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# LOWER PERMIAN ALGAL STROMATOLITES FROM KANSAS AND OKLAHOMA

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## CONTENTS

## PART 1

## PALEOECOLOGICAL OBSERVATIONS ON WELLINGTON ALGAL STROMATOLITES FROM KANSAS AND OKLAHOMA

PAUL TASCH and EVAN KIDSON

### ABSTRACT

Fossil algae have been studied in field and laboratory with emphasis on the kind of paleoecological data for which reports are sparse-to-lacking. Algal facies were found to recur vertically at several localities. Pellet-ostracode zones (one-to-three in number in a given fossil) were found in numerous digitate algal specimens. Mini-erosive events detectable in thin section include: algal breccia and pellet-ostracode infill, ruptured and redistributed pellet-ostracode layers, and interrupted laminae.

Cyclical growth was detected on some slides. One slide showed nine major cycles.

Characteristics and causes of digitation were examined. Generally, this is attributed to ruptured algal mats with subsequent filamentous growth inhibited only in the damaged areas (interdigital).

*Hamispora bifurcata* and numerous other spores were incorporated in the growing algae, and are found aligned with growth laminae. Colometric determinations of phosphate content of various fossil algae and some controls among modern forms point up a possible method for discriminating fresh and brackish-water algae from marine forms.

### INTRODUCTION

The fossil algae to be discussed in the following pages were collected by TASCH at localities and horizons in Kansas and Oklahoma listed below. Some aspects of algal occurrences in the Wellington Formation, Lower Permian, have been discussed and figured previously (TASCH, 1964, p. 484-485, fig. 1). Additional data are set forth and examined here in order to fill out the picture in conjunction with JOHNSON's treatment of paleontology of the algae (Part 2).

## ACKNOWLEDGMENTS

Field and laboratory research on the Wellington Formation has been supported by the National Science Foundation (Grants G-4150, G-7320, G-14141).

Over a period of years Tasch has investigated some of the more obscure aspects of algal growth, little discussed sedimentary and structural features of algal masses, and various paleoecological items for which data are sparse or lacking. Some of the investigations were carried out in collaboration with students, among them Gary Crown, J. M. Lammons, and Evan Kidson. In particular, Kidson prepared numerous thin sections and photographs which serve as the basis of some of the observations reported here.

## LOCALITIES

All collecting localities cited in both Parts 1 and 2 are included. All contain outcrops of strata belonging to the Wellington Formation, Lower Permian. Locality 6 is omitted because it represents a strongly recrystallized algal sample from the Ninnescah Shale which provided no new information.

*Sumner County, Kansas*

Loc. 1. SE¼ SW¼ sec. 11, T. 35 S., R. 1 W.
Loc. 2. SE¼ SE¼ sec. 31, T. 34 S., R. 1 E.
Loc. 3 NE ¼ SE¼ sec. 6, T. 33 S., R. 1 E.
Loc. 4. SE¼ SE¼ sec. 5, T. 33 S., R. 1 E.

*Cowley County, Kansas*

Loc. 5. SE¼ NE¼ sec. 21, T. 34 S., R. 3 E.

*Kay County, Oklahoma*

Loc. 7. NE¼ NW¼ sec. 23, T. 28 N., R. 2 W.
Loc. 8. SE¼ NE¼ sec. 23, T. 28 N., R. 1 W.

*Noble County, Oklahoma*

Loc. 9. SW¼ SW¼ sec. 23, T. 21 N., R. 1 W.
Loc. 10. SW¼ SW¼ sec. 23, T. 24 N., R. 1 W.

# RECURRENT AND PERSISTENT ALGAL FACIES

## RECURRENT FACIES

At several known localities, algal facies are found to recur. In Kansas, at Loc. 1 the lower algal layer (bed 4) is separated from the upper algal layer (bed 7c) by an interval of 9.3 feet of argillite. At Loc. 3 an interval of 18.9 feet separates the lower and upper algal beds. Within this latter is an insect-conchostracan bed.

In Oklahoma at Loc. 7 an interval of 9.9 feet separates a lower and upper algal bed. Here also an insect-conchostracan bed occurs in the interval.

The insect-conchostracan associations reflect shallow fresh-to-brackish-water coastal ponds, and the algae presumably indicate a marine (brackish-water) facies. Ostracodes found in the algal masses (see next section) most likely thrived in interdigital domal pools during regressive phases of the Wellington sea (cf. Tasch, 1964).

## PERSISTENT FACIES

Whereas Wellington algal occurrences generally are restricted in horizontal spread, occurring as biscuits and similar small masses, one instance of a greater spread is found (at Loc. 4). This is an algal bed (Well.-Tp. 1), a biostrome, less than 1 foot thick, which is traceable for several hundred feet along the turnpike.

# PELLET-OSTRACODE ZONES

In numerous digitate algal specimens from the Wellington Formation of Kay County, Oklahoma (Loc. 7, spec. 5; Loc. 8, spec. 14) and Sumner County, Kansas (Loc. 2) pellet-ostracode associations were observed.

Up to three distinct successive zones were found to occur in a single algal mass. One such zone occurs as a continuous traceable band or layer in some specimens (Fig. 1,*1,2*).

The sinuosity of the pellet-ostracode zone is marked. A repetitive sag between digital domes may reflect either deposition of minute shells, etc., in the small-scale troughs between domes or they may be attributable to subsequent compaction. Catastrophic death could account for the ostracode populations in any given zone. Conceivably, silting-up which clearly choked off algal growth partially in certain directions, and ultimately completely, may have been a factor in such uniform and repeated mass death.

# MINI-EROSIVE EVENTS

1) *Algal micro-breccia.*—Algal breccia is found as infill between digital domes (Fig. 2).

2) *Redistributed pellet-ostracode association.*—Turbulent activity is indicated by ruptured and redistributed portions of pellet-ostracode layers.

3) *Pellet-ostracode infill.*—Concentration of pellets and ostracodes (Fig. 3,*1-3*) presumably were in-swept by current or wave action into interdigital spaces.

4) *Irregularities in laminae.*—Mini-erosive effects of turbid waters and microcurrents are well seen in an Oklahoma specimen (Loc. 7, spec. 1c). Laminae occur as both discontinuous (i.e., interrupted) and irregular interlaminae. Silt was deposited between such irregular surfaces.

## SUBSTRATE

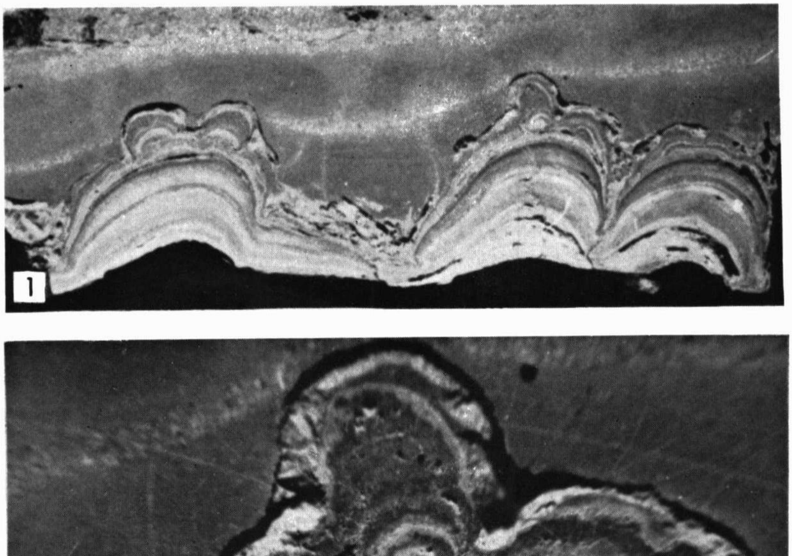
Blue-gray argillaceous micrite (Loc. 7, bed 5) served as a substrate for the start of an algal structure. The basal laminae can be seen to have been deposited on a slightly irregular surface (Fig. 4). Apparently the microtopography of this basinal floor served as well as any other attachment basis for the start of algal growth.

