overgrown the bedded channel fill of Lithofacies IIB (Figures 17 and 18). The same relationships occur on a microscale between Lithofacies I and IIA (Figure 19). Simultaneous growth of these lithofacies is further suggested by the similarity of their fauna and sediment.

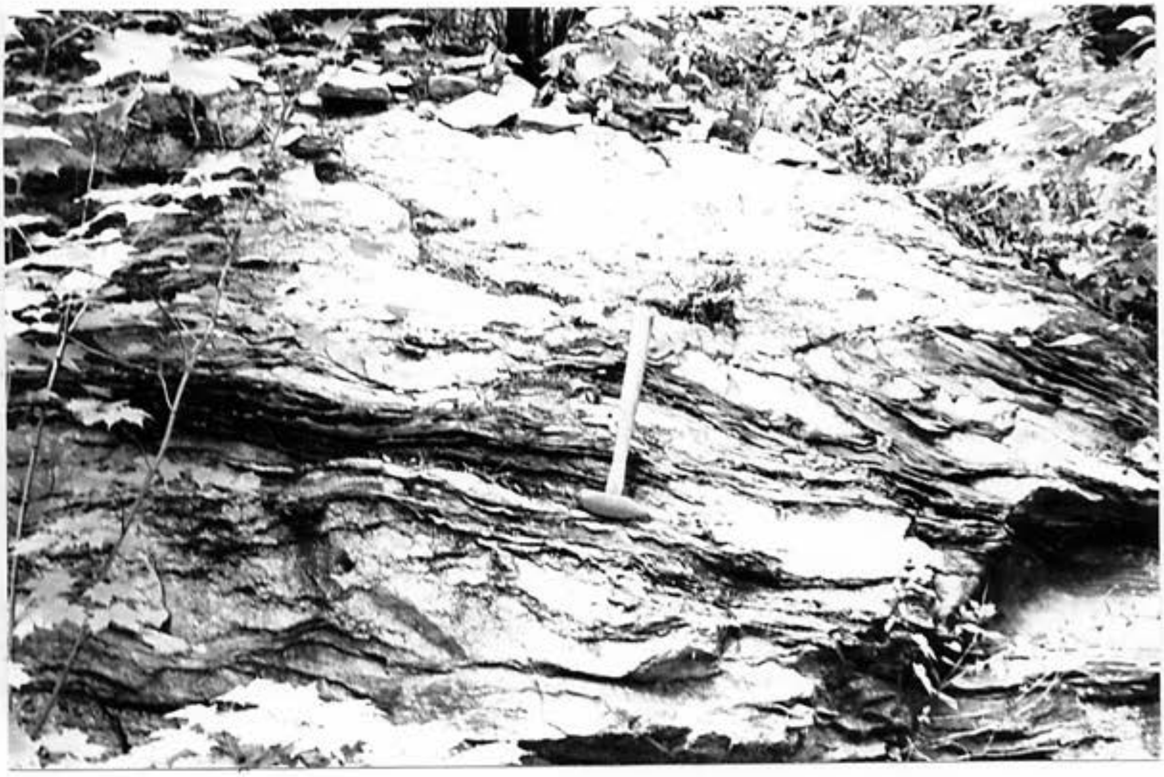

Figure 17. Intertonguing of Lithofacies I on right with Lithofacies IIA; flank of the Axemann mound approximately 95 feet above the base of the Stonehenge Formation.

The intraclasts of Lithofacies II are strikingly similar to those described and figured by Aitken (1969) and Wolf (1965) for channels in algal reefs. Most clasts are cuspate, some are rimmed with micrite, and some contain Girvanella, thought to have been responsible for extensive micritization.

Figure 18. Intertonguing of Lithofacies I and IIB; light material in lower right and upper right is Lithofacies I; Glenside.

