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PRECAMBRIAN STROMATOLITES IN THE PRANHITA-GODAVARI VALLEY (SOUTH INDIA)

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SUMMARY

Stromatolites of various growth patterns occur in a narrow belt from Mancherial to Mulug in the Pranhita-Godavari Valley, in the lower part of the Precambrian Pakhal Group. On the basis of the available radiometric dating, the stromatolites are tentatively assigned a Middle Proterozoic age. Analysis of the stromatolite structures and associated sediments suggests that they represent accumulation in a tidal flat environment, which helps to delineate a Precambrian strand line in the area. The growth pattern of a new type of elongate stromatolite structure has been analysed and it has been suggested that the shape and orientation of these structures are related to the palaeocurrent system.

INTRODUCTION

Precambrian sedimentary rocks are widely developed in different parts of India. So far few traces of undoubted organic remains have been reported from these sediments. However, in recent years stromatolites, indicating the presence of organic activity by algae, have been recorded by several authors in a few isolated Precambrian areas. In the Pranhita-Godavari Valley, on the eastern side of peninsular India, Precambrian sedimentary rocks are extensively developed (Fig.1) and have been studied by several authors since the pioneering work of KING (1881). The occurrence of stromatolites in these rocks was, however, overlooked by earlier workers.

The present study, part of a project undertaken by the Geological Studies Unit of the Indian Statistical Institute, reports the discovery that stromatolites are widely developed in the area. This paper records details of the occurrence of these stromatolites and briefly describes their palaeogeographic and geochronologic significance.

PRECAMBRIAN SEDIMENTS OF THE PRANHITA-GODAVARI VALLEY

Stratigraphy

In the Pranhita-Godavari Valley, the Precambrian sedimentary rocks outcrop in two northwest–southeast trending belts flanking both sides of the valley. The axial part of the valley is covered by the younger Gondwana sediments. The stratigraphic succession of the area was worked out by KING (1881) who recognized the following major divisions:

The Gondwanas
~~~~~~~~~~
The Sullavais
~~~~~~~~~~
The Pakhals { Albaka Subdivision / Pakhal Subdivision }
~~~~~~~~~~
Basement complex
(Archaean)

Of the two subdivisions of the Pakhals, only the Pakhal Subdivision is developed in the southwest side of the valley. The Albaka Subdivision is restricted to the northeast side.

In recent studies of the Precambrian belt along the southwest side of the valley, the Pakhal Subdivision has been divided into two new subgroups, separated by an erosional unconformity. The broad stratigraphic succession on this side of the valley has been worked out as:

Gondwana Supergroup
~~~~~~~~~~
Purana Supergroup (Precambrian) { Sullavai Group
~~~~~~~~~~
Pakhal Group { Mulug Subgroup
~~~~~~~~~~
Mallampalli Subgroup } }
~~~~~~~~~~
Undifferentiated basement complex
(Archaean)

In the Mallampalli Subgroup a lower, arenaceous, Mallampalli Formation and an upper, calcareous, Pandikunta Formation have been recognized (BASUMALLICK, 1967). The stromatolites are restricted to the calcareous Pandikunta Formation of the Middle Proterozoic Mallampalli Subgroup.

The Pandikunta Formation

The rocks of the Pandikunta Formation outcrop in a narrow belt, bounded on the southwest by the underlying Mallampalli Formation and on the northeast by the overlying formations of the Mulug Subgroup. This belt follows the general alignment of the outcrops of the Precambrian rocks and has been persistently traced from northwest of Mancherial (18°52′N 79°28′E) to southeast beyond Mulug (18°11′N 79°58′E). The tract occupied by the rocks of this formation forms
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a flat valley, bordered on both sides by belts of small low-lying ridges, formed by the resistant arenaceous rocks of the Mallampalli Formation and basal formations of the Mulug Subgroup.

The beds of the Pandikunta Formation dip regionally from northeast to north-northeast at a low angle, normally ranging from 10° to 20°. Only near faults are the beds more steeply inclined. The outcrops of this formation are normally well exposed, but a continuous mapping of the formation over a wide area, particularly of the individual rock units, is difficult due to the presence of a large number of faults. This belt of sedimentary rocks is affected by two major sets, one set at a very low angle and the other set at a high angle to the regional strike of the formation. Many offsets of strata due to faulting amount to hundreds of feet.

The maximum thickness of the formation, still preserved in the Ramgundam area beneath the erosional unconformity separating this formation from the overlying Mulug Subgroup is 1,179 ft. The thickness of the formation increases towards southeast and near Mulug it may be 8,050 ft.

The dominant lithology of the Pandikunta Formation is carbonate rock, both limestone and dolomite. The carbonate rock occurs as well-developed, fairly persistent beds. Many thin, individual beds can be traced for tens of feet along the strike. The beds in the lower part of the formation are, in general, thin to medium (McKee and Weir, 1953), but are thinner in the upper part. Some of the thicker beds exhibit thin laminations, but more commonly these thick beds are massive. Other rock types associated with the carbonate rocks are glauconitic sandstone and a few lenses of shale. The sandstone occurs mainly as persistent thin layers, interstratified with the carbonate rocks. Small thin lenses of sandstone, however, are quite common.

The stromatolites are restricted to the carbonate rocks. The beds containing stromatolites are light grey, buff, purple and light pink, weathering black, fine grained, massive, dolomitic limestone.

Different lithotypes of the formation are characterized by the common occurrence of shallow water, primary sedimentary structures, e.g., small-scale cross-bedding and ripple marks. Well developed climbing ripples have been noted in the carbonate rocks. Shrinkage cracks are widely developed. Besides these, intraformational limestone conglomerates occur in a few places. These conglomerates consist of irregular, rounded or angular limestone fragments, which in vertical sections show flat fragments arranged in discrete but discontinuous layer from which the original bedding can easily be reconstructed. Many of the interstitial spaces between these fragments are filled up by carbonate or terrigenous detritus. The mode of occurrence of the fragments suggests that the fragmentation was a desiccation phenomenon. Some of these conglomerates contain fragments of algal colonies.

Stromatolites of the Pandikunta Formation

Stromatolites. The term "stromatolite" was introduced by KALKOWSKI (1908), and is used to designate both organic and inorganic laminated structures. Algal stromatolites are now generally accepted to be laminated structures attributable to the sediment-binding activity of blue-green (Cyanophyta) or green (Chlorophyta) algae. A discrimination has been made between fossil algae where recognizable skeletal structures (e.g., cell walls, reproductive organs etc.) are preserved, and algal stromatolites that exhibit only fine laminations of particulate sediments (REZAK, 1957; LOGAN et al., 1964). The current interpretation of ancient stromatolites as organo-sedimentary structures composed of particulate sediments is based on BLACK's (1933) work on recent stromatolitic sediments in the Bahamas. It has been noted that during periods of non-deposition a thin algal mat is formed and, as the sediment is deposited, the filamentous algae permeate it and bind it together. Lamination due to mechanical deposition is accentuated by the alternation of these organic layers.

Algal stromatolites normally develop as mound-like or head-like structures standing above the contemporary depositional surface. The form and shape of the stromatolite structures probably are largely controlled by the interaction of various factors of the contemporary physical environment (LOGAN et al., 1964; GINSBURG, 1967).

Distribution within the valley. Stromatolitic horizons extend almost continuously for about 45 miles, from Mancherial[1] to Mulug (Fig.1). These structures have been studied in some detail in two areas (Fig.1). One, of about 45 sq. miles, lies around Ramgundam—18°45′N 79°26′E; southwest of Naspur on KING's (1881) map—and the other area, of about 36 sq. miles, occurs southwest of Manthani (18°38′N 79°40′E). The latter area will be named after this village Manthani. The Manthani area lies about 9 miles southeast from that of Ramgundam.

Mode of occurrence. Stromatolites occur either at well-defined horizons, conformable with overlying and underlying carbonate rocks that lack stromatolite structures, or they occur in small irregular bodies, discordant with the host rocks. Virtually, the entire area of such conformable horizons or discordant bodies is formed of algal stromatolites. As an individual algal structure develops from a small "head-like" body and is formed by the piling up of thin algal laminae, the stromatolite-bearing horizons do not develop any persistent internal stratification. Though the presence of large numbers of transverse faults makes the continuous tracing of the stromatolite horizons difficult, yet, when the exposures are good, these horizons, in places, can be traced for well over a mile. The thickness of the

[1] In the *Survey of India*, 1″ to a mile toposheet (1928), the spelling of the area is "Mancheral".