Effectively the closely spaced sequence of original laminae tended to rectify the irregular surface (but without full realization of this tendency). In numerous algal biscuits, etc., smooth, slightly arched sequences of conformable laminae are common for much of the growth cycle. Digitation was a more limited and subsequent growth event.

## MODE OF GROWTH

In one specimen (Fig. 4) nine major cycles were counted along a vertical scan 1.5 cm. long traversing the deepest part of the algal colony on an average slide. Each of the major cycles (light colored bands) contain two to seven subdivisions. On a microscale, the subdivisions in turn consist of alternating light and dark layers. Further systematic study of such cyclical growth could yield geochronological and paleoclimatological data.

Individual algal laminae were found to be composed of fine-grained calcite, with clay and



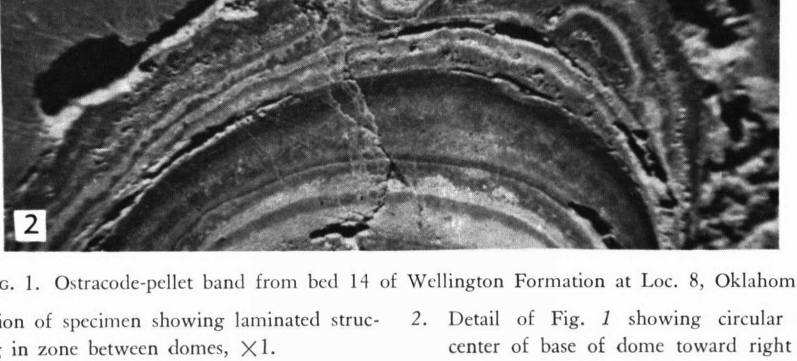


FIG. 1. Ostracode-pellet band from bed 14 of Wellington Formation at Loc. 8, Oklahoma.

*1.* Vertical section of specimen showing laminated structure and sag in zone between domes, ×1.

*2.* Detail of Fig. *1* showing circular encrustation in center of base of dome toward right and portion of sagging ostracode-pellet band, *ca.* ×4.

FIG. 2. Section of specimen from Wellington Formation (Loc. 7, bed 1c). A streak of algal breccia in upper left portion of the photograph, ×8. This is a negative print taken by transmitting light through a thin section, ×8.

organic constituents noticeable. Interlaminae are composed of a coarse, crystalline, calcite matrix, with silt, pellets, ostracodes or other larger-than-silt-sized material.

Gary Crown has reported a positive titian-yellow stain reaction in the laminae of some samples, indicating the presence of gypsum. The interlaminae did not react to the stain. Gypsum apparently replaced the calcite in the laminae. It may be attributed to rather short-term and repetitive influx of higher-salinity waters over the small topographic highs created by the algal biscuits. The fact that the interlaminae are nongypsiferous indicates that gypsification of the laminae must have been penecontemporaneous with each individual lamina, rather than a single replacement following completion of the algal growth cycle.

## DIGITATION

The outstanding characteristics of digitation are: 1) a marked curvature of laminae, and 2) formation of discrete domal processes as a consequence. Only a limited terminal portion of the growth cycle of a given alga of this study displays digitate structures. It is thus reasonable to conclude that some new factor(s) was (were) introduced to explain the change to "discrete domal" in contrast to the earlier "arched sheet-like" growth.

One specimen (Fig. 1,*2*) indicates that at least one digitate process was formed by circular encrustation of some bottom sediment. Subsequently deposited sediment and laminae sharply curve over the circular structure, creating a digitate effect. This specimen shows (at right of the major digit) another arched area which is visible as a concentric semicircle. Here the same effect was achieved without circular encrustation.

The cited examples are hardly applicable to all specimens and may only be relevant to portions of the figured specimen (Fig. 1,*2*). A broader sequence of events, of greater applicability probably involved several factors: 1) the algal mat may have been damaged (torn) by temporary higher-energy conditions (cf. erosive effects previously noted); 2) the influx of silt and clay undoubtedly created temporary turbidity and provided a steady downward movement of suspended sediments; 3) algal filaments of the undamaged portions of the mat would be readily able to penetrate the shallow sediment blanket. On the contrary, filamentous growth would be inhibited in the ruptured portions. It follows that the nongrowing portions of the mat could form interdomal spaces, while the growing portions would become domal and digitate processes.

In several specimens, smooth, arched conformable laminate sequences occur above and below the domal-digitate processes. This indicates that a continuous algal mat existed before, and was restored after, the domal events. This could happen by extension of growing filaments in an interdomal as well as a domal direction.

There are, of course, other controls and influences on algal growth, such as light penetration, salinity, etc. (Tasch, 1963). However, it is not growth predominantly but *growth form* that concerns us here. Turbid waters would naturally cut down the intensity of light penetration and in this sense, "degree of light penetration" may have been a partial determinant of the shape of a given algal colony.

Besides the above-noted possibilities, formation of an initial domal structure was predetermined (at least in some instances) by an original local "high" in the bottom topography.

## PALYNOMORPHS

As is common in several portions of the Wellington Formation, various spores were brought into the basin in the time preceding, *during,* and following algal growth. Some of these palynomorphs are incorporated into the fossil algae and are found aligned with the growth laminae (Fig. 5,*1,2a-c*).

*Hamispora bifurcata,* found elsewhere in the nonalgal beds of the Wellington Formation (Jansonius, 1961, p. 62), is one of the species represented among dozens of specimens found in the fossil algae of this study.

## PHOSPHATE CONTENT

In conjunction with other studies of disseminated phosphate content (1961), J. M. Lammons has analyzed the samples listed in Table 1. Since such data have not been available heretofore, it seemed desirable to obtain this information. The colometric method used to determine percent transmittance closely follows that prescribed by the American Public Health Association (1955). As a control for the Wellington