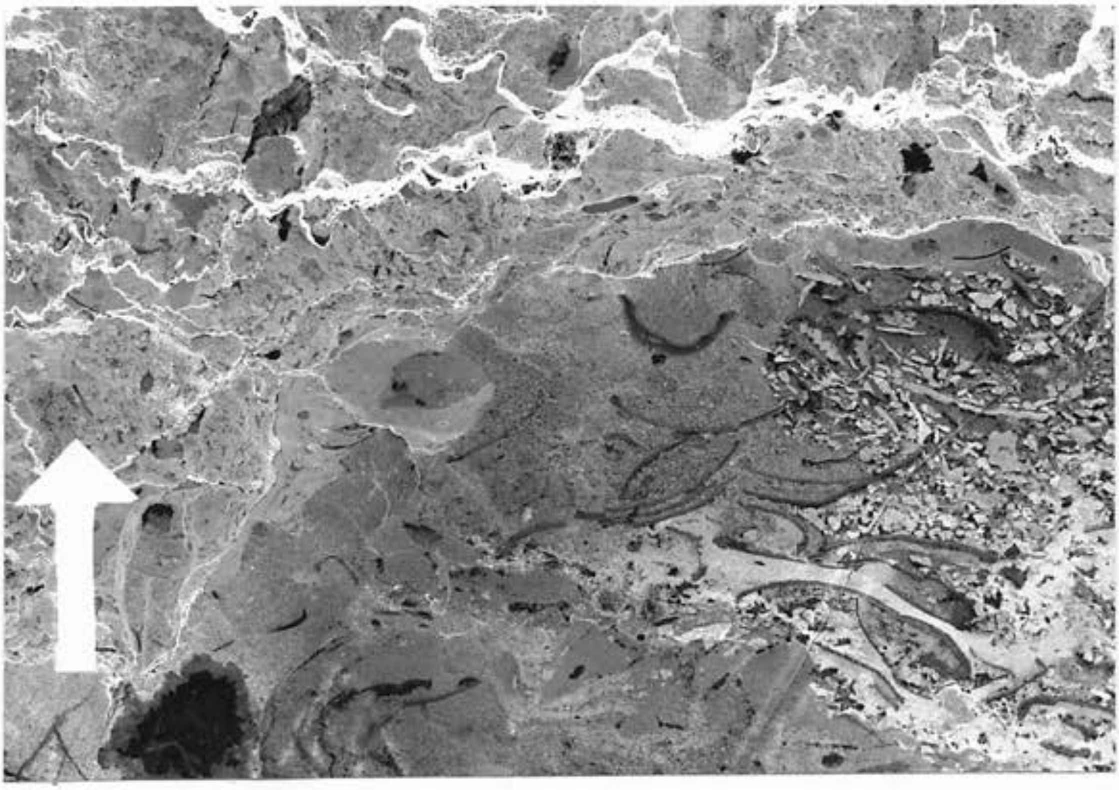

Figure 19. Lithofacies I overgrown on Lithofacies IIA; Axemann.

Wolf (1965) and Aitken (1969) have noted the autochthonous nature of the algal micrite chips associated with algal bioherms and reefs. They interpret these intraclasts as the micritized product of an algal debris facies. Aitken suggested that the formation of the homogeneous pelletoidal internal fabric of the clasts is produced by the boring activities of algae. The occurrence of extensive algal micritization shown in the microfabric of Lithofacies II is taken as further evidence for the presence of a rich algal flora. This fact, accompanied by the evidence of extensive channeling, is further support for the subtidal position of the mounds.

The narrow vertically anastomosing channels of Subfacies IIA are interpreted as surge channels perhaps hydrologically adjusted to the local wave swell or active during tidal flux. Channels similar to these in style but an order of magnitude larger in size are integral to the windward algal ridge complexes of the Indo-Pacific reefs. In this setting, they have been shown by Munk and Sargent (1954) to undercut the waves and dampen their erosive effect on the ridge and to be tuned in size to the period and power of incoming breakers. Channels of the algal ridge are periodically overgrown resulting in a system of labryinthine, roofed tunnels that extend shoreward under the ridge. Wells (1957, p. 615) notes that the floors and sides of surge channels are nearly smooth and upper edges commonly have overhanging eaves of growing algae and a few corals.

The channels of Subfacies IIA probably presented the same aspect on a much reduced scale. It can be seen that channels were frequently overgrown. Tubular channels are present. Subhorizontal lenses exist that probably represent the enclosure of debris in protected pockets on the temporary surface of the mounds.

The channels of Lithofacies IIB are interpreted as tidal channels because of their size, sheet bedding and cross-stratification. Tidal channels in the Recent develop wherever barriers occur in tidewater situations. Along the Trucial Coast, Persian Gulf, channels depth ranges from 4.6 m. to 13 m. Depth to width ratios vary from 1/40 to 1/80 and their cross-sections are related to the areas of lagoons that they serve (Bathurst, 1971, p. 195). Tidal channels of the Great Bahama Bank are of three kinds: (1) rocks and pebbles, (2) rippled sand, (3) stable sand (Bathurst, 1971, p. 129). The nature of the channel floor is controlled by the thickness of unconsolidated sand and the current velocities. Type (1) has a rocky bottom with a 1 cm. veneer of sand. In Type (2) the sand is ripple marked and mobilized during tidal flux and is populated by a suspension feeder. Type (3) channels are colonized by patches of Thalassia and green calcareous algae. Between plants the substrate is immobilized by an algal mat.

