

**GENESIS AND ENVIRONMENTAL POSITION OF THE  
ALGAL MOUNDS OF THE STONEHENGE FORMATION**

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A Thesis Submitted  
to the Temple University Graduate Board

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in Partial Fulfillment  
of the Requirement for the Degree

**MASTER OF ARTS**

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by

Francis T. Manns

January 1973

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Thesis Adviser

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## ABSTRACT

Carbonate mounds of the Lower Ordovician (Canadian) Stonehenge Formation contain evidence of algal origin in the form of convex upward growth structures, stromatolites, and filamentous algae. Facies distribution and thickness relationships of the Stonehenge show that the mounds formed near the margins of a distinct sedimentary basin on the Cambro-Ordovician carbonate platform of Pennsylvania.

Interpretations of the sedimentary environments of the major lithologies deposited in the seaway indicate that the Stonehenge beds were deposited in facies mosaic style. Five major lithologic associations have been described and interpreted in this framework.

1. dolostone cycles.....supratidal facies
2. siliceous dolomitic pelmicrite.....subtidal flat facies
3. intrasparudite-intrasparite.....subtidal channel facies
4. massive calcilutite.....algal mound facies
5. cryptalgal calcarenite.....mound debris facies

The positions of these lithologies in the stratigraphic succession of the Stonehenge indicate that the mounds formed in the base of subtidal channels at the climax of a regional transgression.

## ACKNOWLEDGEMENTS

A large debt is owed a number of people who were directly and indirectly involved in the writing of this thesis. Dr. Peter Goodwin, the principle advisor for the work, has spent uncountable hours with the author, both in the classroom and in the field, arguing and teaching geologic concepts. I sincerely hope that he feels the job is partly finished for the rocks and the student. To Dr. Edwin Anderson I owe a debt for opening horizons of curiosity in ways that he alone could do. I thank Dr. Gene Ulmer for advice, counsel and example. He has contributed greatly, both to the thesis and in personal ways. Thanks go to Paulo Costa for assistance in the field and to the typist, Natalie Everett, for her patience. The contribution of Ravindra Tipnis has been integral to the stratigraphic treatment. Without his aid many questions would have been impossible to answer.

Thanks go to the Department of Geology for financial assistance in the form of a teaching assistantship and funds to attend the short course in calcareous algae at the University of Miami.

## INTRODUCTION

The purpose of this study is to interpret the genesis and environmental setting of the algal mounds of the Lower Ordovician Stonehenge Formation. Mound genesis is, of necessity, intimately related to the evolutionary history of the Lower Ordovician carbonate shelf. The mounds constitute facies developed as specific responses of sediments and organisms to a particular depositional environment. Genesis is interpreted from petrographic analyses, detailed stratigraphy of the mounds and associated lithologies, and position in the environmental sequence of the Stonehenge Formation.

Environmental interpretations are supported by analogy to algal growth habits found in Recent carbonate environments. The relatively unfossiliferous nature of the Stonehenge succession makes it an ideal subject for emphasis of algal structures in the reconstruction of depositional settings.

Until recently, realistic paleoenvironmental and paleogeographic syntheses were hindered by the lack of a useful temporal framework. A time-stratigraphic framework utilizing conodonts is now being developed for the Beekmantown Group (Goodwin, 1972; Tipnis and Goodwin, 1972). The conodont zonation of Tipnis provides the temporal detail upon which the paleogeographic reconstruction rests.

The massive algal units of the Stonehenge Formation were first noted by Donaldson (1959) and Hobson (1963) and employed by them in the subdivision of the Stonehenge into members. Donaldson suggested that the mounds occupied subtidal-lagoonal positions

in the northwestern Stonehenge sea. Hobson suggested that the algal member in the southeastern belt constituted a patch reef formed four to five fathoms below mean sea level. Sando (1957, 1958) and Root (1968) reported a variety of algal structures in the Stonehenge Formation of Washington County, Maryland and Franklin County, Pennsylvania.

Ahr (1971), Riding and Toomey (1972), Toomey (1970), Toomey and Ham (1967) and Pitcher (1964) have studied early Paleozoic carbonate mounds similar to the Stonehenge occurrences. Ahr (1971) has shown that mounds in the Upper Cambrian, Wilberns Formation of central Texas were bioherms and reefs constructed by the algae Girvanella, Renalcis, Epiphyton and Nuia. Toomey (1970) and Toomey and Ham (1967) attributed Lower Ordovician mounds within the McKelligon Canyon Formation of west Texas to the mud baffling of a probable coelenterate Pulchrilamina spinosa, as well as the sponge Archeoscyphia Hinde and the quasi-sponge Calathium. The algal Renalcis and Epiphyton, were added to the list of sediment binding organisms in the McKelligon Canyon Formation by Riding and Toomey (1972). Pitcher (1964) showed five principle biotic assemblages in the Middle Ordovician Chazy reefs of New York State and western Vermont. Each biotic group is considered to be a distinct and primary mound building assemblage. Ranging from earliest to latest Chazy reefs the groups are: algae (Girvanella, Sphaerocodium, Solenopora, and Nuia); lithistid sponges (Zittelella and Anthaspidella); tabulate corals (Billingsaria and others); bryozoans (Batastoma and others); and stromatoporoids (Cytostroma and Pseudstylocidictyon).

These studies of Upper Cambrian, Lower and Middle Ordovician mounds have provided detailed descriptions and partial genetic interpretations of mound occurrences similar to those of the Stonehenge Formation. However, this study is the first genetic appraisal of the evolution of mound horizons within the framework of an environmental succession.

The study was limited to the excellently described Stonehenge sections at Axemann, Centre County and Glenside, Berks County, Pennsylvania and to reconnaissance in the south-central belt. Photographs and descriptions of rock types in the literature on the Stonehenge were field checked and oriented samples of diagnostic lithologies were thin sectioned. A data table (Table I) based on the unpublished sections of Donaldson (1959) and published sections of Hobson (1963) has been compiled to elucidate the lithologic and faunal trends.

The best exposed mound at Axemann was collected on a three-foot grid where possible and additional samples were taken at contacts with internal lithologies. Samples were taken of each significant lithology in the Glenside mound complex. Samples were collected from the contacts of the mounds with nearest neighbors. In addition, samples were taken of all associated lithologies. Petrographic studies were made of 165 two-inch by three-inch thin sections of samples from the mounds and associated rocks.

Photomicrographs were prepared by a one-step process in which oriented thin sections are used in a photographic enlarger and negative prints result. For this reason, sparry calcite appears

as dark patches and micritic calcite is light. Organic films are commonly opaque and produce white images. All orientation arrows are 1 cm. in length.

The mounds contain the diagenetically altered record of an algal flora. Stromatolites, clearly a product of binding filamentous blue-green algae (Hoffman, 1972a) occur at the base of the mounds. The bulk of the mound lithology contains growth structures similar to the growth habits of encrusting calcareous algae. The preserved algal record, however, is limited to stromatolites and to intraclasts of the mound lithology which contain poorly preserved algal filaments identified as Girvanella.

The lithologic sequence of the Stonehenge shows that the mounds formed in the subtidal zone during the climax of a basin-wide transgression. At Axemann the mound occurrences are cyclic whereas at Glenside conditions were more uniform and resulted in a thick accumulation of relatively uninterrupted and complexly intergrown mounds.

## STRATIGRAPHY

## Beekmantown Group.

The Beekmantown Group is part of a thick sequence of Cambro-Ordovician carbonates and terrigenous clastics deposited in tidal flat and shallow subtidal environments of the Appalachian miogeosyncline. The Beekmantown Group is Lower Ordovician (Canadian) in age and crops out in three belts in Maryland and Pennsylvania (Figure 1). The south-central belt crops out in Franklin County, Pennsylvania and neighboring Washington County, Maryland. The northwestern and southeastern belts lie along the margins of the Pennsylvania Valley and Ridge Province.