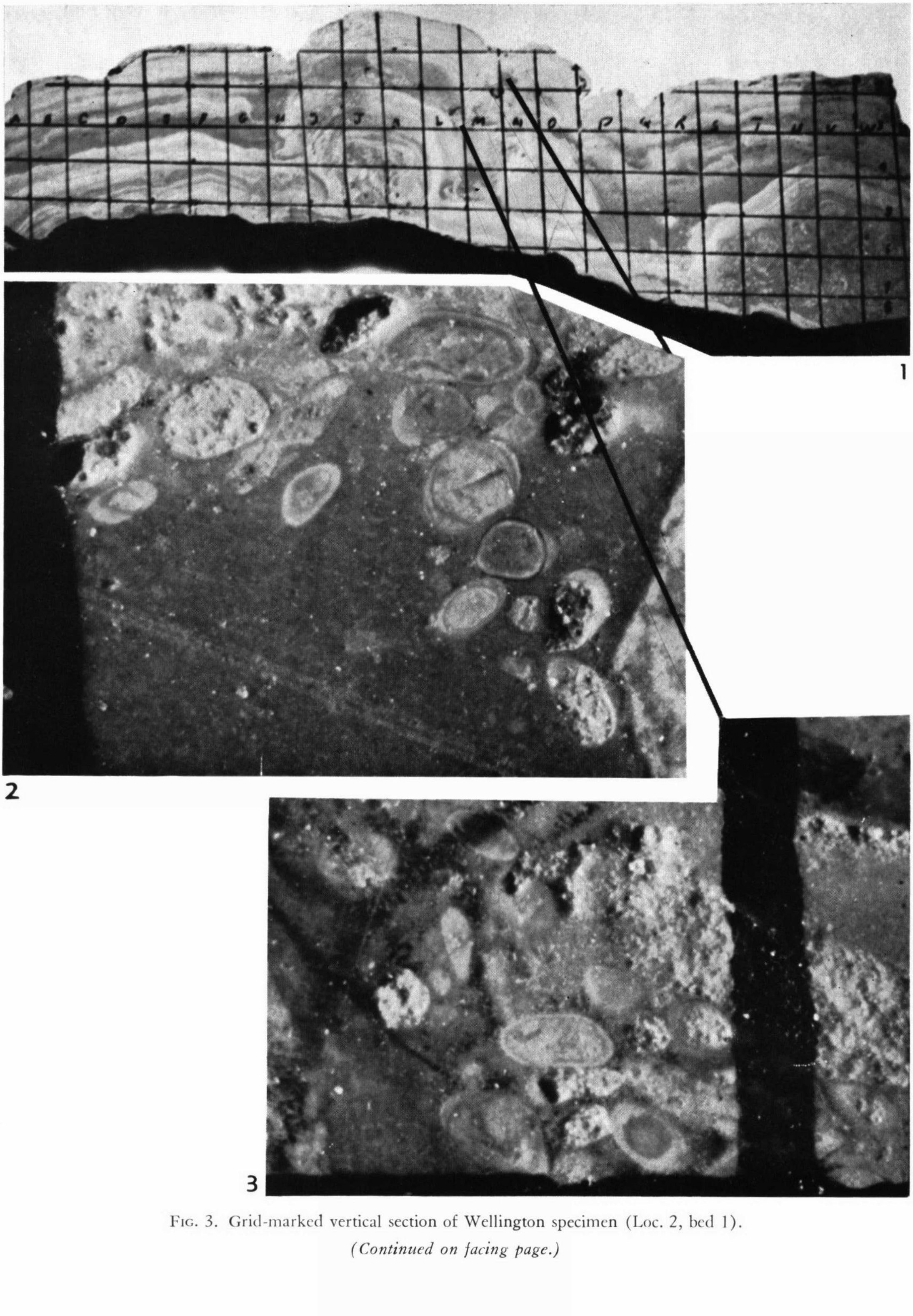


Fig. 3. Grid-marked vertical section of Wellington specimen (Loc. 2, bed 1).

*(Continued on facing page.)*

Fig. 4. Section of Wellington specimen from Loc. 7 (bed 5) showing mode of algal growth (much enlarged). A vertical traverse of 1.5 cm. covered nine major cycles (light-colored bands). Note the irregular surface of the substrate which is a blue-gray argillaceous micrite (slide 20).

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*1.* Polished algal slab showing infill between domes, ×1. (Grid squares lettered left to right and numbered downward.)

*2.* Detail of Fig. *1* showing part of grid square N2 with elliptical outlines of ostracodes, which are most numerous near margin of dark area of silty influx, ×55.

*3.* Detail of Fig. *1* showing part of grid square 3L with concentration of ostracode valves, ×45. Micro-accumulation at lower right of photograph suggests an in-swept collection of valves in a structural low (cf. Fig. 1).

algal samples, two Recent algal aggregates, one from a fresh-water situation (Price Falls, Okla.) and another from a marine one (Duck Key, Fla.) were used.

Table 1 indicates that the modern marine calcareous alga (Duck Key) has two to three times as much phosphate as any of the analyzed fossil specimens and five times the amount found in the modern fresh-water calcareous alga from Price Falls. Successive bands in the same algal biscuit (Loc. 7) were sampled and analyzed separately, and may be said to show negligible differences in percent (by weight) of phosphate.

Between localities one may discern differences in the magnitude of 0.1 percent phosphate (Locs. 1 and 3). Such differences may be attributed in part to effects of leaching.

TABLE 1.—*Phosphate Content of Various Wellington Formation Algae from Kansas and Oklahoma*

[Data by J. M. LAMMONS]

| CALCAREOUS ALGAL SAMPLES | PERCENT OF $PO_4$ (by weight) |
|---|---|
| Loc. 1, bed 4 | 0.358 |
| Loc. 1, bed 8 | 0.218 |
| Loc. 3, bed 7 | 0.261 |
| Loc. 5, bed 4B | 0.205 |
| Loc. 7, band A, spec. 2b | 0.289 |
| band B, spec. 2b | 0.192 |
| band C, spec. 2b | 0.222 |
| Loc. 9, bed 5 (Midco) | 0.126 |
| Duck Key, Florida, spec. 563 | 0.631 |
| Price Falls, Oklahoma | 0.123 |

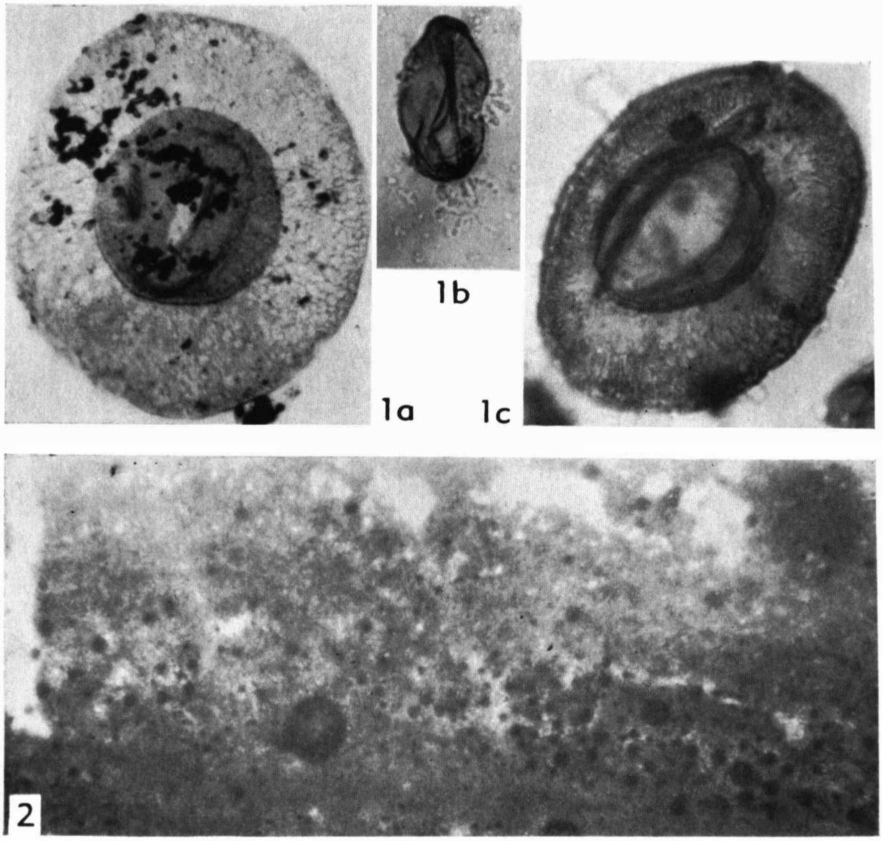

FIG. 5. Spores in Wellington algal stromatolites; section of specimen (slide 2) from Loc. 8 (bed 14) showing:

*1.* Representative spores in stromatolites, which are most common in all algal spore slides of this study. ——*1a.* Spore 16 × 30 $\mu$ in dimensions.——*1b.* Spore 185$\mu$ in diameter.——*1c.* Spore with dimensions of 100 × 150 $\mu$.

