur and are chiefly composed of sandstones, shales and arenaceous limestones. The sandstones are in some places conglomeratic and the shales are often sandy. All these rocks are calcareous though the actual amount of calcium carbonate present is very variable. It is quite probable that most of the lime in these deposits was due to the coral-reef limestones (of the Utatur group) found not far off, whose denudation must have furnished quite a large proportion of the calcareous material, a fact which lends support to the view put forward by Blanford that " the older beds (the Utaturs) were also undergoing denudation to some extent at the time of the formation of the Ariyalurs". The rocks are quite fossiliferous, especially in certain localities and include several groups like Annelids, Corals, Polyzoans, Brachiopods, Lamellibranchs, Gastropods, Cephalopods, and Echinoderms. Among these, the Lamellibranchs are the most common fossils, *Gryphea* being the most abundant form, many of the sandstones being crowded with their shells; the other genera found are *Pecten*, *Arca*, *Lima*, *Pholadomya*, *Cardium* and *Inoceramus*. Serpulidae, mostly of the type *S. filiformis*, are also very frequently seen as clusters of irregularly twisted thread-like tubes encrusting the rocks. Several of the microsections of these rocks also show the presence of small foraminifera. Special mention may be made here of the thin band of a pink limestone noticed about 1½ to 2 miles south-west of Ariyalur, sections of which show under the microscope the presence of abundant algae belonging to the Rhodophyceae.

Some of the best exposures representing the younger parts of the lower Ariyalur division are seen in the nullas to the east of Otakoil about 5 miles north-east of Ariyalur where the prevailing rock is an yellow sandstone, very highly fossiliferous; the most common fossils here are the Lamellibranchs of which *Alectryonia* and *Radiolites* are particularly abundant, together with some Gastropods like *Cerithium* and *Trochus*, 2 or 3 types of *Nautilus*, and a few coiled and uncoiled Ammonites. Brachiopods chiefly of the Terebratula-type are also quite common here and there. Much more abundant than all the above are the Echinoids often exceedingly well preserved, the most common form being *Stigmatopygus*; the other genera also found are *Cyrtoma*, *Hemiaster*, *Cassidulus* and *Cidaris*. The Echinoids of this area provide excellent material for further investigation on the lines now being followed in the study of the Cretaceous Echinoids in other parts of the world.

(*b*) *Middle Ariyalurs.*—Younger than the above rocks of the lower division we have a series of white sands, sandy clays, and shales, mostly unfossiliferous, constituting according to Blanford the Middle Ariyalur division. These rocks run roughly along a north-south belt mainly from about Sendurai in the north to Keelanattum in the south, and are particularly well exposed in the region to the east of Otakoil, and also at a number of places between Otakoil and Vilangudy where they are sometimes locally covered by a thin cap of the Cuddalore sandstones. Throughout their extent these rocks present a monotonous appearance totally devoid of any interest,—all the more so because of their unfossiliferous character.

The only occurrence of fossils,—and it is a very important one—noticed by Blanford in these beds was in the area round about the village of Cullmoad, about a mile east of Otakoil. In the rocks of this locality which are mostly of the nature of white sands full of concretions, Blanford found a few fossil bones which however were " so saturated with water and so very friable that it is impossible, even with the greatest care, to extract them in anything like a recognizable condition". There was one fossil, however, n Blanford's collection which was well preserved and this was later identified by Lydekker as a reptilian tooth belonging to the well known dinosaurian genus *Megalosaurus*; on the basis of this identification, it was concluded that the other bony fragments found in the area were probably also reptilian in character, though much too poorly preserved to be of any use for description or identification.

Very early in the course of our examination of the Ariyalur area, the present author decided to devote some special attention to the Cullmoad beds in search of the possible occurrence of more and better preserved reptilian remains; and as a result of these explorations during the years 1923 and 1924, it was gratifying to note that a fairly good collection of reptilian fossils was made which included several remains of vertebrae together with some recognizable fragments of the limb bones such as the epiphysis of the humerus, the head of a femur, the proximal end of a tibia, and some phalangeal elements. The most valuable find in this collection, however, was a vertebra, which is almost entire and very well preserved.[21] The centrum is about 7·6 cm. long and 5·5–6 cm. wide; it is markedly opisthocoelous and bears a well defined neural canal enclosed by the neural arches. The articulation between the centrum and the neural arches is by a distinct neurocentral suture, which is persistent and well seen in the fossil. The neural arch bears the usual two pairs of processes, the zygapophyses, for articulation with the adjacent vertebrae. Between the two pairs of zygapophyses in the median line above the neural arch is a distinct ridge about 6 cm. long, representing the worn out remains of the neural spine. There is no indication of any articulation of the zygosphene—zygantrum type. From all these characters more fully described by the author elsewhere[24] the fossil was identified as a dinosaurian vertebra belonging to the cervical region of one of the Theropoda, probably *Megalosaurus*.

At about the same time, an excursion party from the Zoology Department of the Central College, also visited the area and obtained a good number of fossil bones a brief account of which was published in 1927 by Prof. C. R. Narayana Rao and B. R. Seshachar.[15] This collection also included a beautiful specimen of a vertebra, together with other remains like " ilia, scapula, coracoid, head of the humerus, a tooth with a broken piece of the dentary, and limb bones mostly in a broken condition". The fine specimen of the vertebra in this material was later studied in detail by Prof. C. R. Narayana Rao and the present author,[16] and it was identified as belonging to the anterior region of a reptile belonging to the family Camarasauridae of the sub-order Sauropoda. This vertebra is squarish in general outline and the length of the centrum is much shorter than the height. It is distinctly opisthocoelous and the centrum is pneumatic. The pre- and post-zygapophyses are broadly developed and there is clear indication of a zygosphene-zygantrum type of articulation. The neural canal is fairly wide; and ventral to this is a transversely concave ridge which receives the corresponding convex ridge on the upper surface of the anterior boss of the centrum.

The report of these finds of reptilian fossils in the Trichinopoly area soon attracted the attention of Dr. C. A. Matley who realised " that this discovery (of ours) is of importance as it is the first time that Southern India has yielded identifiable remains of dinosaurs". He also almost immediately visited this area and made his own collection of reptilian fossils, a brief account of which he published a couple of years later.[13] Referring to his collection he says: " It is remarkable that all the bones found, 10 in number, were limb or girdle bones and not a single vertebra, rib, tooth, scute, or other parts of the skeleton was discovered. One important result of the investigation was to show that these remains do not belong to a megalosaurian as Blanford supposed, as their characters are quite distinct from those of the Theropoda. They are almost certainly Sauropodous bones; some of the smaller are possibly Stegosaurian. None of the bones found is Theropodous, though Blanford's discovery of a Megalosaurian tooth shows that Theropods also lived in this region contemporaneously."

It is evident from the brief reviews of the work done so far,[14, 26] that here in this area we have a most promising field for further exploration in search of reptilian remains. The rocks round about Cullmoad require immediate attention; other localities also where there are indications of the occurrence of such fossils must be looked into very carefully. Such investigations are sure to yield many more valuable remains which would greatly extend our knowledge of the varied reptilian life which must have existed in this part of India during the upper Cretaceous period. A general idea of some of the fossil bones in our collections may be obtained from the figures in Plate XV.

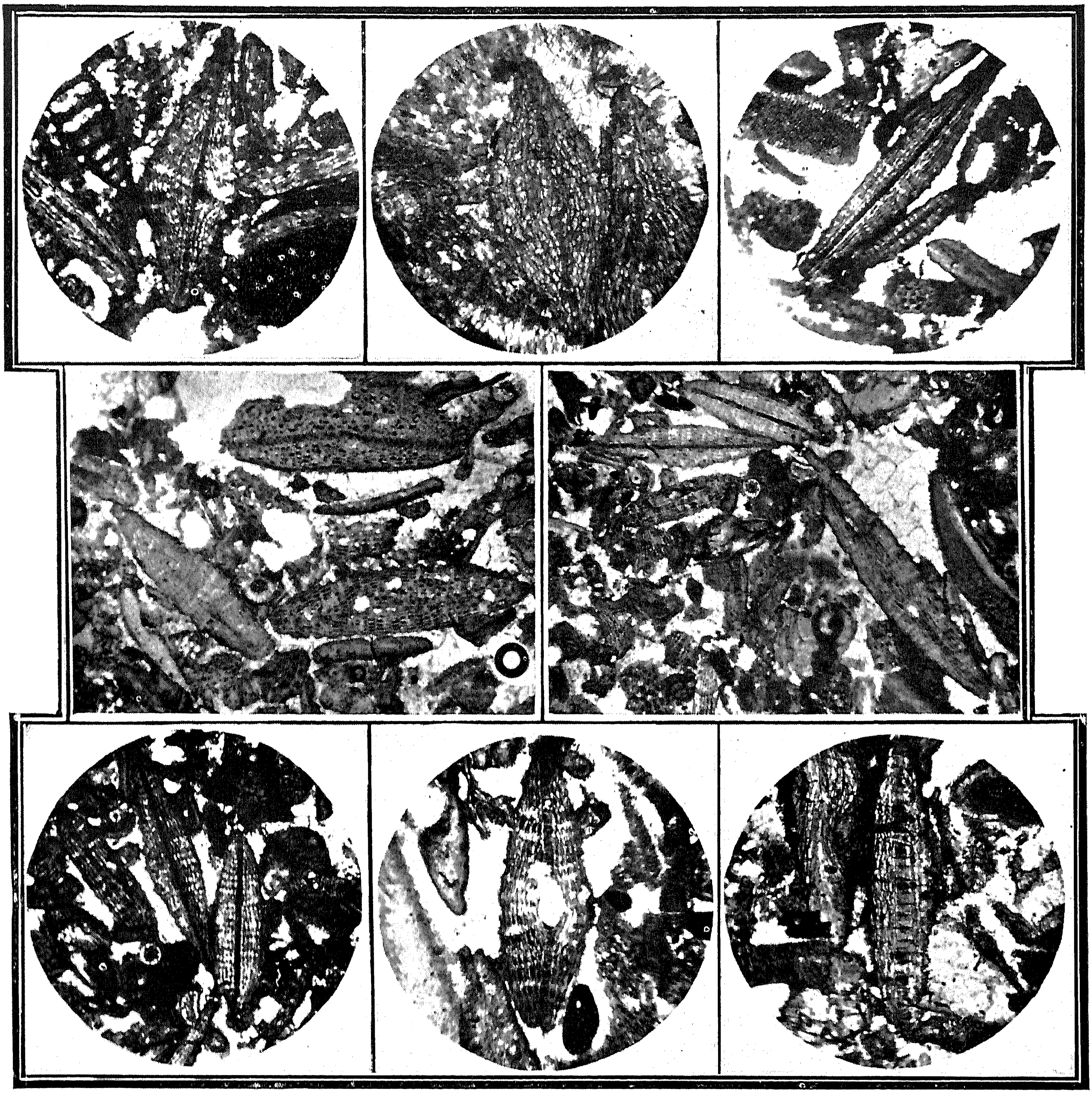
Before leaving the middle Ariyalur division and passing on to the next, we may draw special attention to the occurrence in the Ariyalur area of a few thin bands of an arenaceous limestone (or calcareous sandstone) containing Orbitoids. The presence of this important group of foraminifers in this area had been noticed even by Stoliczka who found them in some of the limestones collected by Blanford from near Niniyur and Chokanadapuram, about 10 miles north-east of Ariyalur. Stoliczka recognised in this material " a single well-defined species, *Orbitoides faujasi* and two doubtful ones". This was practically all our knowledge of the Orbitoids of this area till recently when S. R. Narayana Rao succeeded in finding more of these Orbitoids in the Ariyalur beds near Chokanadapuram, a short account of which he published in 1941.[18] In the course of this paper he has recognised three species (all new) of Orbitoids,—one of *Orbitocyclina* (*O. ariyalurensis*) and two of *Lepidorbitoides* (*L. inornata* and *L. blanfordi*). According to this author the *O. faujasi* described by Stoliczka is a *Lepidorbitoides* belonging to his new species *L. blanfordi* and is not *L. minor* as hitherto believed. A couple of years later, the present writer also collected a few specimens of an orbitoidal limestone near Coothoor (about 4 miles south of Chokanadapuram) and it was interesting to note that the shells here were much bigger in size (about 8–9 mm. in diameter) and probably represent the microsperic forms of the *Lepidorbitoides* mentioned above. Quite recently an extraordinarily rich and varied orbitoidal fauna has been noticed by the writer in the course of his examination of certain rocks collected from a locality about 3 miles east of Ariyalur.[31] It is specially interesting to note that along with the Orbitoids in these rocks we also see the abundant occurrence of *Siderolites* (including the typical form *S. calcitrapoides*) most beautifully preserved. The microphotographs shown in Plates XVI and XVII give a general idea of the types of Orbitoids and Siderolites noticed here. A preliminary study of these foraminifers[33, 34] indicates that some of these forms appear to be new, at least so far as India is concerned, in the sense that they have not been noticed before. In addition to these, numerous small Foraminifera are also seen to occur here, commonly represented by the genera *Robulus*, *Lenticulina*, *Saracenaria*, *Bolivina*, *Textularia*, *Nonion*, *Rotalia*, *Amphistegina*, *Cibicides*, *Anomalina* and *Operculina*, together with what look like small Camerinas (?).

From this brief review, one important fact is clear, and that is that here in this Ariyalur area there occur at a number of places certain undoubted ' Orbitoid-Siderolites ' bearing rocks. Without going into the question of the detailed description and identification of these fossils (which will be done by the author elsewhere) what we are really concerned with here is the problem regarding the stratigraphical position and age of these orbitoidal beds, which we will now proceed to consider.

