ALGAL STROMATOLITE DISTRIBUTION IN RELATION TO SUBSTRATE RELIEF: SHAKOPEE FORMATION (LOWER ORDOVICIAN), ILLINOIS

FRANCES J. HEIN
Department of Geology,
McMaster University,
Hamilton, Ontario, Canada

ABSTRACT.—A quarry wall in the Shakopee Formation in north-central Illinois near Utica exposes a well-preserved algal stromatolite bed which averages 1.5 feet thick and extends for more than 1000 feet horizontally along the quarry walls. The contact between the algal bed and the underlying substrate shows considerable variation in topographic relief. Three distinct facies occur in the algal bed: continuous stromatolite layers, found in areas with little substrate relief; discontinuous stromatolites, which occur in areas of intermediate substrate relief; and a complex facies of mixed stromatolite morphologies, confined to an area of maximum relief. These associations suggest that substrate relief, which is an easily measurable parameter, may be more generally useful as a tool for paleoenvironmental interpretations of stromatolitic deposits in the geologic record.

Much research has been conducted on the effect of various physical environmental factors on the morphology and distribution of modern algal stromatolites (Neumann et al., 1970; Scoffin, 1970; Gebelein, 1969; Logan et al., 1964; Carozzi, 1962; Ginsburg et al., 1954; Black, 1933). Few studies, however, have dealt with the distribution of different stromatolite forms preserved in the geologic record (Hofmann, 1969).

Field studies of the Shakopee Formation in north-central Illinois revealed an excellent exposure of well-preserved stromatolites at the Utica Stone Quarry east of Utica. Distinct morphological forms of the stromatolites occur in a single horizon which extends laterally for over 1000 feet along the quarry walls. The contact with the underlying bed shows considerable variation in topographic relief and thus provides an opportunity to examine the effect of this substrate relief on the distribution of different stromatolite types.

GEOLOGIC SETTING

The Lower Ordovician Shakopee Formation overlies the New Richmond Sandstone and unconformably

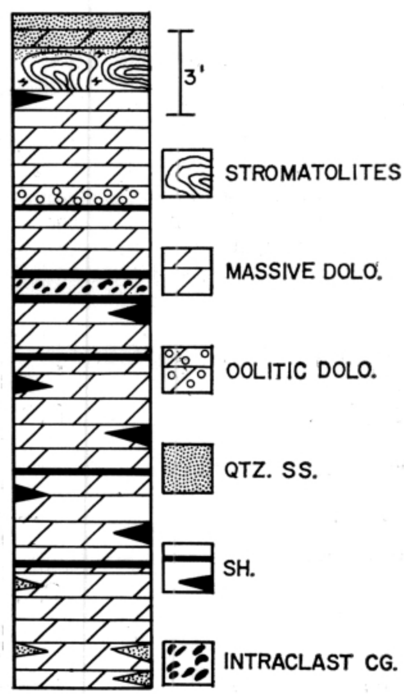


FIGURE 1.—Generalized stratigraphic section of the Lower Ordovician Shakopee Formation at the Utica Stone Quarry.

underlies the St. Peter Sandstone. The Shakopee deposits are composed of mainly underformed massive dolomites which contain sand and shale lenses, occasional intraclast conglomerates, a few continuous beds of calcareous shale and oolitic dolomite, mudcracks, cut-and-fill structures, cross-stratification and stromatolites, suggesting fluctuating shallow marine or intertidal conditions (Figure 1). The stromatolite horizon averages 1.5 feet thick and rests upon a substrate composed of continuous massive gray dolomite occasionally overlain by thin shale lenses. Parts of the section were obliterated through blasting.

A few cephalopods and gastropods are the only fossils other than stromatolites found at the quarry.

Facies Description

Since organic cellular structures are rarely preserved in stromatolites (Ginsburg et al., 1954) they are usually classified by geometrical characteristics (Hofmann, 1969; Logan ea al., 1964). According to most workers, the gross stromatolite morphology and lamination structures are the most important attributes in stromatolite classification. Changes in these attributes result from biological and physical variables (Hofmann, 1969; Logan et al., 1964). It has also been found that identical species of modern algae may generate different gross morphologies in different environments and, conversely, different algal species may exhibit similiar morphologies in the same environment.