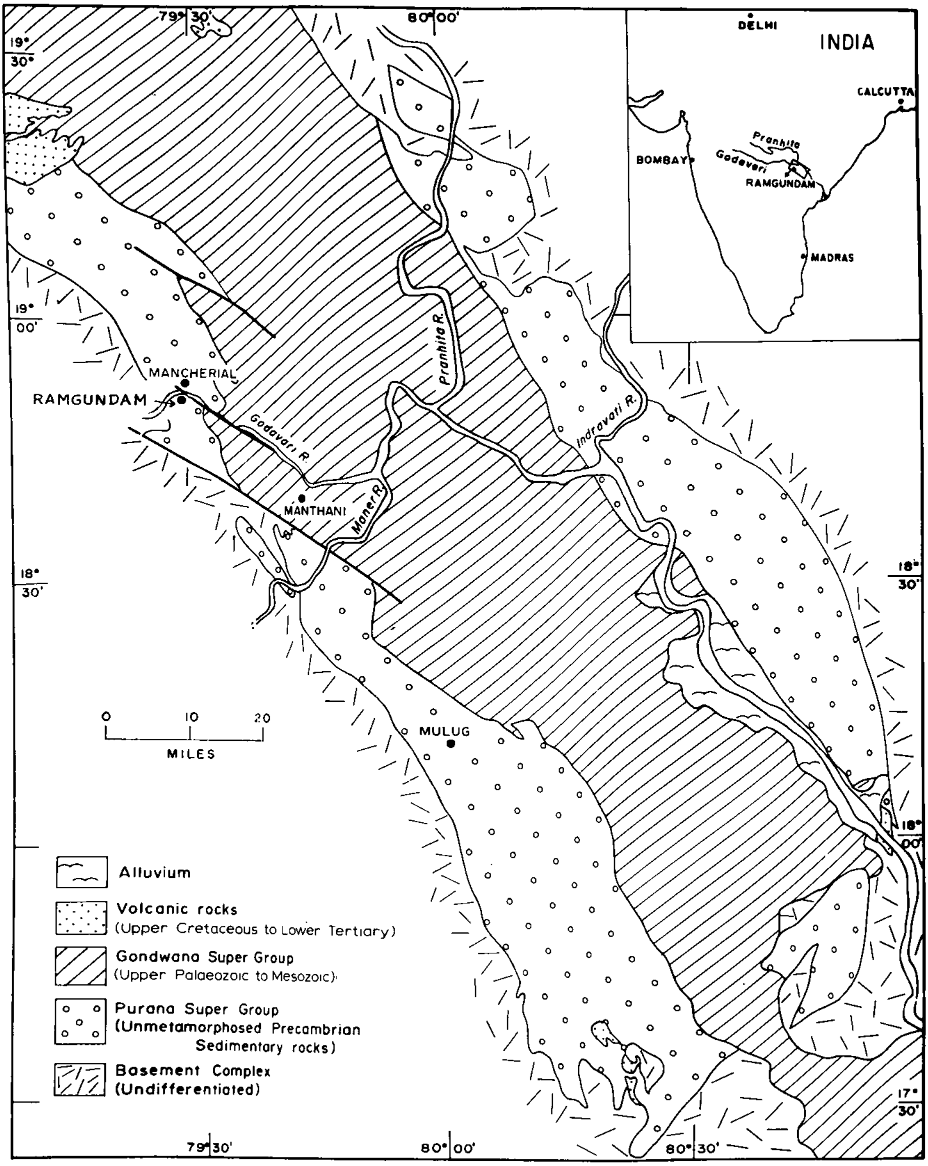

Fig.1. Geological map of a part of the Pranhita-Godavari Valley (modified after KING, 1881). Inset map shows location of Ramgundam. The small rectangle in the inset map delineates the location and the limits of the main map.

individual horizons traced is remarkably constant, and as such long persistent horizons are conformable with the host rocks they seem to have developed as algal biostromes. Small irregular discordant bodies, on the other hand, appear to have developed as mound-like bodies on the depositional surface, i.e., algal bioherms.

In various sections along the general strike of the formation, measured in the Ramgundam area, four biostromes have been recognized at different stratigraphic levels, and in the Manthani area five such biostromes have been noted. Biostromes in different sections appear at different stratigraphic levels. In two sections, the lowermost biostrome occurs right on the top of the sandstone of the Mallampalli Formation, while in other sections, the lowermost biostrome occurs tens of feet above the base of the Pandikunta Formation. In one section the lowermost biostrome is about 400 ft. above the base of this formation. Moreover, considerable variation in vertical stratigraphic intervals exists between the successive biostromes in different sections. These variations clearly suggest that none of the biostromes was continuous over the entire area studied, but that these biostromes developed as disconnected bodies in different parts of the area depending on where and when the conditions were favourable for algal growth.

The thickness of the individual biostromes ranges from 8–186 ft., but the biostromes appear to be persistent in space irrespective of their thickness. Algal structures are best developed in biostromes of the lower part of the formation, though they also occur in the upper part of the formation and biostromes have been recognized just below the unconformity at the top of the Pandikunta Formation.

Small biostromes and bioherms are rare at Ramgundam. These bodies, particularly the bioherms, are numerous in the southeastern part of the Manthani area, where they occur at random throughout the section.

General characters. The algal structures are best exposed in sections normal to the bedding planes and, irrespective of the orientation of the vertical plane of section, the stromatolites appear as arched laminae stacked one above the other, convex upward (Fig.2). Sections parallel to the regional bedding, and lying within these horizons, when available as well-smoothed Quaternary erosion surfaces, clearly exhibit the structures as circular or elliptical in shape, each composed of concentric layers. Normally, however, the surfaces developed by weathering on beds of these biostromes are wavy and irregular, many of them fractured and brecciated, due to differential erosion and solution along primary sedimentary structures such as desiccation cracks. In the present landscape of the area, many of the carbonate rocks within the biostromes occur as small isolated hummocks, which is a typical weathering feature of the stromatolitic zones. It is hardly possible to recognize the stromatolites in such exposures, but once the relation between these hummocky exposures and the presence of stromatolites is established, this weathering feature adequately serves to distinguish the stromatolite zones from the adjacent carbonate rocks with well developed, even bedding.

Intraformational limestone conglomerates are associated in many places

Fig.2. Stromatolites developed on the erosional surfaces of massive carbonate rocks. In the central part, a larger structure has developed covering part of two adjacent structures. At the top, structures of larger diameter have supported multiple structures of smaller diameter. No evidence of erosion at the contact of the different sets of structures.

with the stromatolites. In some places they occur just above the biostromes, but for the most part they occur at various levels within the biostromes, particularly the thicker ones. Small lenses of sandy limestone and glauconitic sandstone have been noted within the biostromes in some places.

The only visible microstructure in the stromatolites is a series of transverse, upwardly convex laminations. Two types of texturally different laminations have been noted. One type consists of dense microcrystalline lime-mud and the other type consists of distinctly discrete fine sand- and silt-size calcareous particles. The coarser-grained laminations, in places, also contain some fine quartz sand and silt. Where the detrital nature of these carbonate particles has been obliterated by recrystallization, the presence of quartz-sand and silt implies the original particulate nature of the laminae. The algal structures basically consist of an alternation of these finer- and coarser-grained laminae. The coarser-grained layers are of more variable thickness than the finer-grained layers and many of them pinch out altogether, in which case the finer-grained layers are directly superposed on each other. The lamination is almost as well defined in thin section as it is in hand specimens.

In the algal colonies, where the algal heads have developed as discrete structures, the interareas are filled up either by structureless, massive carbonate material, or by terrigenous detritus from the size of fine sand to small pebbles, or by both (Fig.3, 8). The size and shape of the infilled voids are controlled by the arrangement of the adjacent heads. These voids occur either as small pockets within the colonies or as thin walls separating two heads, sometimes more than a metre in height (Fig.3, 8). The contact between the algal heads and the infilling materials is usually well defined.

