UPWARD-SHALLOWING CYCLES (PACs)
OF THE OLNEY AND ELMWOOD MEMBERS,
MANLIUS FORMATION, NEW YORK

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Rick

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ABSTRACT

Application of the PAC hypothesis to the Olney and Elmwood Members of the Manlius Formation in central New York supports the general hypothesis that this portion of the Helderberg Group accumulated episodically. This limited stratigraphic interval consists of small-scale upward-shallowing cycles (PACs) which strongly resemble well-documented ancient and Recent upward-shallowing tidal cycles. PACs of the Olney and Elmwood Members constitute a shallowing PAC sequence which developed as a result of eastward progradation of tidal facies. Within this shallowing PAC sequence, paleoenvironments and paleogeography evolved episodically in response to widespread punctuation events at PAC boundaries. Within each PAC of the sequence, paleoenvironments developed gradually as a result of sedimentary aggradation; between PACs paleogeographic patterns were abruptly altered by punctuation events.

PURPOSE & SCOPE

The purpose of this thesis is to investigate a new model for stratigraphic accumulation - the hypothesis of Punctuated Aggradational Cycles (PACs) - a conceptual model that may potentially find wide-ranging application in interpreting sedimentary rock facies. As a partial test of the hypothesis, a detailed study was conducted of the Olney and Elmwood Members of the Lower Devonian Manlius Formation in central New York (Figs. 1 & 4). Attention was directed toward this narrow stratigraphic interval in order to concentrate upon the details of stratigraphic accumulation. Within this context the objectives of this report are to: 1) document the existence of pervasive upward-shallowing cycles (PACs) in the Olney-Elmwood interval, 2) establish specific internal criteria for the paleoenvironmental interpretations of these cycles, and 3) contrast the stratigraphic results of an episodic mode of accumulation with the results of more traditional gradualistic concepts.

THE HYPOTHESIS OF PUNCTUATED AGGRADATIONAL CYCLES

Anderson et al. (1978), Goodwin et al. (1980), and Anderson & Goodwin (1980b) have suggested that nearly all sedimentary rocks accumulate as PACs during periods of aggradational deposition separated by non-depositional or erosional basin-wide transgressive events (Fig. 2). PACs are proposed as thin (1-5 meter thick) upward-shallowing rock units bounded by isochronous surfaces and theoretically

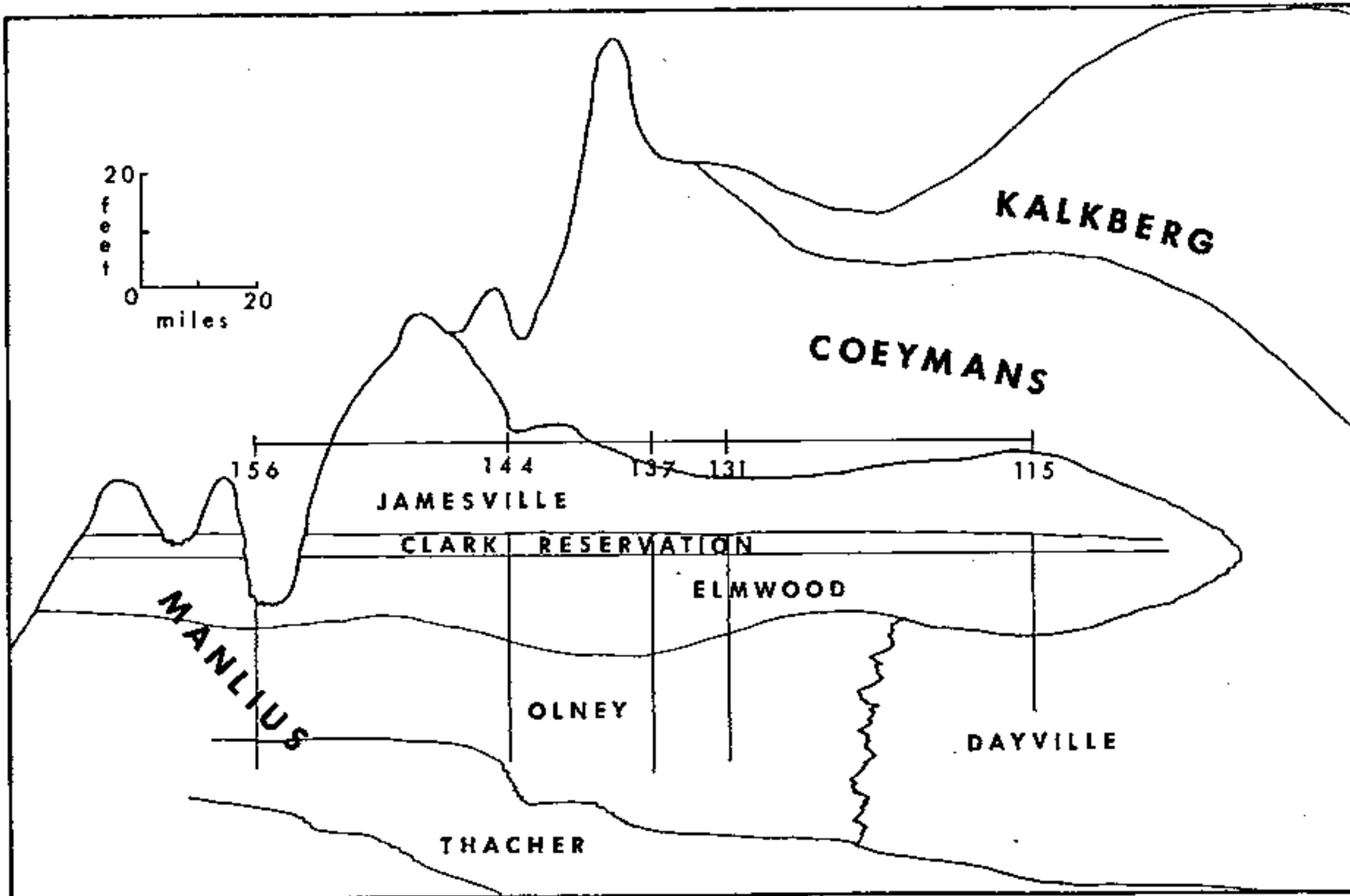


Figure 1 - Helderbergian cross-section (after Rickard, 1962). Numbered localities are those studied.

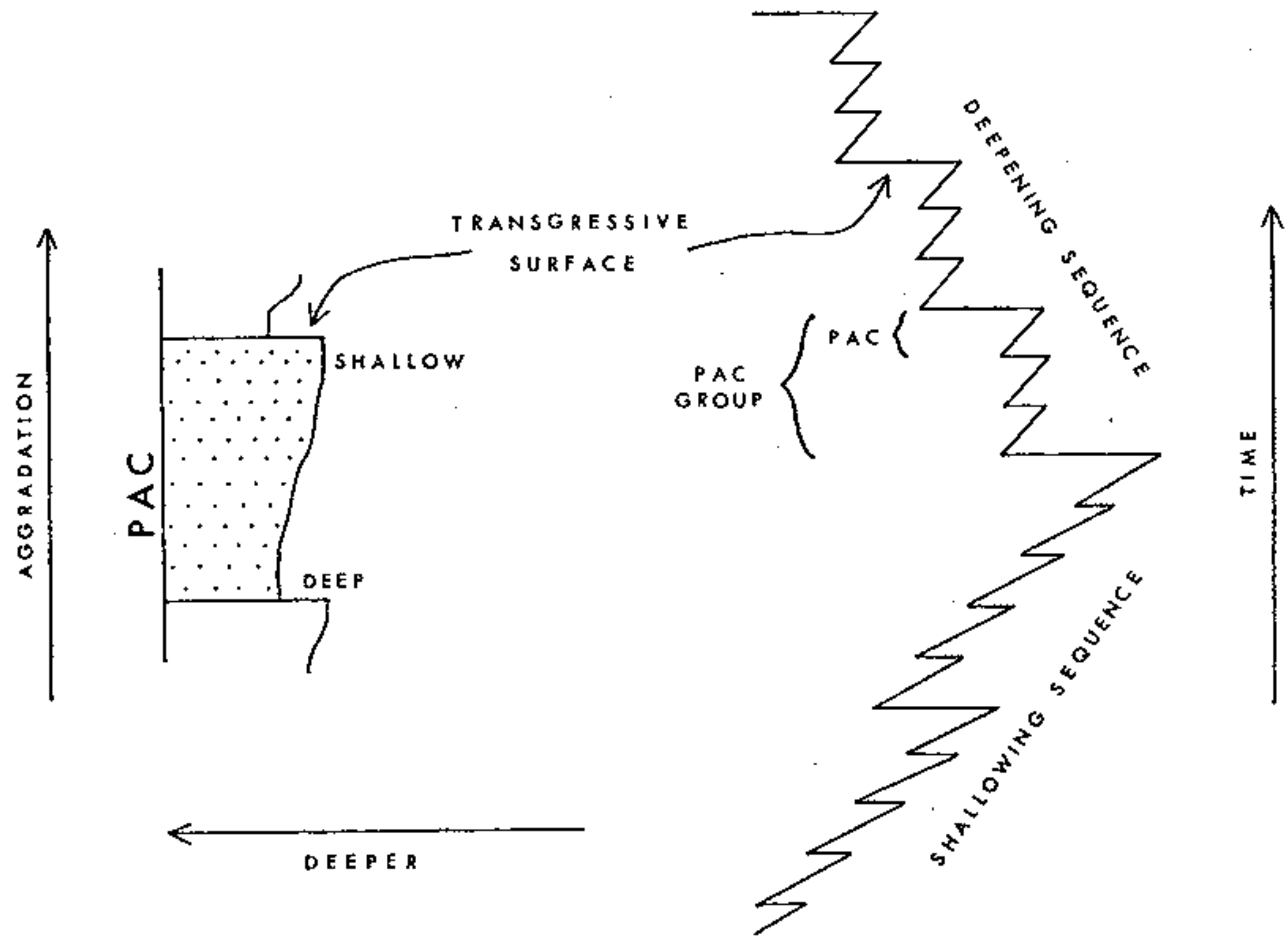


Figure 2 - The PAC hypothesis (from Anderson & Goodwin, 1980b).

traceable throughout the depositional basin. Internally, PACs represent deposition during periods of relative base-level stability. Recognition of PACs is dependent on fine-scale paleoenvironmental interpretations based on criteria specific to each environment. According to the PAC hypothesis, the punctuation events which create PACs are basin-wide and geologically instantaneous; theoretically, PACs are therefore time-stratigraphic units which have considerable potential for establishing detailed intrabasinal correlation.