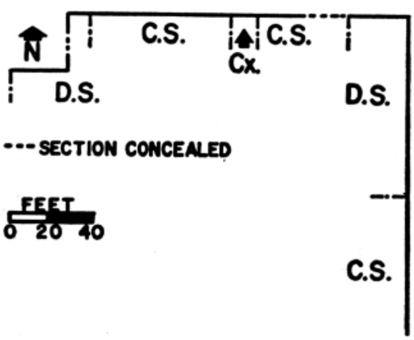


FIGURE 2.—Lateral distribution of stromatolite facies in a single horizon along the quarry walls. D.S.: Discontinuous Stromatolite Facies; C.S.: Continuous Stromatolite Facies; Cx.: Complex Facies.

Hofmann's (1969) classification was used to describe the laminations (which are composed of alternating grey and brown fine-grain dolomite) of stromatolite forms in this study. Three distinct facies are recognized (Figure 2): continuous stromatolite facies (C.S.), discontinuous stromatolites (D.S.), and a complex facies (Cx.).

Continuous Stromatolite Facies

The continuous stromatolites conform closely to substrate topography and extend uninterrupted for over 30 feet in length (Figures 2, 3). The main geometric arrangement of the laminations consists of close-linked undulating (stratiform) laminae (average thickness $\frac{1}{4}$ inch) and occasional small turbinate columns (relief up to 2 inches) which grade vertically into flat stratiform laminae (average thickness $\frac{1}{16}$ to $\frac{1}{8}$ inch) with a few stromatolite nodules near the top of the algal bed (Figure 3). Locally discrete cylindrical columns (Figures 3, 4a) and biscuits (Figure 4b) occur in depressions. Columns have an average basal diameter of 2.5 inches and heights of approximately 4 inches. Biscuits have an average diameter of 11 inches and heights of up to 5 to 6 inches. These discrete biscuits and columns grade up into the undulating and flat stratiform laminae of the upper parts of the facies.

In this continuous facies (Figure 3) the substrate has very little relief. In transition zones which laterally connect the continuous and discontinuous facies (Figure 3) the substrate consists of discrete mounds upon which small domes cap and then coalesce up section forming the typical continuous stromatolite lamination (Figure 3).