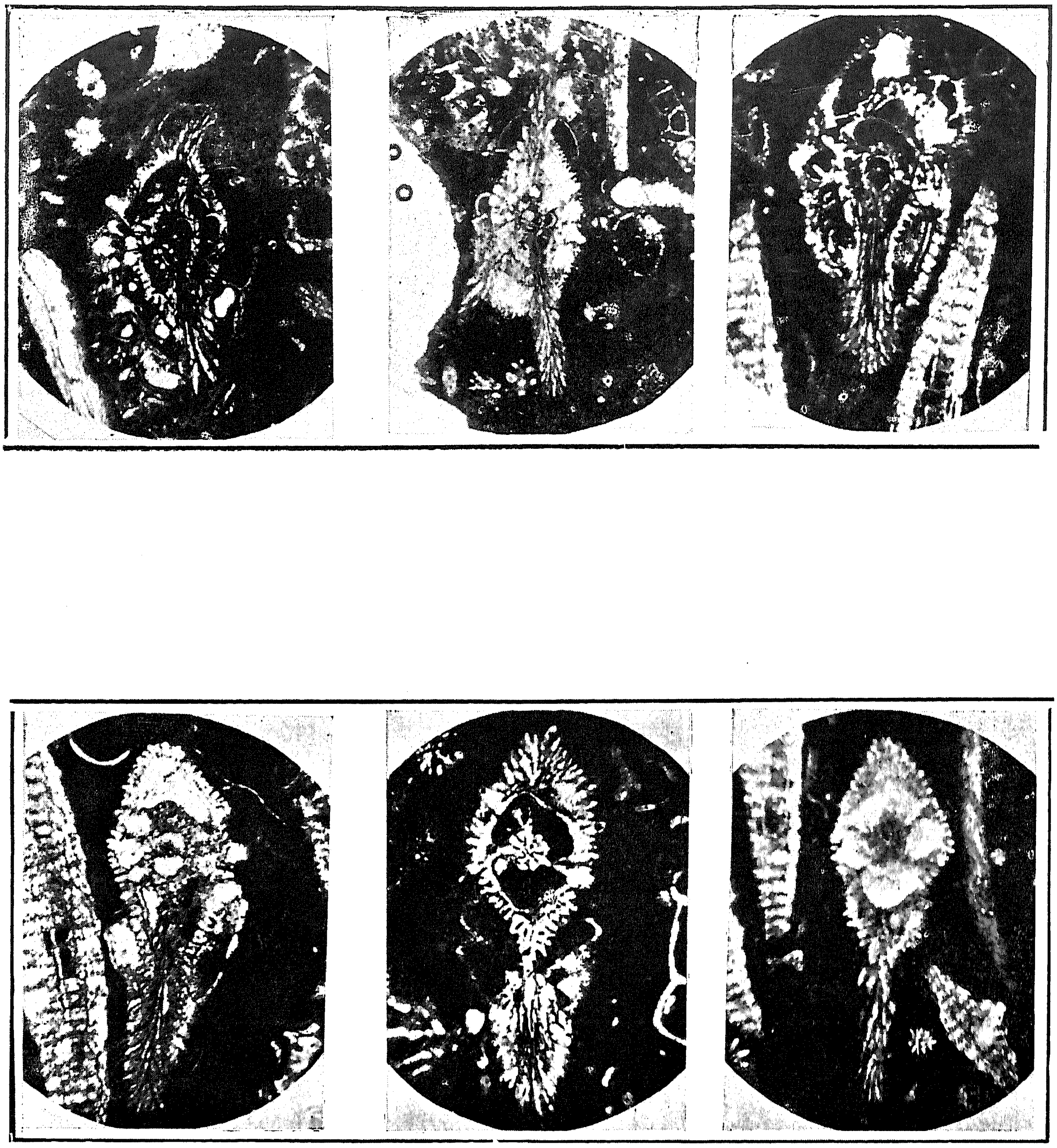
The Orbitoids first noticed by Stoliczka were found, according to him in rocks from two localities which he mentioned as follows: (i) Niniyur, in white limestones, and (ii) Chokanadapuram, in a pinkish earthy limestone. According to Blanford's memoir, the former (locality i) would belong to his *Upper* Ariyalur division which was Danian in age, and the latter (locality ii) would be in his *Lower* Ariyalurs whose age was Senonian. In the light of recent stratigraphical studies it is clear that both these age indications for the Orbitoidal beds are not correct. The white limestone (of locality i) is *not* a member of the Danian Niniyur group as now defined; it is a pre-Danian bed just below the Niniyurs; the pinkish earthy limestone near Chokanadapuram (locality ii) is *not* a bed belonging to Lower Ariyalurs; it is younger and belongs to the upper part of Blanford's ' Middle Ariyalur ' division. It is now evident that both the Orbitoid-bearing beds referred in the two localities mentioned by Stoliczka are of the same age, being younger than Senonian and older than Danian; their exact age would thus be Maestrichtian. This is in fact the age which S. R. Narayana Rao has actually assigned to the bed near Chokanadapuram from which he described the Orbitoids in 1941; the similar Orbitoid-bearing beds subsequently noticed near Coothoor, and more recently near Ariyalur, are no doubt also of the same age. All these occurrences probably represent portions of one and the same band running from near Chokanadapuram in the north to near Ariyalur in the south as indicated in the map of the concerned area given below (Fig. 5). It would be most fruitful to survey the area all along this line and also to look for possible continuations of this band north of Chokanadapuram and south of Ariyalur. The limestone near Kallakudy (Cullygoody) in which Thalmann is reported to have found *Lepidorbitoides* (a reference to which has been made in an earlier part of this paper) is probably a representative of this band at its southern extremity. Further exploration may reveal the presence of beds yielding a rich harvest of Orbitoids and other foraminifers in this region. The occurrences of these orbitoidal rocks noticed in recent years are however enough to indicate the presence of a distinct Maestrichtian horizon forming the youngest part of Blanford's 'Middle Ariyalur' group.

(*iv*) *Niniyur group* (= the *Upper Ariyalurs* of Blanford)

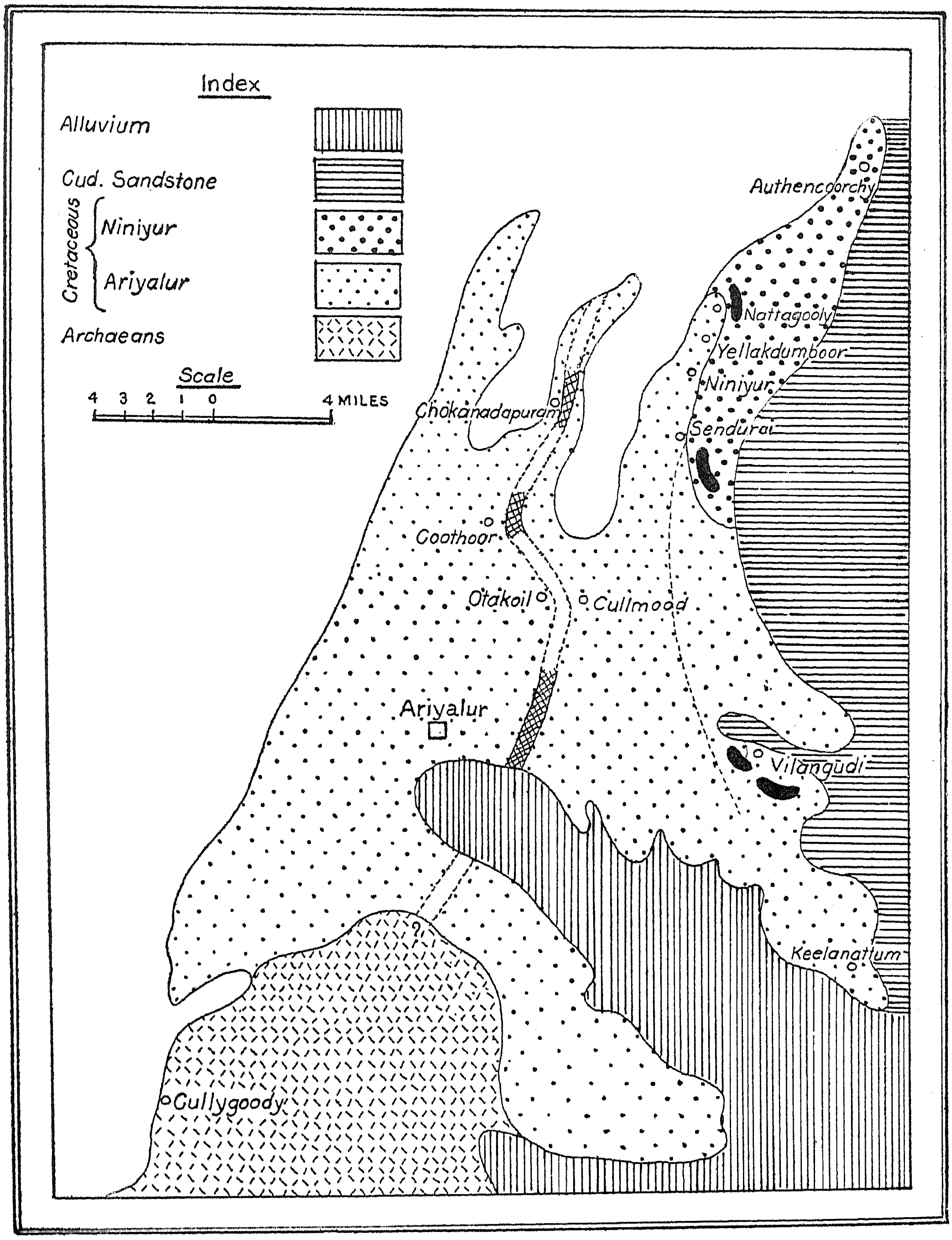
We now pass on to the next and youngest division constituting the 'Upper Ariyalur group' according to Blanford; though small in extent this is in many respects the most interesting and important group of all the subdivisions in this area, and the present writer therefore devoted special attention to the study of these beds from both the stratigraphical and palaeontological points of view. On the basis of these studies it is now clear that these so-called 'Upper Ariyalur' beds of Blanford are so clearly marked off both stratigraphically and palaeontologically from the rest of the Ariyalurs that it is no longer fair or correct to treat them merely as part of the Ariyalur group. They must be recognised as forming a distinct stratigraphical unit and given the same status as the other groups of the Cretaceous succession in this area; this division may be appropriately called the 'Niniyur group'. Although the fact of the 'distinctness' of these beds from the underlying Ariyalurs was in a way broadly recognised even by the earlier workers, no attempt had been made to demarcate the boundaries and establish the identity of the 'Niniyur group' as such, nor was its stratigraphy and palaeontology fully worked out. This the present author did some time back and a detailed account of these studies has been published elsewhere.[36] Only a brief summary of the main points emerging from these and subsequent studies will be given here.



Some of the Orbitoids recently noticed in the Maestrichtian limestone band near Ariyalur.



Some of the Siderolites recently noticed in the Maestrichtian limestone band near Ariyalur. (Reproduced from *Current Science*, 1954, by kind permission of its Editor.)



TEXT-FIG. 5. Map of the Ariyalur area showing the band of the Maestrichtian limestone (full of Orbitoids and Siderolites) and its probable extent. The map also shows the area of the Niniyur group as it is seen today, and its probable former southward extension. The thick dark bands (in the Niniyur area) indicate the 'Flints and Cherts'.

The rocks of the Niniyur group are now confined to a small area of about 25 sq. miles at the north-eastern end of the Trichinopoly Cretaceous area and are well seen near Sendurai, Niniyur, Yellakudumbur, Nattagooly and Authencoorchy (*vide* Fig. 5). The Niniyur group is composed of three distinct beds of which the oldest is an argillaceous gritty limestone full of fossils chiefly corals, lamellibranchs, and gastropods. Of the lamellibranchs, the important form is a species of *Cardita*—*C. jaquinoti*—very similar to if not identical with the well-known *C. beaumonti*. A striking feature of this limestone is that it is ferquently nodular; these nodules are about an inch or two in diameter and are uniformly composed of fine-grained argillo-calcareous material with some secondary calcite infilling cracks and cavities. Overlying this, we get the next younger bed which is chiefly of the nature of a white sub-crystalline limestone full of fossils of which the lamellibranchs and gastropods are the most common. Of the former, big-sized shells of a *Lucina*,—*L. percrassa*,—are particularly abundant imparting the enclosing rock the appearance of a regular shell limestone. Apart from these fossils, we have the significant occurrence here of the well-known species of *Nautilus*—*N. danicus*—the shells of which are also seen to attain large dimensions. Next to this Lucina-limestone, we get the third and youngest bed of the Niniyur group which is well seen near the village of Authencoorchy and may be called the Authencoorchy limestone. This is an argillaceous limestone; and in its texture and general appearance it frequently looks like a 'marl'. It is evidently a shallow water deposit mostly built up by the products of the disintegration of the older fossiliferous sediments. Under the microscope, sections of the rock show the presence of numerous milioline foraminiferal shells; in fact, in some cases, the rock may aptly be described as a Milioline limestone.

The different types of rocks mentioned above may be said to constitute the Niniyur group overlying as a whole the unfossiliferous sands and clays of the Middle Ariyalur division of Blanford. An important point to note is that in many parts of this area these unfossiliferous sands and clays are actually seen below the fossiliferous limestones of the Niniyur group; and in some places where the latter are not seen having been probably removed by denudation, the unfossiliferous sands and clays are alone exposed. From its stratigraphical position and the internal palaeontological evidence, it is obvious that the Niniyur group corresponds to the Danian which marks the youngest division of the Cretaceous system. The importance of the Danian in the study of the Cretaceous-Eocene transition is well known and has been discussed by the writer elsewhere[29]; the Niniyur group of South India is evidently of special interest in this connection,—all the more so because of the intriguing position which it seems to occupy straddling the Cretaceous-Eocene boundary.