Stratigraphic Implications

Stratigraphic implications resulting from deposition consistent with the PAC hypothesis (Anderson & Goodwin, 1980a and Goodwin & Anderson, 1980) are in marked contrast with those stemming from traditional concepts (Shaw, 1964). First, in the PAC view "transgressive" deposition is predicted to be essentially absent in stratigraphic accumulation. In standard stratigraphic analysis such "transgressive" deposition is considered a common phenomenon that results from gradual sea-level rise. Second, the PAC hypothesis views the thin time-stratigraphic PAC as the fundamental paleoenvironmental unit. These become established during periods of base-level stability following a relatively rapid transgressive event. In contrast, facies and formations, basically thick rock-stratigraphic units, are the fundamental paleoenvironmental units of gradualistic stratigraphic analysis. These units, which represent broad paleoenvironmental bands, accumulate as a large-scale mosaic that migrates during periods of base-level instability. Third, the PAC hypothesis predicts that, following a punctuation event, a paleogeographic pattern is established as a spectrum of environments largely unrelated to those which previously existed. Traditional concepts view paleogeography as a system of laterally adjacent environments which maintains its identity and migrates as a body. In this view, paleogeography evolves continuously in response to gradual sea-level fluctuations. Finally, the PAC hypothesis and traditional stratigraphic analysis differ markedly in their approaches to chronologic correlation. Because they are created by rapid basin-wide transgressive events, PACs are thin time-stratigraphic units which permit detailed intra-basinal correlations. Correlations based on facies and formations, thick diachronous rock-stratigraphic units, are not as accurate, even when augmented by biostratigraphic control.

PREVIOUS WORK

The Olney and Elmwood Members of the Manlius Formation serve as an ideal interval for testing the PAC hypothesis. Rickard (1962) has established a comprehensive Helderberg stratigraphic framework, basic correlations, and a general paleogeographic reconstruction (Figs. 1 & 3). Laporte (1967 & 1969), utilizing this foundation, has developed general paleoenvironmental interpretations for the Manlius. These excellent works provide the basis upon which this study heavily relies and from which more refined paleoenvironmental and paleogeographic analyses can be made.

A large number of natural and man-made Helderberg exposures occur within a limited geographic area of New York, and these enabled Rickard (1962) to determine detailed stratigraphic relations of formations and facies. The recognition of fossil assemblage zones, range zones, and key beds complemented the lithic relations in his construction of well-documented stratigraphic correlations. These correlations served as the basis for reconstructing the general basin paleogeography (Fig. 3).

Refinement of paleoenvironmental interpretations and paleogeographic reconstructions was provided by Laporte (1967) in his thorough study of the Manlius Formation. He proposed a facies mosaic concept in which he envisioned coexisting subtidal, intertidal, and supratidal environments (Laporte, 1967, Fig. 29). Within a gradually transgressing Helderberg sea, this environmental mosaic migrated laterally, the stratigraphic result being a complex facies mosaic. Although the relationship of the Manlius facies mosaic to overlying and underlying units (Coeymans and Rondout Formations) was well-documented, the internal relationships of subtidal, intertidal, and supratidal facies within the Manlius were not explained by Laporte's (1967) analysis.

This thesis is proposed as a further refinement of these earlier studies as well as a test of a new approach to the analysis of a portion of these facies. According to the PAC hypothesis, near mean sea-level Olney and Elmwood deposits should demonstrate PAC-scale sea-level fluctuations. Aggradational deposition should occur gradually only within PACs and be abruptly terminated at PAC boundaries. Utilizing this model paleoenvironmental succession and paleogeographic development should reflect an ordered, episodic pattern on a scale not obtained in previous studies. However, the validity of this study is dependent upon the degree to which it departs from the conclusions reached in earlier studies. A continuous monitering system for this study is thus provided by "testing" against these earlier results.

METHODS

Field work for this study began in May, 1980 and was divided into two parts - an initial four-week segment and a two-week return trip at the end of July. Stratigraphic sections were examined at nineteen localities over a distance of about eighty miles (Fig. 4). Stratigraphic columns were constructed from detailed PAC descriptions of each locality; samples and photographs were taken from selected PACs that demonstrated a variety of facies patterns. Thirty-five thin-sections were prepared from slabs cut normal to bedding. Sections were mounted on 46 x 27 x 1.2 mm. petrographic micro glass slides with Conap epoxy adhesive and polished to within about 30 Mm. with 1200 mesh silicacarbide grinding compound in the final polishing stages.

The field observations and microscope analyses of thin-sections indicated the Olney-Elmwood interval consists of a

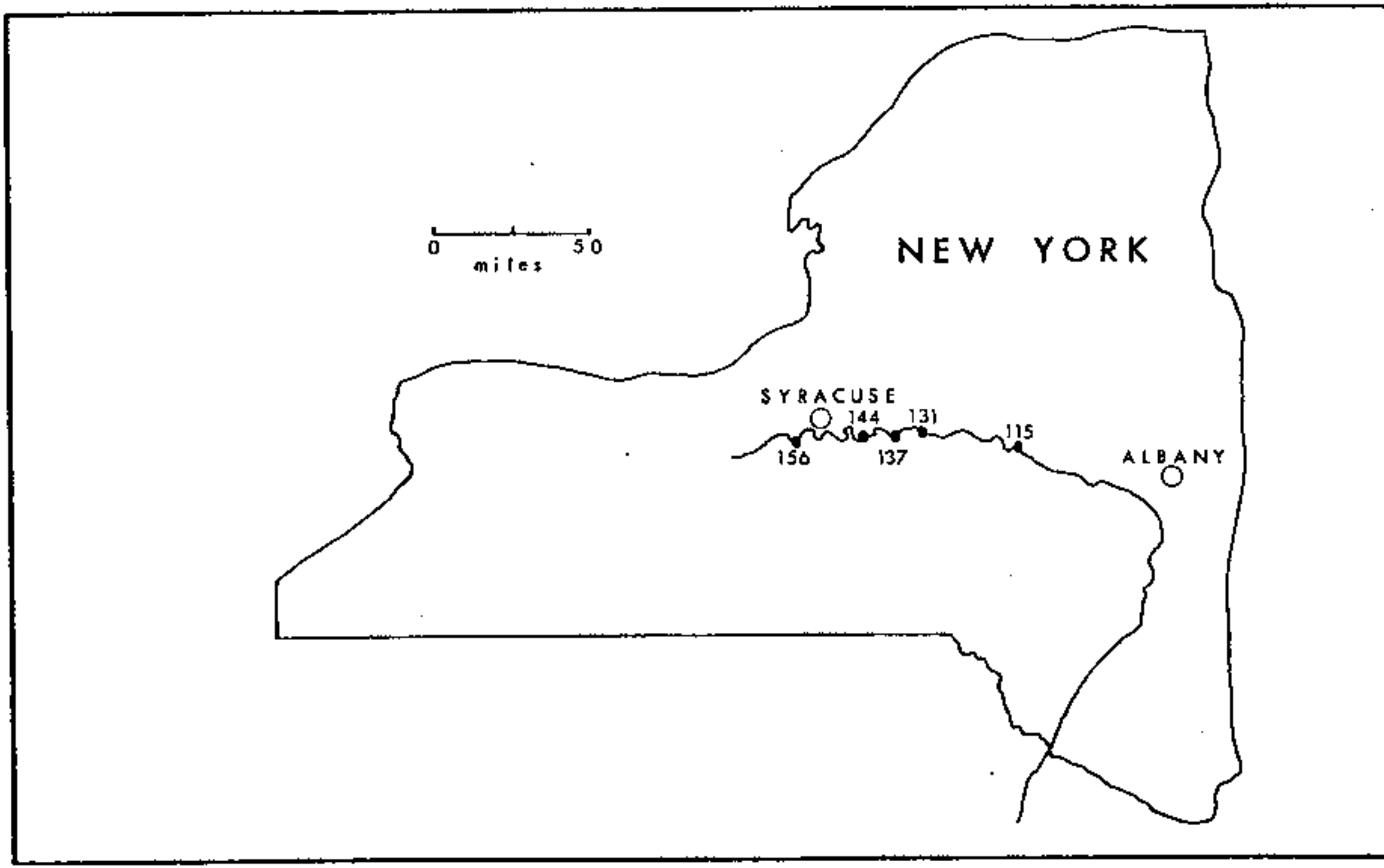


Figure 4 - Lower Devonian outcrop in New York. Study area locality numbers are from Rickard (1962).

series of upward-shallowing cycles deposited in a variety of shallow, tide-dominated carbonate paleoenvironments. To refine these basic interpretations detailed comparisons were made with Recent and ancient carbonate sequences which exhibit the same upward-shallowing cyclicity. What follows are reviews of both Recent and ancient upward-shallowing carbonate cyclic deposits for the purpose of establishing specific criteria for paleoenvironmental interpretation of microfacies within Manlius PACs.

RECENT EXAMPLES

Recent upward-shallowing sequences that demonstrate a subtidal to supratidal depositional motif have received extensive treatment in the current literature. Most notable are the tidal-flat sequences of Shark Bay, western Australia, the cycles of western Andros Island, Bahamas, and the sabkha cycles of the Trucial Coast, Persian Gulf (Fig. 5). Extensive studies in these regions serve as well-documented models for progradational tidal-flat development and each establishes specific sedimentologic criteria for microfacies interpretation.

Bahamas

Shinn et al.(1969) characterize western Andros Island as a low-slope restricted carbonate tidal-flat with three gross geomorphic features: 1) adjacent marine area, 2) channeled belt, and 3) a marsh. The tidal-flat forms a broad belt ten miles wide that parallels the island for 75 miles.