*2.* Dense spore population aligned within laminae of algal material, ×70.

Fresh- to brackish-water calcareous algae may possibly be discriminated from marine forms by phosphate analysis. The smaller figures for the phosphate content of fossils recorded in Table 1 may bespeak fresh to brackish conditions as compared to more saline. More determinations will be needed from fossil and living forms from all environments to test this suggested relationship of relative salinity and phosphate content.

Some recent work (NELSON, 1967) indicates that as one goes from fresh-water to marine environments, the calcium phosphate, and hence the phosphate ratio (Ca and Fe phosphate), in a given argillite will increase. Might this also apply to calcareous stromatolites, i.e., insofar as increase in phosphate content is concerned? Table 1 hints at this possibility. Insoluble residues of the stromatolite from Loc. 8, bed 14, contain about 2 percent of undigested algal clay material. This should suffice for paleosalinity determinations. Assessment of this possibility is under way.

It is desirable to compare the various algae listed by VINOGRADOV (1913, p. 35-69) with those of this study, but he reckoned phosphate in percent $P_2O_5$ in dry matter (i.e., ash); hence direct comparisons are not feasible.

[The colometric method, used to calculate entries in Table 1, determines phosphate according to the equation: concentration of $PO_4 = \log P/P_0$, where P is the transmittance value of the unknown solution and $P_0$ is the transmittance value of the standard.]

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## PART 2

# ALGAL STROMATOLITES FROM THE WELLINGTON FORMATION OF KANSAS AND OKLAHOMA

J. HARLAN JOHNSON

## ABSTRACT

The mega-microscopic aspects of Wellington stromatolites were studied. Flat, laminated, domal, hemispheric, digitate, and spherical masses are characteristic forms. Laminae are paired: darker layer (organic), lighter layer (silt chiefly). Study of thin sections suggests detrital influence (possibly control) on laminae. Thus, where detrital inflow was abundant, laminae are distinct and fairly thick, where it lessened, dark layers are thicker and darker, while the light layers appear thin to absent and if detritus was completely absent, laminae become indistinct.

Algal threads observed in thin sections include vertical threads 18-23$\mu$ in diameter and horizontal threads with well-developed walls 25-30$\mu$ thick.

# INTRODUCTION

Algal stromatolites are laminated sedimentary structures composed of particulate sand, silt, and clay-size sediment, which have been formed by the trapping and binding of detrital sediment particles by an algal film or mat. A variety of forms is produced by the interaction of the algal film, detrital sediment, and other physical environmental factors. The stromatolites may be columnar, digitate, club-shaped, flat undulating, hemispherical, flattened hemispherical, or spheroidal in form.

The organic film or mat, active in the formation of most algal stromatolites, was probably a complex of filamentous or unicellular green (Chlorophyta) and blue-green (Cyanophyta) algae, or both.

Stromatolites are not true fossil algae in the sense of preserving recognizable algal features such as skeletal structure, cell walls, and sporangia or conceptacles; rather, they are trace fossils. They are fossils in the same sense as fossil footprints, worm borings, and "petrified" nests of insects.

"Remains of the organic film or mat are seldom preserved in ancient sediments. The algal stromatolite is usually recognized as a moundlike or headlike mass of laminated sediment standing a few centimeters to many meters above the contemporary depositional interface or in discordant relationship to the bedding of the strata in which it occurs. The sediment comprising the stromatolite is ordinarily fine, calcareous, and often lithologically unlike the sediment in which the structure is imbedded" (Logan, Rezak, & Ginsburg, 1964).

The criteria for recognition of relatively flat, laminated algal stromatolitic sediments have been discussed by Ginsburg *et al.* (1954). Detrital texture, structures which require a sediment-binding surface film, minor domes, bubbles, undulation and micro-unconformities, and confluence of laminae with larger heads are all significant factors in diagnosis.

# WELLINGTON ALGAL STROMATOLITES

## GENERAL

The Wellington stromatolites show a considerable variety of forms. The forms range from simple thin, nearly flat, laminated limestones through irregularly warped, gently domed, to complex hemispherical, digitate, or even spherical masses.

All are laminated. The laminae may be smooth or show quite complex structures.

In describing these structures we use the system formulated by Logan, Rezak, & Ginsburg, 1964. Most of the structural types are illustrated in Figures 6-9.

## DESCRIPTION—FORM AND MEGASTRUCTURE

The most common and widespread form appears to be that represented by specimens from Loc. 1 (bed 4) (Fig. 6,*1*). This consists of relatively flat beds 1 to 2 in. thick with the upper surface covered by closely to widely spaced hemispherical or flattened hemispherical domes (formula *LLH-C* or *LLH-S,* Table 2).

The laminae in the basal part are essentially horizontal but those above become increasingly involved in the domal structures. They are not very conspicuous on freshly broken or slightly weathered surfaces.

The domes commonly range from 2.5 to 4 in. in diameter and 1 to 2.5 in. high.

Table 2.—*Formulas Used in Wellington Algal Stromatolite Descriptions*

[After Logan, Rezak, & Ginsburg, 1964]

| | |
|---|---|
| *SH*[1] | Discrete, vertically stacked hemispheroids |
| *LLH*[1] | Laterally linked hemispheroids |
| *SS* | Spheroidal structures |
| *LLH-C* | Closely linked hemispheroids |
| *LLH-S* | Space linked hemispheroids (space between structures greater than diameter of the structures) |
| *SH-C* | Discrete structure of vertically stacked hemispheroids in which upper hemispheroid laminae reach or overlap the base of the preceding ones without increase in basal radius |

[1] The majority of algal stromatolite structures are compounds of *LLH* and *SH* arrangements.

A somewhat more complex type is shown by specimens from Loc. 7 (bed 1c, incl. spec. 3f) (Fig. 6,*1*). These comprise flattened masses of irregular size and shape or more or less steeply sided hemispherical or elongated helmet-shaped masses. Judging from the hand specimens they may develop as isolated specimens or may be crowded together to form beds or tabular masses.