The thickness of the Beekmantown Group is greatest in the south-central belt where Root (1968) reports 1200 m. The northwestern belt is 1035 m. thick in the vicinity of Axemann, Pennsylvania. The southeastern belt has been shown by Hobson (1963) to be at least 710 m. thick in the vicinity of Glenside, Pa.

The calcareous Stonehenge Formation is the only lithologic unit recognized in all three areas of outcrop (Figure 2). Formations above the Stonehenge in the marginal outcrop belts alternate between dolostone and limestone and contain abundant "primary", laminated, deeply sun-cracked dolostone of probable supratidal origin. The same stratigraphic interval above the Stonehenge Formation in the south-central belt is occupied by the Rockdale Run Formation in which laminated dolostone is relatively subordinate.

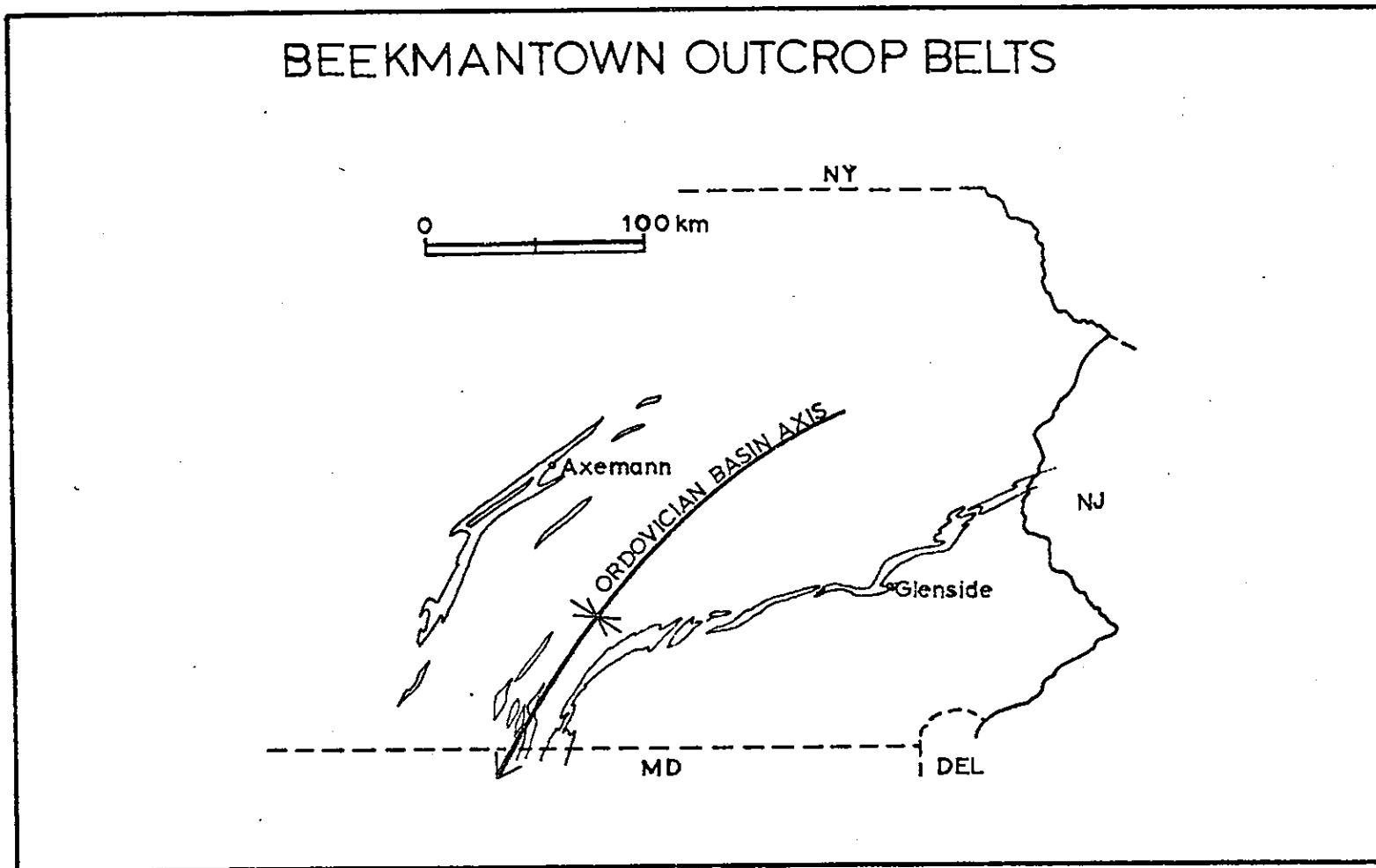


FIGURE 1

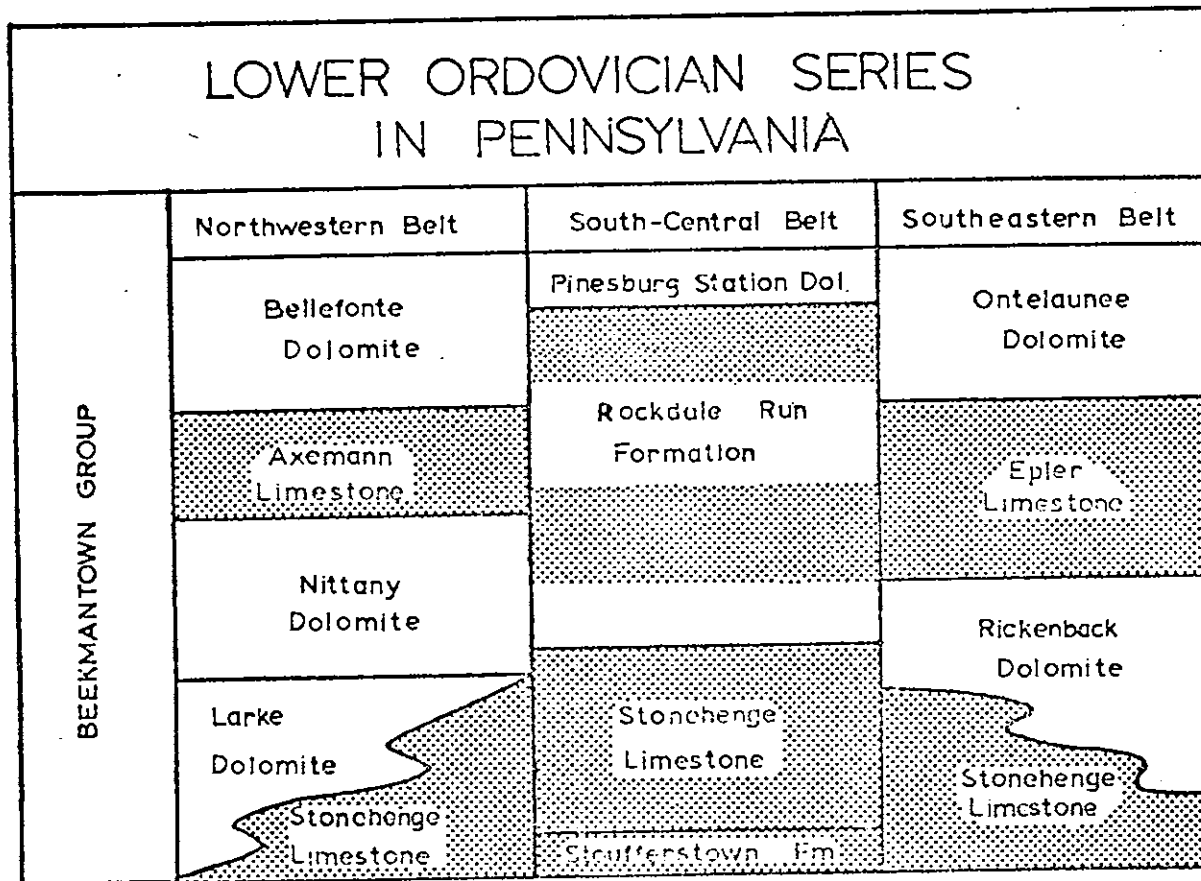


FIGURE 2

## Stonehenge Formation

Northwestern Outcrop Belt: The Stonehenge Formation is well exposed in Centre County at Axemann (Figure 3), north of Logan Branch, along the road to Bellefonte. The Stonehenge may be traced for about 15 miles northeast of Axemann but exposures are limited. Southeast of Axemann the Stonehenge is replaced through facies change by the Larke Dolomite Formation (Donaldson, 1959).