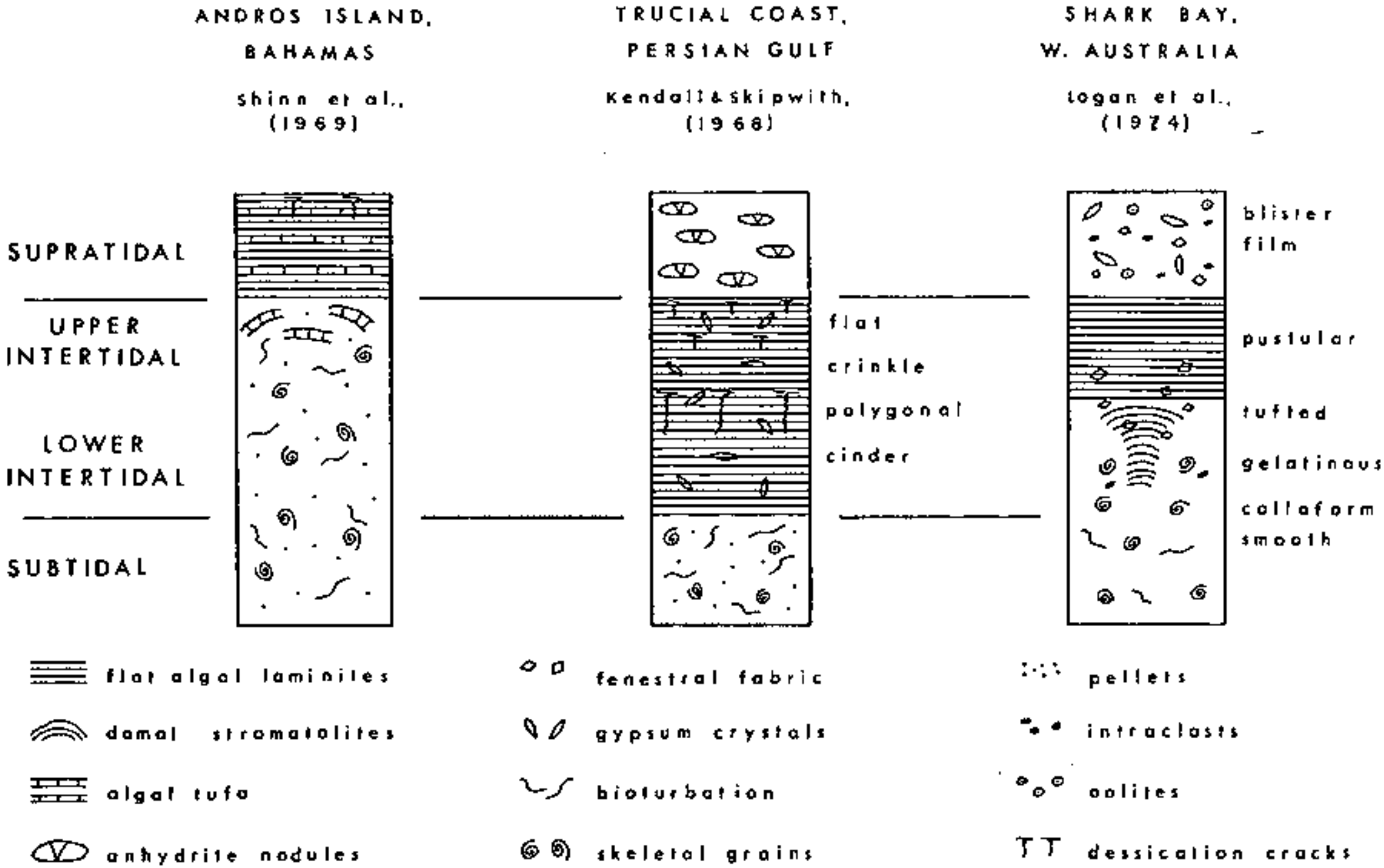


Figure 5 - Idealized Recent tidal-flat progradational sequences, not drawn to scale.

Normally, tidal-flat salinities range from 39-42‰ but reach 5-47‰ in response to the seasonally dry and rainy climate (Hardie, 1977). This seasonality is largely responsible for the ± 6 inch tidal range variation over the mean tidal range of one foot (Hardie, 1977). Based upon vertical tidal fluctuations within the geomorphic areas, subtidal, intertidal, and supratidal zones are recognized by Shinn et al.(1969). In addition, these zones are recognized in the post-Pleistocene progradational sequence illustrated in Fig. 5. This progradational sequence, deposited within the last 5,000 years (Ginsburg & Hardie, 1975), varies in thickness from 2-3 meters.

<u>Subtidal zone</u> - The subtidal zone of deposition occurs in water depths of less than 20 feet and pinches out on an exposed Pleistocene surface 80 miles beyond the shoreline. Sediments consist of light gray, burrowed, 20-50 Mm. aragonitic pelletal muds (Fig. 5) with a strong odor of H_2S. Fauna include high-spired gastropods, foraminifera, and a few pelecypods.

<u>Intertidal zone</u> - The intertidal zone occurs within the vertical range of normal tides and contains light tan to cream colored 40-80 Mm. pelletal sediments (Fig. 5). Except for occasional algal tufa in the upper transitional part of the flat, sedimentary structures in this zone have been destroyed by burrowing worms and red mangrove roots. Fauna consists of gastropods, various polycheate worms, and fiddler crabs.

<u>Supratidal zone</u> - The supratidal marsh is flooded only by

spring high tides and storm tides that can attain a vertical range of four feet. Although normally beyond the reach of tidal flooding, numerous depressions within the marsh are slightly below the level of high tide and are seasonally filled with fresh to brackish water. Sediments are light tan to white, dolomitic pelletal silts and muds with dark organic algal mat laminae (Fig. 5). These laminations, often 1 cm. thick, contain some inclined current lamination and small-scale cross bedding. Birdseye vugs and mudcracks occur on the upper surface of the marsh. Marsh grass and mangrove root structures are abundant, and algal mats form tiny heads called tufa by Hardie (1977). Fauna include land crabs, land snails, and transported foraminifera and gastropods.

Trucial Coast

The Trucial Coast of the Persian Gulf is a low-relief carbonate platform with shallow, offshore, oolitic shoals that form quiet lagoons (Evans, 1969). Infilling of these lagoons by Pleistocene quartzose sand and Recent carbonate and pelletal sediments has created a broad progradational algal tidal-flat (Butler, 1969). The uppermost portion of this salt-encrusted tidal-flat is known as the sabkha (Kinsman, 1969). The climate is hot and arid. Prevailing northerly winds are a dominant factor in establishing evaporation rates as high as 50 inches per year on the sabkha where interstitial pore-fluid concentrations can show salinities 10 times greater than the normal sea water in adjacent lagoons (Evans, 1969). The mean tidal range in the protected lagoons is less than 1 meter (Kendall & Skipwith, 1968). Algal flats immediately offshore from the sabkha are 4-5 km. wide and are divided into four geographical zones based on surface morphology. From offshore landward they are: 1) Cinder, 2) Polygonal, 3) Crinkle, and 4) Flat Zones. In the progradational sabkha system the sediments of one algal zone overlie those of the zone immediately seaward of it. This progradational package accumulated within the last 4,000 years and attained a thickness of from 1-2 meters (Kendall & Skipwith, 1968).

Subtidal zone - Layered carbonate pelletal muds and skeletal sands in the protected offshore lagoons attest to the variety of depositional regimes in this environmental zone.

Intertidal zone - The Cinder Zone algal mats are marked by crenulated bumps 2-3 cm. across and grow mixed with skeletal sands associated with small swash bars. Polygonal Zone mats are characterized by curled-up, sediment-filled, extensive dessication polygons. Polygon edges curl, become rounded, and trap sediment under the curled lip. The Crinkle Zone algae form continuous crinkled or blistered mats with a superimposed polygonal pattern. Sediments are aragonitic mud and lenticular gypsum mush with horizontal birdseye vugs. The landward edge of the Flat Zone marks the air/water interface. Sediments in this zone may be a quartz-rich carbonate sand or mud with large quantities of lenticular gypsum crystals.

Algal mats are very flat, the only relief created by faint dessication polygons (Fig. 5).

Supratidal zone - The supratidal environment begins at mean high water level at the air/water interface with a thin halite crust in tide and wind transported carbonate sediment. Concentration of ground water through evaporation leads to further evaporite formation from gypsum mush to anhydrite nodules high on the sabkha (Butler, 1969).

Shark Bay

Shark Bay is a large, shallow embayment where intermittent continental runoff and a broad offshore shoal create limited marine circulation and hypersaline waters in several restricted depositional basins (Davies, 1970a). The climate is considered seasonally semi-arid with evaporation rates exceeding precipitation rates by 10 times (Davies, 1970a) and basin tidal ranges averaging two feet (Logan & Cebulski, 1970). Progradational tidal-flat sequences, on the order of 2-3 meters thick (Logan et al., 1970), have developed over the past 4,000 years where distinctively textured algal mat communities have flourished. Algal mat development is restricted to the intertidal zone defined between PLWL (prevailing low water level) and WHWL (winter high water level) (Logan et al., 1970).

Subtidal zone - The subtidal zone contains both bioturbated and planar to low-angle cross-laminated grainstones or coquinas with some bioturbated pelletal muds in the upper portions (Fig. 5). In the lower portion molluscs, crustaceans, echinoids, fish, and worms contribute to bioturbation. In the upper more hypersaline areas burrowing organisms and their structures are more limited (Logan, 1970).

Intertidal zone - Algal mats in this zone are characterized by variability in contrast to Andros Island and the Trucial Coast (Fig. 5). Algal sheets are the fundamental algal structure in the low-energy flats, and columnar and domal forms represent algal response to higher energy conditions by tidal-flat channel erosion of algal sheets (Davies, 1970b). Vertical succession of mat types and their occurrence in particular positions of the intertidal zone allow for detailed subdivision of this environmental zone.

Logan et al.(1970) describe algal types from the bottom of the sequence upward in the following manner (see Fig. 5). Colloform mats are yellowish-brown to gray in color and are characterized by 1-3 cm. convexities on their surfaces. They may occur up to two meters below PLWL but are ephemeral and not preserved in that environment. Smooth mats are yellowish-gray to brown and trap large quantities of fine sand-sized particles. Coarse filament tufts project through the surface forming rounded protuberances similar to the algal tufa of Andros Island. Gelatinous mats are yellowish-green to brown and accumulate as an algal peat devoid of sediment. They contain deep polygonal cracks and resemble mats of the Polygonal Zone of the Trucial Coast (Fig. 5).