Discontincous Stromatolite Facies

The main distinction between the continuous and discontinuous stroma-

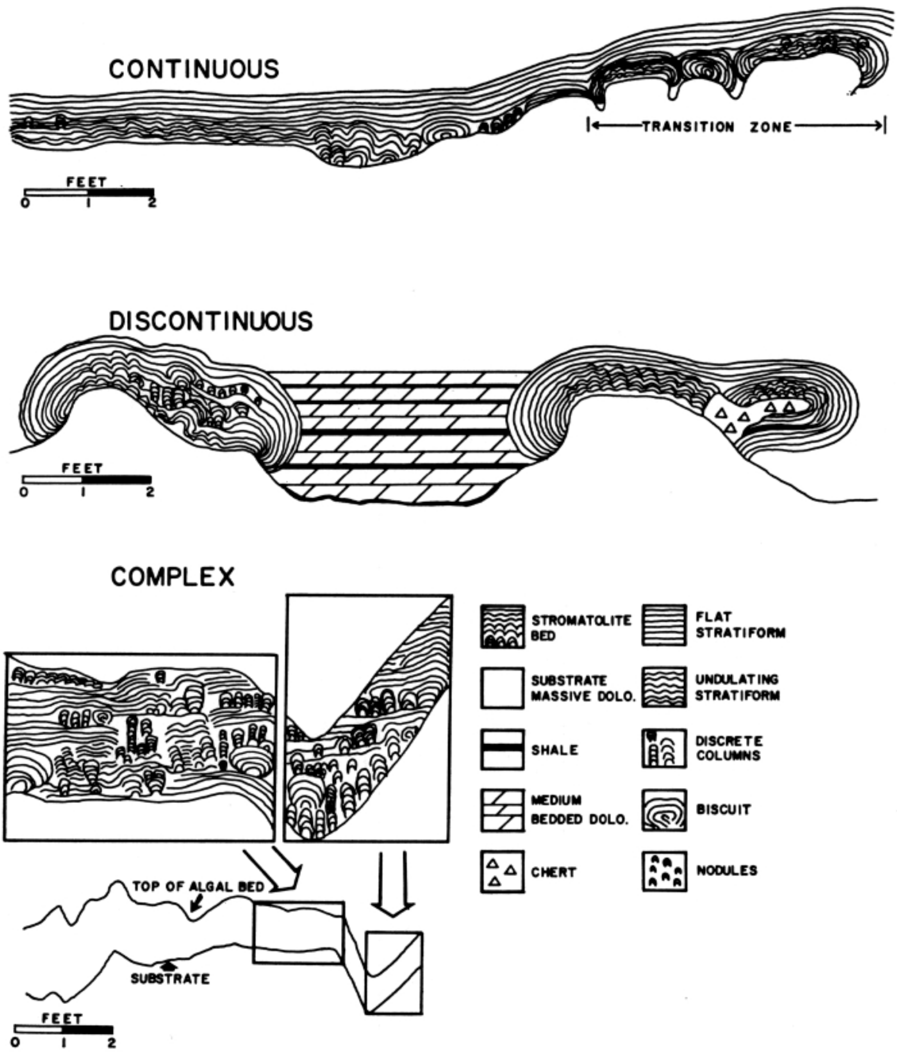


FIGURE 3.—Cross section of typical stromatolite sections exposed along the quarry walls.

tolite facies is the continuity of the algal bed. In the discontinuous stromatolite facies the algal structures cap substrate highs and vary between 1.5 and 7 feet in length. The discrete dome or head-shaped stromatolites are separated by low depressions where the substrate is more irregular (Figure 3). The interdome depressions are up to 3 feet lower than the adjacent stromatolite-capped highs and are filled with medium-bedded dolomite alternating with thin shale lenses. Depressions vary between 2 and 30 feet in width.

None of the individual laminations (average thickness $\frac{1}{16}$ inch) of the algal structures are truncated. Laminations gradually lap upon or wrap around substrate highs (Figure 3), indicating that these discontinuous structures are not merely erosional remnants of a previous continuous layer .Generally the internal structure of the laminations is the same as that found in the continuous facies, where discrete columns anastomose and grade up into undulating and flat statiform laminae.

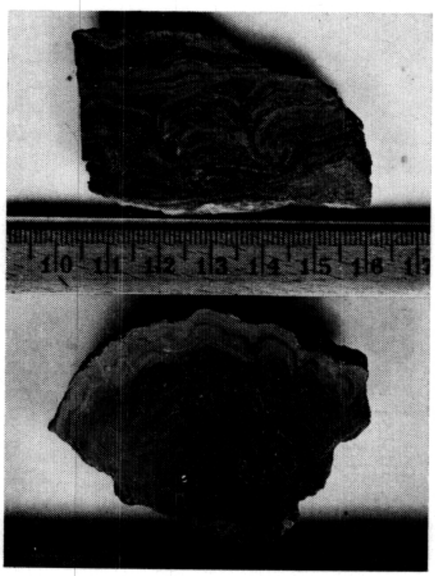


FIGURE 4.—Slab sections of typical small discrete cylinrical columns (a) and biscuits (b) of continuous stromatolite facies.

Complex Facies

A complex facies of randomly associated biscuits, columns, anastomosed columns, undulating and flat stratiform and nodular laminae occurs in an area of maximum substrate relief in one place along the north wall (Figure 3). In contrast to the other facies, there is no definite vertical gradation from columnar and biscuit-shaped structures to flat-lying laminae near the top of the algal bed. Laminations are generally discontinuous and have variable thicknesses.

PROCEDURE

Smith's (1970) "bed relief index" (BRI) was modified to obtain quantitative estimate of the amount of substrate relief associated with the different stromatolite facies. Distances were measured from a leveled carpenter's cord base line which was laid out beneath the substrate bed. The BRI was calculated by subtracting the vertical distance measured from the base line of all relative lows from the vertical distance of each adjacent relative high and dividing this sum by the length of the base line (Figure 5). The resulting quotient is then multiplied by 10. Thus,

$$BRI = \frac{2[E_1+...+E_n)-(e_1+...+e_n)\pm Ex,y]x10}{L}$$

where $E_1+...+E_n$ represents elevations of relative highs, $e_1+...+e_n$ elevations of relative lows, and $E_{x,y}$ the elevations at the extreme ends of the traverse, the sign of which depends on whether they are low or high points. (Smith, 1970, p. 2998). In the above equation and Figure 5 the letter L represents the total length of the base line.