Donaldson, in an unpublished work, subdivided the Stonehenge (148 m. thick) into four members. The Lower two members, the Spring Creek (13 meters thick), and Graysville Member (45 meters thick) are discussed in this study (Figure 3). The basal Spring Creek Member overlies the Cambrian Mines Member of the Gatesburg Formation (Wilson, 1952). The Spring Creek is characterized by mud cracked dolostone, thin bedded, siliceous banded pelmicrite, cross-stratified oölitic intrasparite, and intrasparudite.

The Graysville Member overlies the Spring Creek and underlies the micritic Baileyville Member. The Graysville is composed of cross-stratified oolitic intrasparite, intrasparudite and massive algal bioherms.

Southeastern Outcrop Belt: The reference section in southeastern Pennsylvania is located in Berks County, along the northwest bank of the Schuylkill River near the borough of Glenside. Beds of "edgewise conglomerate" thought to be Stonehenge by Hobson (1963) occur along the Schuylkill River 12 miles to the northeast. These are the easternmost beds reported. Lower Beekmantown beds are not exposed in western Berks County.

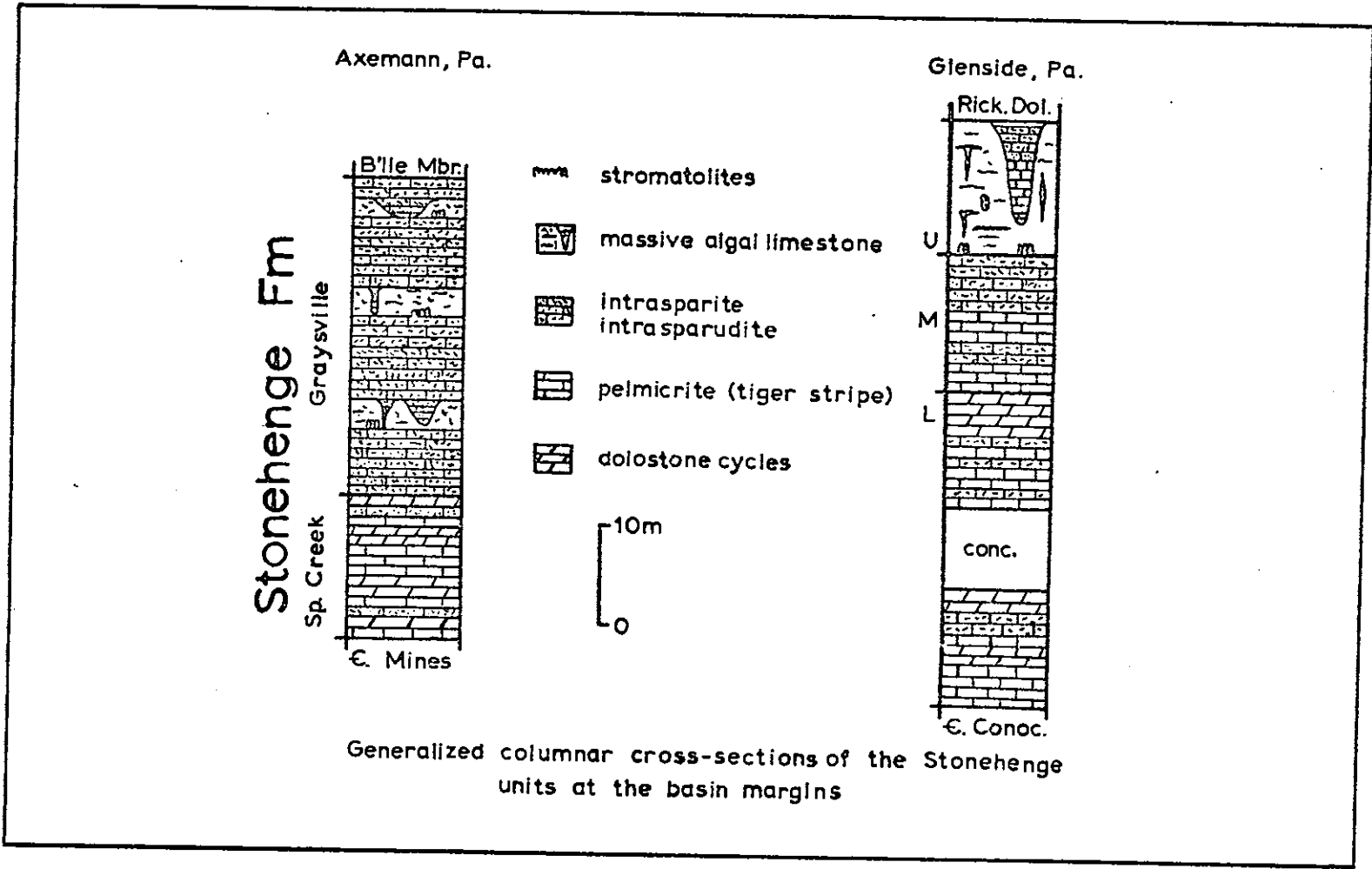


FIGURE 3

The Stonehenge limestones and dolostones lie between the Rickenbach Dolomite Formation and the Cambrian Conococheague Limestone Formation (Figure 3).

Relationships with the Conococheague are unclear because of a persistent concealed interval. The Conococheague limestones in the vicinity of Glenside are characterized by oölites, oölitic chert, quartzose limestone, pink crystalline limestone, dolomite, and stromatolites. These beds are overlain by a covered interval underlying the Rickenbach Formation. Though intrasparite and intrasparudite are found above and below the concealed interval, closely spaced beds of "edgewise conglomerate" are largely confined to beds above the interval and below the Rickenbach. These strata were included by Hobson (1963) in the Stonehenge Formation.

The upper contact with the Rickenbach Formation is poorly exposed and obscured by extensive dolomitization. The Rickenbach apparently thickens at the expense of the Stonehenge to the northeast (Hobson, 1963).

Hobson (1963) subdivided the Stonehenge (72 m.) at Glenside into three members. The Lower Member (36 m.) is composed of laminated sun-cracked dolostone, thinly interbedded siliceous banded pelmicrite and intrasparite, and intrasparudite. The Middle Member (18 m.) is similar to the Lower but contains no laminated dolostone. The Upper Member (18 m.) is composed of massive algal calcilutite with extensive intrasparite, and intrasparudite filled lenses.

Age and Correlation of the Stonehenge Formation: Until recently, the relatively unfossiliferous nature of the Stonehenge made intra-basin correlation of the Stonehenge difficult and speculative. The limited faunas of individual members apparently show strong environmental control. An additional complication, according to Sando (1957, p. 109), is the incomplete understanding of Early Ordovician paleontologic classification. However, the faunas have proven useful for correlation with other areas. Sando (1957, 1958) correlates the type Stonehenge Formation of the south-central belt with the Gasconade Dolomite of the North American standard section.