Tufted mats are greenish-brown to black and contain sharp-crested ridges called scallop structures on their surfaces. Pustular mats, similar to those in the Trucial Coast Cinder Zone (Fig. 5), are reddish-brown and have a rough surface of pustules averaging 3 cm. in diameter.

Supratidal zone - Algal mats laid down in this environment undergo substantial diagenetic overprinting of primary sedimentary structure with the result that algal mats of this zone are recognized by tabular fenestral fabric, intraclast pavements and breccias, and gypsum crystals (Fig. 5). Film and blister-type mats occur in this zone. The film mat is a dessicated variant of the pustular mat, recognized by its dark greenish-gray to black color. Finally, the uppermost blister mats in the sequence are smooth beige and green mats with hollow blisters formed into crenulations. These mats resemble those of the upper Crinkle and Flat Zones of the Trucial Coast.

Comparison of depth zone criteria

Sedimentologic depth zone criteria from these Recent sequences possess a certain commonality that can be applied to the interpretation of similar sequences in ancient rocks. In all three analogues the subtidal zone is recognized by burrowed, skeletal, pelletal mud and/or current bedded sand. Intertidal and supratidal sediments are more variable, and it is difficult to obtain a precise set of characteristics uniformly applicable to all Recent sequences. Hoffman (1973) views this variability as a function of the different hydrologic conditions and regional climates of the three regions. In addition, even within some of the sequences, clear-cut criteria separating depth zones are difficult to establish (Fig. 5). However, as will be discussed below, sufficient information can be obtained to warrant further examination of these zones and their boundaries.

At Andros Island the sedimentologic separation from subtidal to intertidal is gradational, whereas at Shark Bay and the Trucial Coast the separation is the abrupt appearance of stable algal mats. Within the intertidal zone at Andros Island, the sediments become more light tan to cream colored upward as a result of increased iron oxides. Ephemeral algal tufa structures occasionally occur in the upper intertidal. The appearance of algal mats at the subtidal/intertidal boundary at Shark Bay and the Trucial Coast may be a reflection of the greater degree of basin restriction. Drier climates, higher rates of evaporation from higher temperatures, and subsequent increased basin salinities may be dominant factors in limiting extensive development of algal-grazing gastropods and fish. Hypersaline-tolerant algae occupy a non-competitive ecologic niche in the lower intertidal zones where wave turbulence is the primary limit to colonization (Logan & Cebulski, 1970). Algal mat development continues into the upper intertidal zone with the specific sequential morphologic characteristics described earlier.

The intertidal/supratidal boundary is recognized by distinctive sedimentologic and diagenetic characteristics. At Andros Island supratidal zone sediments are recognized by the abrupt appearance of stable algal mats and algal tufa (Fig. 5). Faunal elements are limited to land snails. Grass and mangrove root structures and occasional dessication cracks in dolomitic and black organic-rich laminations characterize the supratidal marsh. In contrast, both the Trucial Coast and Shark Bay lack clear algal mat laminations but contain abundant evaporite minerals in this zone (Fig. 5). High interstitial brine concentrations from high ambient temperatures, high evaporation rates, and prevailing onshore winds preclude algal mat development on the Trucial Coast sabkha (James, 1979). These severe climatic conditions, coupled with limited normal sea water flood recharge, contribute to the origin of early diagenetic anhydrite on the sabkha (Kinsman, 1966; Shearman, 1966; Butler, 1969). Less severe conditions in Shark Bay make gypsum the stable mineral phase on the supratidal flat, but more importantly, blister and film algal mats colonize this zone seasonally but are destroyed during gypsum mineralization (Logan, 1974). Supratidal characteristics, then, most clearly reflect the distinct conditions on the three tidal-flats.

ANCIENT EXAMPLES

The previously reviewed Recent tidal-flat cycles have been cited as Recent analogues of ancient upward-shallowing cycles in a large number of studies. From these abundant carbonate examples, three have been selected for detailed discussion: 1) the Middle Devonian Pillara Formation, Canning Basin, western Australia (Read, 1973), 2) the Lower Ordovician Baumann Fiord Formation, Ellesmere Island, Arctic Circle (Mossop, 1973), and 3) the Upper Cambrian Lyell Formation, Alberta, Canada (Aitken, 1978). As with the Recent examples, each of these upward-shallowing cycles can be separated into subtidal - intertidal - supratidal segments based upon sedimentary and biogenic characteristics (Fig. 6). Nearly complete absence of upward-deeping deposits strongly suggests that all deposition was aggradational and that transgression is recorded as only a non-depositional contact or thin erosional lag between or at the base of cycles.

Lyell Formation

Upper Lyell Formation carbonate subcycles (Fig. 6) consist of repetitious subtidal to supratidal units averaging about nine feet in thickness (Aitken, 1966 & 1978). Subtidal lithologies begin with a thin conglomerate of laminite intraclasts in erosional contact with the underlying cycle and grade upward into thin-bedded to nodular or mottled lime-mudstones and calcisiltites with thin dolomitic partings. Intertidal lithologies consist primarily of dolomitic domal

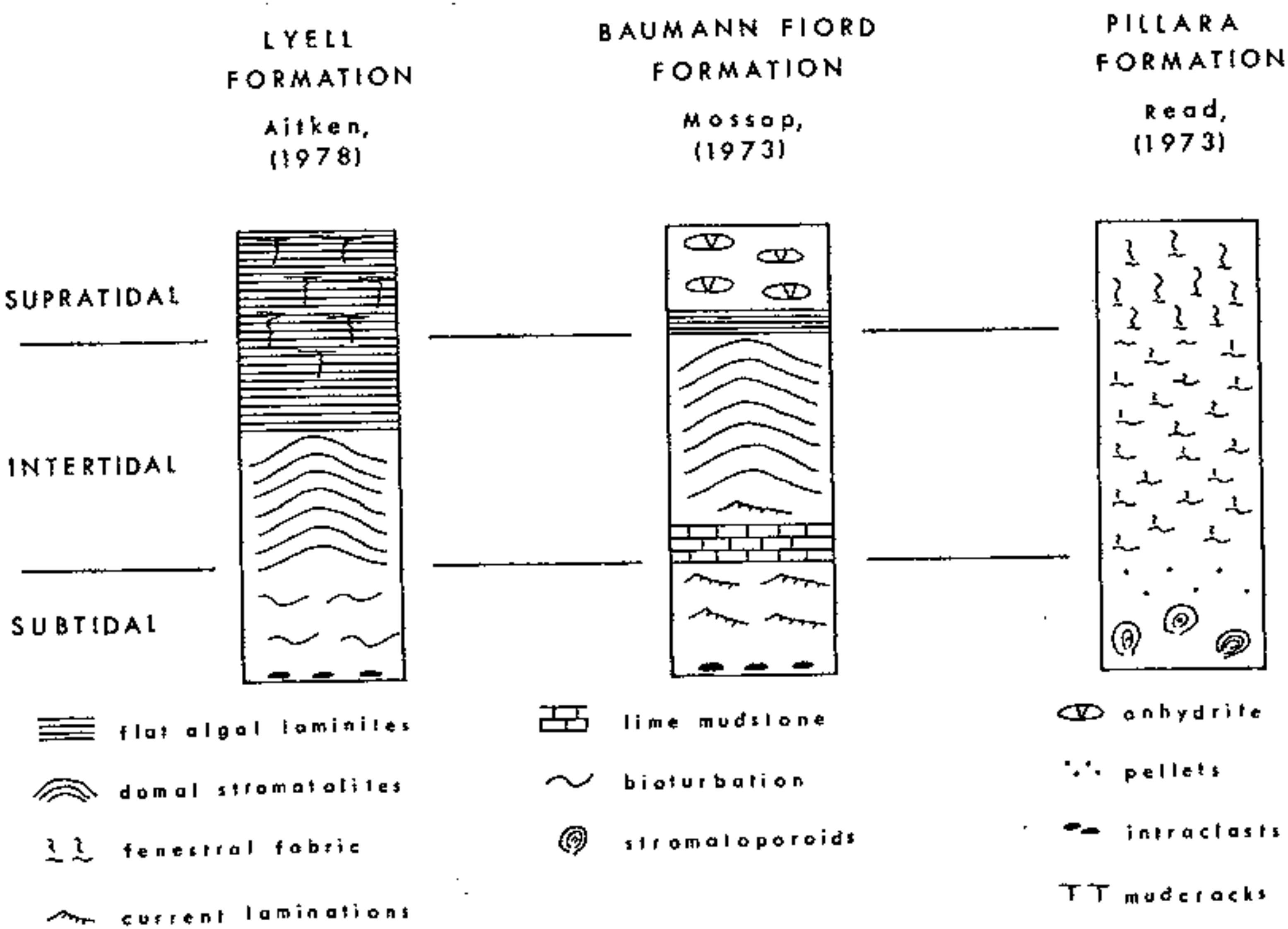


Figure 6 - Ancient tidal-flat upward-shallowing cycles, not drawn to scale.

stromatolites. The upper intertidal and lower supratidal zones are characterized by flat cryptalgal laminites containing polygonal mudcracks (Fig. 6).

Pillara Formation

Pillara Formation type A cycles (Read, 1973) are approximately three meters thick and begin at the bottom with subtidal skeletal packstones and wackestones. These lower subtidal deposits are recognized predominantly by an abundance of subspherical stromatoporoid colonies, corals. dasycladacean algae, calcispheres, gastropods, and ostracodes (Fig. 6). Middle subtidal facies continue upward through massive to medium-bedded wackestones and packstones characterized by cylindrical Stachyodes stromatoporoids to Amphipora stromatoporoid thin-bedded wackestones and packstones of the upper subtidal. Intertidal sediments are marked by pelletal limestone and lime-mudstone with cryptalgal and fenestral fabrics displaying many of the features associated with intertidal algal mats in Shark Bay sediments (Fig. 5). In the upper portion of the cycle the supratidal zone is marked by the first appearance of orange to tan limestones with fenestral fabric. Cycle boundaries are sharp with no real record of transgressive deposition or erosive action as was the case with Lyell Formation cycles.