From a study of the stratigraphical disposition of the Niniyur beds *vis-a-vis* the older rocks of the area, we have also shown that the beds of the Niniyur group were deposited in an independent post-Maestrichtian transgression of the sea in the north-eastern part of the Trichinopoly Cretaceous area. As will be shown in the sequel, there are evidences to believe that the beds of the Niniyur group (and therefore the Niniyur sea) must have at one time extended much further south. The Niniyur beds as we see them now are evidently only the worn out remnants of a thicker and more extensive formation in the past. Talking of the rocks of the Niniyur group, special mention should be made of certain flints and cherts found in the area; of these there are two bands (i) one near Sendurai and (ii) the other near Nattagooly about 5 miles further north. Blanford had also noticed these, and all that he said about them was that they resembled " in the mineral character and the nature of the enclosed organisms the chalk flints of Europe". The Niniyur flints and cherts have now been examined by us in great detail[35] and several significant conclusions have emerged from these studies which will be referred to here in some detail in view of their special importance.

The band near Sendurai is composed of a typical waxy brown flint, massive in appearance; fragments of these flints are translucent at the edges and show a subconchoidal fracture. Immediately to the south-east of Sendurai where we get the first *in situ* exposures of these flints a striking feature is their ' pebbly " character. The ' pebbles ' which are usually well defined and rounded are white in colour while the general mass of the rock is reddish brown, and thus the entire rock gets a characteristic mottled appearance. As we proceed further south-east the pebbly character gradually disappears and the rock becomes more homogeneous and compact. The flints often show a highly weathered appearance on the surface giving rise to irregular cracks, pores, and vesicles filled up by an earthy ferruginous material due to infiltration from the Cuddalore sandstones. It is significant to note that although the general mass of the rock is all siliceous, a few of these flints and cherts here and there still show internally traces of the original calcareous material which can be easily detected with a drop of acid. We can also quite frequently see in hand specimens of these rocks fossil shells (lamellibranchs and gastropods) together with corals and polyzoa. Under the microscope the pebbly nature of some of these flints is also clearly seen; the massive varieties are seen to be composed uniformly of cryptocrystalline silica except in places where we get the organic structures when we can recognise distinct grains of quartz. Of the fossils noticed under the microscope corals are the most common; some milioline foraminifers also occur here and there.

Regarding the other band near Nattagooly, the most striking feature of the cherts here is that superficially they present a highly 'shattered' appearance and readily break up into small splintery fragments. The main mass of the rock is of the gray homogeneous chalcedonic type, sometimes passing into a dull white opal-like material on the surface. Even in hand specimens, the rock is seen to be fossiliferous—polyzoa, corals, and lamellibranchs being the common fossils. When examined under the microscope the main mass of the flints is seen to be composed of homogeneous cryptocrystalline silica; sections of the opal-like portions on the other hand are composed almost entirely of opaque material; in both cases, however, we see that in places where we get the organic structures, the rock texture becomes coarser and distinct grains of quartz become recognizable. Foraminifers of the family Miliolidae are frequently seen in sections of both the types, the common forms being *Biloculina*, *Triloculina*, and *Quinqueloculina*.

The most outstanding feature of these Niniyur flints and cherts from the micropalaeontological point of view is the abundant occurrence of fossil algae noticed practically in all the sections. A fuller reference to the nature of these algae will be made later in this paper; the point to note just now is the fact that the abundant occurrence of these calcareous algae is of the greatest importance in indicating the nature of the parent rocks which have given rise to these flints and cherts. As mentioned above, the other fossils noticed in these are all also the remains of calcareous organisms like foraminifers, corals, polyzoans, lamellibranchs and gastropods. This entire assemblage is exactly similar to what we also see in the regular limestones of the Niniyur group; and from a comparative study of both, it becomes clear that all the flints and cherts of the area are merely the products of silicification of rocks identical with the associated limestones, in the formation of which the algae have played quite an important part. This conclusion is further supported by the fact that in both the Sendurai and Nattagooly areas we see certain limestones alongside these flints; and it is often possible to place side by side samples of both these rocks which are absolutely similar both in hand specimens and in microsections,—the only difference being that in one case the rock is calcareous, while in the other it is all replaced by silica. The recognition of the fact that these flints and cherts are merely the silicified limestones of the Niniyur group is important not only in itself, but more so from the stratigraphical point of view; for it is now clear that they are contemporaneous with and represent the same stratigraphical horizon as the corresponding limestones of the area.

In this connection we must refer to two other occurrences of similar siliceous rocks in this area; these are (i) near Vilangudy about 9 miles S.S.E. of Sendurai and (ii) near Keelanattum about 5 miles further south-east. Of these it is only in the Vilangudy area that we get good *in situ* exposures of these rocks while near Keelanattum the position is not so satisfactory. We may therefore ignore this latter area for the present and proceed to describe the flints and cherts near Vilangudy. Here several prominent *in situ* exposures of these rocks are well seen in the country to the south and south-east of the village; and among them we can broadly recognise two types: (i) the slate-grey homogeneous and compact variety and (ii) the white or gray quartzitic type. Specimens of the former kind are generally very similar to those of the Sendurai area and like them these also show locally some 'pebbly' varieties. The rocks of the second type which are well seen in two outcrops about 1½ to 2 miles south of Vilangudy are more of the nature of fine-grained quartzites, as can be clearly seen in microsections. In some places the rock becomes even more coarsely granular, often white and saccharoidal in appearance, thus presenting the appearance of a typical quartzite, but still showing the fossils—corals, lamellibranchs and gastropods—similar to those of the finer grained varieties. We have in fact noticed here a beautiful example of a typical white saccharoidal quartzite full of big-sized corals, of course, all silicified. A fossiliferous quartzite of this nature appears to be an unusually interesting type of rock. Dr. Lees, in his paper on the Chert Beds of Palestine, refers to a similar rock type which he describes as follows: "In places an unusual quartzite bed outcrops interbedded with Cenomanian limestones. It is intensely white in colour and has a sugary surface texture. Mr. G. S. Blake showed me some definite, though indeterminate, fossil shapes in these quartzites which aroused suspicion as to its real nature. A thin section shows nothing but a regular mosaic of quartz crystals. Several opaque patches suggest some organic structure." Obviously, Dr. Lees is here speaking of a rock very similar both in nature and origin to the saccharoidal quartzite now being described from Vilangudy; but whereas the fossil structures he has seen are 'indeterminate' and 'suspicious' those in the Vilangudy type are quite clear and convincing.

The most significant feature, however, of the fossil contents of these Vilangudy rocks is the fact that in sections examined under the microscope, these also show plenty of algal remains similar to those found in the flints and cherts of the Niniyur group; there is no doubt that all these Vilangudy cherts and quartzites are also the result of silicification of an original fossiliferous rock containing a large abundance of algae together with numerous corals and some foraminifers, lamellibranchs and gastropods. In view of the prevalent quartzitic nature of these rocks, it seems also reasonable to conclude that in this case the original rocks must have been of the nature of fossiliferous sandstones—the degree of coarseness or fineness of their grains determining the corresponding texture in the resulting quartzites after silicification.

The important question now to consider is the stratigraphical position and age of these Vilangudy cherts and quartzites *vis-a-vis* the flints and cherts found further north in the Niniyur group. Blanford who had also noticed these siliceous rocks near Vilangudy found them lying in an area where the surrounding rocks were the unfossiliferous sands and clays and therefore described these as part of his Middle Ariyalur division, while in the case of the flints and cherts further north near Sendurai and Nattagooly he considered them as part of his Upper Ariyalurs (now recognised as the Niniyur group) evidently because he found in that area plenty of fossiliferous limestones belonging to his Upper Ariyalur division lying alongside these flints and cherts. Recent studies regarding the mode of origin of these siliceous rocks and a close examination of their palaeontological contents and stratigraphical relationship lead to a different conclusion. The Vilangudy cherts and quartzites are also the result of silicification of original fossiliferous rocks containing a large proportion of algae together with plenty of corals, numerous milioline foraminifers, and some molluscs similar to those of the northern areas; and they also similarly overlie the unfossiliferous sands and clays of the Middle Ariyalur division. In view of the identical stratigraphical position of both these sets of silicified rocks and the striking similarity in their fossil contents, we might reasonably conclude that the fossiliferous cherts and quartzites of the Vilangudy area are the stratigraphical equivalents of the flints and cherts of the Niniyur group and are of the same age. This means that the Niniyur sea must have extended as far south as Vilangudy and that the Niniyur beds, immediately after deposition, must have covered all this area. In the intervening country between the two areas, we now seem to get only the Middle Ariyalur unfossiliferous sands and clays without any beds of the Niniyur group. This is merely an effect of denudation; it is also at the same time not unlikely that a fuller exploration of this intervening area may actually reveal the presence of remnants of the Niniyur beds here and there, thus connecting up the Niniyur group as we see it now with what is evidently its outlier in the Vilangudy area. In the accompanying map (Fig. 5), the original extent of the Niniyur group as visualised by the author on the basis of these recent studies is indicated.

Fossil Algae

By far the most interesting feature of the Niniyur group from the palaeontological point of view is the abundant occurrence of fossil algae in many of these rocks. It was in the year 1931 that the present writer discovered the presence of abundant fossil algae in this area.[23] They were first noticed in the nodules of the argillaceous gritty limestone (belonging to the lower part of the Niniyur division), found near Yellakudumbur village. When broken open, these nodules were seen to be composed of a compact calcareous material of a dirty white colour which was traversed by numerous irregularly wavy or roughly concentric bands of a lighter coloured fine-grained material. A microscopic examination of these bands revealed that they were all algal in nature, the algal structure being exceedingly well preserved in most of them. In view of the importance of this find, all the other Niniyur rocks were also taken up immediately for study, and hundreds of sections were prepared and examined. Practically all of these revealed the presence of algae of one kind or another, with the result that we were very soon able to get together from the rocks of this area some excellent material for detailed studies. It is signicant to note that the algae were found not only in the limestones but they were also equally abundant in the associated flints and cherts; in fact, the algal structures in the latter are much better preserved, and some of our best sections belong to this material. The detailed study of these Niniyur algae was soon taken up in collaboration with Dr. Julius Pia and a full description of these was published as a Memoir in the *Palæontologia Indica* Series (of the Geological Survey of India) in the year 1936.[36] A perusal of this paper will give an idea of the richness of this algal flora and the excellent state of its preservation, constituting according to Pia "the most interesting algal flora" he had ever studied; it has also the additional importance of being the first of its kind reported from any of the Cretaceous rocks of India. In view of these considerations it will be appropriate to give here a brief account of these fossil algae from the Niniyur group.

There are four families of algae represented here; in the order of abundance they are (i) the Corallinaceae, (ii) the Solenoporaceae, (iii) the Dasycladaceae and (iv) the Chaetophoraceae. Of these the first two have played an important part as rock builders while the third, though not so abundant, is of special value from the stratigraphical and palaeobotanical points of view. It is interesting to note that in this area, the Dasycladaceae and the Corallinaceae never seem to occur together in the same rock and appear to be mutually exclusive, probably because the ecological conditions favourable for one was repugnant to the other. Of the Corallinaceae the most common form present is the primitive genus *Archaeolithothamnium* (belonging to the sub-family Melobesieae) represented by *A. lugeoni*, *A. aff. provinciale* and *A. cf. lycoperdioides*. From a study of these forms it is evident that the difference between perithallium and medullary hypothallium, between protuberances and branches, is not a fundamental one in this genus; and this feature constitutes one of its primitive characters. Many of the sections also show " the development of a recurrent basillar hypothallium out of an older perithallium " so characteristic of *Archaeolithothamnium*.