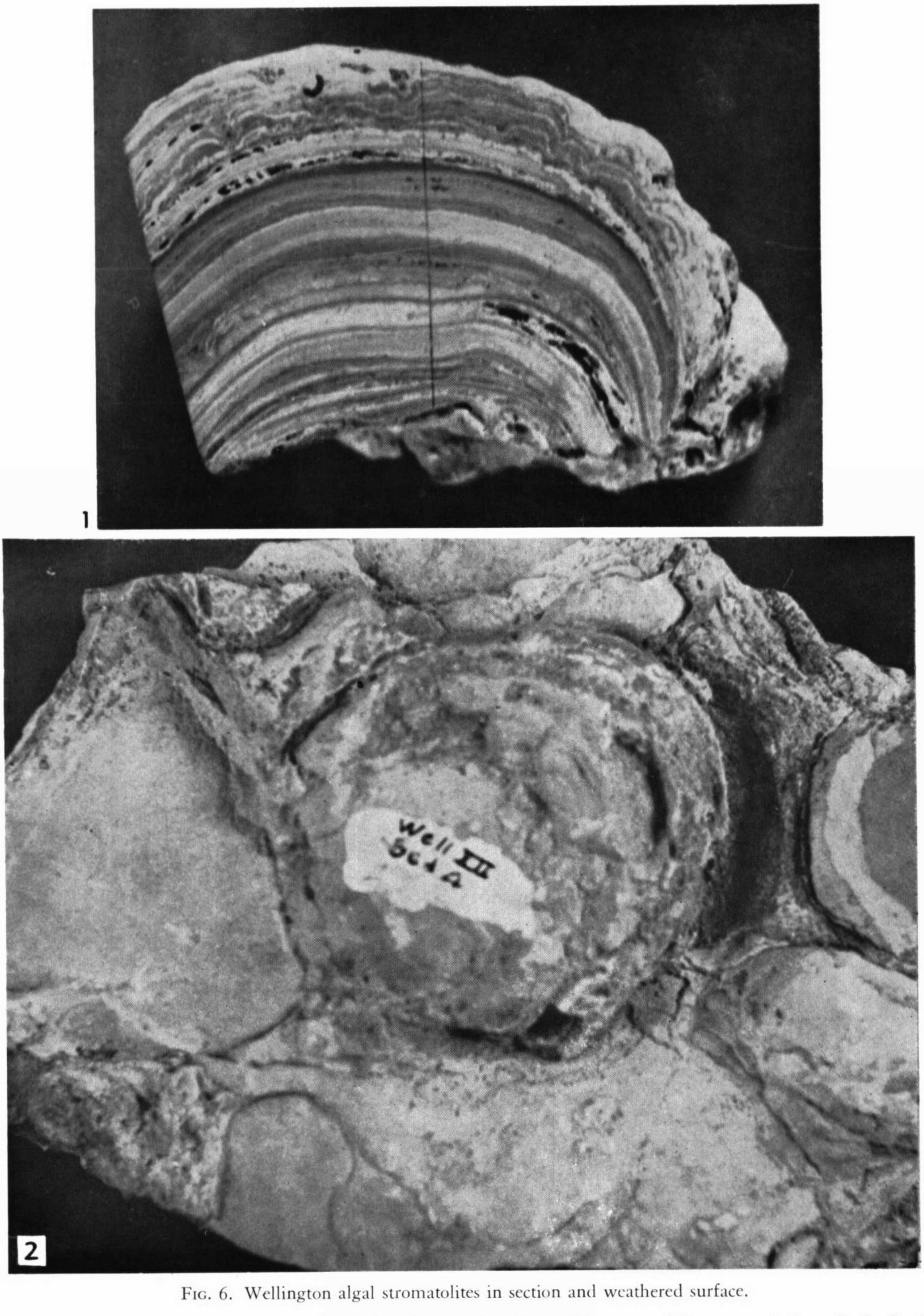

FIG. 6. Wellington algal stromatolites in section and weathered surface.

*1.* Vertical section of specimen 3f (Loc. 7) with a large flattened hemispherical mass at the base overlain by closely packed warty growths, ×1.

*2.* Piece of limestone slab composed of nearly flat laminae with widely spaced flattened hemispherical algal stromatolite domes (specimen from Loc. 1, bed 4), ×0.5.

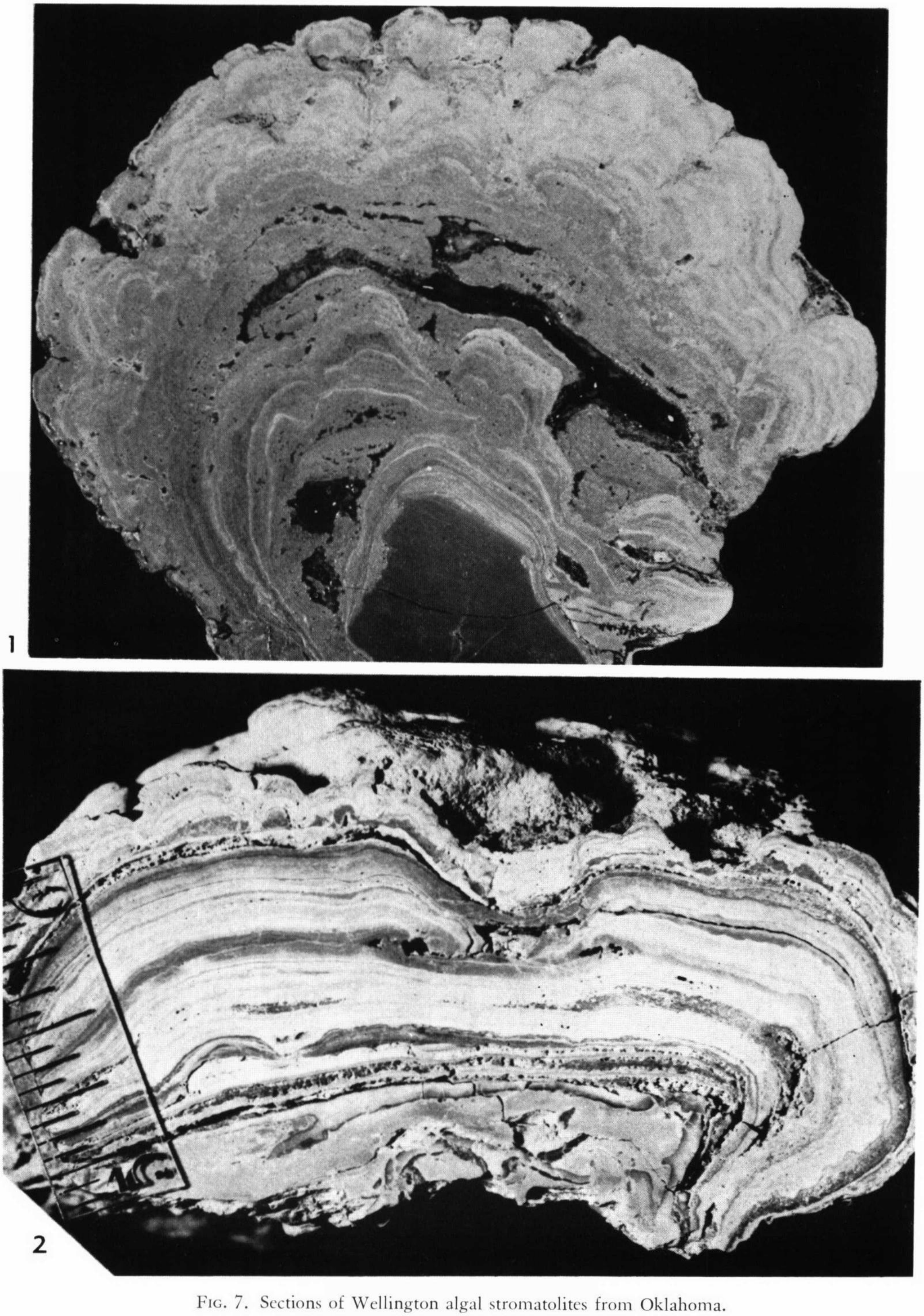

FIG. 7. Sections of Wellington algal stromatolites from Oklahoma.