Baumann Fiord Formation

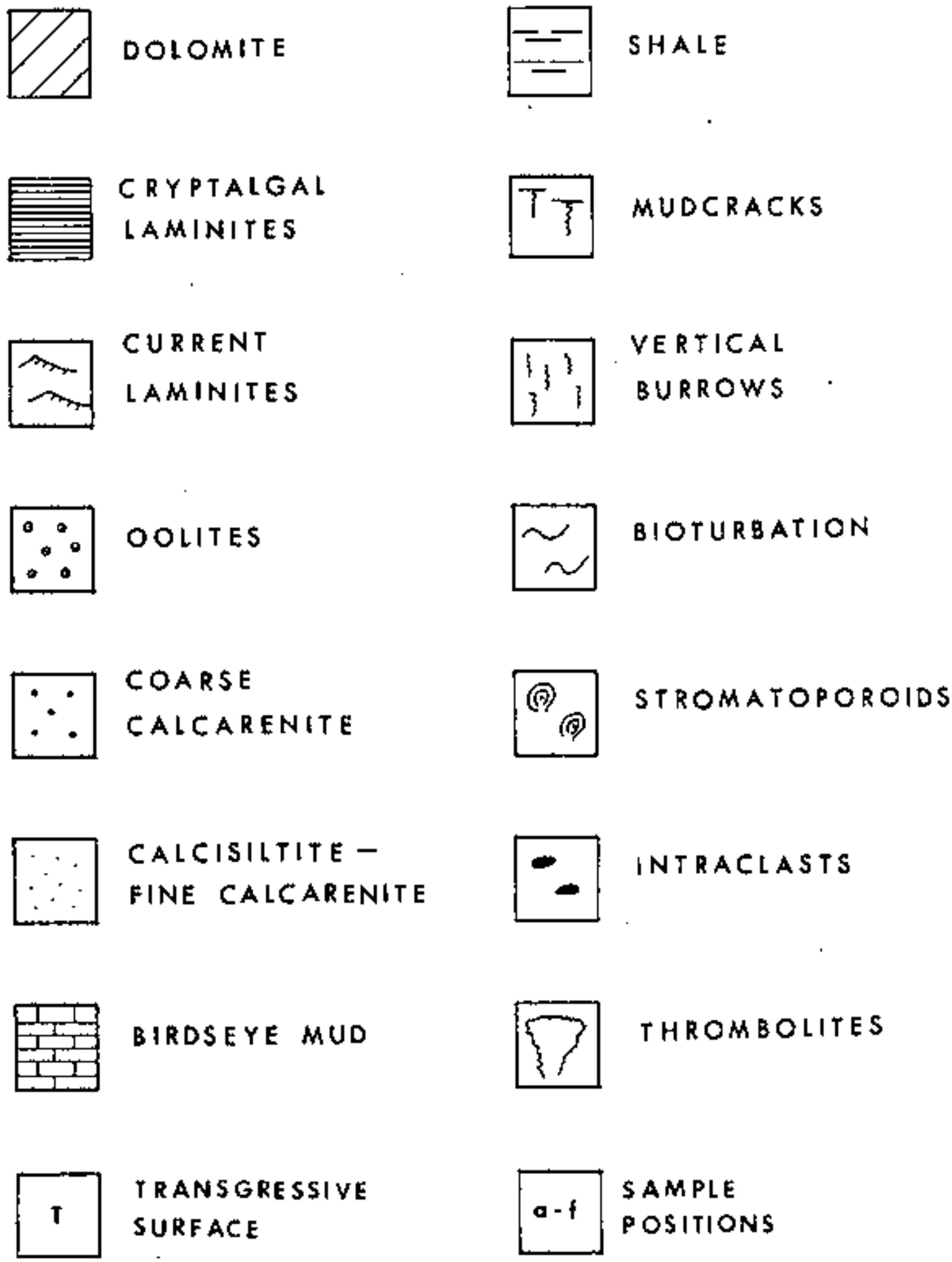
Baumann Fiord Formation cycles (Mossop, 1973) are about three meters thick and, like Lyell Formation cycles, are initiated at the bottom with thin lenses of micritic pebble conglomerate passing upward into unfossiliferous, mostly structureless lime-mudstone with occasional ripple-laminated horizons (Fig. 6). This subtidal lithology is replaced upward by digitate, domal, and polygonal cryptalgal laminites of the intertidal zone. The lower supratidal zone is often marked by a thin horizon of poorly-laminated microdolomite with occasional dessication cracks. Thinly layered or bedded anhydrite makes up the remainder of the supratidal deposits and caps the cycle.

Summary

From this brief review of ancient upward-shallowing tidal-flat cycles, certain characteristics seem to be commonly utilized as key environmental indicators. Massive to thin-bedded fossiliferous calcisiltites and pelletal micrites exhibiting bioturbation or current bedding indicate a subtidal environment. The intertidal zone is marked by the first appearance of cryptalgal laminites or fenestral fabrics as were two of the three Recent examples. Subdivisions of the intertidal zone are variable, probably reflecting differences in physical parameters for algal colonization. Specific criteria characterizing the supratidal zone are more cryptic and difficult to establish. In cycles of the Lyell and Pillara Formations, the supratidal zone occurs as a continuation of the upper intertidal zone. Increased dessication features or color mottling seem to be the best distinguishing features. In contrast, supratidal facies of Baumann Fiord cycles are clearly defined. Vaguely-laminated, dessication-cracked microdolomites commonly underlie bedded anhydrite in this zone.

MANLIUS UPWARD-SHALLOWING CYCLES (PACs)

The Olney-Elmwood interval consists of small-scale upward-shallowing cycles (Fig. 7). These cycles resemble those described in the previous sections of this report, and they were deposited in tidal environments similar to those of Andros Island, Shark Bay, and the Trucial Coast. However, no single analogue or combination of analogues, ancient or Recent, completely accounts for all features of Manlius PACs. To achieve better insight into Manlius paleoenvironments and stratigraphic dynamics, the full spectrum of lithologic variation in the Olney-Elmwood cycles must be considered. For this purpose six representative PACs have been selected for detailed analysis. These six, lettered A through F, are shown in their relative straigraphic positions in Fig. 7.



Legend for stratigraphic columns in Figures 7,8,10,13,15, 17, & 19.

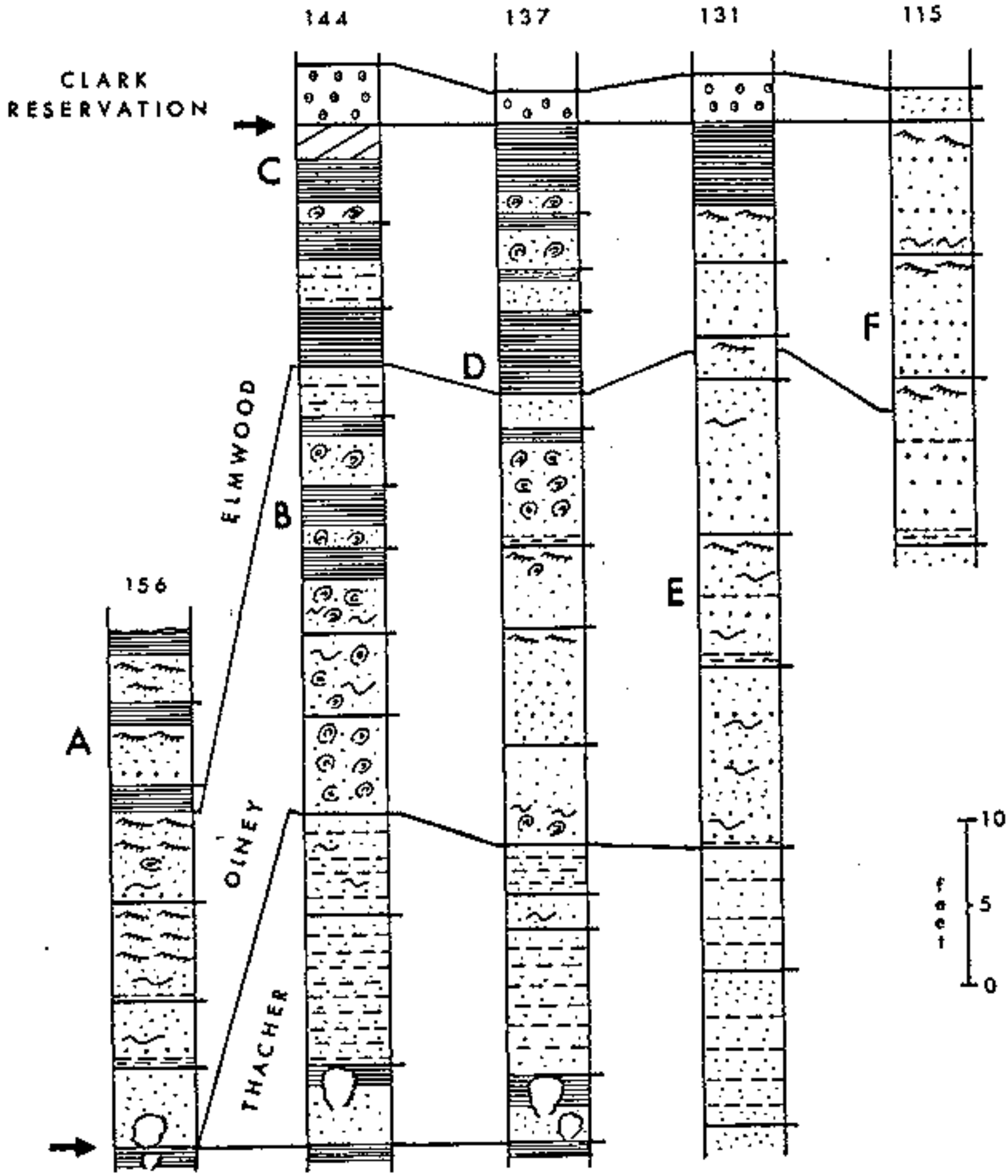


Figure 7 - Correlation of lower Manlius PAC sequences.
Cycles studied in detail shown by bold letters.
Arrows show correlation line.