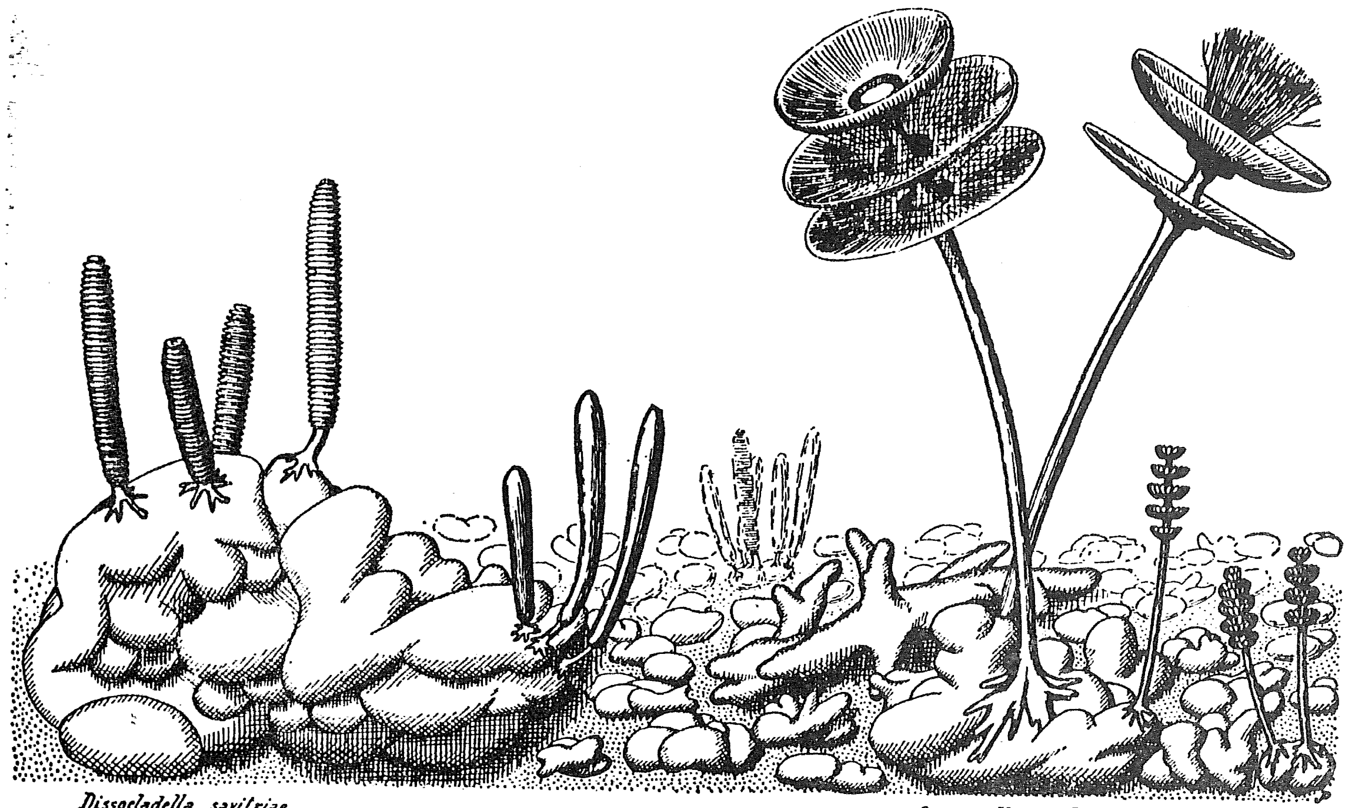
The family Solenoporaceae is represented here by a new species of *Parachaetetes* named *P. asvapatii*, of which we see both longitudinal and transverse sections. The disposition of the cell rows is often 'fountain-like' and the transverse walls in the adjacent cell rows are 'corresponding' in position. A differentiation between a hypothallium and a perithallium is sometimes indicated, but the boundary between these is not sharply defined.

The Dasycladacaee found in the Niniyur rocks are particularly interesting. The most common form is *Dissocladella* represented by a new species *D. savitriae* of which we get several beautiful sections showing all the important characters. The thallus is cylindrical or claviform and is built up by a series of superposed annular segments. The primary branches which occur in whorls are almost at right angles to the axis of the thallus and bear secondary twigs which unite to form a fairly continuous cortical layer as in the recent genera *Cymopolia* and *Neomeris*. In some respects the present form resembles the African species *D. undulata*, but is nevertheless distinct and different; the African form may in a way be considered as the direct ancestor of *D. savitriae*. Side by side with *D. savitriae* there also occurs in many of the sections the new form *Indopolia satyavanti*. While the thallus here is also more or less cylindrical, there is no trace of a division into joints. The primary branches, of which there are about 28 in a whorl, have a markedly oblique disposition and bear two kinds of secondary appendages—assimilatory twigs and sporangia. The sporangia are spherical or pear-shaped, and their number on each primary branch is generally greater than one; usually they are two. The other genera comparable with this form are *Neomeris* and *Jodotella*; but a detailed study makes it clear that *Indopolia* is really a new genus, a distinctive character of which appears to be the presence of two cortical cells and two sporangia on each primary branch. Along with the *Dissocladella* and *Indopolia* mentioned above, several of the slides also contain the remains of the spicules of *Acicularia* of which a new species *A. dyumatsenae* has been recognised; its sections are circular or elliptical in outline, with the sporangial cavities forming a single layer along the periphery. The spicules are about $2\frac{1}{2}$ times as long as broad, and their nature distinctly suggests a possible connection between this genus and *Terquemella*. It is likely that part of the

Terquemellae are primitive ancestors of *Acicularia*; if so, the line of division between the two genera cannot naturally be expected to be a sharp one. Another interesting form found here is a species of *Orioporella—O. malaviae* sp. nov.—which was evidently the stateliest plant among the Dasycladaceae, possessing a disc nearly 13 mm. in diameter with about 100 compartments. In addition to the above three families, the Chaetophoraceae (an obscure but interesting group of perforating thallophytes) is also represented in the Niniyur material by a species of *Palaeachlya*. A picture showing the reconstruction of part of the Niniyur sea floor showing the more important algae as they must have appeared in the living condition is given below (Fig. 6). After giving the description and identification of these Niniyur algae, Pia has also discussed their stratigraphic character and pointed out the ' transitional ' position of this flora between the Cretaceous and the Tertiary, and that therefore they cannot be employed to decide stratigraphic questions in Southern India, particularly since many of the species are new. The most important point, however, is, as Pia points out, " that the sequence of strata in this region will later on be a typical section. Algae will be used to correlate strata in other parts of the earth with those in the Trichinopoly District and thus to fix the geologic age of these foreign sediments".

The publication of the 1936 memoir dealing with this rich and varied algal flora of the Niniyur group naturally gave a great impetus for further work and opened out a whole field of research on fossil algae in India which has been actively pursued by a number of workers within recent years resulting in several valuable contributions to our knowledge of this interesting fossil group in India. In the Trichinopoly area itself more algae have been since noticed in the different limestones of the Cretaceous succession and a brief account of these recent finds is given below.

In addition to the algae described by us from the Niniyur group in 1936, C. P. Varma has recently recorded the presence in the same beds of the remains of *Clypeina* (Dasycladaceae) which he described and identified[48] as a new species *C. sahnii* closely allied to the well-known Eocene form *C. infundibuliformis*. This find is important as it is the first record of the occurrence of this genus in India. We have since found more of these Clypeinas in some of the cherts of the Niniyur group of which two distinct species have been described.[39] All these Clypeina remains are undoubtedly valuable since their study will add considerably to our knowledge of this interesting alga about which we now know so little; such studies will also enable us to discuss more fully and conclusively the systematic position of this genus in the Dasycladaceae about which there has been some difference of opinion. In the same material,



TEXT-FIG. 6. Tentative reconstruction of part of the sea floor, during the deposition of the Niniyur strata, showing the more important calcareous algae as they appeared in the living condition. (Reproduced from the *Pal. Indica Memoir*, 1936—by kind permission of the Director, Geological Survey of India, Calcutta.)

Varma has more recently noticed[49] the presence of *Neomeris*, of which two species *N.* (*Decaisnella*) sp. A. and *N.* (*Vaginopora*) sp. B. have been described; along with these, a new species of *Acicularia*, *A. indica*, has also been figured and described.

In addition to the above S. S. Gowda has recently recorded the interesting occurrence of a *Holosporella*[41] in one of the Niniyur cherts. This genus was first erected by Pia in 1930 to designate a primitive endospore Dasycladaceae which he found in certain upper Triassic rocks from the Burmo-Siamese frontier and named *H. siamensis*. In the year 1936 S. R. Narayana Rao and K. Sripada Rao recorded the occurrence of a *Holosporella*, very similar to *H. siamensis*, in some of the inter-trappean limestones (early Eocene) of the Rajahmundry area. The existence of an endospore Dasycladaceæ here in so high a geological horizon is, as Pia puts it, " quite unexpected " and " obviously most perplexing". The present find of a similar *Holosporella* in the Danian Niniyur beds is evidently another example of such an " unexpected " occurrence. S. S. Gowda has also more recently found in the Niniyur material another very interesting Dasycladaceous alga, of which both longitudinal and transverse sections are available; and from a detailed study of these (an account of which will soon be published elsewhere) it is shown to be a new genus to which the name *Piania* has been given. The other genera comparable with this new form are *Physoporella*, *Gyroporella*, *Uragiella*, *Morelletpora* and *Indopolia*; but closer studies clearly indicate that the present form is quite distinct from all of these, and has an individuality of its own. This new type has been named *P. niniyurensis*.

In connection with this account of the Niniyur algae, special attention should be drawn to the occurrence of *Solenopora* recently noticed by us in one of these cherts. This form has been described and recognised as a new species, *S. tiruchiensis*.[40] The presence of a *Solenopora* at so young a horizon as the Danian and in the same rocks which contain the Corallinaceae described above is of remarkable importance; there is also the fact already mentioned above that we have found a *Solenopora*—*S. sahnii*—side by side with an *Archaeolithothamnium* in the same specimen of a coral-reef limestone from the base of the Utaturs (*vide* Plate XIV). Both these occurrences are of outstanding significance, since for one thing they show the incorrectness of the prevailing idea that the coralline algae made their appearance (in the Cretaceous) only after the Solenoporaceae became extinct (in the Jurassic) is no longer tenable; and for another, they provide valuable material for the study of the mutual chronological and evolutionary interrelationships of these two important families of fossil algae.

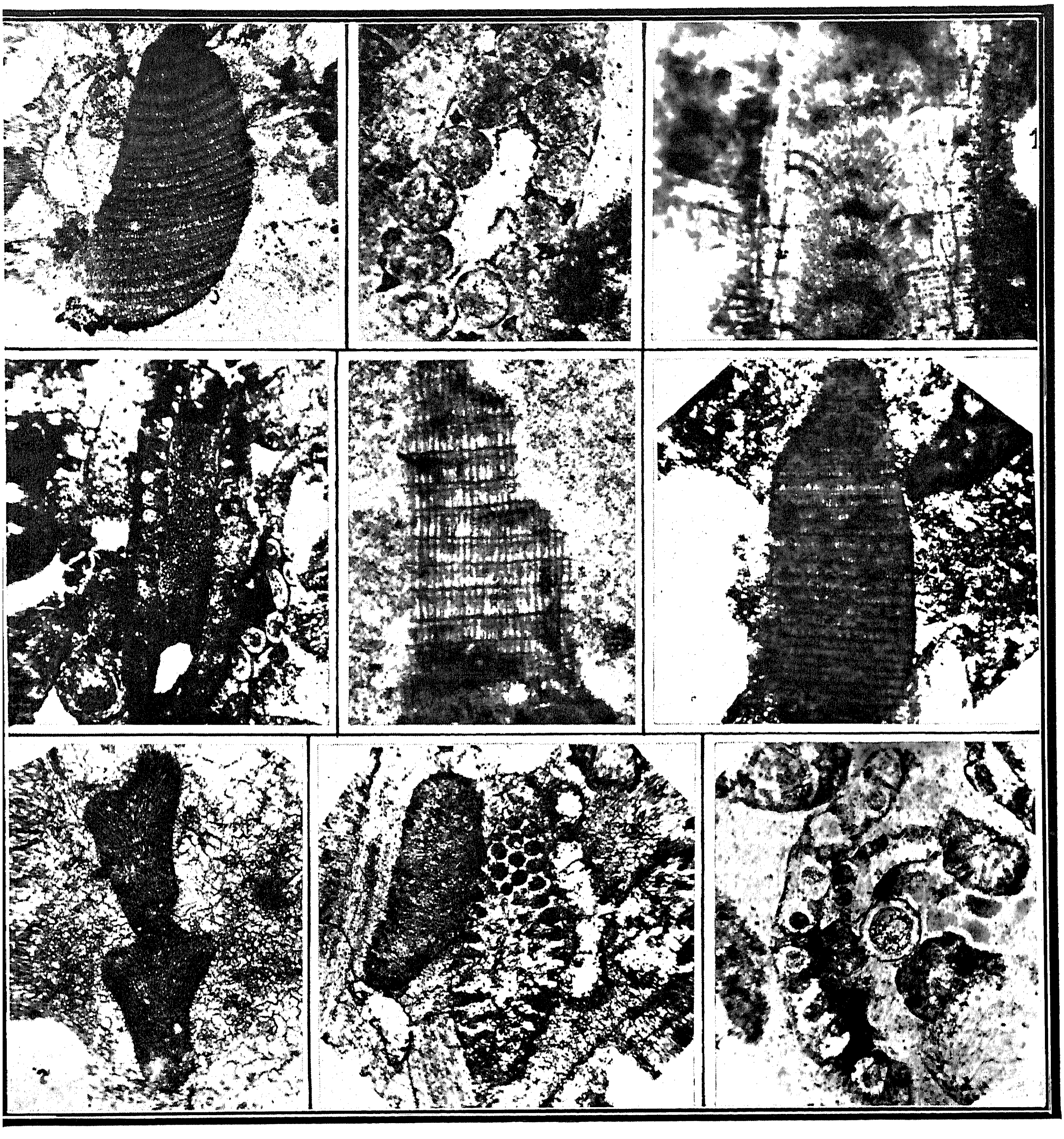
The following list shows the fossil algae described and identified so far from the Trichinopoly Cretaceous.

List of Fossil Algae described from the Trichinopoly Cretaceous

	Reference
DASYCLADACEAE	
Dissocladella savitriae sp. nov. ..	(L. R. Rao & J. Pia, 1936)
Indopolia satyavanti gen. nov. sp. nov.	(L. R. Rao & J. Pia, 1936)
Acicularia dyumatsenae sp. nov. ..	(L. R. Rao & J. Pia, 1936)
Acicularia sp. ind.	(L. R. Rao & J. Pia, 1936)
Orioporella malaviae sp. nov. ..	(L. R. Rao & J. Pia, 1936)
Neomerearum gen. ind.	(L. R. Rao & J. Pia, 1936)
Holosporella sp.	(S. S. Gowda, 1953)
Clypeina sahnii	(C. P. Varma, 1952)
Clypeina sp. 1	(L. R. Rao & S. S. Gowda, 1953)
Clypeina sp. 2	(L. R. Rao & S. S. Gowda, 1953)
Piania niniyurensis gen. nov. sp. nov.	(S. S. Gowda, 1956)
Neomeris sp. A.	(C. P. Varma, 1954)
Neomeris, sp. B.	(C. P. Varma, 1954)
Acicularia indica sp. nov.	(C. P. Varma, 1954)
CORALLINACEAE	
Archaeolithothamnium lugeoni ..	(L. R. Rao & J. Pia, 1936)
Archaeolithothamnium aff. provinciale ..	(L. R. Rao & J. Pia, 1936)
Archaeolithothamnium cf. lycoperdioides	(L. R. Rao & J. Pia, 1936)
Archaeolithothamnium sp. ind. ..	(L. R. Rao & J. Pia, 1936)
SOLENOPORACEAE	
Parachaetetes asvapatii sp. nov. ..	(L. R. Rao & J. Pia, 1936)
Solenopora jurassica	(S. R. N. Rao, 1947)
Solenopora coromandalensis sp. nov. ..	(S. R. N. Rao, 1947)
Solenopora sahnii sp. nov.	(L. R. Rao & S. S. Gowda, 1954)
Solenopora tiruchiensis sp. nov. ..	(L. R. Rao & S. S. Gowda, 1954)
CHAETOPHORACEAE	
Palaeachlya sp.	(L. R. Rao & J. Pia, 1936)

Some more of these algae which have been recently noticed and are awaiting full description are shown in Plate XVIII.