Correlation by Hobson (1963) of the Middle and Upper Members at Glenside with the type section in Franklin County, Pennsylvania, is based on lithologic similarities, stratigraphic position and fauna identifiable to generic level.

Sando (1958) lowered the Stonehenge-Conococheague boundary in the type area to include 67 m. of beds previously included in the Upper Conococheague. These beds, termed by Root (1968), the Stoufferstown Formation, are lithologically similar to the Middle Member of the Stonehenge at Glenside.

Larke Dolomite of the northwestern belt is correlated to the Gasconade Dolomite by Prouty (1954 in Donaldson, 1959) on the presence of Helicotoma uniangulata. Donaldson (1959) demonstrated the Stonehenge-Larke equivalence and inferred the correlative nature of the Axemann Stonehenge with the Stonehenge of the south-central belt.

New data are now available in the form of a conodont zonation

by Tipnis (personal communication) which indicates Tremadocian and earliest Arenigian ages for the Stonehenge Formation. Tipnis has further shown that the algal mound units, the Graysville Member at Axemann and the Upper Stonehenge at Glenside fall within the Cyrtoniodus brion-Paltodus bassleri zone and are therefore time equivalent.

#### Synthesis of the Stratigraphic Pattern

The thickness variations of the Beekmantown Group are thought to represent regional variations in the subsidence rates on the carbonate platform. The Beekmantown Group is 200-500 m. thicker in the south-central belt than at Axemann and Glenside. The Stonehenge Formation mimics this pattern ranging from 76 m. at Glenside to approximately 300 m. in the south-central belt and thinning to 138 m. at Axemann in the northwest.

Sando (1957, p. 12), using the oolite deformational analysis techniques of Cloos (1947), has shown that the thickening of the Beekmantown Group in the south central belt can not be accounted for by post-depositional deformation. Oolite analysis yielded -7% to +5% thickness change for the Beekmantown Group and these values fall within the possible range of error for the unit measurements.

Lithologic variation is also remarkable (Figure 2). The marginal outcrops of the Group are characterized by the major dolostone formations, each containing a high proportion of replacement dolostone and laminated sun-cracked dolostone. The

equivalent interval in the south-central belt is occupied by the Rockdale Run Formation in which limestone predominates and laminated sun-cracked dolostone is only important in the upper third.

These facts indicate that the beds of the south-central outcrop belt were deposited in a more rapidly subsiding and predominantly subtidal setting. The equivalent beds at Axemann and Glenside were contemporaneously deposited in a shallower occasionally supratidal setting. The Basin axis has been inferred through the south-central outcrop belt and extrapolated between Axemann and Glenside (Figure 1).

DESCRIPTION AND INTERPRETATION OF THE  
ALGAL MOUND HORIZONS

The Graysville Member at Axemann and the Upper Stonehenge Member at Glenside contain massive and stromatolitic algal calcilutite with a distinctive faunal assemblage of orthid brachiopods and hystricurid trilobites. In the Graysville, this lithology occurs in two to three m. thick biohermal units (Figure 4). Intrabiohermal rocks are principally cross-stratified calcarenite, oolitic calcarenite, and calcirudite with varying amounts of micrite matrix. At Glenside, algal calcilutite comprises the bulk of the Upper Stonehenge. The entire Upper Stonehenge is a complex of intergrown mounds.

The units are grouped as lithofacies on the basis of composition, texture, and geometry. Lithofacies I is composed of massive algal calcilutite. Lithofacies II is predominantly calcarenite and calcirudite.

Lithofacies I

Description: Lithofacies I (Figure 5, Figure 6) weathers to light gray compact dolomite-mottled calcilutite. The lithology is easily distinguished by its color and massivity and by the presence of subvertically oriented bodies of darker medium to coarse grained calcarenite and calcirudite. Distinct stratification is lacking but closely spaced stylolites and rusty weathering dolomite mottles are generally parallel to bedding in adjacent facies.

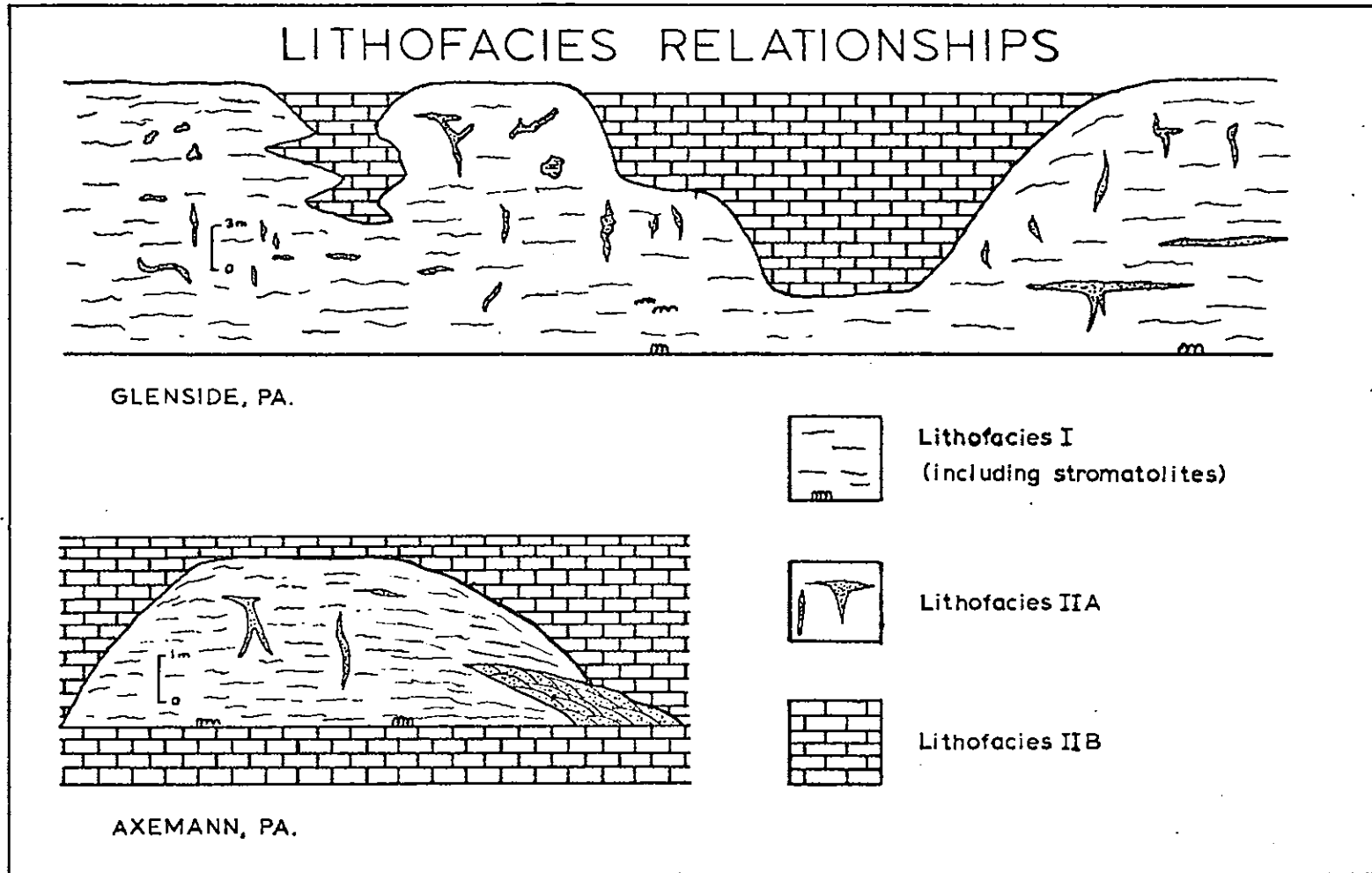


Figure 4- Schematic diagram of the relationship between Lithofacies I and II.