Split Rock (Cycle A)

At Split Rock quarry a series of five cycles occurs in a stratigraphic section exceeding thirty feet (Fig. 8). The second cycle down from the quarry top is selected as representative of upward-shallowing Elmwood tidal-flat cycles with current-washed calcarenites in the lower portions. The basal deposits of this cycle (Cycle A) lie abruptly above cryptalgal laminites containing occasional thin lenses of ostracode-rich current laminites in a coarse calcisiltite matrix (Fig. 9-A). The basal deposits consist of diversely fossiliferous, bioturbated, pelletal micrites and calcisiltites with biosparite lenses (Fig. 9-B). Fauna include several varieties of impunctate and pseudopunctate brachiopods, ostracodes, crinoid stems, and trilobite fragments. This lithology is replaced upward by fossiliferous calcisiltites and fine calcarenites (Fig. 9-C). These lithologies are as faunally diverse as the basal deposits (Fig. 9-B) but contain two new elements, bryozoans and gastropods, and are lacking trilobite fragments. Higher in the cycle these relatively diversely fossiliferous calcarenites are replaced by faunally less diverse ostracode-rich calcisiltites and pelletal micrites (Fig. 9-D). These calcisiltites are current-washed and contain dolomitic partings (Compare with Lyell Formation upper intertidal zone, Fig. 6). Well-sorted, dolomitic, fine to medium calcisiltites in mudcracked, poorly-preserved cryptalgal laminites (Fig. 9-E) cap the cycle (Compare with Baumann Fiord Formation lower supratidal zone, Fig. 6).

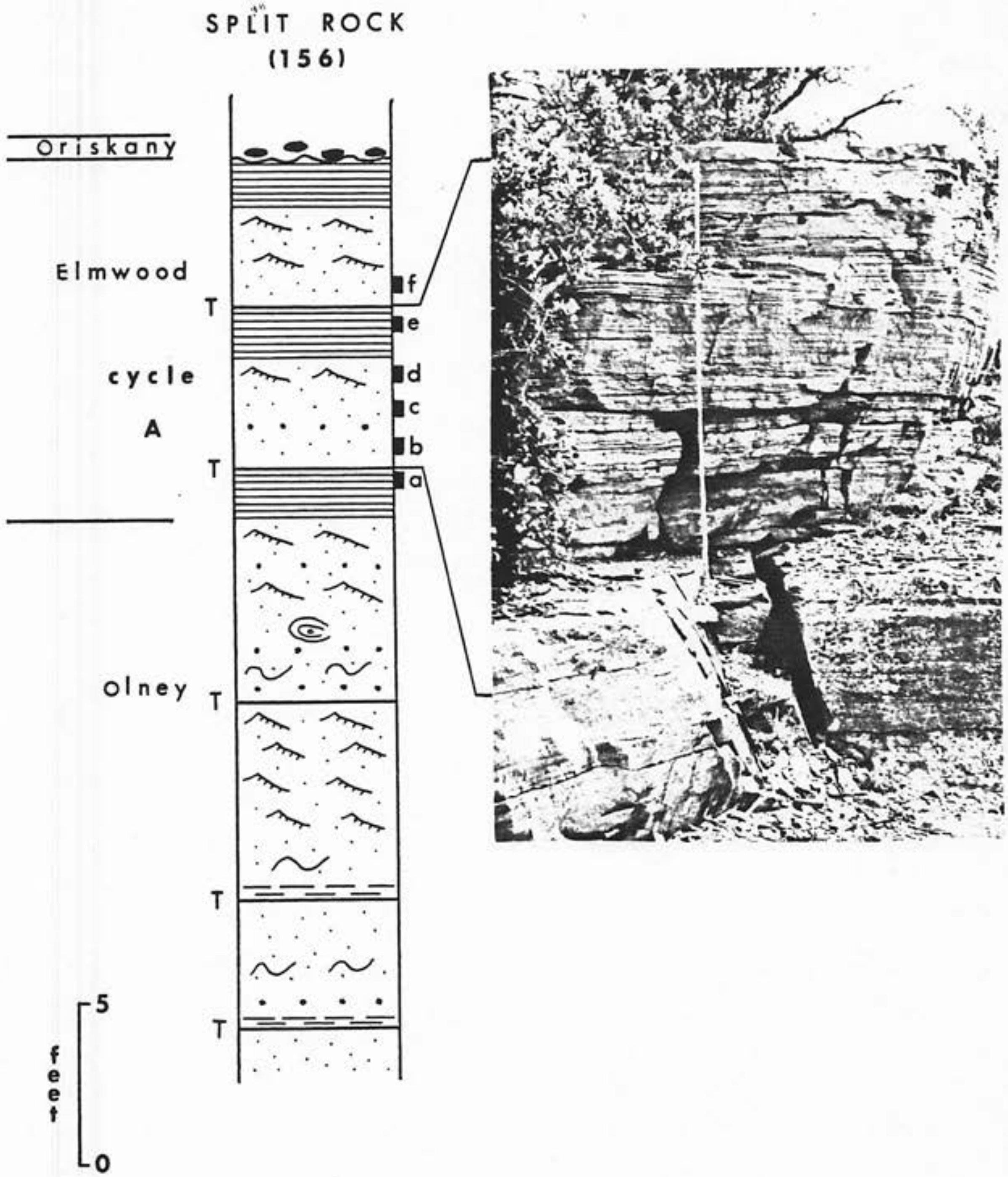


Figure 8 - Cyclic stratigraphic section at Split Rock quarry. Letters at column right refer to photographs in Fig. 9A to 9F.

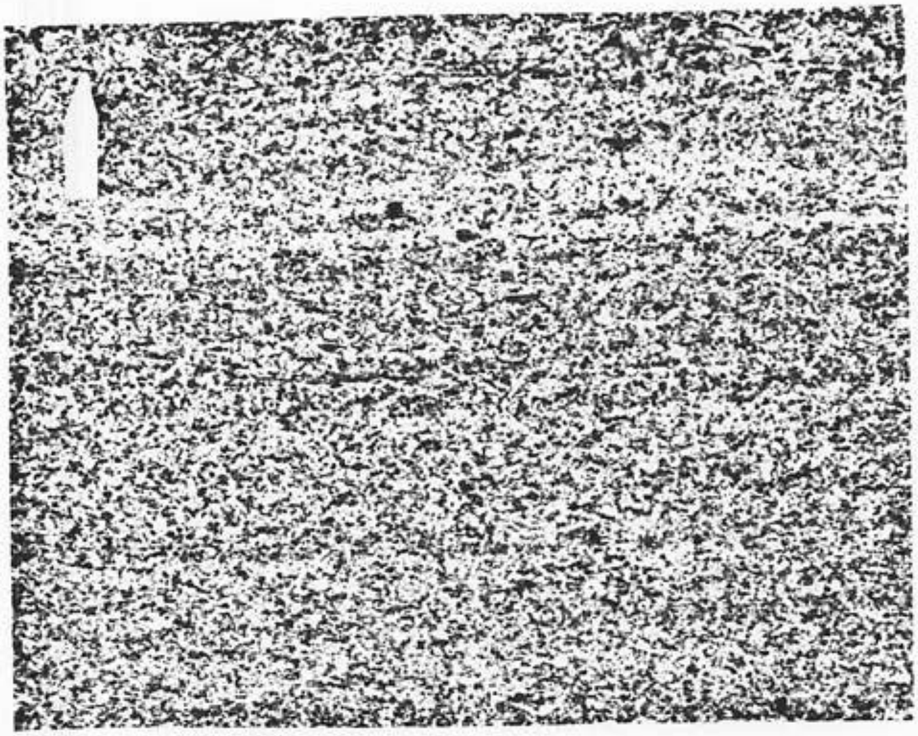


Figure 9-A. Top of underlying cycle.

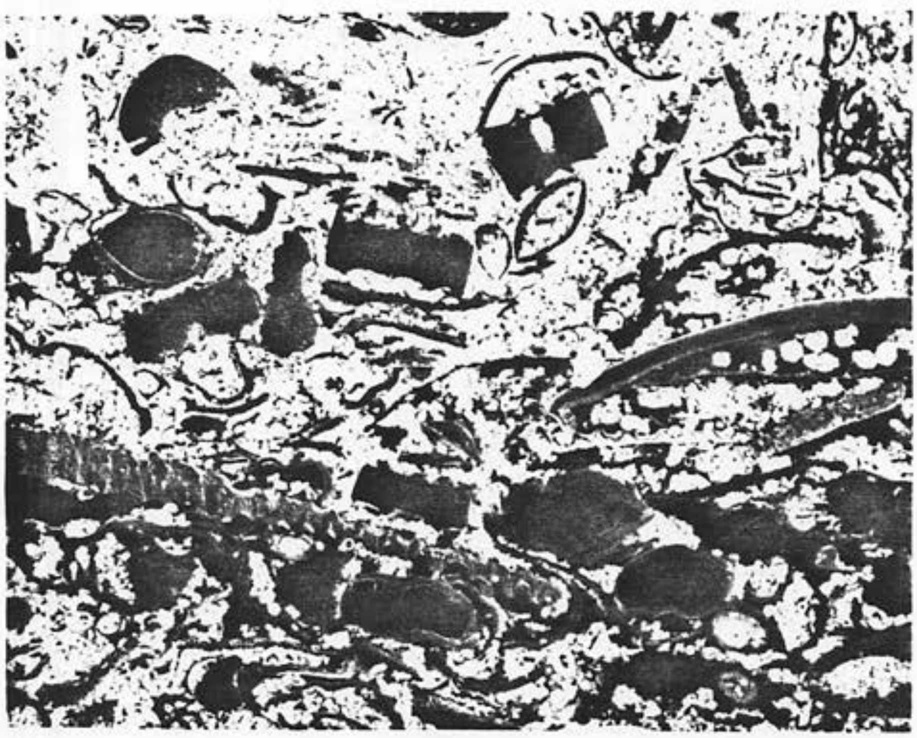


Figure 9-B. Base of Cycle A.

Figure 9 - Photonegative prints surrounding and within Cycle A. Arrow = 1.0 mm. in length.