Following up the discovery of this abundant and varied algal flora in the Trichinopoly area, similar rocks in the other South Indian Cretaceous areas like Pondicherry and Rajahmundry were also looked into for algal



Some of the fossil algae more recently noticed in the rocks of the Trichinopoly area.

remains with successful results. In addition to these, it is also gratifying to note that more and more fossil algae have now been noticed in the Cretaceous and Eocene rocks of other parts of India as well, accounts of which have been published from time to time by S. R. Narayana Rao, K. Sripada Rao, and C. P. Varma. It is thus evident that a whole field of research on fossil algae in India has now been opened out "of which only the fringe has yet been touched"; there is no doubt that further studies in this fascinating field from the various fossiliferous sedimentary rock formations of India will yield results of the greatest interest alike to the stratigraphical geologist and the palaeobotanist.

4. Vridhachalam Area

Having described the Trichinopoly Cretaceous rocks, we may now pass on to another small occurrence of the Cretaceous (about 50 sq. miles in extent) found a few miles further north near Vridhachalam. The country in between is all covered over by soil and alluvium; and even at Vridhachalam we get only a few small and thin patches of the Cretaceous exposed here and there from below the cover of the overlying Cuddalore sandstones and alluvium, as for example near Paroor, Yermanur and Chendamangalam. After examining these exposures, Blanford[1] recognised two distinct beds of the Cretaceous here, (i) an older sandy limestone (with some lamellibranchs like *Trigonia*, *Spondylus* and *Pecten*) overlaid by (ii) a younger series of fine sands and shales which are practically unfossiliferous. On comparing these with the rocks of the Trichinopoly area, Blanford expressed the view that the Vridhachalam beds belong to the Ariyalur group, the older belonging to the Lower Ariyalur division, and the younger representing the unfossiliferous sands and clays of his Middle Ariyalur group. He summarised his correlation as follows: "The fine sands with casts of fossils which occur near the boundary of the group at Killanur and Chendamangalam remind us of the similar beds in the upper part of the same zone (Lower Ariyalur) near Coothoor; and in the same way, the unfossiliferous sands and clays which appear to constitute the whole of the beds to the eastward may be the continuation of the unfossiliferous zone in Trichinopoly, as indeed the strike of the bedding would seem to indicate."

Subsequent to Blanford, the Vridhachalam Cretaceous has not been re-examined, and all our knowledge of this area is still confined to Blanford's preliminary report. In view of the fact that the Cretaceous beds of the Trichinopoly area have since been studied in detail and considerable additions have been made to our knowledge of the stratigraphy and palaeontology of these rocks, the adjacent Vridhachalam area needs immediate re-examination with a view to determine the exact nature of the Cretaceous rocks here and their correlation with those of the type Trichinopoly area. Blanford for instance refers to the possibility of the unfossiliferous sands and clays in the Vridhachalam area as representing the similar rocks of the Middle Ariyalur division and probably representing their northern extension. In the Trichinopoly area we now know that there are certain bands of a highly fossiliferous arenaceous limestone full of Orbitoids and Siderolites towards the top of the Middle Ariyalur group, and representing a distinct Maestrichtian horizon. As already pointed out above, these limestones are of the greatest interest and importance from both the stratigraphical and palaeontological points of view; it will be worthwhile to look for similar fossiliferous bands in the Vridhachalam area containing these foraminifers. There is every chance of their being found there also.

Then again, according to Blanford, what we get in the Vridhachalam area are only the equivalents of his Lower and Middle Ariyalur divisions; no beds representing his Upper Ariyalur division (now demarcated as the Niniyur group) have been noticed by him. This is a point requiring further attention. In the light of our recent detailed knowledge of the Niniyur group it would be worthwhile to thoroughly explore the Vridhachalam area and see if rocks representing the Niniyurs do not occur there. It is not at all unlikely that such a re-examination may reveal the presence of these Danian beds in this area also,—particularly since these beds reappear in the Pondicherry area. If the occurrence in the Vridhachalam area of beds belonging to the Niniyur group could be established, it will be an important contribution as it would enable us to know more about this group and the exact correlation of its equivalents in the different South Indian Cretaceous areas. In view of the very interesting position which the Niniyurs occupy in the Cretaceous-Eocene transition, any addition to our knowledge of this division would be most welcome.

5. PONDICHERRY AREA

About 30 miles to the north-east of Vridhachalam, we get another occurrence of the Cretaceous rocks in the neighbourhood of Pondicherry. Compared with the Trichinopoly area this is also a very small patch, just about 30 sq. miles in area; most of this ground here again is covered over by the Cuddalore sandstone and alluvium with the result that good exposures of the underlying Cretaceous are very few and fragmentary like those noticed round about Valadavur, Rautankuppam, Royapudupakam, Saidarapet, and Usteri. Nevertheless the Cretaceous rocks of this area have a special interest especially in view of certain recent observations and we will therefore proceed to consider them in some detail here.

It was Blanford who first gave us a description of these rocks[1]; based on his field studies he concluded that there were two distinct subdivisions in the Cretaceous succession here,—a lower Valadavur group corresponding to the Utaturs of the Trichinopoly area and an upper, representing the Ariyalur group—with an unconformity between the two. According to Blanford, a dark gray compact sandstone forms a prominent member of the lower division; the rock is highly fossiliferous, the ammonites being quite common, the general nature of the fossils being similar to what we get in the Utaturs; and hence his correlation with that group. In the upper group conglomeratic and calcareous sandstones are the usual rock types, and these also contain numerous fossils. On examining his collection of fossils from the different rocks of this group, Blanford thought that there was an admixture here of forms from both the lower and upper subdivisions of the Ariyalur group in the Trichinopoly area; and he also noticed that some of these rock specimens were very similar lithologically to those found in the Middle Ariyalur beds of Trichinopoly. Thus he came to the conclusion that his upper division in the Pondicherry area is equivalent to the entire Ariyalur group and comprises within itself in an abridged manner equivalents of all the three subdivisions of this group,—lower, middle, and upper—noticed in the Trichinopoly area.

Some years later, Warth re-examined the Pondicherry area and made a large and systematic collection of fossils from the different Cretaceous rocks here; and from a study of these, he recognised six distinct horizons in this succession,—three of which would fall in the lower (Valadavur) group of Blanford, and three in his upper (Ariyalur) group. The entire material collected both by Blanford and Warth was again restudied more fully by Kossmat together with the field observations made by these pioneer workers, and a most important contribution to our knowledge of these rocks came out in the paper on "The Cretaceous Deposits of Pondicherry" published by him in 1897.[9] After reviewing the entire evidence, both stratigraphical and palaeontological, he pointed out that Blanford's recognition of two distinct subdivisions in the Pondicherry area (one representing the Utatur and the other the Ariyalur division in the Trichinopoly area) was not correct, and that *all* the Pondicherry Cretaceous beds belong only to the Ariyalur group.

After establishing this main conclusion, Kossmat proceeded to classify this Cretaceous succession on a palaeontological basis and recognised three subdivisions. Starting from the oldest these are (i) the Anisoceras beds, (ii) the Trigonoarca beds and (iii) the Nerinea beds. After comparing the fossils in each of these subdivisions with those of the Ariyalur group in the Trichinopoly area and elsewhere, Kossmat concluded that subdivisions (i) and (ii) are equivalent to the Lower Ariyalurs being of Campanian (Upper Senonian) age, while the youngest (iii) Nerinea beds are equivalent to the Upper Ariyalurs of Blanford (now distinguished as the Niniyur group) and belong to the Danian. The Nerinea beds of Pondicherry, like the Niniyurs of Trichinopoly, are quite distinct from the rest of the succession; Ammonites are totally absent from both of them, and *Nautilus danicus*, a typical Danian fossil is found in both. The equivalence of the Nerinea beds with the Niniyur group has been further supported by the present author's study of some of the limestones of this division from both the areas. The Nerinea beds as developed near Usteri (in the Pondicherry area) include some nodular limestones, the nodules showing inside wavy bands of a cream-coloured compact homogeneous material; there are also other limestones which present a striking "pebbly" appearance—the "pebbles" again being composed of the same cream-coloured material. Both these types of limestone closely resemble some of those typically found near Sendurai in the Niniyur area; and what is more, these limestones reveal in microsections the presence of numerous algae and foraminifers of the same kind as those in the Niniyurs. Thus there is no doubt that the Nerinea beds of Kossmat (representing Horizon F of Warth) in the Pondicherry area are the equivalents of the Niniyur group and are of the same age (Danian). It must however be pointed out that the Ariyalur—Niniyur succession near Pondicherry is by no means so complete as in the Trichinopoly area.

Of the fossils from the Pondicherry beds, the Foraminifers are by far the most important. In this connection special attention may be drawn to the abundant presence of *Siderolites* recently noticed by the author[34] in one of the rocks of this area. A solitary occurrence of this form here had already been recorded by R. S. Sharma[43] in 1953; in some of the rocks now under study by the author we get this fossil in abundance, apparently represented by two or three different types. Attention has already been drawn to the occurrence of numerous *Siderolites* in some of the Ariyalur beds in the Trichinopoly area; these together with the forms now noticed in the Pondicherry area will obviously constitute valuable material for a full study of *Siderolites* and its associated many-sided problems of great interest,—all the more so since we know very little of this fossil from India. A paper on this subject is under preparation by the present writer and will be published shortly; suffice it to point out at this stage that the occurrence of a *Siderolites*-bearing rock in the Pondicherry area clearly establishes the presence of a Maestrichtian horizon in this Cretaceous succession. This will evidently occupy a stratigraphical position just below the Danian Nerinea beds and thus probably fix the age of the youngest part of the underlying Trigonoarca beds.

We may now proceed to consider another very interesting and important occurrence of Foraminifera recorded by Kossmat, *viz.*, the presence of certain *Orbitoides* in the Nerinea beds, which according to him " appear in great numbers and fill the matrix of the larger fossils". In one of the rocks collected from S.S.E. of Valadavur, he noticed many of these *Orbitoides* shells together with the remains of *Amphistegina*. Since Blanford and Stoliczka had already shown the presence of similar *Orbitoides* in some of the Niniyur beds of the Trichinopoly area, their occurrence here confirmed Kossmat in the opinion he had already formed on other evidences that the Nerinea beds were the equivalents of the Niniyurs. He wrote: " The sandy limestone of the Nerinea beds of the uppermost division of the Cretaceous is completely filled with well-preserved Foraminifera among which the genus *Orbitoides* is particularly striking by its frequency. As Stoliczka was able to prove the existence of this genus in the Niniyur beds of Niniyur, Trichinopoly District, this circumstance increases the agreement which exists already elsewhere between the two groups of beds." The two genera mentioned by Kossmat, *viz.*, *Orbitoides* and *Amphistegina*, have also been figured by him, but no detailed descriptions of these fossils are available.

In his review of the " Cretaceous Orbitoides of India " published in 1908, Vredenburg[50] also referred to these *Orbitoides* remains from the Pondicherry area, and described them in some detail. He pointed out that these shells which were lenticular and very convex were comparatively speaking of very small dimensions (diameter less than about 2 mm.); the equatorial chambers according to him tend to be hexagonal in outline and the lateral layers (as seen in transverse sections) are " numerous, thin, regularly piled upon one another, traversed at equal intervals by numerous thin calcareous pillars gradually widening from the megasphere to the outer surface ". After studying all these characters, Vredenburg concluded that these forms do not belong to the same species as those figured by Stoliczka and said: " These specimens (from Pondicherry) probably represent an undescribed species for which the name *O. minima* might be suggested; but the available material is not sufficient for a complete diagnosis." According to him they indicate a horizon younger than all the other Orbitoides zones in India.

In the course of his study of some of the rocks from the Pondicherry area in 1939, the present writer[27] noticed that one of the limestones collected from near Valadavur contained a foraminiferal fauna of extraordinary interest, and revealed the presence of abundant *Nummulites* (*Camerina*) together with plenty of *Discocyclina*. The discovery of such a striking association of these two forms in a limestone coming from an area which had all the time been considered as composed exclusively of Cretaceous rocks naturally arrested our attention since they clearly indicated an early Tertiary age for the containing rock. In view of the outstanding interest and importance of this find, these foraminifers were studied in some detail and it was concluded that the bed containing these foraminifers is undoubtedly Eocene and belongs to a stage very low down in that system,—comparable to the Paleocene beds (Ranikot) of N.W. India.[38] It was thus evident that here in this ' Cretaceous area ' there is undoubtedly a part of the lower Eocene also present overlying the Cretaceous series. This conclusion is also supported by the fact that in the Rajahmundry area, further north along the east coast, we have a similar occurrence, of certain marine (inter-trappean) beds containing fossils definitely indicating a lower Eocene age.