Figure 5. Lithofacies I containing darker lenses and dikes of Lithofacies IIA; Upper Stonchenge Member, Glenside, Pennsylvania.



Figure 6. Lithofacies I; Bioherm in the Graysville Member 27 m. above Mines Dolomite; Axemann, Pennsylvania.

The microfabric (Figure 7) consists of convex upward bands of patchy pelmicrite enclosing lenses of micritic intraclasts and skeletal debris. The suggestion of Bathurst (1971, p. 547)

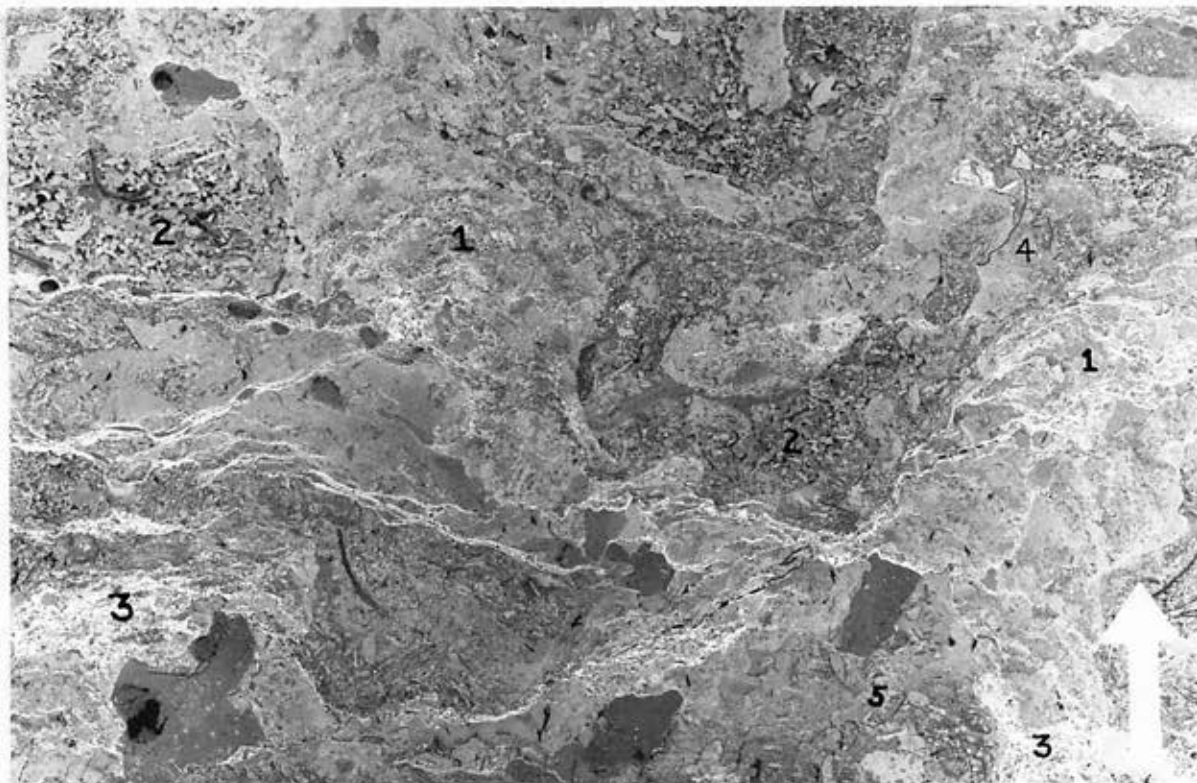


Figure 7. Lithofacies I; algal biolithite showing convex upward bands of pelmicrite (1) surrounding lenses of intraclastic and bioclastic debris (2); pressure solution commonly destroys this texture (3) and produces opaque films usually associated with rhombic dolomite. Sparry calcite allochems in (2) are enclosed in micrite envelopes. Various views of trilobite carapaces are present (4, 5).

is followed that "peloid" be substituted for "pellet" in reference to allochems formed of microcrystalline or cryptocrystalline material because these grains cannot always be identified as fecal pellets, but may have originated in other ways. Thus, a pelmicrite is defined as a limestone composed of peloids in a matrix of micrite. Bands range from light pelsparite to nearly opaque pelmicrite. Individual bands are frequently enclosed by stylolitic seams. A much

more common occurrence, where stylolites are more abundant, is for banding to be disrupted into discrete clots showing little or no convexity. In general, stylolites follow the boundaries of bands and clots, affecting them by solution at the margins but not internally. Sparry patches are common. Fecal pellets are found in many spar filled borings (Figure 10).

The skeletal allochems are orthid brachiopods, trilobites, and pelmatozoan debris. Gastropods are rare. The only recognizable alga is Girvanella, a filamentous green or blue-green genus characterized by flexuous tubes of uniform diameter. Girvanella is found in loosely entwined clusters in some fragments in the detrital lenses (Figure 8).

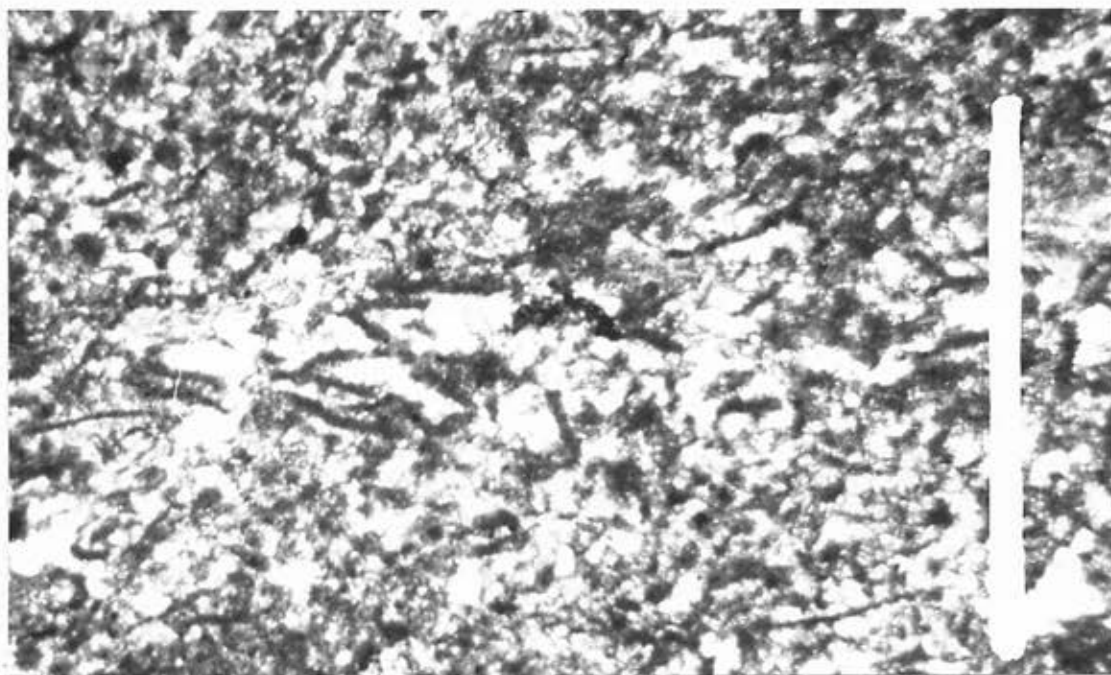


Figure 8. Girvanella threads in clast of algal pelmicrite. Positive print; length of the bar is 1 mm.