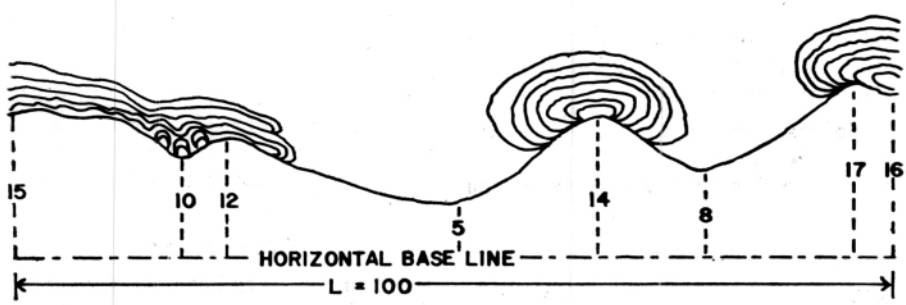
Bed relief indices were measured for the substrate under the different algal stromatolite facies. Horizontal traverses varying in length from 50 to 90 inches were measured at 26 representative sections of the algal bed. Because portions of the bed are naturally discontinuous and some regions were destroyed by blasting, traverse lengths were determined by the continuity of the exposure. The average traverse length was arbitrarily chosen to be 60 inches because of the many relief changes which occur over short horizontal distances.

RESULTS

Field data indicate a correlation between the amount of substrate relief and the type of stromatolite facies. Flat continuous stromatolites are found in areas of low substrate relief along the north and east quarry walls (Figure 2) where the mean BRI is 2.07 with a standard deviation of .71. In both regions (Figure 2) the flat stromatolite layers lap off substrate highs and extend continuously for over 30 feet in shallow basins. Discontinuous forms occur in areas of greater substrate relief with an average BRI of 4.25 and standard deviation of .79. Here stromatolites cap substrate highs and do not occur in the depressions between algal domes. The complex facies with discontinuous laminations of variable thickness occurs in a local area along the north wall (Figure 2) with maximum substrate relief where the BRI is 7.02 and standard deviation of .75. A plot of stromatolite facies in relation to substrate bed relief index illustrates these relationships (Figure 6).

DISCUSSION

Differences in location, exposure, tidal amplitude, substrate relief, rates of sediment movement and current



$$\text{SUBSTRATE BRI} = (15-10)+(12-10)+(12-5)+(14-5)+(14-8)+(17-8)+(17-16) \times 10$$

$$= \frac{2[(12+14+17)-(10+5+8)]+15-16}{100} \times 10$$

$$= 3.90$$

FIGURE 5.—Calculation of substrate bed relief index (BRI) modified after Smith (1970).

velocity produce morphologic differences in modern stromatolites (Gebelein, 1969; Ginsburg et al., 1954; Logan et al., 1964). Although it is rarely possible to say that any one environmental factor is responsible for a particular stromatolite form, some workers have correlated stromatolite morphologies with given sets of environmental conditions.

Gebelein (1969) found that stromatolite morphology, distribution and abundance are controlled by the energy of the environment, expressed in terms of current velocity and rates of sediment movement. Flat algal mats occur where surface current velocity is less than 15-20 cm/sec and bottom sediment movement is less than 60-80 gm/hr/ft. Discontinuous algal domes and biscuits form between 1 and 11 cm/sec current velocity and between 8 and 60 gm/hr/ft bottom sediment movement. Continuous mats form in either high or low energy environments and discontinuous structures form in intermediate energy environments.

Hoffman and others (in press) have also noted that the environmental setting is a main control of the morphology of stromatolites in Shark Bay, Australia. In low intertidal areas, flat smooth mats are found in protected embayments, low elongate domes are found along semi-protected coasts, and high circular bulbous-columnar stromatolites occur in exposed headlands. In intertidal zones the degree of wave turbulence and sediment movement control the gross morphology of stromatolites.