Most of the algal heads have developed on the small irregularities of the bottom surface. Irregularities produced by slight erosion of the bedded limestone are the most frequent bases on which the domed algal structures have formed

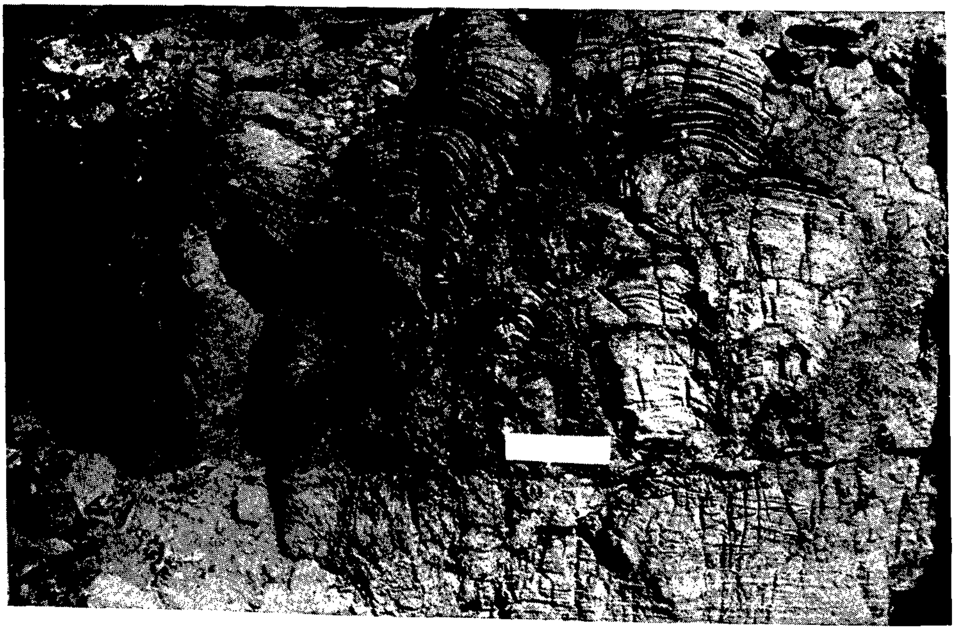

Fig.3. LLH → SH compound structures with irregular sand-filled interareas. Slightly irregular, horizontal algal laminae in the lower right corner. Erosional basal surface seen below the scale. The scale is 6 inches long.

(Fig.2, 3). Small sand lenses and intraformational conglomerates have also supported the growth of the colonies. In a small bioherm, the polygonal shape of the coarse detritus-filled space between small structures, developed upward as slender rods, strongly suggests that these structures have developed over desiccation cracks (see Fig.9). Development of the colonies over pre-existing algal domes (Fig.2) is a common feature in this area. The pre-existing domes, except in rare cases, have suffered no erosion. Stromatolites, however, have also developed over regular bedding surfaces of the underlying limestone. In such cases, the structures usually start as slightly irregular horizontal laminae differentiating upward into domes and interareas (see Fig.5).

Nomenclature. Stromatolites were at first considered to be fossils of animal affinities, and hence the system of binomial nomenclature has been widely used to erect a large number of genera and species to describe the different structural forms. However, differences of opinion developed among workers regarding the application of generic and specific names to the stromatolites. As stromatolites rarely preserve any organic structure, it is difficult to correlate each type of stromatolite structure to a particular organic species. Modern studies have clearly pointed out that the algal mats may contain a large number of different species (GINSBURG et al., 1954) and thus the application of binomial nomenclature to stromatolites would be a purely artificial one.

Studies on recent stromatolite formation have proved that stromatolite structures do not represent biological entities, but are the products of interaction of physical sedimentation and algal mats, and that different forms of stromatolite structures are closely controlled by differences in environmental factors. The binomial system now used is not capable of expressing clearly these significant environmental differences. These difficulties clearly suggested the need to abandon the binomial nomenclature and to introduce a new one capable of expressing clearly the environmental differences controlling physical sedimentation.

A new classification has recently been proposed by LOGAN et al. (1964). This classification is based on the arrangement of the hemispheroids and spheroids, the basic geometric units which form the stromatolites of common *Collenia*, *Cryptozoon*, and *Oncolite* structures. The stromatolite structures have been divided into three broad groups, type LLH, type SH and type SS, depending on whether the base of the structures is attached to the substratum or not, and if attached, whether the algal layer is continuous from the top of one structure to the adjacent structure or whether the domical structures develop as individual discrete bodies. Within each of three broad groups, subgroups or modes have been formed.

(1) Type LLH: Laterally Linked Hemispheroids. The structures of this type are attached to the substratum and the algal layers are laterally continuous over the adjacent structures.

Two modes (subgroups) of lateral linkage have been classified on the basis of the distance between the adjacent structures: (*a*) LLH-C mode, close-linked hemispheroids; and (*b*) LLH-S mode, space-linked hemispheroids. In the LLH-C mode, the space between the adjacent structures is less than the diameter of the structures, and in the LLH-S mode, the space between the structures is greater than the diameter of the structures (Fig.4).

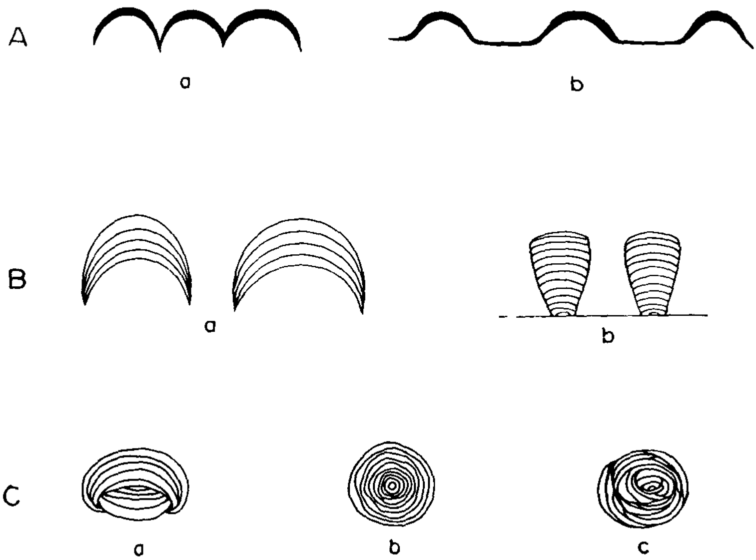

Fig.4. Illustrates the arrangement of lamination in different types of structures in the classification of LOGAN et al. (1964). A. LLH-type structure: *a* = LLH-C mode; *b* = LLH-S mode. B. SH-type structure: *a* = SH-C mode; *b* = SH-V mode. C. SS-type structure: *a* = SH-I mode; *b* = SH-C mode; *c* = SH-R mode. (After LOGAN et al., 1964.)

(*2*) *Type SH: Discrete, Vertically Stacked Hemispheroids.* This type of structure is attached to the substratum and is formed by the vertical stacking of discrete hemispheroidal algal layers. The structures are not laterally linked to one another.

Two modes have been differentiated in this type: (*a*) SH-C mode; and (*b*) SH-V mode. In the SH-C mode, the upper hemispheroidal laminae reach or overlap the base of the preceding ones, the basal radius of the succeeding layers remaining *constant*. In the SH-V mode, the upper hemispheroidal laminae do not reach the base of the preceding ones, the basal radius of the succeeding layers being *variable* (Fig.4).

(*3*) *Type SS: Spheroidal Structures.* The structures of this type are not attached to the substratum. Here the algal mats do not coat a surface on the substrate, but coat shell or lithic fragments lying on the depositional surface.

Three modes have been identified in this type: (*a*) mode "I"-inverted, stacked hemispheroids; (*b*) mode "C"-concentrically stacked spheroids; and (*c*) mode "R"-randomly stacked hemispheroids (Fig.4).

Studies of recent stromatolites indicate that the formation of these different geometric patterns, particularly the three broad types, is closely related to differences in environmental conditions. Recognition of these different types in ancient sediments, therefore, would greatly facilitate palaeoecological interpretations. The new classification of LOGAN et al. (1964) is used here to describe the Precambrian stromatolites from the Pranhita-Godavari Valley.

In addition to its utility in environmental interpretation, this classification has proved to be very convenient in the description of the megascopic features of the structures, particularly those compound structures formed by alternation of LLH- and SH types. Some differences, however, have been noted between the geometry of the structures observed here and the geometric pattern described by LOGAN et al. (1964).

The basic geometric pattern of LLH- and SH types has been described as hemispheroids by LOGAN et al. (1964). This hemispheroidal pattern of the algal layers is also common in structures of the Pandikunta Formation. But more frequently, the arched layers are hemiellipsoidal, and the structures are elongate in plan and are more similar to those illustrated by HOFFMAN (1967). However, the main distinguishing criterion, i.e., the discrete development or the lateral linkage of the structures, is present, so the nomenclatorial scheme of LOGAN et al. can usually be applied without difficulty. Field observations of different types of SH structure suggest that the criteria used by LOGAN et al. (1964) to distinguish the two modes of SH type do not always apply, and some types exist which are intermediate between SH-V and SH-C modes. For these reasons, different SH-type structures have been given separate description, and when appropriate, have been compared with either SH-V or SH-C modes.

Description of the structures. LLH and SH arrangements are the two most common types of stromatolite structures in the Pandikunta Formation. SS-type structure is rare.

(*1*) *LLH-type structures.* In sections, vertical to the bedding planes, LLH-type structures appear as laterally linked arched layers, with the upward convex portions of the layers stacked one above the other (Fig.5). Of the two modes of this type, LLH-C and LLH-S, only LLH-C occurs in this region. The component arched laminae of the individual structures are also characterized by LLH-type structures on a smaller scale. These smaller structures within the component laminae have been defined by LOGAN et al. (1964) as microstructures. These micro LLH-type structures noted within the larger structures, i.e., within the macro-structures, are always of LLH-C mode.