Stromatolites (Figure 9) are found at the base of Lithofacies I in both sections. At Axemann, stromatolites occur as

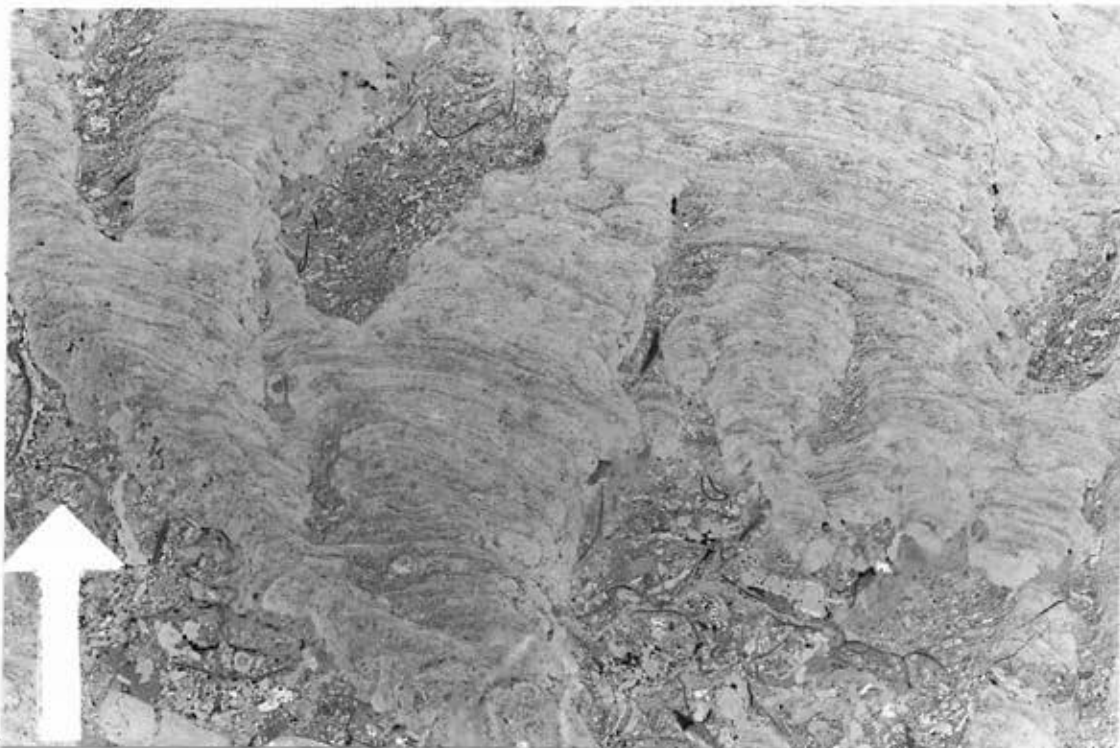


Figure 9. Stromatolite from the base of a Graysville mound, closely spaced digitate SH forms (stacked hemispheroids of Logan, et al, 1964) which coalesce upward into LLH forms (laterally linked hemispheroids) (Figure 9). Spaces between digitate processes are filled with loosely packed skeletal and intraclastic silt and micrite. Patchy pelmicrite typical of Lithofacies I encrusts the upper surfaces of the stromatolites. At Glenside, dolomitized stromatolites of the SH type occur at the base of Lithofacies I and as cobbles in immediately subjacent beds. A few unlaminated domes about 10 cm. in diameter with about 4 cm. relief are present near the base. These are recognizable only because they are rimmed with halos of darker dolomitized calcarenite.

Dolomite mottling occurs in several habits, but most commonly as burrow filling and as concentrations along stylolitic seams.

Dolomitization encompasses a complete range of alteration from lightly dolomitized rock in which isolated crystals have grown at stylolitic boundaries to large portions of completely altered burrow fillings, seams and calcilutite. Dolomite crystals are enclosed in a dark, presumably organically stained, cryptocrystalline calcite matrix. Dolomitization is most extensive in Lithofacies I at Glenside proximate to the overlying Rickenbach Dolomite. Dolomite occurs in the Graysville mounds only in burrows and along stylolitic seams.

Interpretation: The bulk of Lithofacies I is a lithology rarely encountered and only poorly understood. Evidence for environmental position is found in the fauna, the relationship with the stromatolites, and the relationship with the associated lithologies. Evidence for the origin of the microfabric is mainly petrographic. The nature of the organisms responsible for the construction of the mounds is determined by integrating field evidence, petrographic evidence and comparisons with Recent algal growth habits.

The close association of winnowed lenses of intraclastic debris and pelmicrite (Figure 7) is difficult to explain with any orthodox hydrodynamic interpretation. This dilemma is further emphasized by the larger scale associations of lithofacies I and II (Figure 5) where coarse calcarenites are enclosed within massive calcilutite. The absence of organisms commonly found in early Paleozoic carbonate mounds and attributed to have had mud baffling potential is also remarkable.

The origin of the microfabric and the identity of the organism or organisms responsible for production of the Stonehenge mounds are difficult to determine. Most, if not all, of the texture is

a product of the destructive habits of boring organisms, diagenesis, pressure solution, and carbonate diagenesis.

Several alternate hypotheses will be discussed and their relative merits evaluated before discussing the environmental position of the mounds because it is clear that a number of processes other than mechanical sedimentation can be involved in the production of pelletoidal calcilutite.

Divergent views on the origin of pelletoidal calcilutite have been expressed by Cayeaux (1935) and Beales (1956). Cayeaux believed that "structure grumeleuse" evolved by the growth of a network of calcite from a homogeneous micrite matrix. Beales, on the other hand, felt that "... many closely packed grains (peloids) appear to have merged on recrystallization into a homogeneous microcrystalline rock." The resulting texture consists of a two-component clotted fabric that ranges from dense micrite to dense patches of micritic peloids imbedded in a microspar matrix.

Bathurst calls attention to the autochthonous nature of pelletoidal calcilutites.

"The outstanding characteristic, and most puzzling aspect of this fabric is the merged patches of micrite with 'des adherences multiple' (Cayeaux, *ibid*, p. 271). This obviously cannot be a primary fabric of mechanically deposited peloids: it must be a secondary feature. Once this is granted, the field is open to speculation on the diagenetic evolution." (Bathurst, 1971, p. 512).

In the microfabric of Lithofacies 1, it can be seen (Figure 7) that the pelletoidal bands bear an encrusting relationship to debris lenses and preexisting bands. Debris lenses have been loosely deposited between projecting clotted masses and are

overgrown from the sides by clots. The fabric shows no evidence of internal compaction other than stylolitization, the last of the diagenetic events. Spar filled borings through the pelmicrite remained open (Figure 10). Extremely delicate orthid valves and