The largest and best exposed channel in the Glenside mound is in transitional contact at the base with the mound lithology. The character of the channel lithology changes gradually upward. Bedding thickness increases. Texture changes from calcilutite to calcarenite to calcirudite (Figures 14 and 15).

The implication exists that current intensity, as inferred from grain size and bed thickness, increased as the mounds and channels grew. This could have been a function of an enlargement of the volume of the seaway lying to the northwest and north or to the coalescing of the mounds causing preferential restriction of flow through fewer but more active channels.

Summary and Speculation: The mounds are interpreted to have grown in the circulatory channels of the carbonate platform. They appear to have lined the floors and sides of these channels. The small channels of Lithofacies IIA were necessary to protect the mounds from destruction by wave action. The large channels of Lithofacies IIB developed to provide the necessary circulation on the platform. As the algal masses grew, they provided a habitat for brachiopods, trilobites, gastropods, and a rich algal flora.

The absence of mud baffling organisms from the Stonehenge mounds and channels and the lack of positive proof of the presence of encrusting forms of algae is highly significant in the face of the genetic interpretations of other Early Paleozoic mound complexes. The common thread of interpretation found in the literature of carbonate mounds is that mud baffling organisms and mechanical sedimentation are integral to mound or reef genesis. The occurrences of the Stonehenge indicate that algae alone have had the ecological potential to build self-sustaining structures free of obvious skeletal or bound structure. An extension of this reasoning is that the organisms found in other mound complexes are overemphasized and the role of algae is minimized when the two occur together. Instead, it may be argued that other environmental factors may be involved in the colonization of a carbonate mound. It is this author's contention that mounds merely provide an ecological niche that was commonly exploited by sponges and the early corals.

STONEHENGE PALEOENVIRONMENTAL SEQUENCE

Several lithologic trends have been determined for the Stonehenge Formation. By calculating the percentages of the lithologies measured and described by Donaldson (1959) and Hobson (1963), distinct patterns of sedimentation evolve for each section (Table I). Probable sedimentary settings are interpreted for the lithologies by analogy with Recent carbonate environments (Table II).

Lithologic Trends

Laminated, sun-cracked dolostone is restricted to the lower Stonehenge. In the Spring Creek Member, laminites comprise 28% of the unit. In the Lower Member at Glenside, laminites comprise 35% of the unit.

Laminites of the Stonehenge contain concave upward, sun-cracked polygons, deep joints, "birds eye" structures and thin bituminous films (Figure 20). Laminated, sun-cracked dolomitic pelmicrite is found in supratidal, dominantly evaporitic conditions in the Recent (Shinn, Ginsburg, and Lloyd, 1965). Dolomite production is, at least in part, caused by the elevated ratio of magnesium to calcium (Folk, 1972). Dolomitization may also be enhanced by the alteration of thinly interbedded algal laminations and pelletal mud. Gebelein and Hoffman (1969) show that the magnesium content of the algal laminae is sufficient to produce one millimeter of dolomite from two millimeters of algal mat. In the Stonehenge laminites, dolomite and bituminous films could have resulted from this process.

TABLE I

Lithologic Type as Percentage of Member Thickness and Faunal Diversity*

	AXEMANN		GLENSIDE		
	Spring Creek	Graysville	L	M	U
oölites	present	present			
intrasparite and intrasparudite	45%	69%	9%	45%	15%
"tiger stripe"	27%	trace	56%	55%	absent
laminated dolomite	28%	trace	35%	absent	absent
massive algal calcilutite	absent	31%	absent	absent	85%
fauna	4 Phyla 6 Genera	5 Phyla 18 Genera	absent	4 Phyla 4 Genera	4 Phyla 5 Genera
thickness in meters	13	45	36½	16-18	18

*Compiled from the lithologic descriptions of the measured sections of Donaldson (1959) and Hobson (1963).

Laminites of the lower Stonehenge beds and throughout the Beekmantown commonly occur in cycles gradationally overlying burrow mottled, coarser crystalline, occasionally fossiliferous dolostones. In the ideal cycle, the base is a surface of discontinuity. Limestone beds, laminites of previous cycles, and structureless dolostones occur below surfaces of discontinuity. Hobson (1963) has shown that the density of burrow mottling decreases upward in the ideal dolostone-laminite cycles.

Detrital quartz ranging in size and texture from well rounded, frosted sand to angular silt are arranged in streaks and as floating grains in most dolostones. Sarin (1962), in a study of cyclicity in the Rockdale Run Formation of the south-central belt, found that both abundance and grain size of the quartz decreases upward. Four or five fining upward cycles have been found in some dolostone-laminite cycles.