In light of these recent studies of modern stromatolites possible interpretations can be made for the Shakopee deposits. Flat continuous stromatolites which occur in areas of low substrate relief show no evidence of reworking or scouring of the algal bed. These continuous stromatolites may have been deposited in low energy basins or protected embayments. Discontinuous head or dome-shaped stromatolites with intermediate substrate relief may have occurred in higher energy zones where stromatolites grew on substrate highs, separated by small depressions which later became filled with sediment. The complex facies occurs in a local area with maximum substrate relief and contains discontinuous laminations of variable thickness. It may represent a tidal channel where current velocity and rates of sediment movement were highly variable.

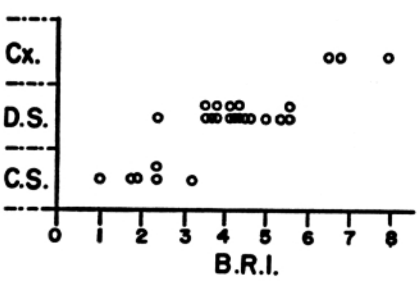


FIGURE 6.—Relationship of stromatolite facies and bed relief index (BRI) of the substrate. Cx.: Complex facies; D.S.: Discontinuous stromatolite facies; C.S.: Continuous stromatolite facies.

CONCLUSIONS

Much work has been done to define the ecological range in which different modern stromatolite morphologies are found. Many of these studies have concentrated on environmental factors which are difficult to estimate in ancient stromatolitic deposits. The data of this study suggest that certain stromatolite associations correlate well with substrate relief, which along with other sedimentary structures may give a clue to the energy of the environment in which the stromatolites grew.

ACKNOWLEDGMENTS

The author is grateful to N. D. Smith for many rewarding discussions through out the study. He, C. D. Gebelein and K. S. Rodolfo critically reviewed the manuscript and offered many helpful suggestions. Margaret M. Kinnally and S. Zyrkowski assisted in the field. The writer wishes to thank Mike Sitterly of the Utica Stone Quarry for his cooperation.

LITERATURE CITED

BLACK, MAURICE. 1933. The Algal Sediments of Andros Island. Royal Soc. (London) Phil. Trans. ser. B. 122: 165-192.

CAROZZI, *A. V.* 1962. Observations on Algal Biostromes in the Great Salt Lake, Utah. J. Geology 70: 246-252.

GEBELEIN, C. D. 1969. Distribution, Morphology and Accretion Rate of Recent Subtidal Algal Stromatolites, Bermuda. J. Sedimentary Petrology 39: 49-69.

GINSBURG, R. N., L. B. ISHAM., S. J. BEIN and JOEL KUPERBERG. 1954. Laminated Algal Sediments of South Florida and Their Recognition in the Fossil Record. Unpublished Rept. No. 54-21, Coral Gables, Florida, Marine Laboratory, Univ. Miami: 1-33.

HOFMANN, H. J. 1969. Attributes of Stromatolites. Geological Survey of Canada Bulletin 69-39: 1-58.

HOFFMAN, *P*AUL, B. W. LOGAN, and C. D. GEBELEIN. (in press). Morphology and Internal Structure of Recent Algal Stromatolites, Shark Bay, Western Australia.

LOGAN, B. W., RICHARD REZAK, and R. N. GINSBURG. 1964. Classification and Environmental Significance of Algal Stromatolites, J. Geology 72: 68-83.

NEUMANN, A. C., C. D. GEBELEIN, and T. P. SCOFFIN. 1970. The Composition, Structure and Erodability of Subtidal Mats, Abaco, Bahama. J. Sedimentary Petrology 40: 274-297.

SCOFFIN, T. P. 1970. The Trapping and Binding of Subtidal Carbonate Sediments by Marine Vegetation in Bimini Lagoon, Bahamas. J. Sedimentary Petrology 40: 249-273.

SMITH, N. D. 1970. The Braided Stream Depositional Environment: Comparison of the Platte River with Some Silurian Clastic Rocks, North-Central Applachians. Geol. Soc. Amer. Bull. 81: 2993-3014.

Manuscript received July 6, 1971.