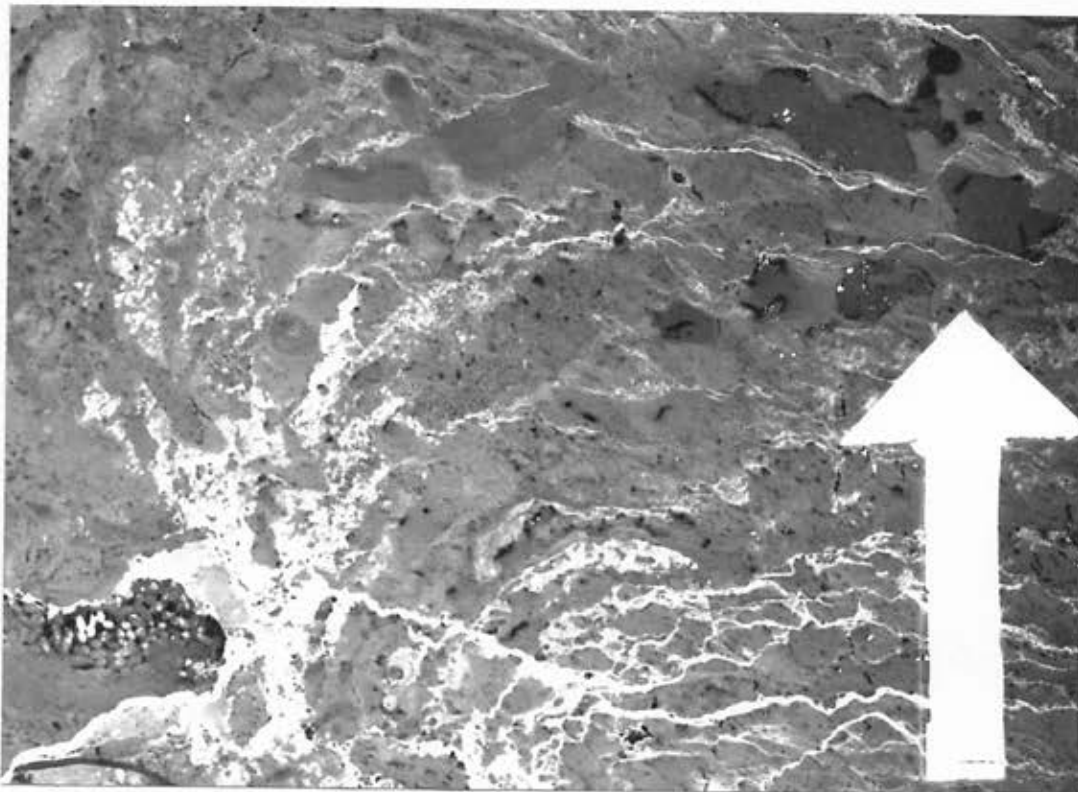


Figure 10. Algal pelmicrite showing pelleted burrow at bottom left and micrite filled burrows at top right.

thin trilobite carapaces (Figure 7) are unbroken demonstrating the supportive function of the projecting clotted masses and induration upon formation.

Alteration of algal reef rock to micrite was studied by Wolf (1965a, 1965b) who has shown that grain-matrix-cement ratios do not necessarily reflect the degree of turbulence and winnowing in a carbonate environment. He has demonstrated a range of textures in encrusting Rothpletzella colonies from unaltered cellular colonies to pelletoidal calcilutite in the Lower Devonian algal

reefs of New South Wales, Australia. These pelletal calcilutites contain Girvanella and are texturally identical to Lithofacies I.

Goldman (1929) and Wolf describe partial alteration of living calcareous algae to micrite taking place in a span of a few years. Goldman described the process as "... some change, addition, or rearrangement of material which obliterates cell structure." Wolf uses the term "grain diminution" for the process because the alteration mechanism is not understood. He follows Hadding (1958), who suggested that algal tissue may provide a source of nutrition for bacteria which destroy the algae's cellular structure.

An alternative explanation for the origin of Lithofacies I is offered by comparison with the Recent. Hoffman (1972a) has noted that well laminated stromatolites are restricted to the lower intertidal zone of Hamlin Pool. The upper intertidal heads are laminated at the base and unlaminated above. This is similar to Lithofacies I where laminated stromatolites are succeeded by pelletal calcilutite. At Hamlin Pool, this transition is due to a recent lowering of sea level and a replacement of filamentous algae by desiccation resistant coccoidal blue-green algae (Hoffman, personal communication, 1972).

Evaluation of the merits of these hypotheses leads to the conclusion that the mounds are more likely the product of coccoidal algae than cellular encrusting genera. While modern encrusting algae have the ecological potential to build mounds the size of those in question, these occurrences are limited to the most turbu-

lent of marine environments, the windward edge of coral reefs. Modern encrusting cellular algae can only thrive in the active breaker zone of the most exposed portion of the reef tract (Wells, 1956). The lithologies associated with Lithofacies I make this combination extremely unlikely for any environment on the shallow Stonehenge shelf. The complete absence of preserved cellular algae from Lithofacies I supports this conclusion.

The ecological potential of coccoidal algae has not yet been well established for the Recent. However, the liferitics of the Alpine Triassic (Fisher, 1964) are thought to have been formed by coccoidal algae (Hoffman, 1972a). It is highly likely that this is also the case for Lithofacies I of the Stonehenge.

An undetermined portion of Lithofacies I may have been the result of boring algae. Bathurst (1966, p. 16) wrote:

"... micrite content is not solely a function of turbulence but is also influenced by other factors, notably the formation of micrite by algae."

Bathurst is referring to the production of micrite by infilling of algal borings. The origin of the micrite is, as yet, undetermined. The fabric which results is one of pelletoidal micrite in patches up to 5 to 7  $\mu$  in diameter caused by the infilling of a myriad of crosscutting algal borings. Both aragonitic filling (Bathurst, *ibid*) and high magnesium calcite fillings (Winfield, 1968) have been found in Recent micrite envelopes. Presumably, diagenesis has altered original structures of the aragonitic type (Land, 1967).

Burrowing organisms, other than algae, though abundant, have not destroyed an originally laminated texture. Burrowing is readily

identified in thin sections as dolomitized patches or patches of sparry calcite with floating fecal pellets. Clotted and banded pelletoidal calcilutite contains clearly visible burrows and is unlaminated in unburrowed portions (Figure 10).

Evidence for the environmental position of the mounds is based on fauna and the interpretation of associated lithologies.

Orthid brachiopods occur in far greater abundance in Lithofacies I than in any of the lithologies above or below the mound horizons. The condition of preservation of the brachiopods Finkelburgia and Nanorthis, though very delicate forms, is very nearly perfect. Broken specimens are extremely rare and abrasion effects are not evident. Clearly, transportation of the brachiopod fauna is not likely. Their abundance in Lithofacies I and relative absence from other lithologies is taken as evidence that they inhabited protected pockets within the mounds. The paleoecology of early orthid brachiopods is not yet well known but it seems certain that articulated brachiopods were limited to a well circulating subtidal environment because of the necessities of filter feeding. Pelmatozoan abundance is also taken as evidence for the subtidal environmental interpretation of Lithofacies I. The pelmatozoans, however, are disarticulated and some transportation may have been involved in their emplacement in the mound lithology.

Stromatolites are evidence for intertidal (or subtidal) genesis of Lithofacies I. Stromatolites have been reported from a variety of intertidal and subtidal settings in the Recent. Black

(1933) reported a variety of stromatolites from the upper reaches of the broad tidal flats of Bermuda. The four types he described are all basic morphologic variations imposed by algal growth and degree of desiccation on sun-cracks and bear little resemblance to stromatolites of Lithofacies I. More analogous are the intertidal stromatolites of Hamlin Pool, Shark Bay, Western Australia (Logan, 1961), and the subtidal stromatolites of Bermuda (Gebelein, 1969). In these the style of vertical accretion more closely resembles the Stonehenge stromatolites. Though subtidal, it is possible that if coccoidal algae were involved the tops of the mounds may have become stabilized in the intertidal zone in the manner of the algal reefs of Hamlin Pool.

Horizontally burrowed intrasparudites and intramicrudites are also associated with Lithofacies I (Figure 11). These are interpreted as subtidal in origin. Horizontal burrowing has been shown



Figure 11. Horizontally burrowed intrasparudite in the Graysville Member immediately below the mound shown in Figure 6. Axemann.

by Rhoades (1967) to be a function of environmental position. He found in a study of modern marine burrowers that subtidal environments are characterized by shallow burrowing mud-eaters.