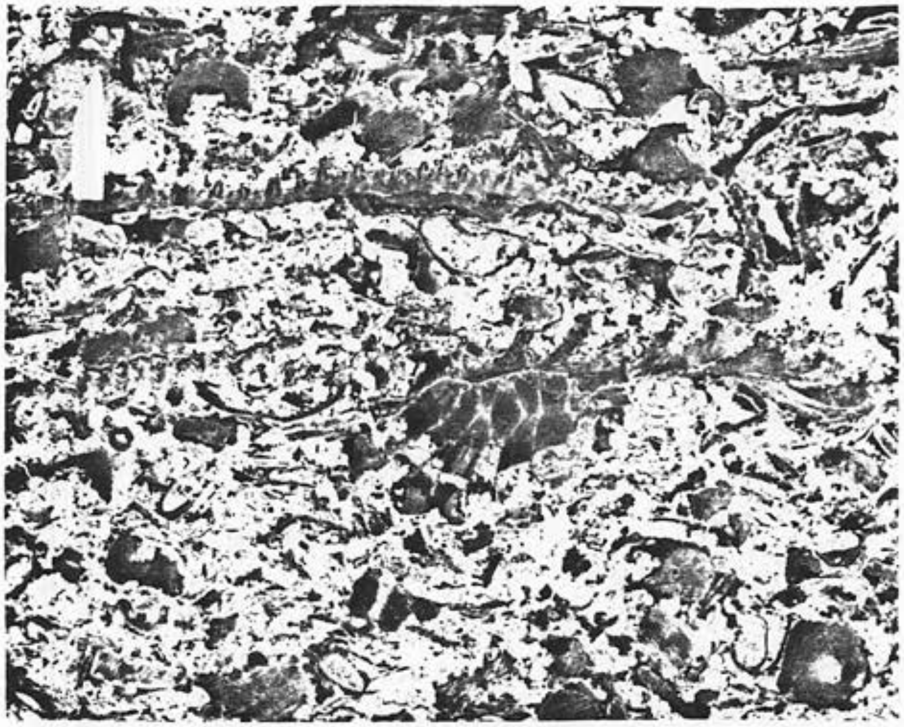


Figure 9-C. Lower middle of Cycle A.

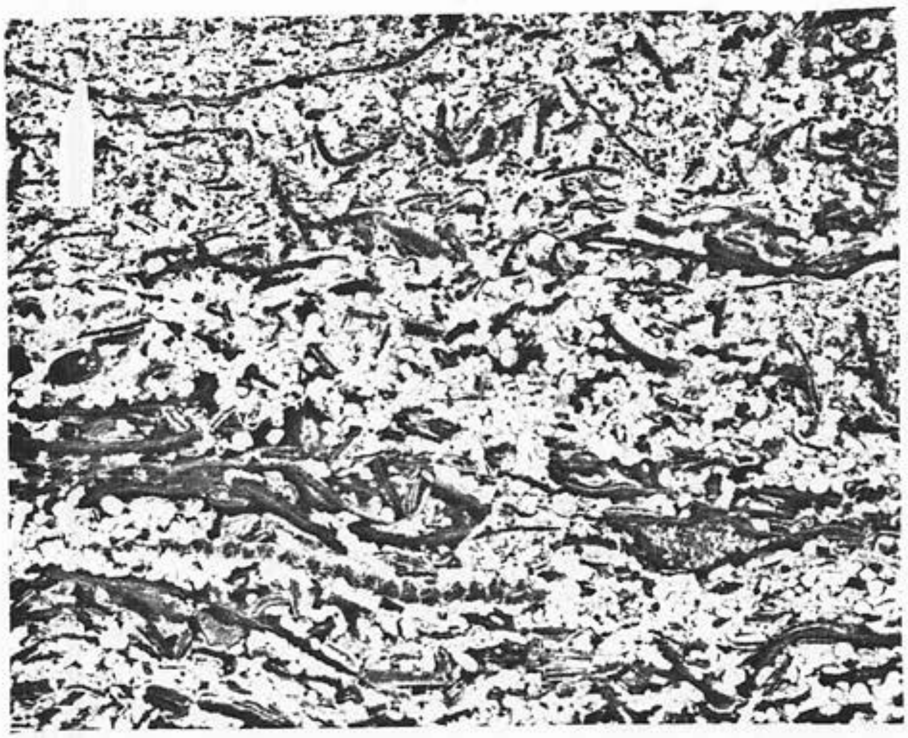


Figure 9-D. Upper middle of Cycle A.

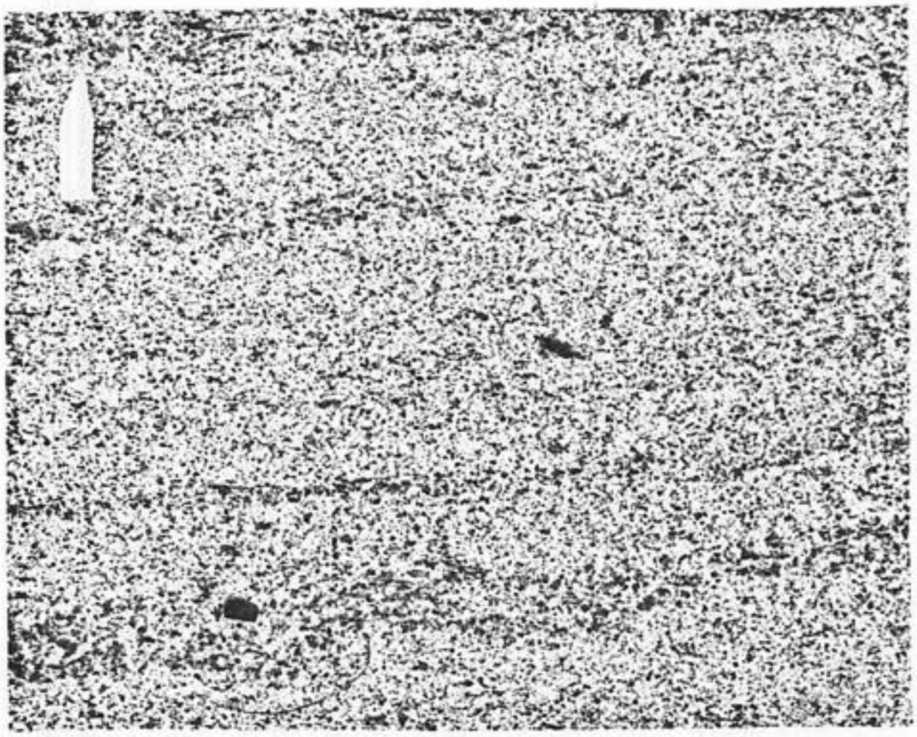


Figure 9-E. Top of Cycle A.

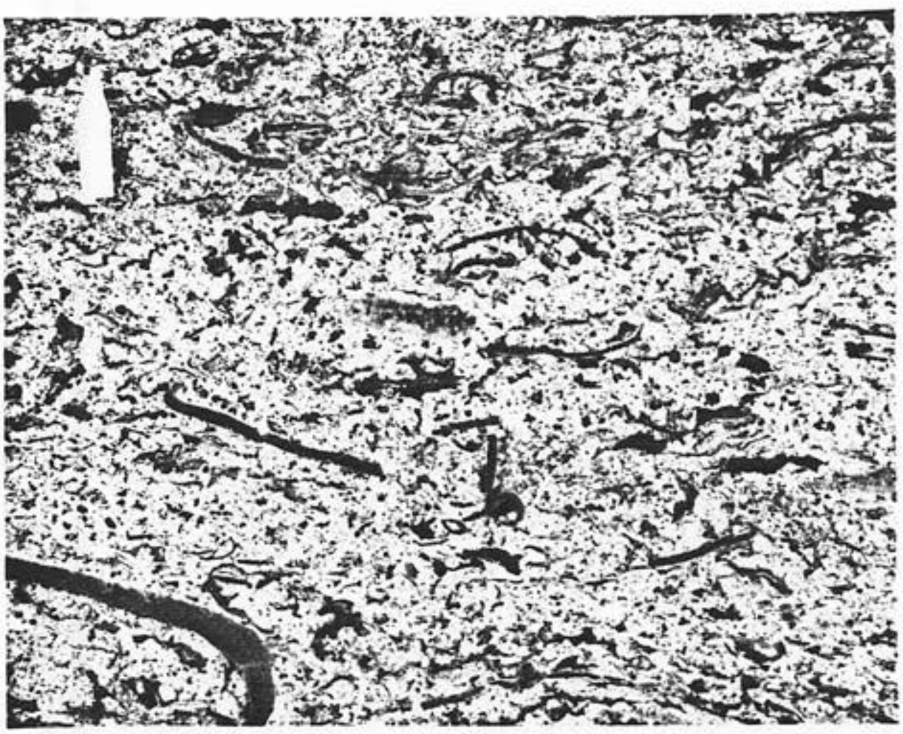


Figure 9-F. Base of overlying cycle.

The cycle ends at a sharp contact. Above this contact the basal deposits of the overlying cycle consist of fossiliferous pelletal micrites and calcisiltites (Fig. 9-F) similar to the subtidal lithologies of the cycle just described (Figs. 9-B & 9-C).

An environmental interpretation of upward-shallowing subtidal to lower supratidal deposits is attributed to Cycle A. Subtidal lithologies are recognized in Figs. 9-B & C by fossiliferous fine calcarenites. The intimately mixed very thin layers of both pelletal micrite and biosparite testify to the variable hydrologic conditions in this environment. Some of these lithologic and faunal characteristics can be seen in all of the subtidal portions of the ancient cycles previously described (Fig. 6). The intertidal environment is recognized in Fig. 9-D. Current activity, compared to the underlying lithologies, has been substantially diminished until only the finer calcisiltites and fossil fragments remain. Persistent tidal-exchange currents are believed to be responsible for deposition of this facies. A lower supratidal interpretation is attributed to the lithology at the cycle top (Fig. 9-E) largely for its resemblance to the Baumann Fiord lower supratidal lithology. However, Park (1977) has shown that Recent algal laminites are well-preserved when decomposition by bacterial action is limited by continued wetting in the intertidal zone. Prolongued periods of subaerial exposure on the supratidal flat leads to poor preservation of algal laminae and increased occurrences of dessication features in ancient rocks.

As seen in Cycle A, the transition from intertidal to supratidal deposits within a single cycle is often gradational in the Olney-Elmwood interval. Although no one set of criteria is uniformly applicable to the resolution of this problem, Park's (1977) recognition of poorly-preserved cryptalgal laminites occupying a supratidal position is a key often relied upon in the analysis of the Olney and Elmwood cycles. Since this lithology commonly overlies fine current laminites, it appears to be the best known criterion for establishing an intertidal/supratidal boundary.

As previously illustrated Split Rock quarry possesses one of the most western exposures of Elmwood rocks in New York state, presumably very near the Helderberg basin margin (see Fig. 3). And yet, the diverse fauna reported here suggests a relatively open environmental position. Indeed, when compared with the five succeeding examples, Cycle A contains one of the most diverse fossil assemblages encountered. This diversity is explained by its stratigraphic position (see Fig. 7). Cycle A, which is the stratigraphically lowest cycle selected for study, was deposited when the Helderberg basin was more open than later in Elmwood time.