*1.* Nearly vertical section through specimen B-3 (Loc. 2), lower portion consisting of closely packed flattened hemispherical domes with digitate masses above, *ca.* ×1.

*2.* Specimen from Loc. 2 (bed 11) showing large flattened hemispherical domes with growth of smaller closely packed domes above, forming warty protuberances on upper surface, ×1.5.

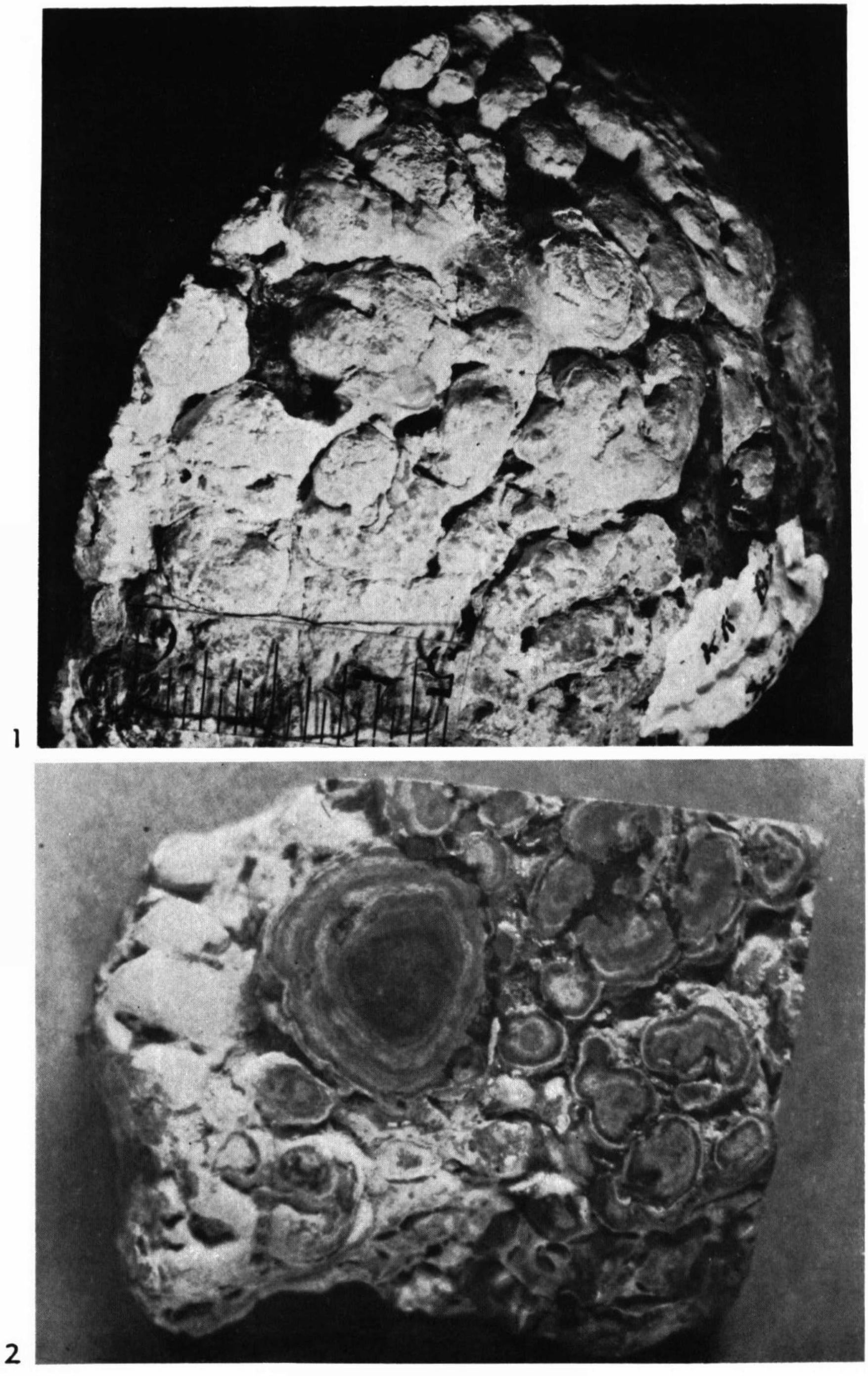

FIG. 8. Algal stromatolites from Wellington Formation in Oklahoma (Loc. 7).

*1.* Top view (slightly oblique) of specimen B-3 showing domed tops of digitate growths seen in Fig. 7,*1*, ×1.5.

*2.* Top view of polished specimen B-3, no. 5, showing small hemispherical domes and their structure, ×1.25.