It is most interesting to find that at about the same time as the publication of our papers referred to above, Furon and Lemoine[4] also announced the presence of certain nummulitic rocks in the Pondicherry area, based on their examination of certain old borings from depths of 150–180 metres which revealed a limestone containing *Assilina granulosa* (of Lutetian age) and a sandstone with *Discocyclina pratti* (of Bartonian or Stampian age). These are undoubtedly Eocene beds but obviously different from what we had noticed as mentioned above. Referring to these finds the present writer said in 1942: " From all these recent observations one thing is clear, and that is, that in the Pondicherry area we have also got beds of Eocene age in addition to the Cretaceous. Further work is now necessary to determine the exact ages of these beds and their relation to one another; and the results will no doubt be of great interest in the study of the Cretaceous-Eocene transition in this area."

Work on these lines is now being pursued by the author and many interesting observations have since been made. Before dealing with these, it is first necessary to clarify the position regarding the occurrence of *Orbitoides* in beds of Danian age both in the Trichinopoly and Pondicherry areas, a feature which perplexed Vredenburg[50] very much; he said: " I am not aware of any recorded observations as to the occurrence of *Orbitoides* in strata of true Danian age, if this term be restricted to the beds characterised by *N. danicus* and newer than the last zones of ammonites and hippurites." As has been already pointed out in dealing with the Niniyur group of the Trichinopoly area, recent studies have shown that the beds containing the *Orbitoides* there do *not* belong to the Niniyur group (Danian) as demarcated now; they are pre-Niniyur beds and constitute the youngest part of the Ariyalurs lying just below the Niniyur; the same beds also contain plenty of *Siderolites*; and these two fossils together fix the age of the containing beds as Maestrichtian. So the anomaly which Vredenburg worried about regarding the so-called occurrence of *Orbitoides* in Danian beds does not really exist in the Trichinopoly area. Now coming to the Pondicherry area where Vredenburg thought there was another instance of such a Danian occurrence of *Orbitoides*, here again our recent studies have clarified the position and eliminated the so-called anomaly recorded by Vredenburg. It is now seen that the *Orbitoides* mentioned by Kossmat in connection with his Nerinea beds and referred to as such by Vredenburg is really not *Orbitoides* at all; the form is really a *Discocyclina*, and the associated foraminifer in the same bed which Kossmat thought was *Amphistegina* is really *Nummulites* (*Camerina*). There are no true *Orbitoides* in the Nerinea beds of Pondicherry and thus no problem of ' Danian Orbitoides ' exists in this area either. If one should expect to come across true *Orbitoides* in the Pondicherry area, he must look for them in the *Siderolites*-bearing rock of Maestrichtian age mentioned above. The recent finding of abundant Orbitoids and *Siderolites* together in a bed of Maestrichtian age in the Ariyalur area (just below the Niniyur beds) warrants the belief that a fuller search in the Pondicherry area will reveal a similar occurrence of Orbitoids in the Maestrichtian horizon (just below the Nerinea beds) the presence of which is already indicated to us by the abundant *Siderolites* recently noticed.

While the above exposition helps us in eliminating the alleged anomaly regarding ' Danian Orbitoides ' in the Pondicherry area, it raises other questions of the greatest importance bearing on our recently discovered lower Eocene bed here *vis-a-vis* the Nerinea beds. From the way in which we have developed the argument above it would seem to appear that if the so-called *Orbitoides* and *Amphistegina* came from the Nerinea beds as recorded by Kossmat, the newly recognised *Discocyclina* and *Nummulites* (which are merely the forms previously described as *Orbitoides* and *Amphistegina* respectively) would also automatically belong to the Nerinea beds of Danian age. If so, there is no case at all for postulating the existence of a lower Eocene horizon in this area on the evidence of these fossils; indeed such a view has been recently put forward by R. S. Sharma[44] according to whom what we have in the Pondicherry area is merely an occurrence of *Discocyclina* and *Nummulites* (the latter form is what he recognises as *Operculinoides*) in the Danian Nerinea beds and nothing more, a conclusion in support of which he has also sought some local stratigraphical evidence.

But the position is by no means so simple. The point to consider now is whether the newly found foraminifers *really* come from the Nerinea beds. On stratigraphical and other palaeontological evidences, the Nerinea beds are to be considered as the equivalents of the Niniyurs. The type area for the Niniyur group is in the Trichinopoly District where as has already been described above we have a good succession of beds covering the Danian with probably even a Tertiary touch towards the top. Although foraminifers are quite commonly seen in these rocks, nowhere do we get here anything like the *Nummulites* and *Discocyclina* seen in the Pondicherry area. This according to Sharma " may be due to facies difference "—a suggestion difficult to accept in view of the known lithological and palaeontological similarities in other respects between the rocks of these two adjacent areas. The question whether the *Nummulites* we reported in 1939 in the Pondicherry beds is " the same as the form that has now been recognised as *Operculinoides* " by Sharma is also very doubtful in view of the known confusion and controversy even now regarding the identification and nomenclature of some of these Camerinid genera; and further, it is by no means certain that all the Camerinids found here are referable only to the genus *Operculinoides*; we seem to have there '*Nummulites*' also side by side. In any case, whether we call these forms *Nummulites* and/or *Operculinoides* makes no essential difference to their value as age indicators. In dealing with this question it is also not safe, as the present writer has pointed out elsewhere,[29] to attempt long distance correlations of the so-called Danian beds in different parts of the world, for in many cases we do not know what exactly their " Danian " is ! In fact, recent studies in many of those areas have shown that the so-called " Danian " beds there are really part of the Lower Tertiary.

The present author has recently examined more of the Pondicherry rocks containing these foraminifers of which several species are recognisable; and a separate paper on this subject will be published shortly. It is hardly possible to go into the details of this work here; suffice it to say that the evidence on hand clearly supports the conclusion that the rock in Pondicherry containing *Discocyclina* and *Nummulites* is a true Paleocene bed and has a distinct palaeontological individuality of its own as such, and cannot be considered as belonging to the Nerinea beds. What is happening here is that both the beds which are almost horizontal are found together in small patches, the former overlying the latter; and since both of them are of very small thickness and are lithologically similar, and the area has been subjected to irregular denudation, we get the impression at first sight that there is only one bed there and all the fossils collected in the locality come from a single horizon. A careful re-examination may be expected to bring out the real position regarding the occurrence of two distinct beds and show that the present confusion is merely due to an indiscriminate collection of fossils from the area on the assumption that they are all coming from one and the same bed. On the evidence even now available it is clear that here in the Pondicherry area we have a true lower Eocene (Paleocene) bed overlying the Danian Cretaceous. The finding of *Distichoplax biserialis* Diet. in this area recently reported by the author[32] further confirms this conclusion, for it is well known that this alga is characteristically a Paleocene form. The younger horizons of the Eocene here are represented by the beds of " Lutetian " and " Bartonian " ages described by Furon and Lemoine. All these studies clearly indicate the presence of an Eocene succession overlying the youngest Cretaceous division (the Nerinea beds) in the Pondicherry area. While this general conclusion may now be considered as well established, further detailed field-work, aided by borings if necessary, is required to get at all the Eocene beds of the area, determine their sequence, and work out the complete succession. The Pondicherry area is most interesting from this point of view as furnishing the only instance of its kind in Peninsular India where we have a marine Eocene series directly overlying the upper Cretaceous and thus affording a splendid opportunity for the study of the Cretaceous-Eocene transition in this area as part of the bigger problem of the Cretaceous-Eocene boundary in India and outside; and what is much more important, the Eocene succession in this area, when fully worked out, may also lead to the possibility of prospecting for oil in this region.

6. Rajahmundry Area

Having described the Trichinopoly, Vridhachalam, and Pondicherry areas which together constitute the most important group of the South Indian Cretaceous rocks, we may now pass on to another exposure of the Cretaceous found nearly 350 miles away along the coast, and that is the one near Rajahmundry. This is indeed a very small patch; but nevertheless it is quite interesting and important. Good outcrops are seen near Pungadi, Gowripatam, and Dudkur, and the common rock type is a gray sandy limestone containing abundant shells of lamellibranchs and gastropods. The first systematic account of these rocks and fossils was given by William King so far back as 1880[8]; they have not been examined in any detail ever since. After describing these rocks, King naturally compared them with those of the Trichinopoly area with a view to determine their equivalence and age in terms of the Trichinopoly sequence. The Rev. S. Hislop who was the first to examine these beds—even much earlier than King—had expressed the view that they were all lower Eocene in age. After considering all aspects, however, King wrote: " The majority of fossils are such as are usually considered as of Tertiary age, particularly the Gastropods; but the prevailing *Turritella* appears to be very close to *T. dispassa* Stol. a Cretaceous species from the

Ariyalur beds of the Trichinopoly District. The *Volutilithes* is very like *Voluta torulosa* Desh. which is a Calcaire Grossier species." Medlicott and Blanford who also went into this question at about the same time as King, expressed the view: "Although the whole facies is Tertiary, there is a remarkable absence of characteristic genera, and the chief distinction 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......the balance of evidence is rather in favour of referring the latter (Pungadi beds) to Cretaceous times rather than Tertiary. They may be of intermediate age." It may be noted that this view is strikingly similar to what H. F. Blanford said regarding the age of the Niniyur beds in the Trichinopoly area. He wrote: "There is much resemblance between some of these species (of the Niniyur fossils) and those of the Rajahmundry beds the fossils of which have been described by the Rev. Hislop; and one species of *Turritella* appears to be identical with *T. prælonga* of that formation......... It will be seen from the above that the Tertiary aspect of the fossils of the Niniyur bed is more due to the absence of characteristic Cretaceous forms than to the presence of those which we have been accustomed to think as peculiar to Tertiary deposits; but the latter are not entirely wanting." Attention may also be drawn to the occurrence of the important fossil *Cardita beaumonti* in the Rajahmundry beds recorded by Douville so far back as 1928, and again a few years later by H. C. Das Gupta. It is now known that this form is very similar to, if not identical with, the *C. jaquinoti* found in the Niniyur beds.

From the above resume it is clear that the Rajahmundry Cretaceous beds must be considered as belonging to the uppermost part of the Cretaceous, almost on the border-line between that system and the Tertiary. This position is almost exactly the same as that of the Niniyur group in the Trichinopoly area as has been explained above. It would be absolutely safe therefore to equate the two formations and assign them to the Danian. In this connection it must be noted that this question of the exact age of the Rajahmundry Cretaceous beds is important not only in itself but more so because of its bearing on the problem of the age of the Deccan Traps; for here in this area we have a unique example of an outlier of the Deccan Traps overlying this marine fossiliferous formation, thus furnishing a reliable means of determining the age of these lava flows; the interest in this stratigraphical position is further heightened by the fact that the Trap flows themselves include among them as 'inter-trappeans' certain fossiliferous sediments of a marine (or estuarine) character. Without going into the details of the evidence of this area on the "Age of the Deccan Traps" problem which has been fully discussed by the author elsewhere,[37] it is necessary to refer to this question here briefly in dealing with the Cretaceous of the Rajahmundry area. As has been pointed out above, the Rajahmundry Cretaceous beds below the Traps are of Danian age; the fact that the Deccan Trap flows overlie these beds with a distinct unconformity clearly indicates that these traps are post-Danian and therefore of lower Eocene age, a conclusion which is further confirmed by the internal evidence of the fossils in the inter-trappean beds themselves as worked out by S. R. Narayana Rao and K. Sripada Rao.[17, 46] It is thus obvious that the Rajahmundry area is most interesting from many points of view and calls for further work on the stratigraphy and palaeontology of the Cretaceous beds together with those of the overlying 'traps and inter-trappeans'.

7. Assam Area

Having described the four important areas in South India where we get the marine Cretaceous rocks along the Coromandel coast, we may now pass on to Assam where again we have another exposure of similar rocks. Although Assam is not in South India and its inclusion in this paper may therefore seem to be irrelevant, it is important to note that the Cretaceous rocks there were deposited by the same marine transgression which gave rise to the South Indian rocks; and from the geological point of view any study of these would be incomplete without a reference to the Assam area also; in fact, the occurrence in Assam of Cretaceous rocks belonging to the South Indian facies is a feature of special interest and importance as will be seen from the sequel. The presence of Cretaceous rocks in Assam has been known for quite a long time; and even the early workers observed that in their general development and palaeontological features these rocks were more similar to those of the Trichinopoly area in the far off south than to the much nearer Cretaceous rocks of the northern type. The Assam area is further important because we have there a good development of the lower Tertiary also above the Cretaceous and the entire succession has been examined in some detail within recent years.

Confining our attention for the present to the Cretaceous rocks of Assam, it would be interesting to compare them with those of South India and determine their equivalence in terms of the typical Trichinopoly succession. The most important contribution on this subject is the paper published by Spengler in 1923[45] based on a study of a representative collection of fossils from this formation including lamellibranchs, gastropods, ammonites, and echinoids. On this evidence, Spengler concluded that the Cretaceous rocks of Assam belong to the Ariyalur group indicating an upper Senonian (Campanian) age and that no older Cretaceous horizon is represented here—thus superseding the earlier view which had been expressed by Stoliczka that in the Assam Cretaceous two distinct divisions could be recognised, an older corresponding to the Utatur group and the younger to the Ariyalurs. According to Spengler: "In Assam we do not know an older Cretaceous horizon than the upper Senonian and the transgression began with this stage in that region. This conclusion agrees strikingly with that arrived at by Kossmat in the Pondicherry District where contrary to Stoliczka's statements, only a Senonian horizon was proved to exist." Spengler recognised in the Assam rocks a number of species identical with those of the Ariyalur group in the south; and taking the entire fossil assemblage in the Assam area, he worked out that nearly 60% of the forms were characteristic of the upper Senonian, thus clearly supporting his correlation of the containing beds with the Ariyalur division. The more valuable part of Spengler's contribution is his analysis of the relation between this upper Senonian Assam fauna with those of corresponding age from Baluchistan on one side and Trichinopoly on the other. This work has an important bearing on the study of the palaeogeographical conditions during the period, and will be taken up for further discussion later on in this paper while dealing with this topic.