The structures of LLH-C type developed in this region are characterized by considerable variation in both size and shape. The size variation is more pro-

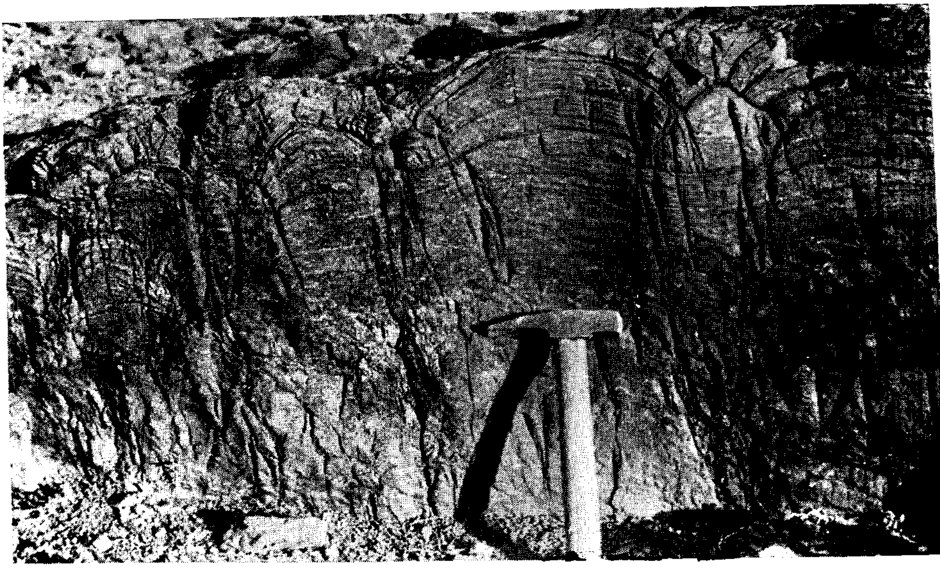

Fig.5. Slightly irregular horizontal algal laminae differentiating upwards into LLH-C structures. Massive carbonates form the substrate.

nounced between the structures occurring in different biostromes than between structures occurring within a biostrome. Within individual biostromes also, the size variation is characterized by a vertical zonal arrangement. The diameter of the component laminae of any individual structure, without exception, increases towards the top. As measured in available sections, the diameter of the topmost laminae of the structures, where these are most expanded, normally ranges from 5–15 inches. Heads with smaller diameter are infrequent, but numerous heads are as large as 60 inches in diameter. These structures start either with initially upward convex layers or with slightly irregular horizontal layers that differentiate upward into multiple heads (Fig.5). The nature of the starting layer of the structures is controlled by the nature of the basal surface, whether even or irregular. The nature of the substrate is also very important in controlling the size of the structures. The larger irregularities in the substrate normally initiate structures with larger basal diameter. Most such large basal irregularities are provided by the tops of preexisting structures. Crowding of larger structures towards the upper part of some biostromes is readily attributable to this feature.

The shape of the structures, as seen in steeply inclined sections, is controlled by the convexity of the component laminae, and by the rate of expansion in the basal diameter of the laminae from the base to the top of the structures. In some structures the upward increase in the basal diameter is slight, but normally the difference between the diameter of the laminae at the base and top of the structures is 3–5 inches, and may occasionally be 8–10 inches. The convexity of the component laminae of the structures also increases upwards. The thickness of the arched laminae is slightly greater near the apex of the arch than at the sides. Within any individual head, the difference in the height or amplitude of the arched laminae may be as much as 4 inches; within different heads the height of the amplitude ranges from ¼–8 inches. Variation in the amplitude of the laminae mostly is more conspicuous in structures with large basal radius. In one such structure, where the diameter from the base to the top ranges from 12–20 inches, the amplitude of the convexity ranges from 4–12 inches.

(*2*) *SH-type structures*. The algal zones show a prolific development of SH-type structures, this type being more abundant than the LLH-type structure. In sections, these structures appear as discrete columns formed by the vertical stacking of upwardly convex laminae (Fig.2, 8). Microstructures are commonly developed within macrostructures, and the microstructures have formed irrespective of the scale of the macrostructures. LLH-C is the only mode of the microstructures.

The SH structures are characterized by upward increase in both the convexity and the basal diameter of the component laminae, except in a few structures that comprise one particular type. This increase is occasionally only slight, but in the majority of the structures, it is more conspicuous than in the LLH structures. The convex laminae are, without exception, thicker at the apex of the arch and thinner at the two sides, and this thickness variation of the laminae accentuates their convexity. Reversal of the general trend in the size variation has been noted in a few structures, where the heads become smaller upward. In such cases the interareas are filled up with coarse sand which may transgress on to the structures on both sides. In these structures the contact between the infilling sands and algal layers is sharp but irregular.

SH structures developed in this region exhibit remarkable variation in size, and, as in the LLH structures, this size variation is more conspicuous between structures occurring in different biostromes than between structures of any one biostrome. Within a biostrome the size variation shows a vertical zonal arrangement. Where LLH structures are the substrate for the SH types, the size of the former seems to exert a control over the size developed by the latter. Certainly there is an observable association of larger SH structures developed above the larger LLH-type stromatolites in this area.

The columns normally stand almost vertically on the substrate. The larger columns, however, have not everywhere maintained their vertical growth position, but have curved over, in some places attaining an almost horizontal attitude (Fig.6). Branching structures are absent, but development of new heads covering either a part of, or more than one of the complete preexisting heads, is a common feature (Fig.2).

The SH structures developed in this region display several growth patterns. Only one of such patterns strictly conforms to the SH-V mode, but others show

Fig.6. Large SH structure of type a, part of the column resting almost horizontally.

some departure in their geometry from both SH-V and SH-C modes. Two different criteria are considered by LOGAN et al. (1964) to be important in separating SH-V and SH-C modes. These criteria are: (*1*) the constancy or variability of the basal diameter of the component laminae; and (*2*) whether the component laminae reach the base of the preceding ones or stop at some height above the base. As "V" and "C" stand for "variable" and "constant", greater emphasis has been placed on the first criterion. In a structure where each of the laminae reaches the base of the preceding one, each of the laminae reaches the base of the structure itself. In such a structure, the two criteria for the SH-C mode, i.e., the constancy of the diameters, and at the same time component laminae reaching the base of the structure, appears to be contradictory. If the diameters remain constant, the laminae must stop somewhere above the base of the structure, pinching out on the two sides of the preceding arched laminae. But if the layers reach the base of the structure as distinctly separate entities, then the diameter must increase by twice the width of any layer. In smaller structures with only a small number of component laminae, this increase in the basal diameter might be insignificant, but in larger structures would inevitably be significant. Therefore, the criterion of the constancy of the basal radius cannot be very rigidly applied, and some flexibility must be allowed in its use in the classification.

Observation of a large number of SH structures in the field suggests that the use of the single criterion of constancy of basal radius, even with some flexibility, but without any reference to the other criterion, i.e., where the different laminae stop, leads to confusion in the classification. Structures transitional between SH-V and SH-C modes might occur. Moreover, in most of the structures with virtual constancy of radius of the laminae, these laminae do not reach the base of the preceding laminae, but stop against the sand-filled interareas. In some structures similar to the SH-V mode, but in which the convexity of the laminae is conspicuous (Fig.7), if the laminae were allowed to reach the base of the structure, the increase in the basal radius would be slight relative to the height of the structure, and could probably have been included in the SH-C mode of LOGAN et al. (1964).

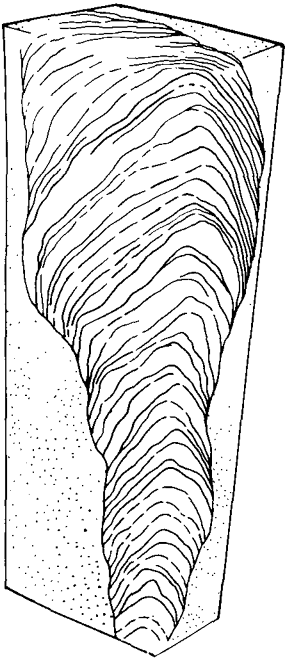

Fig.7. Club-shaped SH structure of type a. The basal radius and convexity of the component laminae increase upward.

Cause of the failure of the laminae to reach the base is not everywhere clearly exhibited by these fossil structures. In some places, this failure can be related to lack of sufficient space, caused by rapid sedimentation and infilling of the interareas simultaneous with the development of algal layers, or it can be related to mechanical erosion, probably caused by strong contemporary current action. Studies of present-day structures might lead to a better understanding of the relationships of laminae in individual SH structures.

From the preceding discussion it becomes clear that in the classification of SH structures more emphasis should be placed on criterion (*2*); criterion (*1*) may be used as a complementary one.