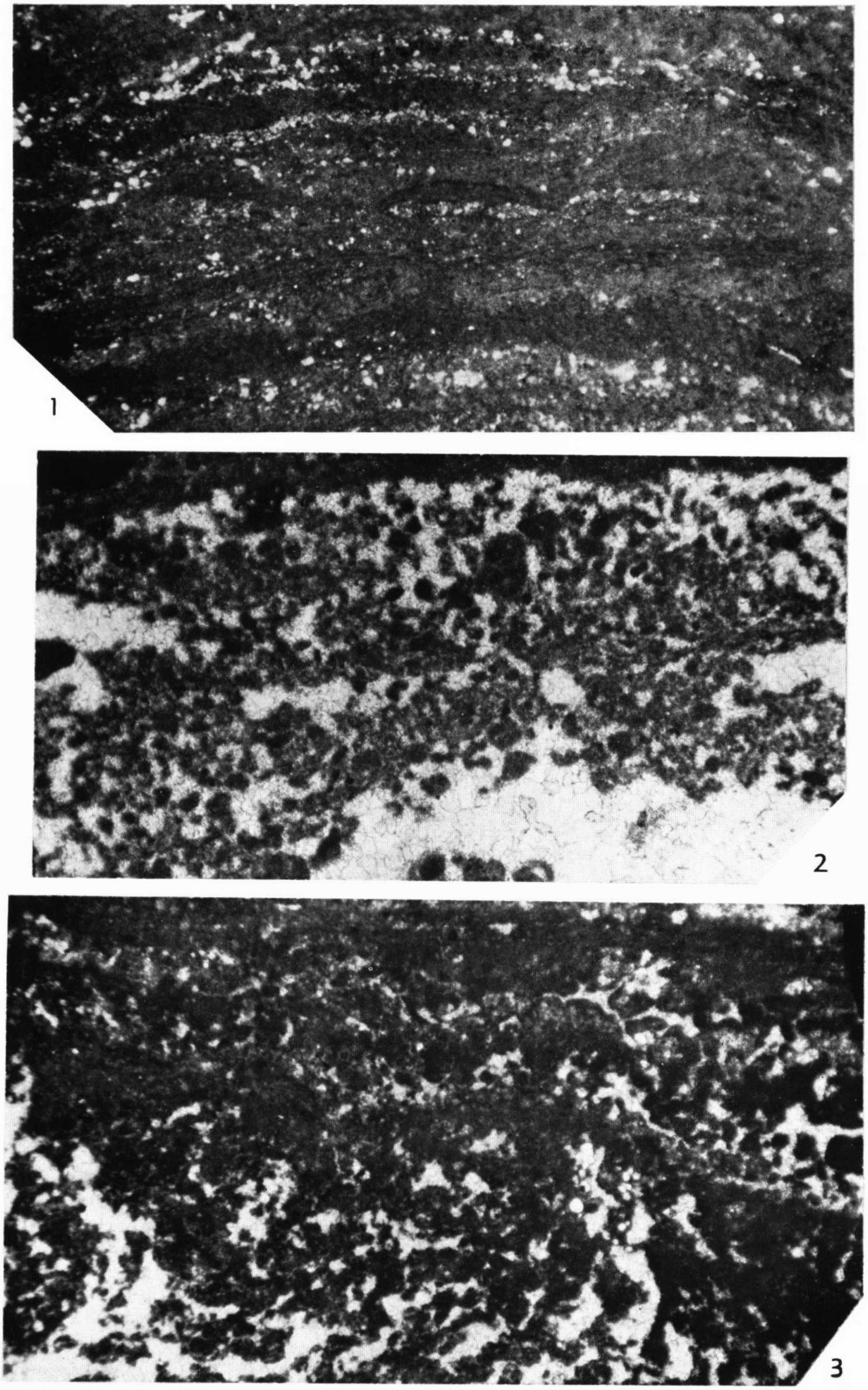

FIG. 9. Microstructure of Wellington algal stromatolites. *(Continued on facing page.)*

*1.* Specimen B-3 (slide 2993) from Loc. 7 showing laminae with suggestions of horizontal threads, ×30.

2. Specimen B-3 from Loc. 7 showing algal "clots" (dark), white areas being recrystallized sedimentary

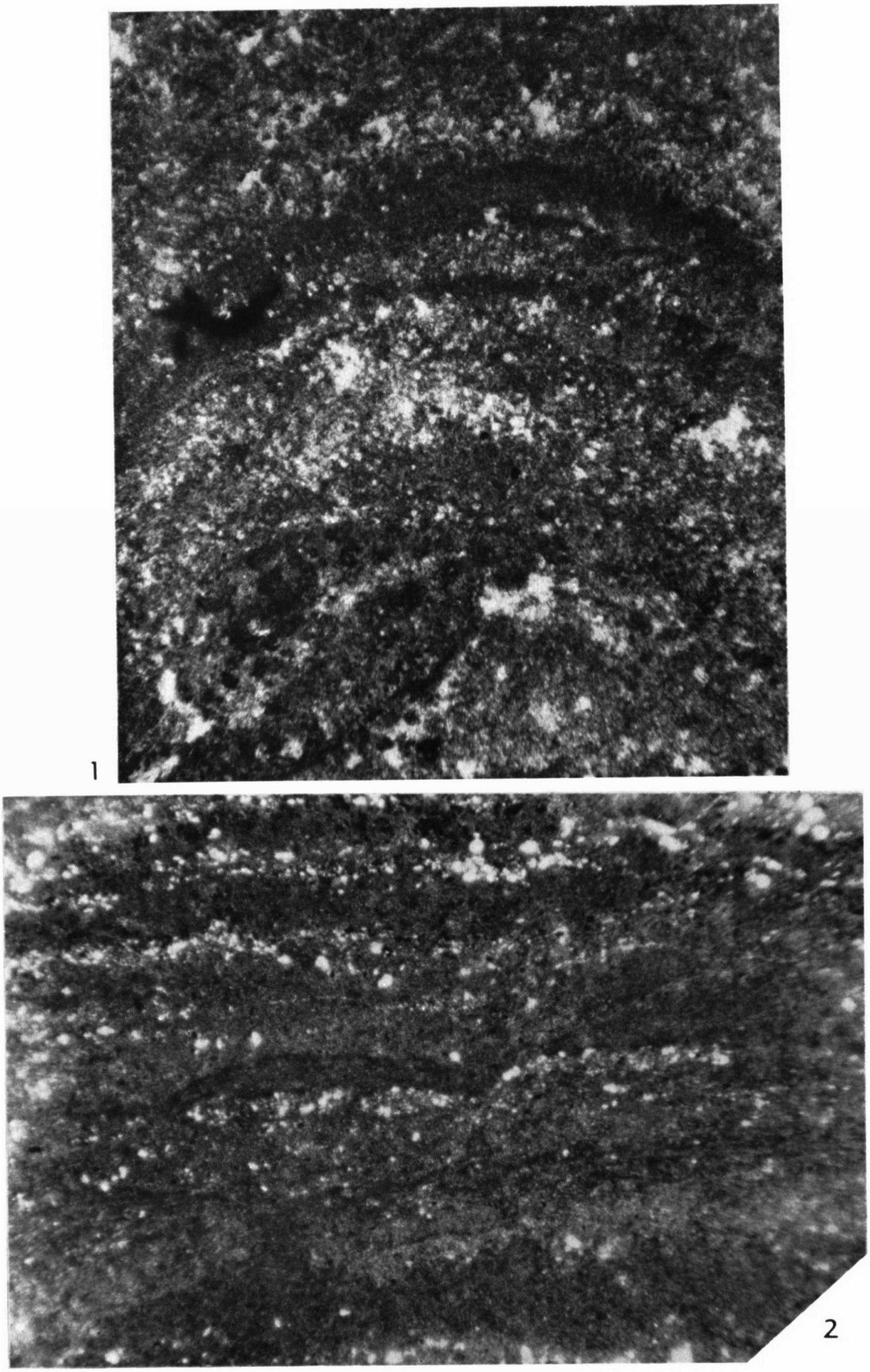

Fig. 10. Microstructure of Wellington algal stromatolites.

*1.* Specimen B-3 (slide 2993) showing laminae of "fingers" with suggestions of coarse threads, ×30.

*2.* Specimen N-V, B-5 (slide 2994) showing laminae with coarse threads and small amount of debris (white), ×30.

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debris, ×30.

*3.* Specimen from Loc. 2 (bed 1) showing irregular laminae (dark layers with some molds of algal threads, white largely recrystallized sediment), ×30.