A further contribution to our knowledge of the Assam Cretaceous was made by H. C. Das Gupta[2] in a short note on the Cretaceous fauna of the Khasi Hills which he published in 1929. In this paper Das Gupta referred to several other species of fossils in addition to those described by Spengler and showed that these also further supported the upper Senonian age assigned to the Assam beds. Das Gupta further observed: "The Khasi Hills specimens are remarkably poor in ammonites and this fact coupled with the presence of *Pyrina ataxensis* and *Echinocyamus kamrupensis* n. sp. may lead one to think that the Khasi Cretaceous beds represent a stage corresponding with the top of the Ariyalur beds, and that their relationship with the Niniyur beds must be *sub judice* until a thorough investigation of these latter beds has been worked out."

The fact which we may now consider as well established that what we have in the Cretaceous of Assam are beds belonging to the Ariyalur group, raises quite a number of interesting questions for further study in the light of the recent advances in our knowledge of these rocks in the Trichinopoly area described above. Two of these questions which call for immediate investigation in the Assam area are the following: (i) whether we have there a clear Maestrichtian horizon like the one recently found in the Ariyalur area by the beds containing a typical "Orbitoid-Siderolites" assemblage; and (ii) whether we have in the upper Cretaceous succession of Assam a division corresponding to the Niniyur group (Danian) of South India as we understand it now. A more intensive study of the Assam Cretaceous area with special reference to these two problems would be a most valuable contribution.*

8. Palaeogeographical Conditions in India during the Cretaceous Period

Having described the Cretaceous rocks of South India, we may now proceed to consider the light they throw on the general question of the palaeogeographical conditions which obtained in India during this period. A full study of this problem would involve a detailed reference not only to the Cretaceous rocks in other parts of India but also a comparison of all these with those outside the country; for it must be remembered that when once we begin to deal with palaeogeographical problems we must widen our outlook as far as possible. It is also necessary for purposes of reconstructing the complete chain of changes to take into consideration the palaeogeographical position in the immediately preceding period, *viz.*, the Jurassic on the one hand, and that in the succeeding period, *viz.*, the Eocene on the other. Such an elaborate study is obviously outside the scope of this paper; but nevertheless it will be interesting to review the position briefly so far as India is concerned.

It may at the outset be pointed out that quite a number of workers in and outside India have already dealt with this problem and expressed their views from time to time. So far back as 1897 Kossmat gave an account of "the zoogeographical conditions of the Indo-Pacific region" during the Cretaceous times based on his work on the Cretaceous deposits of Pondicherry and a comparative study of their fossils with those of other regions. Among the later geologists who have made valuable contributions on this subject, special mention may be made of E. Spengler (1923), A. W. Grabau (1927), C. S. Fox (1930), Von Huene and Matley (1933), A. K. Dey (1937)

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* The results of the investigations made by the Geological Staff of the Assam Oil Co. are embodied in a note by Messrs. Wilson & Metre (1953). According to this note the succession in the neighbourhood of the Cretaceous-Eocene boundary is:

Lakadong Limestone
Therria stage
Langpar stage
Mahadek stage.

Of these, the Mahadek stage is of Maestrichtian age and the overlying Langpars have been regarded as Danian (Ghosh, 1940) from the presence of a Nautilus related to *Hercoglossa danicus*. The rocks of the Therria stage contain mostly small foraminifera in a hard limestone, and are as such difficult to determine specifically; the overlying Lakadong limestone, however, is highly fossiliferous and contains a typical foraminiferal and algal assemblage indicating Ranikot age.

From these observations, it is clear that the Maestrichtian horizon is undoubtedly represented in the Assam Cretaceous; the probable presence of the Danian is just indicated, but not yet conclusively established.

and L. M. Davies (1940). The present writer also dealt with this topic in a general way in the course of his Presidential Address to the Geology Section of the Indian Science Congress in 1940 on the " Recent advances in our knowledge of the Upper Cretaceous and Lower Eocene Beds of India, with special reference to the Cretaceous-Eocene Boundary". In dealing with this question here the author has reconsidered the entire position and arrived at certain conclusions based on a synthesis and reinterpretation of the observations made and the views expressed by the earlier writers; a new picture has thus been evolved of the palaeogeographical conditions in India during the Cretaceous period which in his opinion would meet the needs of the situation on a more satisfactory basis and be helpful in unravelling the geographical history of the areas concerned.

According to the commonly prevailing view based on earlier studies the Cretaceous rocks of India fall into two distinct groups: (i) including those of northern and north-western India laid down in the sea of Tethys and its extensions right down to the Narbada valley; and the other (ii) including the Cretaceous rocks of South India and Assam (those described in this paper) which were deposited during a transgression of the southern sea (the Indo-Pacific) in this region. It is also usually believed that these two seas were quite distinct being effectively separated by the Indian portion of Gondwana land in between, so as to prevent all intercommunication and consequent migration of faunas from one to the other (*vide* Fig. 1). This conclusion was generally accepted as being fully supported by all the available evidence. Recent and more detailed studies in India and elsewhere however make it necessary to re-open this question and examine the validity of the prevailing view. Various observations having a bearing on this problem have been made from time to time within recent years by workers in different areas; and from a careful review of these it would appear that a different picture of the palaeogeography of India during the Cretaceous period has now to be conceived.

Before proceeding further in this discussion we may for a moment go back to the Jurassic and note the distribution of sea and land in India during that period. On the north-western side the Sea of Tethys had even then already transgressed as far down as Cutch giving rise to the marine Jurassic rocks in that area. The southern sea had also transgressed at about the same time along the east coast as is evidenced by the thin but undoubted marine sediments occurring here and often found intercalated with the upper Gondwana beds of this region. What we see in the next period, *viz.*, the Cretaceous is a further development of this picture with both the transgressional seas becoming more extensive; it would be most interesting therefore to examine in detail the sedimentary transition from one system to the other particularly in Cutch on the northern side and in the east coast, on the southern. In both cases, we have been accustomed to consider that sedimentation ceased at some time in the Jurassic, and was resumed only later by the subsequent middle Cretaceous transgression; but recent studies indicate that this is not so. We now know that according to Dr. Rajnath, the topmost beds (the Bhuj series) of the so-called Jurassics of Cutch go into the next younger system and are about Aptian in age; and from a comparative study of these Jurassic-Lower Cretaceous faunas of Cutch and their affinities with those of Mombasa and Madagascar, Spath actually came to the conclusion that "the Indian Ocean, in upper Jurassic times, differed from its modern representative chiefly in being open to the Tethys in the north". In the east coast of South India also, undoubted lower Cretaceous (Neocomian) horizons have been recently noticed in the so-called 'Jurassic areas' as has been shown by Spath's work on certain ammonites collected from some of these beds. Thus it would appear that in both the regions, the seas which invaded the land areas during the Jurassic times stayed on into the lower Cretaceous also; and it was these very seas that further advanced at about the middle Cretaceous times constituting the great Cenomanian transgression. The recognition of this fact will be very helpful in dealing with many controversial problems in the geological history of these regions and prove particularly valuable in tracing the evolution of the contemporary palaeogeographical conditions in India during the Jurassic-Cretaceous times.

Now coming to the Cretaceous itself, as has already been pointed out, we have an extension of the northern sea starting at about the beginning of the upper Cretaceous period along what is now the Narbada valley; at about the same time, we have also the further transgression of the southern sea along the east coast and extending from Trichinopoly in the south to as far north as Assam, giving rise to the upper Cretaceous rocks of these areas. Recent studies of the faunas of both these series of Cretaceous deposits—the northern and the southern—in India, and their corresponding representatives in the adjacent countries have revealed the important fact that the two sets of faunas are not so exclusively distinct as we thought they were. Several cases have been brought to light where we have the so-called 'northern' types occurring in the typical 'southern' areas and *vice versa*. In fact, even so far back as 1895, Kossmat had already pointed this out and said: "The fauna of Southern India comprises the most important types of the two great areas (the Indo-Pacific and the Atlantic) and thus serves as a connecting link between them.... The fauna of the Trichinopoly Cretaceous have remarkable affinities to the European fauna especially if we have regard not only to identical but also to closely allied forms." More instances of such 'commingling' are being noticed, as for example in the presence of typical South Indian elements in the Cretaceous of the Narbada valley as also the occurrence of Tethyan forms in the South Indian areas. Outside India, in the countries bordering the two marine provinces, such evidences are also becoming more and more common, the most striking example being in Persia where according to Grabau the upper Cretaceous marine fauna "shows a mingling of Indo-Pacific species from Ariyalur with Western European species from Aix-la-Chapelle". In the light of these observations it follows that the old idea of the complete and exclusive separation of the two seas can no longer be maintained; it is now clear that there *were* some interconnections between the two here and there, though local and temporary, permitting a movement of faunas to and fro; and such means of intercommunication should form an important part of the picture showing the distribution of land and sea during the Cretaceous period. In discussing this problem more fully we have to focus our attention on two areas in India (i) the Narbada valley and (ii) Assam; and we will now proceed to deal with each of these regions in some detail.

The Bagh beds of the Narbada valley clearly indicate the presence of an arm of the sea there during the upper Cretaceous period; and this was evidently an extension of the Tethys from the north. This sea which had already come down as far south as Cutch during the lower Cretaceous period now advanced further during the subsequent upper Cretaceous times and occupied the region of the present Narbada valley. Towards the close of the Cretaceous, this sea began to recede not only from this area but also gradually from the other parts of north-western India over which it had transgressed; and this 'retreat' was complete by the dawn of the Tertiary period. Although it is true that in several parts of this region we *have* true marine deposits (the Ranikot series) belonging to the earliest Tertiary division, the Paleocene, it is most important to note that, as has been pointed out by L. M. Davies,[3] this Ranikot sea was not a remnant of the sea of Tethys which had previously occupied those areas, but arose separately as a narrow arm of the southern sea (Indian Ocean) starting in the region of the Arabian Sea near Sind and extending as far north as Kashmir (and even beyond) *via* Baluchistan, parts of the Punjab, and N.-W. Frontier Province and constituting a marine province quite distinct at that time from the Tethyan. Putting these two palaeogeographical pictures together—the uppermost Cretaceous and the lowermost Eocene—and trying to work out the transition from one to the other in north-western India, and paying at the same time due regard to the examples of "commingling' of the 'Northern' and 'Southern' faunas in the Narbada valley and elsewhere during the upper Cretaceous period, it seems reasonable to conclude that the Indian Ocean was already connected on the north-western side with the southern end of the Tethyan arm probably in the region of Cutch during the Cretaceous times (as it was, even in the upper Jurassic, according to Spath). Such a conclusion would not only provide the possible route for the exchange of faunas, though perhaps on a limited scale, between the northern and the southern seas, but would also help in explaining the 'change over' from one sea to the other in north-western India during the Cretaceous-Eocene transition period. According to the picture now proposed, it would follow that as the arm of the Sea of Tethys was withdrawn from this region at the close of the Cretaceous period, its place was occupied *pari passu* by the southern sea which was already there near Cutch and now transgressed northwards in the form of a long and narrow arm extending from Sind to as far north as Kashmir, and giving rise to the beds of the Ranikot series in this region. This mode of 'change over' from the old order to the new would be easy to understand and accept under the above circumstances; according to the older ideas, it is difficult to find a suitable explanation for the manner of this transition.