In the absence of other sedimentary structures, presumably lost during dolomitization of the units, the combination of basal burrow mottling and fining-upward quartz cyclicity are interpreted as the result of fluvial processes. These cyclic dolostones are interpreted as the alteration products of progradational sheets of carbonate distributed by laterally migrating streams. Oomkens (1970) has described fining-upward fluvial cycles in the Rhône delta complex. These are offered as a possible analogue for the Beekmantown carbonate cycles.

The "tiger stripe" lithology of Donaldson (1969) was described as thin bedded, calcilutite containing subreticulate siliceous laminae by Hobson (1963). This lithology comprises 27% of the

TABLE II

Comparison of Stonehenge with Modern Analogues

Stonehenge	Recent Analogue	Reference
Laminated mud cracked dolomite	Bermudan tidal flat	Shinn et al, (1965); Gebelein and Hoffman (1969); Folk (1972)
"Tiger stripe"	back reef areas of Florida Keys	Ginsburg (1957)
Intrasparudite	tidal channels in Florida Keys; subtidal occurrences in the Bahamas	Jindrich (1969) Gebelein (1969)
Horizontal burrow structures	Barnstable Harbor, Mass.	Rhoades (1967)
Fining-upward cycles	Rhone delta	Oomkens (1970)

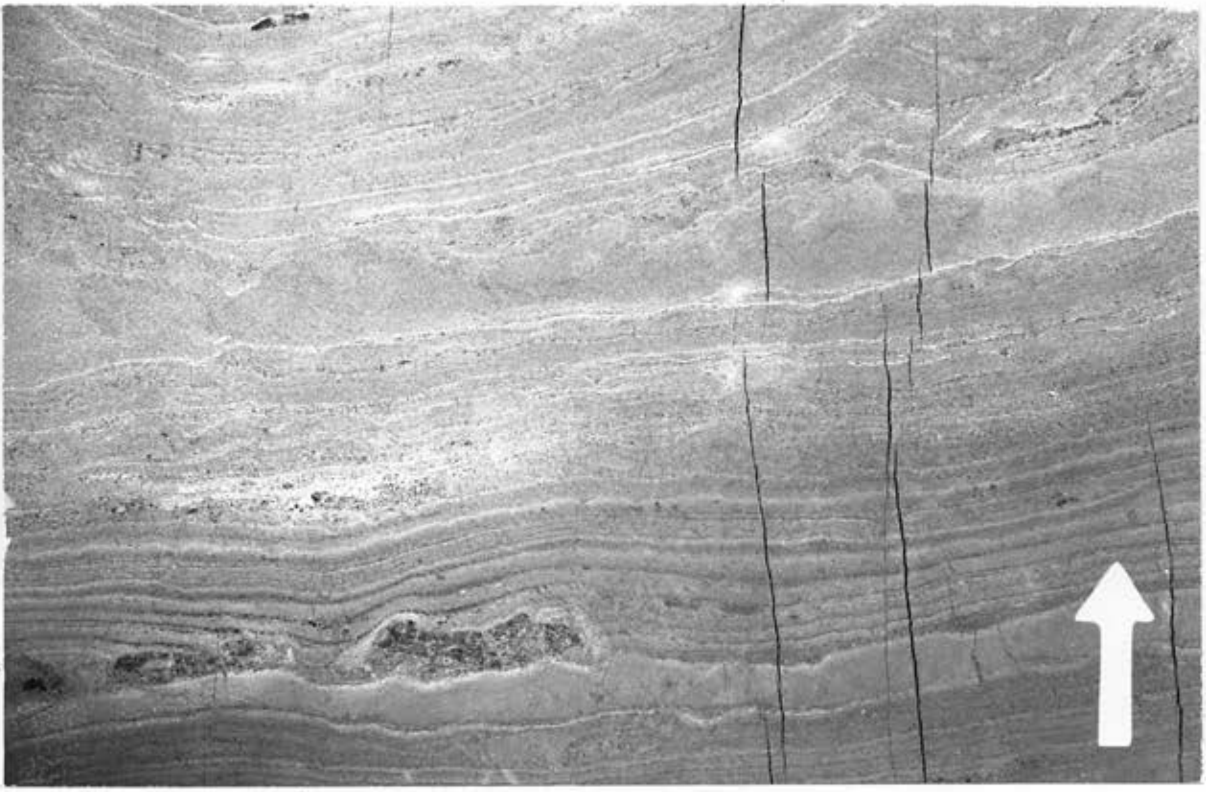

Figure 20. Laminated dolostone; lower Stonehenge, Glenside.

Spring Creek and 56% of the Lower Member at Glenside. The "tiger stripe" is minor in the Graysville but is just as abundant in the Middle Member at Glenside as in the Lower Member (55%).