Table 3.—*Consolidated Data on Microstructure of Wellington Algal Stromatolites*

| Specimen | Slide Number | General Description | Thickness of Laminae Dark | Thickness of Laminae Light | Indications of Original Algae | Remarks |
|---|---|---|---|---|---|---|
| Loc. 1, bed 1 | JA 2985 | Occasional irregular laminae mainly of fine sediment. | | 950-2350μ | Molds of coarse branching threads in some areas. Some coarse threads at base parallel to basal surface. | Fig. 9,3 |
| Loc. 7, spec. 2A.C | JA 2986 | Laminae distinct arched into hemispherical domes, alternating light and dark. | 500-1375 | 300-750μ | Coarse threads 9-15μ diam. rounded or elliptical masses 15-33μ diam. | |
| Loc. 7, spec. 3A | JA 2987 | Distinct laminae, nearly smooth boundaries. Mostly dense and nearly black at top, looser and more spongy below. Some alternation of light and dark layers, then 7 to 11 dark layers to each light one. | In series C. 750-1125μ of dense up to 1750μ and loose or 2000μ layers<br>diam. 40-150μ<br>length 250-1100μ | | Some dark layers show definite threads 15-19μ thick. | Light layers silt scarce, rounded 18-110μ, now mostly recrystallized fine calcite. |
| Loc. 7, spec. 3A | JA 2988 | Similar to above. | Dense 50-140μ, spongy 70-800μ | 65-110μ, mainly calcite | Abundant spongy pelletoid masses. | Relatively little silt. |
| Loc. 3, bed 11 | JA 2989 | Most of slide a gray algal felt. White angular particles scattered throughout the mass. Laminae indistinct, irregular breaks of clear calcite. | 500-2200μ, commonly 875μ | Calcite breaks 60-375μ wide | Abundant molds of short straight threads 7-9μ diam. and up to 300μ long. One mass of radiating threads 28-30μ diam. | |
| Loc. 4, lower algal bed | JA 2991 | Alternating irregular laminae. Dark algal mats, thin clastic debris and shell fragments abundant. | Thin | Irregular | Vague suggestions of algal threads, horizontal at base but thinner vertical threads above growing upward through the debris and around the larger pieces. Some rhombic crystals. | |
| Same as above | JA 2992 | Same as above. | | Very little well defined structure | | |

TABLE 3. *(Continued.)*

| SPECIMEN | SLIDE NUMBER | GENERAL DESCRIPTION | THICKNESS OF LAMINAE |  | INDICATIONS OF ORIGINAL ALGAE | REMARKS |
|---|---|---|---|---|---|---|
|  |  |  | DARK | LIGHT |  |  |
| Loc. 7, spec. B-3 | JA 2993 | Good thin laminae, nearly parallel but digitate developments above, probably cut somewhat obliquely by slide. | 200-310$\mu$<br>65-325$\mu$,<br>C. 100-135$\mu$ in fingers | Below<br>75-350$\mu$,<br>C. 88-125$\mu$ | Three types of structure probably referable to algae in different areas:<br>1. Clots—aggregates of rounded masses;<br>2. Thin approximately vertical molds of threads;<br>3. Mats of coarser, darker, straight to sinuous approximately horizontal threads. | Fig. 9,*2*<br>Fig. 9,*1*<br>Fig. 10,*1* |
| Loc. 9, spec. B-5 | JA 2994,<br>JA 2995 | Nearly horizontal to gently arched laminae. Laminae mostly dark of varying thickness, broken now and then by streaks of fairly coarse clear particles. Very little sediment. | 115-425$\mu$ | 25-27$\mu$ | A few small areas of horizontal threads with well defined walls, mainly 25-30$\mu$ thick. | Fig. 10,*2* |
| Loc. 2, spec. B-5 | JA 2996 | Some fairly regular thin laminae at top and bottom but most of the slide is a mixed up mess—areas of algal mat, clusters of coprolites, several small thin shells, considerable sediment. | Poorly defined |  | No good material. |  |
| Loc. 2, spec. B-1 | JA 2997 | Laminae, largely of algal material with streaks and irregular masses of recrystallized calcareous detrital materials and clusters of small shells. Similar material scattered through some of the laminae. | Not measured |  | No good material. | Whole small shells of pelecypods and linguloid brachiopods. |
| Loc. 10, spec. B-5 | JA 2998 | Thin slightly wavy laminae with breaks of sediment between them which sometimes thicken to lenses or laminae. | 125-620$\mu$ | 38-225$\mu$ | Numerous vague suggestions of short vertical threads in a number of laminae. |  |
| Loc. 10, (?) | JA 3014 | Thin well defined dark laminations, light to white detrital material scattered throughout including numerous fragments of small spines or crystals. | 125-650$\mu$, commonly about 325$\mu$ |  | Vague suggestions of very thin vertical threads. Several patches of radiating threads 18-23$\mu$ in diam. |  |

The domed or helmet-shaped stromatolites are built of hemispherical or flattened hemispherical laminae, more or less vertically stacked one on the other, with upper laminae reaching or overlapping the base of the lower ones (formula *LLH* or *SH-C*).

Above this is an irregular assemblage of closely packed wartlike growths 0.25 to 0.75 in. wide and 0.25 to 0.6 in. high. They are built of vertically stacked laminae (formula *SH-C*).

One of the most interesting structural types is that composed of digitate shapes. Each consists of vertically stacked, gently to steeply domed, laminae following the formula *SH-C*. Normally these fingerlike growths are more or less circular in horizontal section. Commonly they expand slightly upward so that the top is wider than the base. A few may branch, commonly into two.

Several variants of the type are found. They may be loosely packed with appreciable space between them or tightly crowded together with little or no space between. In other specimens spherical or flattened spherical heads may develop. Specimen B3-sp. 3 (from Loc. 7) is a good example. It is approximately 4 in. in diameter and 3 in. high. Growth started around a small piece of loose rock. Thin laminae envelop this but soon start to arch upward and extend to one side. Growth continued until a flattened rounded mass 1.75 in. high and 2.5 in. wide had developed with a formula approximating *LLH*. Then the development of closely packed digitate forms commenced covering the top and upper sides. These grew upward and outward 0.5 in. or more before branching, then continued 0.5 to 1 in. farther. The top is covered by rounded domes or warty protuberances, some with several coalesced into irregular masses (Fig. 8,*1*).

## LAMINAE

In some specimens the laminae show quite clearly on weathered or cut surfaces, but in others are not noticeable. They become much more evident if a rock slice is wet, etched, or polished. The thick varicolored laminae which show up so well on a polished specimen, however, actually are seen in thin sections to be composed of much thinner ones.

Commonly the laminae occur in pairs, a lighter one above and a darker one beneath. The dark layers are colored by carbon and organic compounds. The lighter layers are composed largely of silt or other detrital material.

The study of thin sections strongly suggests that development of the laminae, their character and thickness is strongly affected, if not controlled, by the supply of detrital material present. Where detrital material was abundant, the laminae appear to be distinct and fairly thick. The lower dark layer commonly shows a thin dark streak at the base, but because of rapidly increasing amounts of detrital material it becomes lighter-colored above. Commonly a thicker layer of detritus forms above it with distinct boundaries.

If the supply of detrital material becomes less, the dark layer is darker and thicker, contains less detritus, becomes more of a spongy felt, the upper boundary of the layer is more irregular and less distinct, and the detrital layer above is thinner, absent, or represented only by irregular streaks or lenses.

Should detrital material be absent or scarce, lamination becomes very indistinct or almost absent. The algal deposits form dark irregular layers or masses. Commonly these commence as a dark, fairly dense, basal mat which develops upward into a loose felt, or small dark-colored irregular rounded masses, or aggregates, which probably represent tiny colonies or aggregates of spherical cells coated or impregnated with "algal dust" or fine chemical or more probably biochemical precipitate of calcium carbonate.

## MICROSTRUCTURE

The most conspicuous feature of the microstructure is the laminae. These usually have a well-defined dark-colored base, representing the bottom of the algal mat. Detrital material may be quite conspicuous or absent. Indications or even remains of the original algae may be preserved or absent.

The basic data from 15 slides condensed in Table 3 should give a good idea of the microstructure. Actually, in most stromatolites previously studied by me, the slides show very little except the laminae. This Wellington collection shows more than usual.

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