Jindrich (1969) reported the formation of flat pebble lag in the Tidal delta of Blue Fish Channel near Key West in the Florida Keys. On the delta and near the head of the channel, currents occasionally erode extensive areas of algally bound mat to produce flat chips. These chips are rotated and tilted by currents and buried by current driven sand ripples to produce a flat pebble lag with a sandy matrix similar to the Stonehenge beds below the mounds.

Gebelein (1969) noted similar occurrences to depths greater than 30 feet in Harrington Sound, Bermuda Island, and enclosed basin where sediment is moved only during storms.

Stromatolite growth could have been a response to a change in a small number of environmental parameters. Gebelein (1969) has shown that the subtidal stromatolites of Bermuda flourish in protected areas where sediment is predominantly silt or fine sand and currents and sediment supply are uniform.

Encrusting organisms require the presence of a stable non-shifting substrate in order to be successful. Colonization of the channel floor appears not to have been possible until the substrate had been prepared by the growth of stromatolites.

The genetic scheme thought most likely for the development of the Stonehenge Mounds is one of successive colonization of a shifting channel floor by stromatolites which are in turn colonized by the mound building algal genus or genera.

## Lithofacies II

Description: Lithofacies II is distinguished from Lithofacies I on the basis of texture, bedding, and geometry. Weathered surfaces are light gray and contrast with the very light gray color of the algal mound facies. The lithologies range from intrasparite and brachiopod biomicrudite to coarse intramicrudite. Sheet bedded and cross-stratified beds occur. Lithofacies II occurs both within the mounds and flanking them (Figure 4). On the basis of geometry and bedding style, Lithofacies II has been separated into subfacies IIA and IIB.

Lithofacies IIA is contained in 10 to 20 cm. wide subvertical anastomosing lenses and dikes. These bodies are poorly bedded and are usually in sharp contact with the mounds (Figure 5). Subvertical dikes may occasionally be traced as much as a meter before pinching out or joining subhorizontal lenses. Tubular bodies are also present.

The fauna is composed of unbroken unabraded orthid brachiopods, hystricurid trilobites and scattered pelmatazoan debris. Brachiopod beds and micritic intrasparudites are locally common. Skeletal allochems are rare except in shell beds.

The microfabric is dominated by cusped, occasionally rimmed clasts of dolomitic micrite in a matrix of microspar or micrite (Figure 12). The cement is equant sparry calcite. Clasts vary from silt and sand grade to pebbles. Current-bedded intrasparudite is locally abundant (Figure 13).

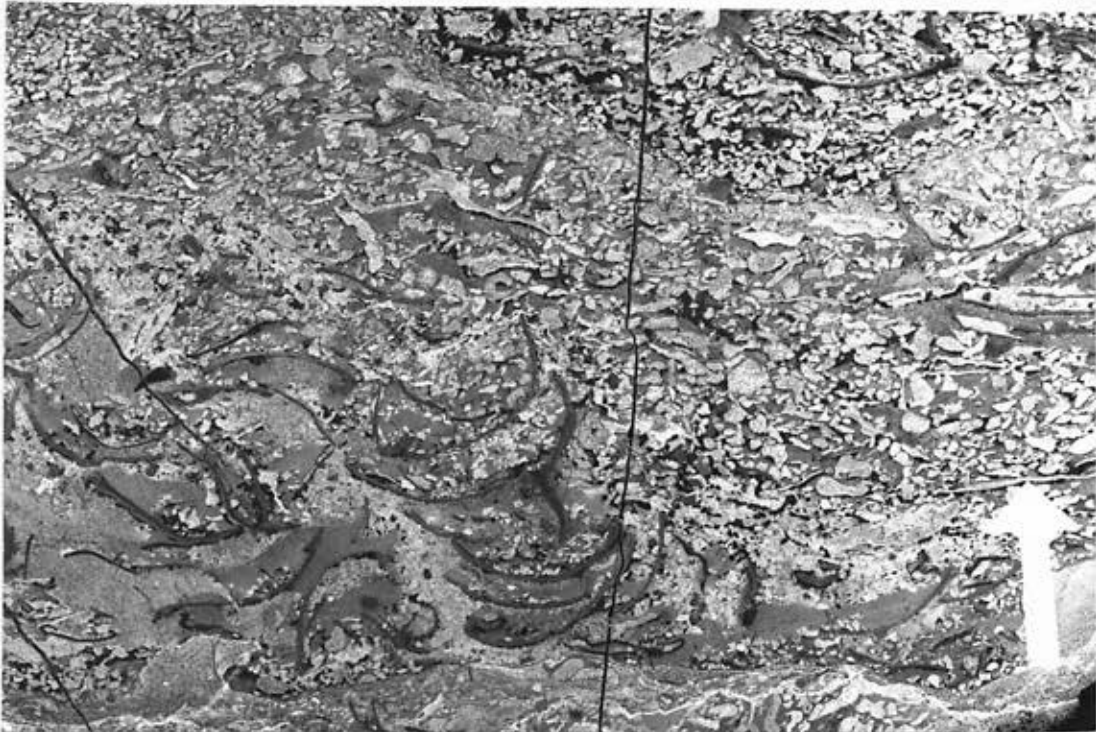


Figure 12. Lithofacies IIA: micritic brachiopod intrasparite (Nanorthis?), Glenside.



Figure 13. Lithofacies IIA: micritic intrasparudite, Axemann.

Lithofacies IIB is composed of 3 cm. to 15 cm. thick tabular beds and lenses of yellow weathering dolomitic intrasparite, siliceous banded pelmicrite, dolomitic intramicrudite and dolomitic intrasparudite. The microfabric of this facies is similar to that of Lithofacies IIA.

Lithofacies IIB forms upward widening bodies ranging from 1 m. to 8 m. in width within the algal mound complexes at Glenside (Figures 4, 14, 15). At Axemann this facies flanks the isolated algal mounds and constitutes the dominant lithologic association for that part of the Graysville Member containing the mounds (Figures 4 and 17):



Figure 14. Lithofacies IIB: Lithofacies I in right foreground overlain by siliceous and dolomitic calcilutite; Glenside.



Figure 15. Lithofacies IIB: Background of Figure 14. Dolarenite, dolomitic intrasparite and dolomitic intrasparudite; conglomerate in lower left and foreground; Glenside.



Figure 16. Lithofacies IIB: Dolomitized intrasparudite; Glenside.

Contacts with the mounds are normally sharp but gradational and overhanging relationships are also present.

The largest of three such bodies at Glenside is in gradational contact with Lithofacies I at the base (Figure 14). The lower 2 m. of this body contain thin-bedded pelmicrite and intrasparite with siliceous dolomitic partings. These beds are replaced upward by thicker-bedded dolomitic intrasparites and intrasparudites (Figure 16). The rocks above these are bedded calcarenites (Figure 15) containing relict pelmatazoan and brachiopod debris similar to the fauna of Lithofacies I and IIA.

In the Graysville Member at Axemann, Lithofacies IIB does not form distinct bodies as at Glenside. Instead, the facies comprises most of the interval containing the mounds which are smaller and more isolated than the coalescing mounds of the Upper Stonehenge at Glenside. Therefore, the distinguishing characteristic of this facies is its shape and position relative to the mound complex. Lithologically these deposits are similar, if not identical, to those of the Middle Stonehenge at Glenside and most of the Graysville Member.

Interpretation: Sharp contacts, sedimentary textures and current bedding are evidence for channel deposition within and around the mounds.

The contemporaneity of channel activity and the buildup of Lithofacies I are shown by the intertonguing nature of some lateral contacts. At these contacts, large portions of Lithofacies I have