The "tiger stripe" consists of calcilutite with anastomosing and subreticulate siliceous dolomitic laminae and bands. The calcilutite is intercalated with thinner cross-stratified lenses and laminae of intrasparite. The intrasparite contains brachiopod and pelmatazoan skeletal debris. The calcilutite layers average about 1 cm. or less and the intercalated intrasparite is arranged in discontinuous lenses with a maximum thickness of 2 cm. (Figure 21).

These beds are interpreted as subtidal deposits on the basis of horizontal burrowing and association with cross-stratified sands. The anastomosing and subreticulate silty dolomitized burrows have a

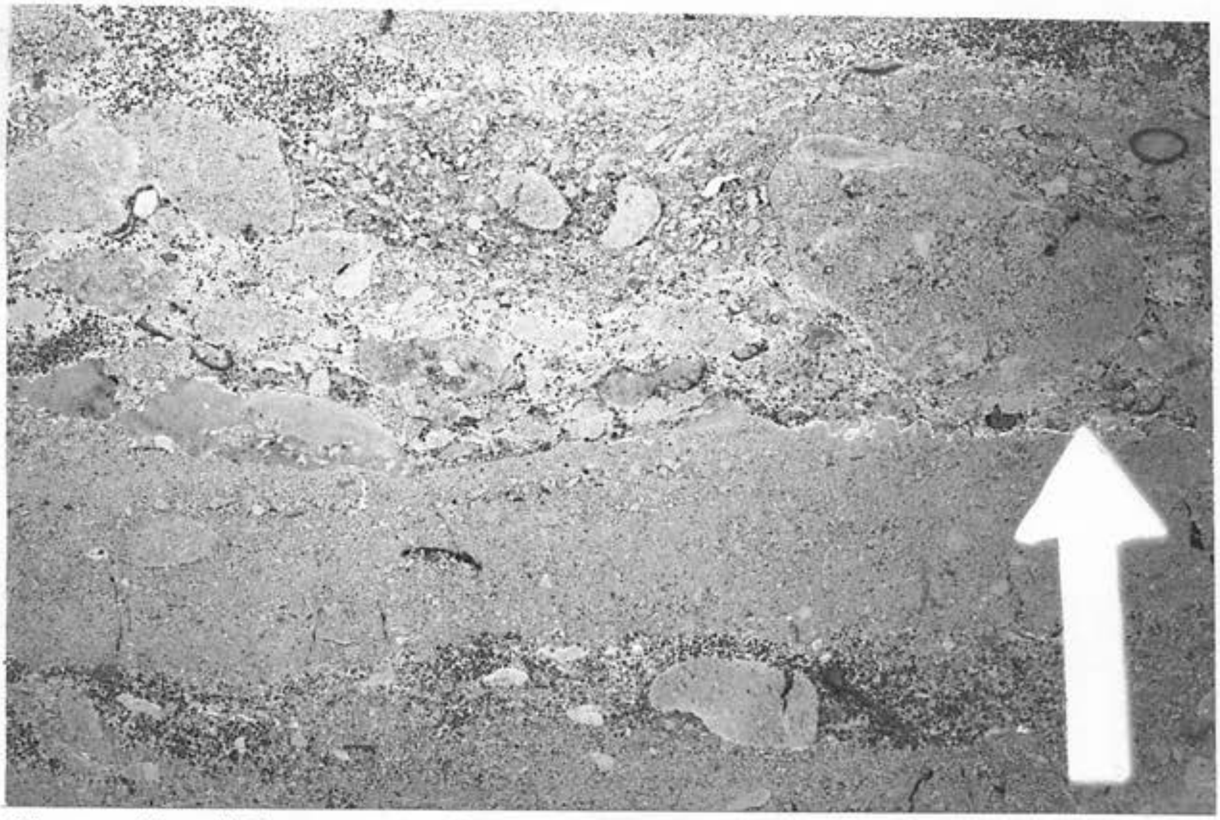

Figure 21. "Tiger stripe" : calcilutite with siliceous dolomitic burrows interbedded with intrasparite; Graysville Member, Axemann.