Four different types of SH structures have been recognized in the field-region studied. In differentiating these structures, major emphasis has been placed on the second criterion of LOGAN et al. (1964) and two other features have also been considered, namely the constancy of the basal radius of the component laminae, and the nature of their curvature.

Type a. In this type of structure the individual arched laminae do not reach the base and the form expands upward by an increase in the basal radius of the laminae (Fig.2, 7). This type displays a remarkable variation in the size of the individual heads. The height of the structures ranges from 1–26 inches, and the radius of the arches of the topmost layers of different heads ranges from 1–63 inches. The difference between the radius of the arched laminae at the base and at the top of the individual columns normally ranges from 1–3 inches. In a few larger structures a difference of up to 6 inches has been noted. The convexity of the laminae, without exception, increases upward.

The variation of size and convexity of the layers has largely controlled the shapes of the discrete heads, as also the shape of the interareas. Where the upward differentiation in size and convexity of the layers is greater than the average, the heads commonly form club-shaped and even mushroom-shaped structures (Fig.7).

Fig.8. SH stromatolite, type b. Interareas filled up with coarse sand. The convexity and basal radius of the structures are practically constant from base to top. The scale is 6 inches long.

Such upward increase of the adjacent heads has sometimes resulted in the fusion of the heads at the top, and in these cases the interareas between the basal part of the structures assume the shape of small pockets (Fig.3). This is the most widely developed pattern and constitutes about 90% of the total SH structures developed.

Type b. This type of structure is similar to type a, but here the basal radius of the component laminae remains practically constant from the base to the top of the structures. The convexity of the laminae also remains fairly constant throughout each stack (Fig.8). In vertical section these structures appear as parallel to sub-parallel columns. This type of arrangement has been noted mainly in the smaller structures. The height of the heads normally ranges from 1–6 inches, but columns about 18 inches high have also developed at a few places. The radius of the laminae normally ranges from 1–2½ inches and the range of variation of the convexity in different columns is ¼–1½ inches. Type b is in many places associated with small scale SH structures of type a.

Type c. This type of SH structure is formed by vertical stacking of flat topped, horizontal layers that curve down slightly at the two sides. In a few places, this marginal curvature of the laminae is absent. The radius of the laminae remains practically constant from the base to the top of structure (Fig.9). In vertical sections these structures are similar to the type b. The only difference is that in this type the component laminae, except at the two sides, are horizontal.

This type of structure has been noted only in one place in the area studied,

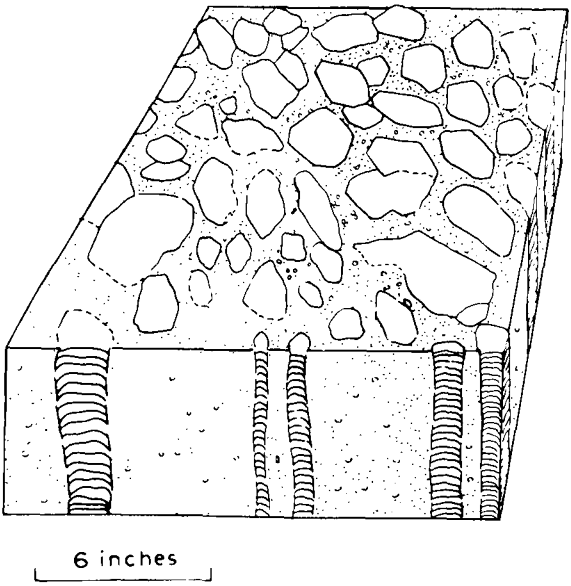

Fig.9. Polygonal networks formed by sand-filled interareas. Width of the structures is practically constant up to the substrate. SH structure of type c (top—drawn from photograph sides—shows the arrangement of the laminae as observed in the field).

in a small bioherm at Ramgundam. The interareas are filled with coarse sands. These sand-filled interareas, in sections, appear as vertical columns of constant width that alternate with the stromatolite columns. The width of the interareas normally ranges from ½–1½ inches. Interareas narrower or wider than this average width, however, are not rare. On the bedding surface, the sand-filled interareas form a network with polygonal outlines that encloses the stromatolites. The stromatolitic structures of this type, also, instead of being circular or elliptical on the surface, are characterized by fairly straight margins forming polygons. In the individual heads of this type, the laminae that curve down at the two sides usually pinch out at the sides of the preceding one. Some of the laminae, however, instead of curving downwards, curve upward. In a few laminae, the marginal curvature is absent and such straight laminae stop against the sand-filled interareas. The arrangement of the component laminae of this type is very similar to that illustrated by BLACK for his type C structure (cf. REZAK, 1957, p.143, fig.54). The height of the columns normally ranges from 12–24 inches and the width of the polygons varies from 1–3 inches, so that these structures considered in three dimensions occur as slender rods that stand almost vertically on the substratum.

The development of the type C of BLACK (1933), which is very similar to the type c observed at Ramgundam, has been attributed to desiccation of successive algal mats. The polygonal shape of the interareas and of the stromatolites of the type described here, strongly suggests that desiccation of continuous, horizontal algal layers might be an important controlling factor in the development of these structures as observed near Ramgundam. It is unlikely that these rod-like structures could withstand the current action in a semilithified state unless infilling of the interareas was continuous with the development of the structures. The presence of coarse sand and also some pebbles in the interareas indicates the presence of a fairly strong current. It is probable that repetition of a process having the steps: (*a*) formation of continuous mats; (*b*) development of desiccation polygons affecting several successive mats; (*c*) partial lithification of desiccated mats; and (*d*) infilling of the cracks, gave rise to these structures.

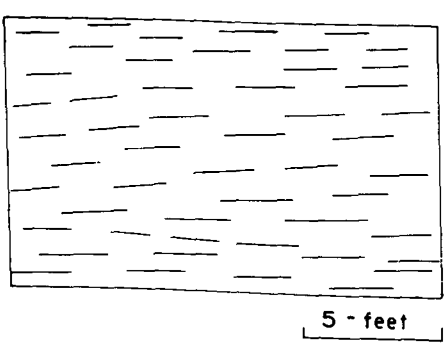

Fig.10. Approximate arrangement of the elongate structure in plan.

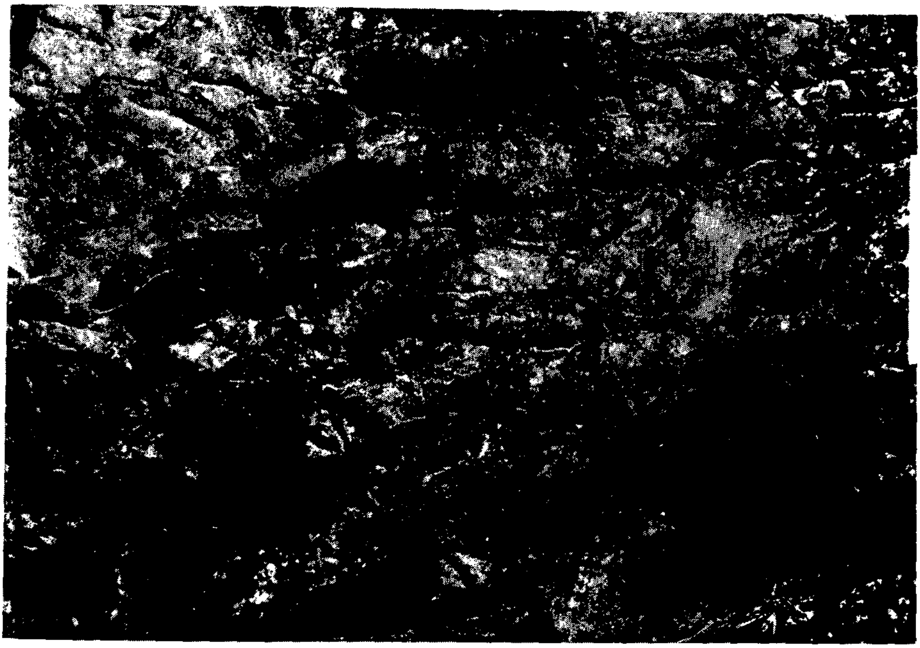

Fig.11. Top surface of elongate stromatolites arranged in rows. Elongate interareas and the space between individual elongate structures in a row are filled up with structureless lime-mud. Elongate structures show a preferred direction of orientation. The vertical scale on the right margin is 6 inches long.