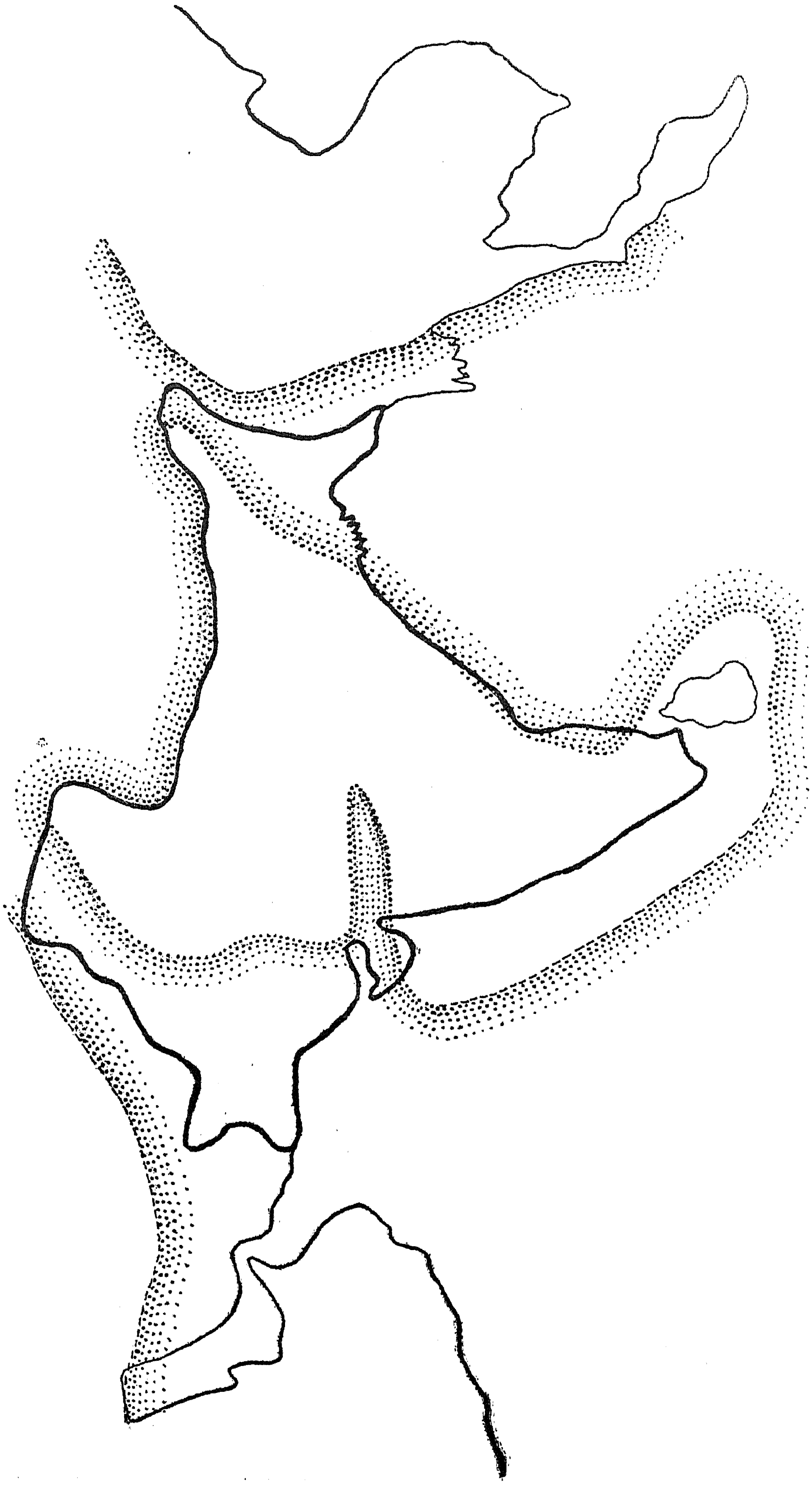
We will now turn our attention to the Assam area where again we have an interesting situation having a bearing on this study of the Cretaceous palaeogeography in India. In his paper on "Contributions to the Palaeontology of Assam" published in 1923, Spengler[45] has given an account of the fauna noticed in the Cretaceous rocks of this region and fixed their age as upper Senonian; he has further gone on to give an analysis of this fauna and discuss their affinities with those of beds of corresponding age in South India (due to the southern sea) on the one hand, and those of Baluchistan (due to the northern sea) on the other. As pointed out by Spengler this study brings out the important fact that "the fauna of Assam occupies a medium position between that of South India and that of Baluchistan. But Assam does not lie between Baluchistan and South India. The three areas form the corners of an equilateral triangle, the sides of which have a length of 2,000 km. The relationship is much less clearly marked on the line connecting Baluchistan and South India than on the two others..... Since typical Mediterranean elements are missing altogether in Assam, we are forced to believe that the upper Senonian transgression of Assam started from the Indo-Pacific Ocean. To explain the simultaneous relation to the Cretaceous fauna of Baluchistan, we may assume that the junction of the Indo-Pacific Ocean with the Tethys perhaps lay not far to the north-east of Assam". Since Spengler thought that there was still the old Gondwana land barrier in the south, he expressed the view "that exchange of faunas was possible not across India but on the line of S. India-Assam-Baluchistan".

The most significant suggestion made by Spengler as a result of his studies is that the Cretaceous sea of Assam (which undoubtedly was a part of the Indo-Pacific) actually joined with the Sea of Tethys at the north-eastern end of Assam, thus making it possible for the marine faunas of the southern sea to migrate *via* Assam into the Tethys of the Himalayan region and ultimately find their way to the seas of north-western India covering N.-W. Frontier Province, Baluchistan and Sind. According to the suggestion made by the present author above, another route connecting the two areas was also available for migration, *viz.*, from Assam along the east coast of South India, southwards rounding Ceylon and going parallel to the west coast and ultimately joining up with the Northern Tethyan Sea in the Cutch-Sind region. Thus a certain amount of intercommunication between the northern and southern marine biological provinces was possible along both of these routes; as to which of these routes was the more probable in any given group of fossils, as also the actual direction of movement from the starting centre, are questions to be decided on the merits of the evidence available in that particular case.

So far as South India is concerned, the sea which had transgressed along the east coast during the Cretaceous seems to have retreated from all over the region by the close of the period; the only exception being in the Pondicherry area where it stayed on into the Eocene. As to how long it continued to stay on here during this period is a matter than can be decided only after the complete succession of the newly discovered Eocene beds of the area is worked out.

A concrete picture of the distribution of land and sea as visualised by the author and described above is given on the accompanying Map (Fig. 7). On the basis of such a disposition of the land and sea areas, all the known affinities and relationships of the contemporary faunas, together with the several cases of the 'admixture' or the 'commingling' of the Tethyan and the Indo-Pacific types not only in India but also in the other adjacent countries like S. Africa, Madagascar, Burma, and W. Australia, can be satisfactorily explained. It is also interesting to note that according to this picture, the main land mass of Peninsular India was, at least for some time during the upper Cretaceous period, an island surrounded on all sides by some sea or another; this idea had in fact been already suggested in a way by Spengler and Palmer.

It must however be pointed out that this map (Fig. 7) gives only a generalised idea of the land and sea distribution during the Cretaceous; it is not equally true in details to all the parts of that period, for several local changes



TEXT-FIG. 7. Map of India showing the probable distribution of land and sea during the Cretaceous period, as now proposed by the author. Dotted areas represent the Sea.

were taking place now and then during the Cretaceous itself. Nevertheless it serves to bring out the essential features of the land and sea configuration of those days, particularly as it stood during the latter half of the Cretaceous period, and may serve as a useful starting point for further discussion. Future studies on the distribution of the Cretaceous faunas and their mutual relationships especially in India and the adjacent countries may be expected to confirm the correctness of the proposed picture in its essential features.

9. CORRELATION OF THE SOUTH INDIAN CRETACEOUS AREAS

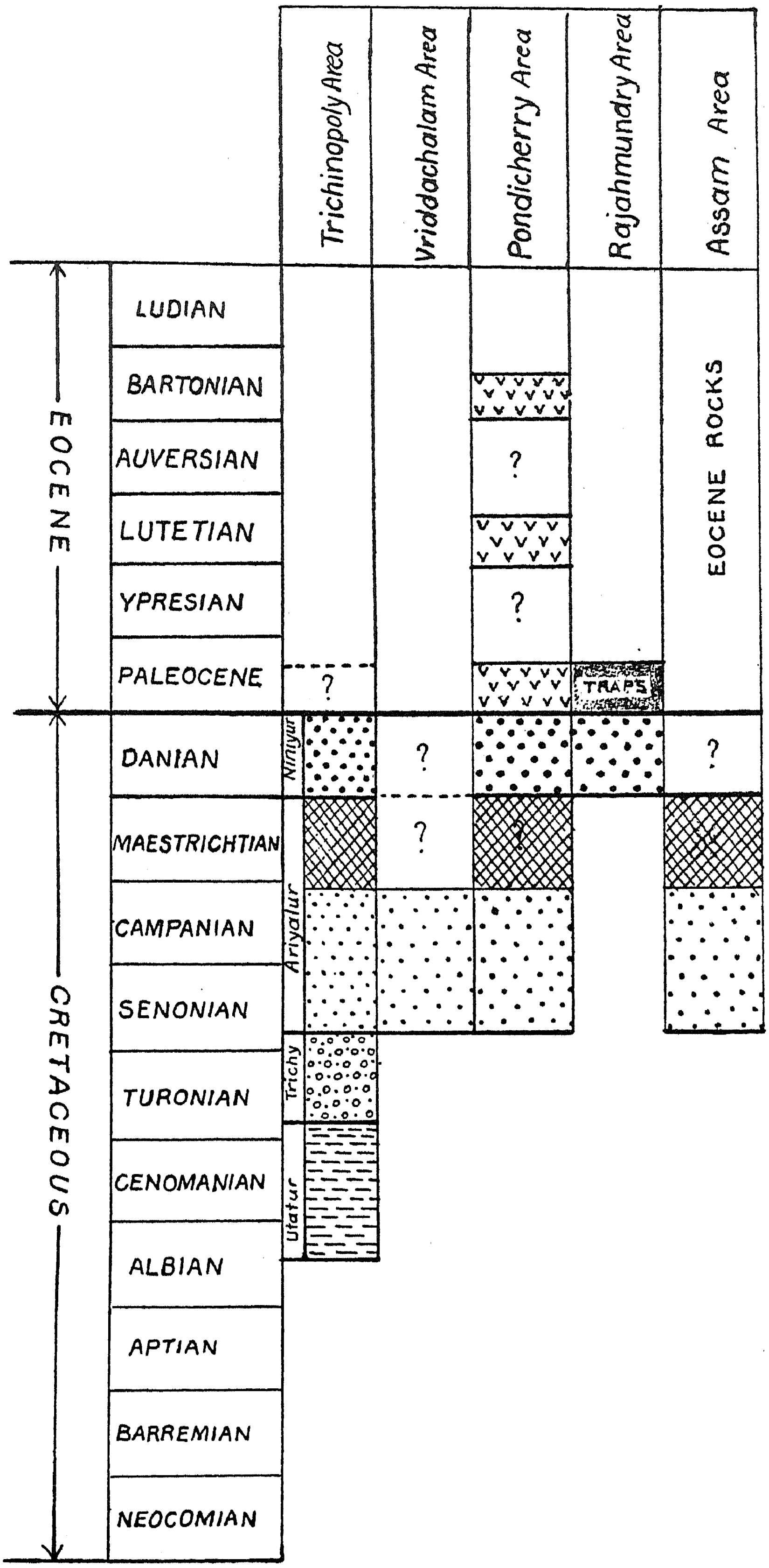
The above is a brief account of the Cretaceous rocks found along the east coast of India of which there are 5 areas now noticed between Trichinopoly in the south and Assam in the north. Although it is generally true that these were all deposited as a result of a marine transgression in this region during upper Cretaceous times, it is evident that this transgression did not take place simultaneously throughout nor did the transgressive sea later retreat at the same time from all points. A study of the formations in each of these areas and their comparisons shows that what has been broadly termed as the Upper Cretaceous marine transgression along the east coast may be actually resolved into 5 separate movements of the sea involving readjustments due to local transgressions and regressions from time to time. To facilitate this line of investigation, a chart showing the succession of these rocks in the different areas and their mutual correlation and age indications in terms of the standard stratigraphical scale has been prepared and given below (*vide* Fig. 4); a study of this brings out certain important points which we may now proceed to consider.

It will be seen at the very outset that of all these Cretaceous areas, the one in the Trichinopoly District is obviously the most important; for it is only here that we get a full succession of the upper Cretaceous ranging from the upper Albian right up to the close of the Danian, and it is also the area which has been best studied. For these reasons it is only natural that this is taken as the type area for comparing and correlating the rocks of the other smaller areas. From a study of the disposition and stratigraphical relationships of the rocks in the Trichinopoly District, 5 oscillations of the sea involving local transgressions may be inferred:—

(i) Upper Albian .. the first marine transgression giving rise to the beds of the Utatur group.

(ii) Lower Turonian giving rise to the beds of the Trichinopoly group.

(iii) Lower Senonian giving rise to the beds of the Ariyalur group included in the lower and a large part of the middle subdivisions of Blanford.



TEXT-FIG. 4. Chart showing the correlation and age of the Cretaceous rocks of South India. (Not to scale.)

(iv) Maestrichtian .. giving rise to the newly discovered 'Orbitoids-Siderolites' bearing beds, representing the topmost horizon of Blanford's Middle Ariyalur subdivision.

(v) Danian .. giving rise to the beds of the Niniyur group.

In the light of these observations in the type Trichinopoly area, the comparative position in the other 4 areas may be summarised as follows:

1. In the Vridhachalam area so far as we know at present the beds are only those due to transgression No. (iii); whether rocks due to (iv) and/or (v) are represented here is a matter requiring further exploration.

2. In the Pondicherry area we have beds due to (iii) and (v); the presence also of beds belonging to (iv) in between is indicated by the "Siderolites-bearing rock" which has just been noticed. Further work may reveal the occurrence of beds (like those recently found near Ariyalur) characterised by the 'Orbitoids-Siderolites' assemblage so typical of the Maestrichtian. This area is however unique in that we have a marine fossiliferous Eocene succession also here (though only in parts) directly overlying the youngest Cretaceous (Danian).

3. In the Rajahmundry area we have beds belonging only to (v) representing the Danian. The most interesting feature here is that overlying this Danian, we get a small outlier of the Deccan Traps with marine (or estuarine) fossiliferous inter-trappeans of lower Eocene age.

4. Lastly in the Assam area, it is now clear that we have there formations belonging to both (iii) and (iv); whether there are no beds representing (v) we are not sure; a fuller investigation is necessary for deciding this. The fact that there is a good Eocene succession here overlying the Cretaceous is of course well known.

10. CONCLUSION

The present paper gives a connected account of our present knowledge of the Cretaceous rocks of South India, with special reference to recent studies and their outstanding interest and importance in the elucidation of the geological history of India at one of its most interesting periods. This review is also helpful in revealing the vast scope there is for further exploration and research in these areas, especially in the field of micropalaeontological studies which are of such fundamental importance at the present day. It may also be pointed out that Peninsular India occupies a key position in the study of the geological history of the Southern Continents during the Cretaceous period; studies in this region will thus have a most important bearing on the correct understanding and interpretation of their mutual stratigraphical and palaeogeographical relationships, and will also undoubtedly help in the proper reconstruction of Earth History, as a whole, during the Cretaceous times.

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