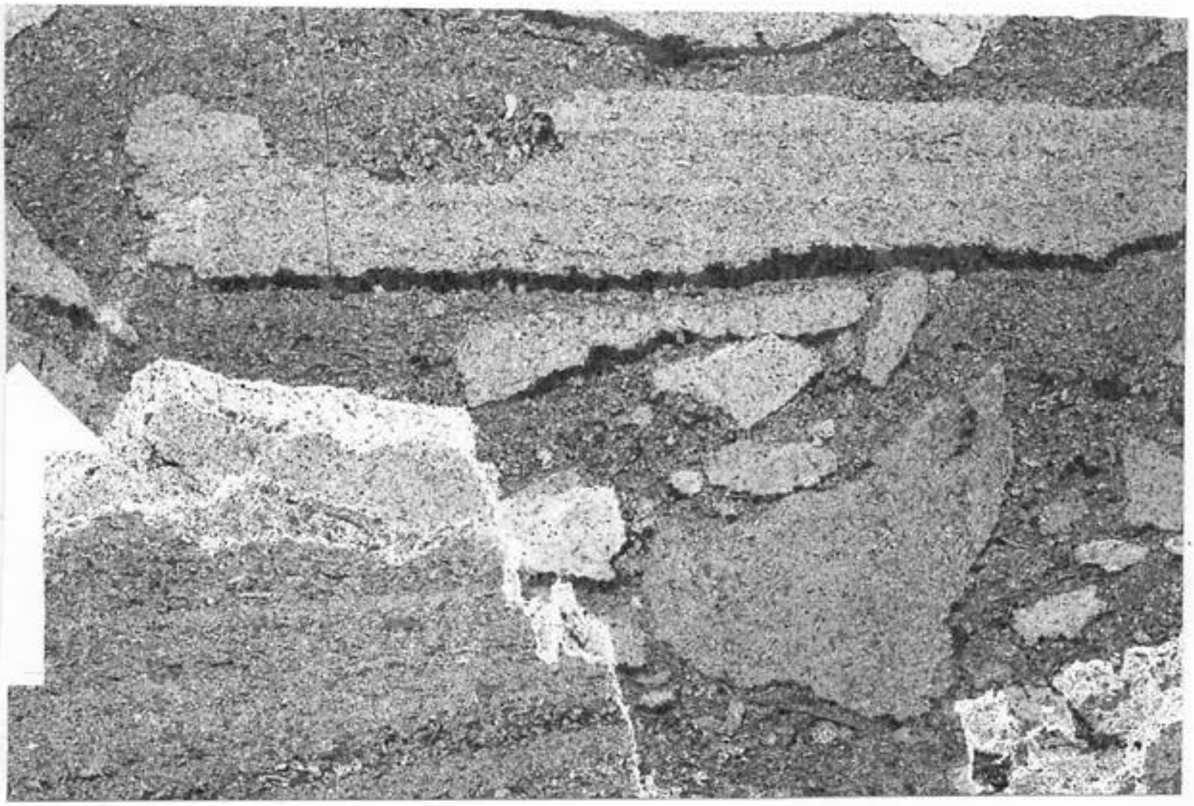

Figure 22. Intrasparudite: Graysville 140 feet above the Mines Dolomite.

pronounced horizontal orientation. Rhoades (1967) has described horizontal burrowing from modern subtidal settings. Cross-stratified sand in isolated ripples and thin sheets is a common occurrence on muddy semi-indurated substrates where sand supply is low or constricted by grass beds (Ginsburg, 1956).

Intrasparites and intrasparudites are lumped because of their intimate field association. All intrasparudites examined in this study had intraclastic matrix. The lithologies are less abundant in the lowermost Stonehenge in both localities than higher in the sections. The proportion increases from 45% in the Spring Creek to 69% in the Graysville. At Glenside the lithology increases from 9% of the Lower Member to 45% of the Middle Member.

The intrasparites and intrasparudites are thick bedded, sparry, frequently contain horizontal burrows and are occasionally cross-stratified (Figures 11, 13, 16 and 22). They are interpreted as subtidal channel deposits on the basis of burrows (Rhoades, 1967). Abundant sparry calcite cement and cross-stratification are indications of emplacement by moderately strong currents. Gebelein (1969) reported the occurrence of flat chips of algally bound sediment from Whale Bay, Bermuda Island to depths greater than 30 feet. Jindrich (1969) described the mode of formation of flat chips on the tidal delta of Blue Fish Channel, near Key West, Florida. Here, in the base of the channel, currents erode portions of algally stabilized mat into flat chips. The chips are rotated by currents and buried by advancing ripples of *Halimeda* sand.

Faunal Trends

The Fauna of the Axemann Stonehenge expanded from 6 genera in 4 phyla of which 3 genera are gastropods in the Spring Creek to 18 genera in 5 phyla of which trilobites and orthid brachiopods are the most abundant, in the Graysville.

The lower member of the Stonehenge at Glenside is unfossiliferous. The middle member contains fragmented brachiopods, trilobite, and gastropods and abundant pelmatazoan debris. The upper member contains orthid brachiopods, pelmatazoans, trilobites and gastropods in both algal mound and channel lithofacies.

Faunal data from each section taken separately clearly indicate that faunal diversity and circulatory restriction decrease upward paralleling the circulation trends reflected by the lithologies. Mound horizons of both sections coincide with the most highly energentic and faunally diverse lithologies of the Stonehenge.