Type d. Most structures of type d are elongate. On the weathered bedding plane surface, these elongate structures make a slightly higher relief, ½–1 inch high, than the surrounding sediment-filled interareas and appear as fairly straight, very elongate, oval stromatolites, about 2 inches in average width. These elongate stromatolite structures are characterised by a preferential arrangement of the longer direction. When they occur in groups, they are normally arranged in regularly spaced parallel to sub-parallel rows or ridges. Each individual ridge is formed by a row of a few preferentially oriented structures (see Fig.10–12). The space between the adjacent rows of ridges, as well as the gaps between the individual elongate stromatolites occurring in a ridge, is filled up with structureless lime-mud. Pebbles and sand-sized clastic particles, are almost entirely absent from the interareas around these structures. The lime-mud filled interareas, by differential erosion, give rise to furrows alternating with the ridges formed by the stromatolites.

The width of these elongate stromatolites encountered in different parts of Ramgundam differs from 1–3.5 inches. The length, in general, ranges from 3–25 inches. In one place, in the low ground about 0.75 mile north of the Ramgundam Thermal Power Station, the average length of the elongate stromatolites ranges from 40–60 inches, and a few exceed 85 inches (Fig.13). The axial ratios (ratio of the larger axis to smaller axis as measured on the surface) of these structures

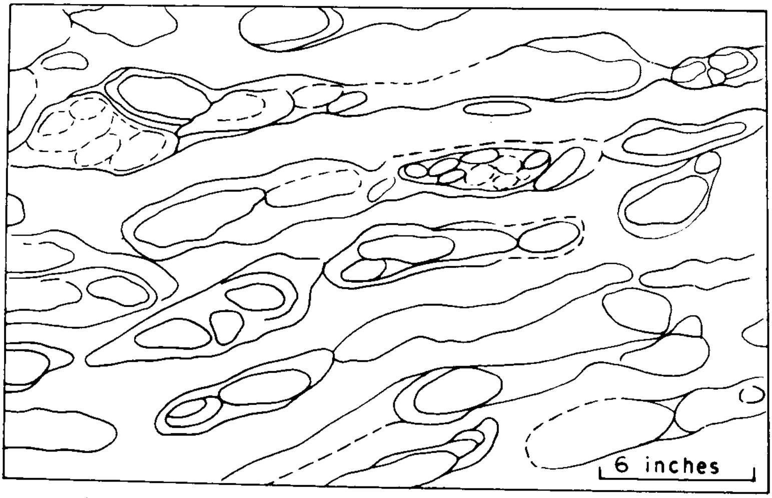

Fig.12. Outlines of elongate stromatolites drawn from Fig.11. Longer structures have developed by encompassing closely spaced smaller structures.

normally vary from 3 : 1–6 : 1, but in some beds the axial ratios of these structures are as great as 25 : 1. The height has been noted to vary from 2–15 inches. On the surface, the ridges are normally straight, but a few, particularly the longer ones, are often quite sinuous (Fig.13). In three dimensions the structures appear as walls, normally standing vertically on the substrate. A few structures, however,

Fig.13. Elongate stromatolites forming long ridge and furrow structure; ridges are slightly sinuous. Transverse section exhibits SH type b arrangement of laminae. The scale is 6 inches long.

have been noted to bend slightly to either side from their vertical growth position, resulting either in their coalescence with an adjacent ridge, or in widening the adjacent furrows. The width of the furrows normally varies from ½–3 inches and the gap between succeeding structures in a ridge normally does not exceed 4–5 inches.

Both field and laboratory observations suggest that the basic geometry and arrangement of the component laminae of these structures, as well as their interrelationship, are more complex than those of types a, b and c. In the field, where only the upper parts of these structures are exposed, the laminae, as seen in transverse vertical sections, are always upwardly convex. But in longitudinal sections, the laminae are nearly horizontal and slightly undulatory. When these longitudinal sections are examined casually in the field it appears that the laminae, in their build up, do not follow any definite geometric arrangement.

A few of the elongate stromatolite structures of this type were therefore examined in polished sections, to study the details of the growth pattern of the laminae. Vertical sections both parallel and transverse to the long axis of the structures, as well as horizontal sections, were cut and were etched in dilute hydrochloric acid. The etching brought out clearly the alternate coarse and fine grained layers. The polished sections clearly show that the component laminae of the structures do follow a fairly well defined geometric pattern. This pattern, however, differs in some respects from that in type a and type b, and, in three dimensions, may be described as the shape of half an egg, or ovoid.

Studies of the polished sections clearly demonstrate that each elongate stromatolite structure is composite, formed by coalescence of smaller elongate structures or elements arranged in a line. The separate identity of these smaller component elements is distinct in the lower part of the ridge. Each of these component elements is formed by diagonal stacking of inverted ovoid laminae. In this type, however, the laminae, unlike those in types a and b, are not equally well developed on all sides of the element and do not always uniformly cover up the preceding laminae. The more pointed end of each ovoid lamina tends to coalesce with the preceding ones, whereas the blunt ends of these laminae are set widely apart from each other (Fig.14). The diagonal stacking of each ovoid lamina is such that a line joining the centre of gravity of each is inclined upwards and along the direction of elongation of each composite stromatolite (Fig.14). The overlap of these ovoid laminae is, however, not always entirely symmetrical (Fig.14). The orientation of the coalescent, or of the widely spaced, ends of successive elements in each composite structure is always in the same direction. Successive elements, formed of ovoid laminae, tend to join up in line, or be linked together in line by more irregularly stacked smaller elements. The linked elements are then surrounded by larger, very elongate ovoid laminae, whose upper portions are sub-horizontal or undulatory, and the accretion of these larger laminae produces each elongate, ovoid, composite stromatolite (Fig.14). The linear arrangement of the composite

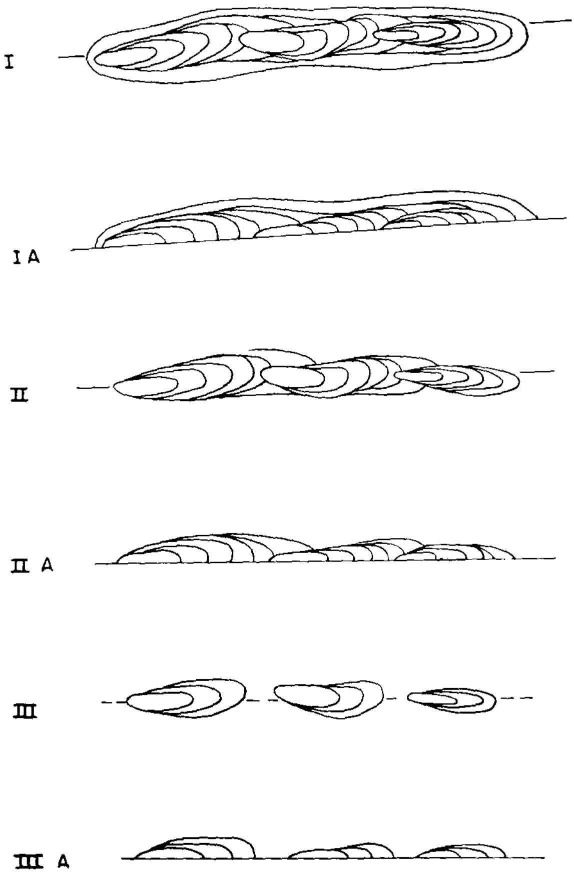

Fig.14. Schematic diagram showing the different stages in the development of type d structures. I, II and III illustrate on plan, final, intermediate and initial stages of development. IA, IIA and IIIA illustrate vertical longitudinal sections corresponding to I, II and III respectively.

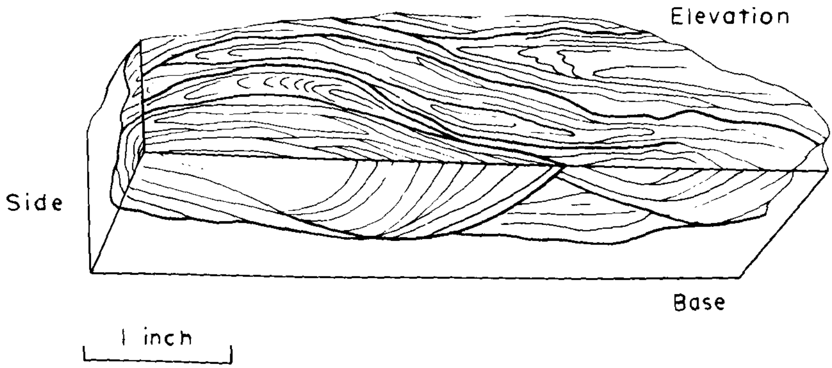

Fig.15. Arrangement of laminae in elongate structures as revealed in polished sections. Horizontal basal section and vertical sections parallel and transverse to the long axis (drawn from etched polished sections).

stromatolites results in the formation of the ridges.