Summary of Lithologic and Faunal Trends

(1) Laminites are found in the lower beds only.

(2) Intrasparites and intrasparudites are increasingly abundant in the upper beds.

(3) Faunal diversity and abundance increase toward the top of the unit.

Conclusions drawn from these trends are:

(1) Three end member facies coexisted in the marginal areas of the Stonehenge Sea during emplacement of the Spring Creek and Lower Stonehenge: a supratidal flat; a subtidal flat facies; a subtidal channel facies.

(2) Three facies existed during emplacement of the Upper Stonehenge beds: a subtidal flat facies; a subtidal channel facies; an algal mound facies.

(3) The overall sequence of the Stonehenge is transgressive.

BASIN EVOLUTION AND PALEOGEOGRAPHIC SYNTHESIS

In Pennsylvania, the Early Ordovician sea was restricted to a northeast-trending belt several hundreds of miles wide and bordered on the northwest by a large low relief interior land mass (Schuchert, 1955). The eastern edge of the North American continent during the Cambrian and Early Ordovician has been delineated by Rodgers (1968) on the basis of facies change from shallow water carbonates of the Conococheague and Beekmantown Groups to the deeper water Conestoga Limestone (Figure 23). The carbonate breccias of the Conestoga have been interpreted by Rodgers as a bank edge facies of the Beekmantown.

Bird and Dewey (1970) offer an explanation for the existence of the margin and the relative purity of the carbonate bank sediments from the perspective of pre-Mesozoic plate tectonics. They postulate that late Pre-Cambrian rifting along the trend of the developing continental margin led to the opening of a Proto-Atlantic ocean between North America and Europe. They attribute the thickness and purity of the Cambro-Ordovician carbonate sequences to position on the tectonically stable edge of the continent. Purity of the carbonate sediments is thought by them to be a function of great distance from the tectonically active spreading centers of the oceanic crust.

Thickness and dolostone-limestone facies relationships of the Beekmantown Group indicate that a distinct sedimentary basin developed on the continental margin carbonate platform during this episode.