The basal surface and both the transverse and longitudinal vertical sections of an elongate, oval, composite stromatolite are illustrated in Fig.15, that gives a typical example of the growth pattern of these structures. The basal surface clearly shows two small elongate component elements arranged in a line. Both these component elements grow towards the right by successive addition of layers that merge and pinch out towards the left hand side. By addition of layers, these two individual elements have merged into one. Near the constriction formed at the merging points of these two elements, another small element has developed, part of which is seen in the basal section. In the longitudinal section a small elongate bulge is seen to have developed at the top of the element on the right hand side. Above this, two more bulges have developed that in each case have shifted slightly towards left.

Observations of the polished sections make the following points clear:

(*a*) The composite stromatolites have developed by coalescence of smaller closely spaced elements.

(*b*) The component smaller elements are also elongate in growth pattern.

(*c*) Enlargement of the component laminae of each of the smaller elements takes place in one definite direction.

(*d*) The component laminae are better developed in the direction of growth.

(*e*) The axis of the elongate structure gradually shifts in the direction of growth.

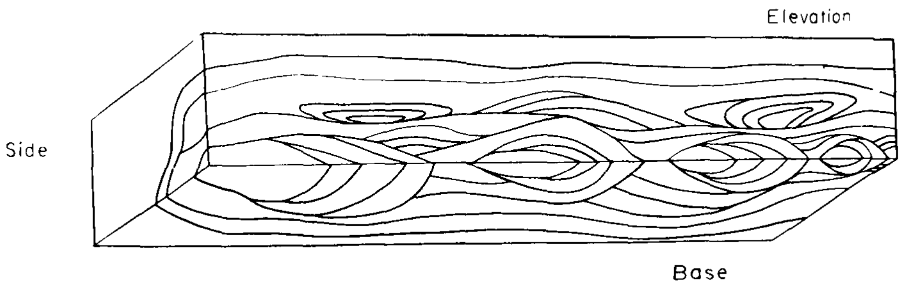

Fig.16. Generalized diagram showing the growth pattern of elongate structures.

The generalized growth pattern of these structures is illustrated in Fig.16. Observations in different parts of the field suggest that this addition of successive elongate structures occurring in a row, takes place in all different scales and such addition results in the development of the long ridges (Fig.12). Slight difference in the orientation of long axes of the elongate composite structures explains the sinuosity of the longer ridges (Fig.13).

An elongate growth pattern is also very commonly exhibited by the structures of types a and b. But these elongate structures differ from type d structures in the following aspects:

(*1*) The degree of ellipticity of type d structures normally is much greater than that exhibited by structures of types a and b, although there might be some gradation.

(*2*) In types a and b, the arrangement of the laminae remains virtually similar in different sections. In type d, the arrangement of the laminae appears to be different in different sections (Fig.14, 15).

(*3*) In types a and b, the component laminae are characterised by the uniform and well-defined geometric pattern and regularity of their arrangement. The position of the axis of successive laminae remains practically constant. In type d, the laminae are less uniform in their build up and the axis of each lamina slightly shifts from that of the preceding one.

(*4*) Structures of types a and b occur as single units. But type d structures are all composite structures.

Suggested mechanism of the development of type d structures. Factors controlling the development of all types of stromatolite structures, other than type d, have been directly observed from areas of recent carbonate sedimentation. Structures similar to type d, however, have not so far been reported from any such areas, and therefore the mechanism of development of these structures can only be suggested from the pattern of the structures and the nature of the associated sediments.

Development of SH structures, as observed by LOGAN et al. (1964), primarily depends on two factors: (*1*) inability of the algal mats to traverse the interareas between the adjacent structure; and (*2*) the destruction of the mat in the interareas. Factor (*1*) is closely controlled by comparatively high relief between the highs and the depressions on an irregular substrate. If any such basal irregularity was responsible for the development of these very elongate structures, it must be assumed that the basal highs were also persistent and linear in their arrangement. The alternate ridges and furrows formed by the linear arrangement of the composite structures on the bedding plane surface, very closely simulate long symmetrical ripples. The presence of ripples on the substrate may initiate development of small, discrete stromatolite structures in a line along the crests of the ripples. A rippled substrate, however, unaided by other interacting factors, would fail to explain the subsequent development of the arrangement of the elongate laminae, namely, their diagonal stacking and a preferred direction of better development of the laminae, and coalescence of the succeeding structures in the same direction. These internal characteristics of the type d stromatolite structures cannot be very satisfactorily explained by such factors as development of linear shrinkage cracks, prolonged wetting in a particular direction, for example along the troughs of the ripples, or by heavy sedimentation in a persistently regular direction.

That very elongate stromatolite structures may develop in response to current action has been demonstrated, both from an area of recent sedimentation, by LOGAN (1961), and also from a Precambrian formation, by HOFFMAN (1967). In the recent structures of Shark Bay, Western Australia, it has been observed by LOGAN (1961) that the run-off tidal waters, and translatory motion of the waves concentrated in depressions in the littoral surface, inhibit the continuous development of the algal mats by simple scouring effect and mechanical fragmentation, and consequently develop elongate algal domes, parallel to the current direction. In the Precambrian Pethei Formation, very elongate structures, closely paralleling the palaeocurrent direction, have been extensively documented by HOFFMAN (1967) on a regional scale. Though the structures described by HOFFMAN (1967) are of LLH type, the internal arrangement of the laminae closely resemble that of the SH structures described here in the following respects: (*a*) the axes of the structures gradually shift in a particular direction due to slightly diagonal stacking of the successive laminae; and (*b*) each lamina is slightly thicker in the same direction.

A close scrutiny of the nature of the component laminae of the SH-type d structures considered here, suggests that the growth of the algal film was probably impeded on one side of the structure. The film flourished on the other side, resulting in the better development and enlargement of the algal-bound layers in this direction. This was a persistent feature during all stages of the development of the composite structures. Mechanical action of a persistent current system, namely, tide and ebb flow on a tidal flat may, probably, give rise to a similar growth pattern, as the mat in the seaward direction of the structure would be more strongly affected by the current than the mat on the opposite side. In such a case, the elongate structures, however, would be expected to parallel the current flow direction. Such a parallelism between the elongation of the structures and the palaeocurrent direction has actually been noted by evaluating the palaeocurrent from a few cross-stratifications in the adjacent beds. Thus, comparing these structures with other current controlled elongate structures and considering the internal character of the component laminae, it seems reasonable to assume that, though in the initial stage some linear structure on the substrate may help to arrange the small discrete elements in a line, in the later stages the growth pattern of these structures was more closely controlled and shaped by the mechanical action of the current operating in the depositional site.

(*3*) *SS-type structures.* These spheroidal structures are not common in this area. This type has formed by development of concentric spheroids around a nucleus which is either a small carbonate fragment or a detrital sand grain. Some of the component laminae are of LLH type, whereas others are smooth. Most of these nodular structures are slightly elongate in shape and the larger diameter ranges from 0.5–2 inches (Fig.17). This type occurs in the small bioherms and the topmost biostrome at Ramgundam, and in two biostromes at the top of the stromatolite horizon in the Manthani area in association with small detached SH structures.

(*4*) *Compound structures.* The majority of the stromatolite structures in this area, particularly the larger ones, are formed by the compounding of LLH- and

Fig.17. SS-type structure, mode "C" (polished, etched surface). Length of the specimen is 1.2 inches.

SH-type arrangements (Fig.3). The structure, starting either as LLH- or SH type, changes upward into the other type. Some of the structures exhibit a repetition of these two arrangements. Such compound structures have given rise to heads up to 50 inches high.

Discussion. Studies on recent stromatolites (LOGAN et al., 1964) suggest that these organosedimentary structures form by the sediment-binding activity of blue-green algal mats. Dome differentiation and formation of different types of structures have been attributed to several interacting factors. Field evidence suggests that the following factors, either acting separately or in combination, have caused the doming of LLH-type structures: (*1*) lateral growth expansion in the mat; (*2*) doming over pre-existing irregularities such as erosional relief features of the substrate: pre-existing algal domes; (*3*) more active sediment binding in the highs resulting in the differentiation of the relief features; or (*4*) evolution of gases beneath the algal mats.

The discrete SH-type structures were formed by: (*1*) high relief between the top and the base of the domes already formed or of the initial irregularities on which the structures started; (*2*) fragmentation of the mats by mud cracking;

(*3*) destruction and inhibition of growth of the algal mats in the interareas by heavy sedimentation; and (*4*) destruction of the interareas of algal mats by scouring effects of tidal currents.

The rapid lithification of the algal-bound sediments helped in the maintenance of the discrete heads as small wave-resistant bodies. Rapid induration of the carbonate sediments is a feature of the littoral environment (RODGERS, 1957). Evidence of rapid lithification of the algal heads in the Ramgundam and Manthani areas can be summarized as follows:

(*a*) Some of the algal heads have been truncated by erosion and above these other heads have developed. This feature, along with the occurrence of stromatolite fragments in the adjacent penecontemporaneous conglomerates, suggests subaerial exposure and lithification before burial.