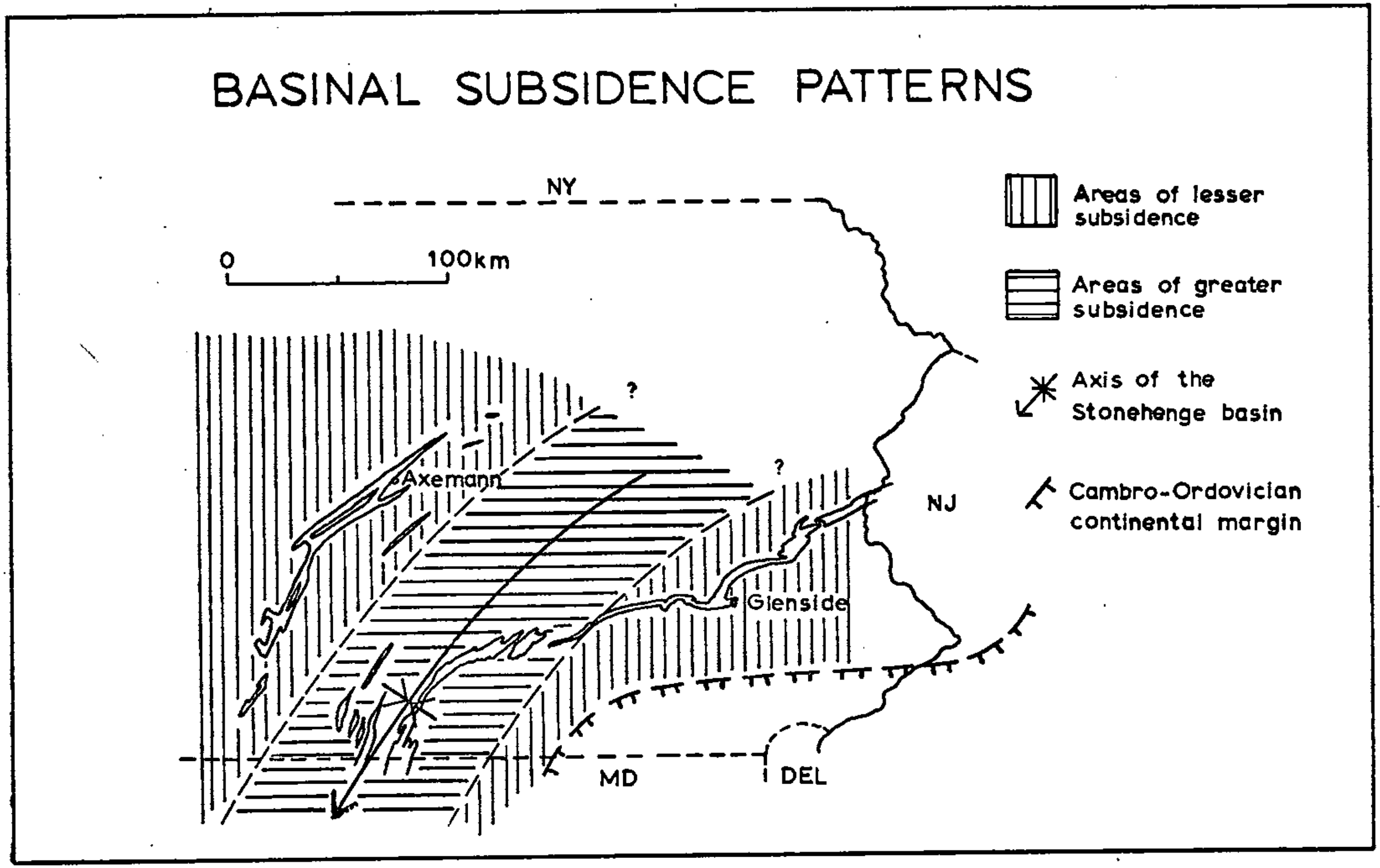

FIGURE 23— Generalized, schematic, sedimentary framework of the Appalachian platform during deposition of the Stonehenge Formation; data compiled from sources cited in text.

The Rickenbach-Stonehenge and Stonehenge-Larke facies pattern of the margins when compared to the thicker Stonehenge-Rockdale Run limestone intervals of the south-central belt show that the Stonehenge seaway developed as a true epicontinental sea bordered by tidal flats on the northwest and southeast (Figure 23).

The Upper Cambrian beds beneath the Stonehenge at Axemann and Glenside (Wilson, 1952; Hobson, 1963) are characterized by supratidal and intertidal lithologies including laminites and large algal heads similar to those of Hamlin Pool (Logan, 1961). The lower Stonehenge beds along the margins of the basin include three end-member facies: a supratidal facies; a subtidal flat facies; and a subtidal channel facies. Since the lowest Stonehenge beds were formed in more predominently subtidal conditions than the Conococheague and Mines beds, it is concluded that the transgressive sequence began in the Cambrian and climaxed with the development of the Stonehenge mounds.

The supratidal facies of the lower Stonehenge beds are taken as proof that tidal flats existed lateral to Glenside and Axemann during the early development of the seaway.

The Stonehenge sea spread along the axis of the basin as the seaway expanded over the northwestern, northern and northeastern tidal flats. The correlative Tribes Hill Formation, exposed near Albany, New York, is also transgressive (Braun and Friedman, 1969) and indicative of the regional scale of the event. During this interval, connection to an open seaway east of the continental margin is unlikely.

The continued transgression of the Stonehenge sea resulted in its broadening. The progradation of laminites into the seaway ceased in the southeast. Along the northwestern margin a few thin laminites were occasionally deposited during the Graysville interval.

The depositional style of the Stonehenge is similar in some respects to that of the Devonian Manlius Formation of New York State described by Laporte (1967). Manlius lithologies, like those of the Stonehenge, are relatively restricted pelletoidal muds, sands, intraformational conglomerates, and laminites deposited in a low energy seaway. Environmentally diagnostic lithologies replace each other vertically in close succession. This character of the Manlius led Laporte to describe the environmental sequence as a facies mosaic.

The mosaic of Stonehenge lithologies is also quite complex. Conodont bearing intrasparites and intrasparudites indicative of subtidal, well circulating currents are cyclically interbedded with unfossiliferous supratidal dolostones. Following this reasoning, any short vertical increment will show all the lateral facies equivalents for the period of time represented by the local column.

The facies mosaic displayed in the lower beds indicates that the submarine topography of the Stonehenge platform may have been much like the present Bahama Bank with broad shallow subtidal areas where "tiger stripe" lithology was deposited. These areas were bordered by shoals as is evidenced in the laminite-dolostone cycles and dissected by subtidal channels where intrasparites and intrasparudites were formed.

Further transgression led to the growth of mounds in the subtidal channels. Large mounds formed along the margins and smaller mounds developed in the center of the seaway (Hobson, 1957, 1958; Root, 1968).

The development of extensive algal mounds coincides with the explosion of the most diverse fauna of the marginal Stonehenge. The possibility exists that during deposition of the Upper Stonehenge and Graysville members, the continued transgression of the Stonehenge sea flooded the southeastern tidal flat and a direct connection existed between the epicontinental and intercontinental seas.

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