(*b*) Formation of discrete, slender, rod-like SH structures and narrow, elongate ridge-like structures indicates that the material bound by algal films was fairly well indurated. The presence of coarse sands and even small pebbles in the interareas of such structures clearly suggests that these structures were strong enough to withstand a current capable of carrying coarse detritus.

(*c*) Bending down of some of the large algal heads from the vertical growth position appears to indicate locally developed vigorous current action. The individual laminae in such heads, however, show no deformation, and this suggests rapid induration.

(*d*) Occurrence of algal intraclasts with internal lamination and oxidation in some places.

In their classification of the stromatolites, LOGAN et al. (1964) have assumed the basic arrangements of the geometric forms of the laminae in the structures as hemispheroids or spheroids. Though this classification is followed here in describing the structures, observations at different points indicate that in a majority of the structures, the geometric arrangement of the laminae cannot be simple hemispheroids. No conceivable section of hemispheres can give rise to an elongate, elliptical form on a planar surface, a form that is more frequent than the circular form. There are different sizes and shapes of elongate forms, from roughly circular through slightly elongate to the ridge structures showing the best-developed elliptical pattern. Forms of a small SS-type and SH-type structure in the polished sections were analyzed by drawing perpendiculars to tangents at different points of a lamina. The wide divergence of the perpendiculars from each other indicate that the laminae are not the arcs of any circle, and that the geometric form is not a hemispheroid. The majority of LLH-type structures has also developed a similar elongate pattern. The true geometric form of these structures, as developed in this area, is yet to be determined.

The elongate form of SH-type d structures may be a manifestation of the current flow pattern of the depositional site. The direction of elongation of LLH structures as well as of SH structures of types a and b probably roughly parallels the palaeocurrent direction. However, in this area the data are insufficient, as yet, to establish the suggested relationship between the direction of elongation of the structures and the current flow regime.

PALAEOGEOGRAPHIC AND CORRELATIVE SIGNIFICANCE OF THE PANDIKUNTA STROMATOLITES

By analogy with stromatolites of recent origin, those from ancient sediments have been widely used as a key to environmental and palaeogeographic reconstructions (YOUNG, 1935; REZAK, 1957). The discovery of algal stromatolites in the Pandikunta Formation, which is otherwise without any sign of organic activity and is unfossiliferous, has opened possibilities for ecological as well as palaeogeographical interpretations of these rocks. Because they are diagnostic of an intertidal, or of a supra- and sub-tidal environment, the stromatolites occurring in a narrow belt from Mancherial to Mulug delineate the trend of the Precambrian strand line on this side of the basin. The area of deposition appears to have been one of ever changing configuration, sometimes permitting accumulation of fine lime-mud and at other times being exposed to periodic flooding that introduced coarse detritus. The abundance of intraformational conglomerate, evidence of erosion of algal heads, frequent occurrence of mud cracks and close association of penecontemporaneous dolomite point to the intermittent emergence and desiccation of an extensive part of the tidal flat during low tide, and submergence during high tide. The diversification of the forms of the stromatolites takes place in response to differences in location, exposure, tidal amplitude (LOGAN et al., 1964) and current flow regime. LAPORTE (1967) has used the different growth patterns of the stromatolites, in association with other features, to interpret the sub-environments of a larger environmental complex. In the present area, also, the concentration of small, detached SH-type and SS-type structures in the uppermost biostrome and in small bioherms, compounded LLH→SH-type structure, occurrence of intraformational conglomerates and mud cracks in the lower part of the formation, and other sedimentologic features, help in differentiating the subfacies, e.g., supratidal, intertidal and subtidal, representing a complex of environments of generally littoral carbonate deposition.

The use of stromatolites in differentiating biostratigraphic horizons as index fossils, still remains a controversial possibility. But stromatolites can be useful in intrabasinal rock-stratigraphic correlation. Sections demonstrating the Precambrian sedimentary sequence of various localities from Mancherial to Mulug clearly establish that the stromatolites in this region are confined to the calcareous Pandikunta Formation of the Mallampalli Subgroup. This has been a valuable criterion in recognizing and correlating this formation in different parts of the valley even where the formation is disturbed by faults or poorly exposed. As the better-developed, larger structures are restricted to the lower part of the formation, the nature of the stromatolite structures broadly suggests the relative position of any part of the formation in the stratigraphic sequence where both the upper and lower contacts are concealed.

STROMATOLITES IN INDIA

In India, stromatolites have been reported from several isolated areas and most of these examples come from Precambrian rocks. The Precambrian stromatolites are recorded mainly from peninsular India and a few from the Himalayas. Phanerozoic stromatolites, which are few in number, are restricted to the Himalayan region.

As radiometric age datings are scarce and the correlation of the different Precambrian sedimentary formations of India is yet in a preliminary stage, chronologically stromatolites from the Pakhal Group can be compared with other reported occurrences only in very broad terms. A tentative and broad correlation of different Precambrian formations of the peninsular India is suggested in Table I.

The oldest stromatolites in India occur in the Bhagwanpur Limestone of the Raialo Series (RAJA RAO and MAHAJAN, 1965) in Rajasthan. The Raialo Series overlies the Aravallis (Archaean) and is overlain by the Delhi System (KRISHNAN, 1968) of the Purana Supergroup.

Stromatolites are known from the lower part of the Cuddapah Group (SRINIVAS RAO, 1949; VAIDYANADHAN, 1961; VISWANATHIAH and RAJULU, 1963), of Madras State, and in the Lower Kaladgi Subgroup (VISWANATHIAH et al., 1964; RAJULU and GODWA, 1966) of Maharastra State. In both the Cuddapah and the Kaladgi groups, stromatolites are confined to the calcareous formations. The Cuddapah Group, on the basis of lithology, was correlated with the Pakhal Group (KING, 1881) and this correlation, later on, has been substantiated by radiometric age dating. Galena from the carbonate rocks in the upper part of the Cuddapah Group gives an age of 1,400–1,470 millions of years (ASWATHANARAYANA, 1962) and a few datings of glauconite from the Pandikunta Formation of the Pakhal Group suggest them to be 1,400 $\pm$ 70 millions of years old (VINOGRADOV et al., 1964). The Kaladgi Group is on the lithological similarities regarded as correlative with the Cuddapah and the Pakhal groups.

DUTT (1963) describes "crocodile-skin structures" from the uppermost stage of the Indravati Series in the Bastar district of Madhya Pradesh. Examination of the photograph-illustrations by DUTT suggests that these structures are the weathered surface of oncolites. The Indravati Series of the Bastar District is considered to be the equivalents of the Cuddapah Group and its analogues (PASCOE, 1950).

Stromatolites have also been reported from the Semri Series of the Lower Vindhyans (AUDEN, 1933; MATHUR et al., 1958; KRISHNA MOHAN, 1968). Glauconites from the Semri Series have been dated to be about 1,110 $\pm$ 60 millions of years old (VINOGRADOV et al., 1964). These radiometric age data suggest that the

TABLE I

A TENTATIVE CORRELATION OF DIFFERENT PRECAMBRIAN FORMATIONS OF PENINSULAR INDIA

Stratigraphic scale	*Andhra Pradesh*	*East Madras*	*South Maharastra*	*East Madhya Pradesh*	*North Madhya Pradesh*	*Rajasthan*
Cambrian (?)						
Late Proterozoic					VINDHYAN SYSTEM — Bhandar Series	
					Rewah Series	
	Sullavai Group	Kurnool Group	Bhima Group		Kaimur Series	
	PAKHAL GROUP — Mulug Subgroup	CUDDAPAH GROUP — Sub-group I — Kistna Formation	KALADGI GROUP — Sub-group I — Upper Kaladgis		Semri Series[1]	
Middle Proterozoic		Nallamalai Formation		Indra-vati Series[1] — Raipur Formation		DELHI SYSTEM
	Mallam-palli Subgroup	Sub-group II — Cheyair Formation[1]	Sub-group II — Lower Kaladgis[1]	Chand-rapur Formation		
		Papaghni Formation[1]				
						RAIALO SERIES[1]

[1] Indicates the occurrence of stromatolites.

Semri Series is slightly younger than the Cuddapah and the Pakhal groups.

Stromatolites reported from different areas of the Himalayan region range from Late Precambrian to Devonian in age (MISRA and VALDIYA, 1961; VALDIYA, 1967).

Precambrian stromatolites are widely developed in different parts of the world. The distribution of the Precambrian stromatolites in time and space has been summarised by GLAESSNER (1966, p.35, fig.2). In his scheme, Glaessner has placed the stromatolites from the Cuddapah Group in the Middle Proterozoic. According to the presently available datings, stromatolites from other Precambrian formations, namely, the Kaladgis, the Pakhal Group, the Indravati Series and the Vindhyans, also belong to the Middle Proterozoic.

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