Perryville (Cycles B & C)

At Worlock Quarry, Perryville two cycles (Cycles B & C) have been selected as variations on a similar theme (Fig. 10). The fifth cycle down from the Clark Reservation Member is representative of an upward-shallowing Olney tidal-flat cycle containing stromatoporoids in the lower portion. The basal deposits of this cycle (Cycle B) occur immediately above crenulated, dolomitic cryptalgal laminites (Fig. 11-A). These lower deposits are dominated by stromatoporoid pelmicrites and calcisiltites with ostracode, brachiopod, trilobite, and dasycladacean algae fragments (Fig. 11-B). Above these a return to crenulated, dolomitic cryptalgal laminites (Fig. 11-C) completes the cycle. Immediately overlying the sharp contact marking the upper limit of Cycle B, the basal deposits of the succeeding cycle consist of stromatoporoid-rich biosparites with fragmented crinoid stems and brachiopods (Fig. 11-D).

Cycle C is in many ways similar to Cycle B just described with the lowermost deposits of Cycle C again occurring above dessicated, dolomitic cryptalgal laminites (Fig. 12-A). These lowermost deposits closely resemble the lower deposits of Cycle B with pelmicrites and calcisiltites containing stromatoporoid, trilobite, brachiopod, and ostracode fragments (Fig. 12-B). These are overlain by dolomitic cryptalgal laminites (Fig. 12-C). Unlike Cycle B, however, the uppermost lithology of this cycle consists of thin-bedded, dolomitic fine calcarenites with 1-3 mm. opaque and non-opaque intraclasts and 0.10-0.25 mm. oolites

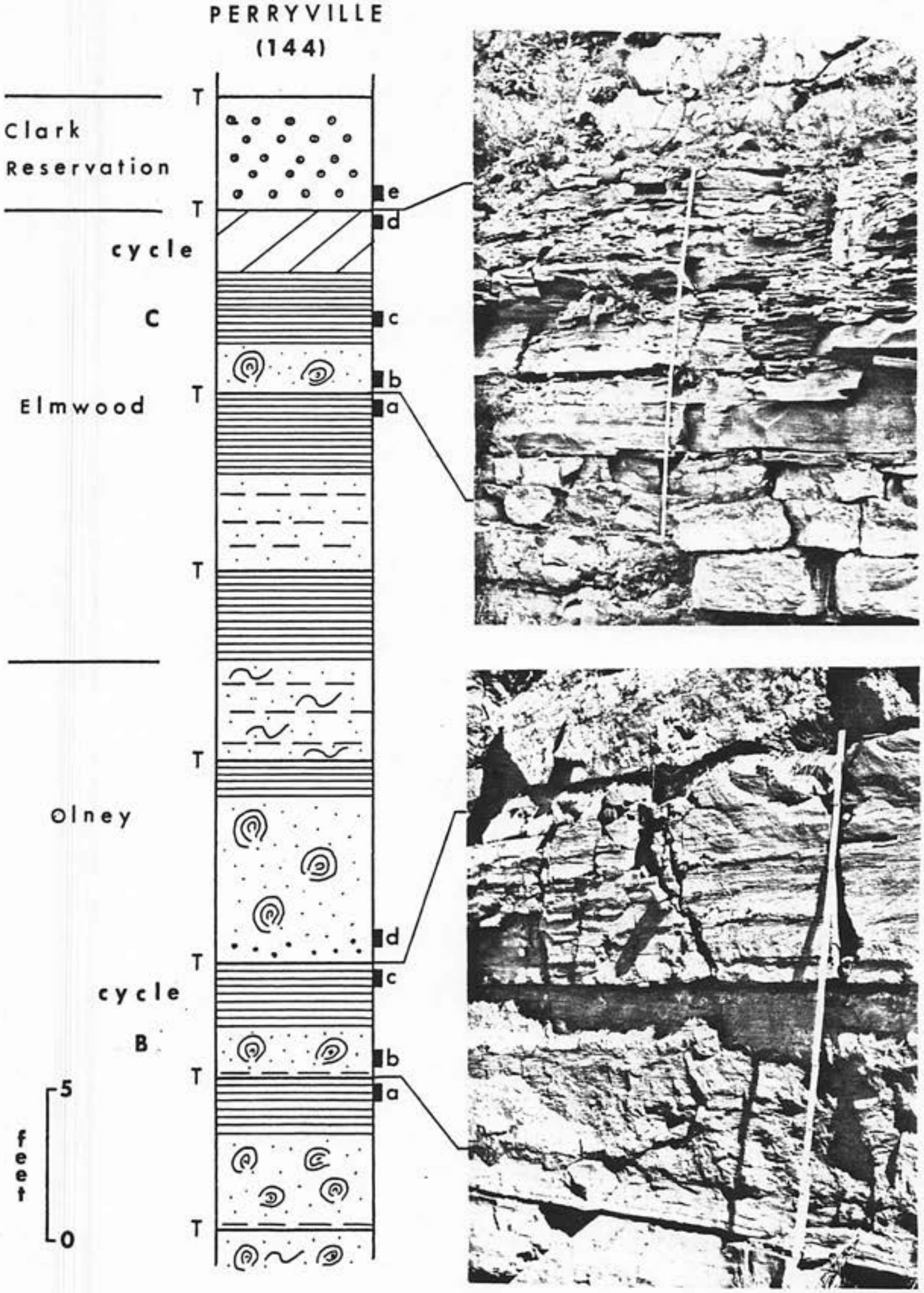


Figure 10 - Cyclic stratigraphic section at Worlock Quarry. Letters refer to Figs. 11A to 11D and 12A to 12E.

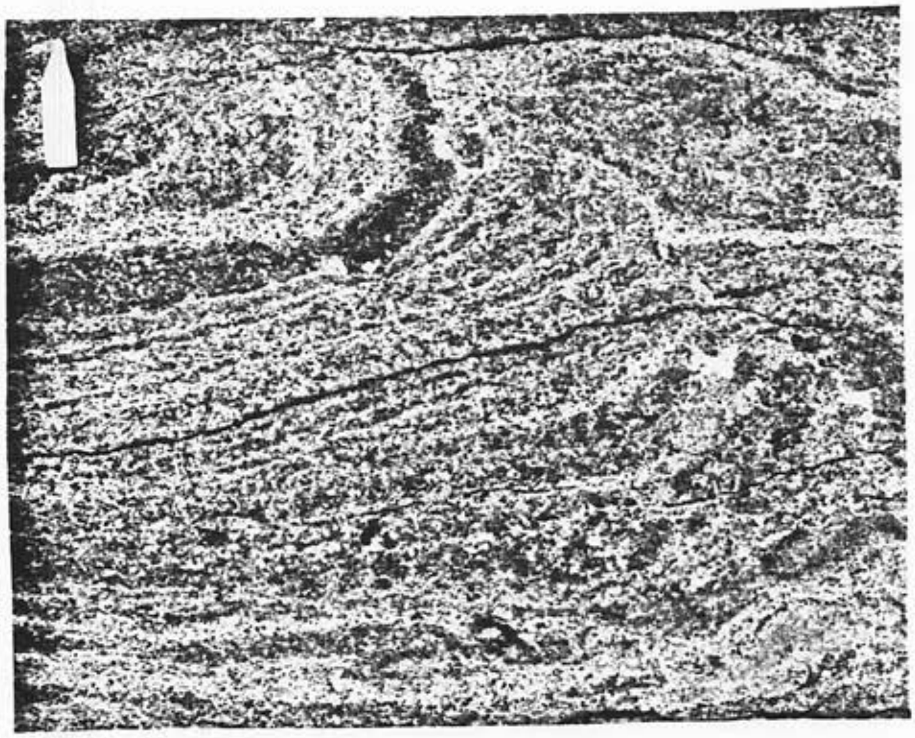


Figure 11-A. Top of underlying cycle.

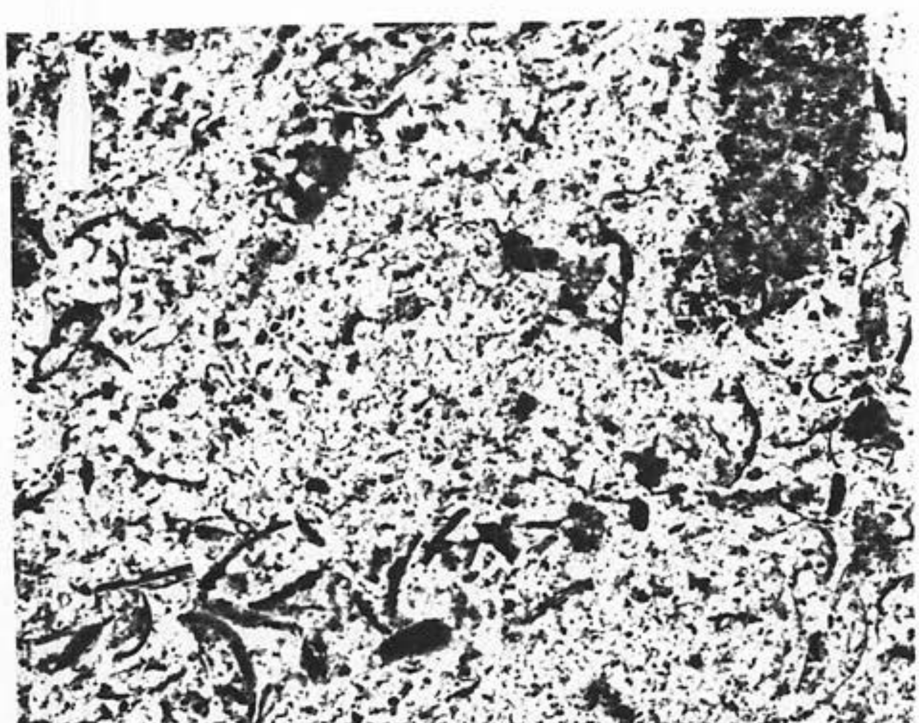


Figure 11-B. Base of Cycle B.

Figure 11 - Photonegative prints surrounding and within Cycle B. Arrow = 1.0 mm. in length.

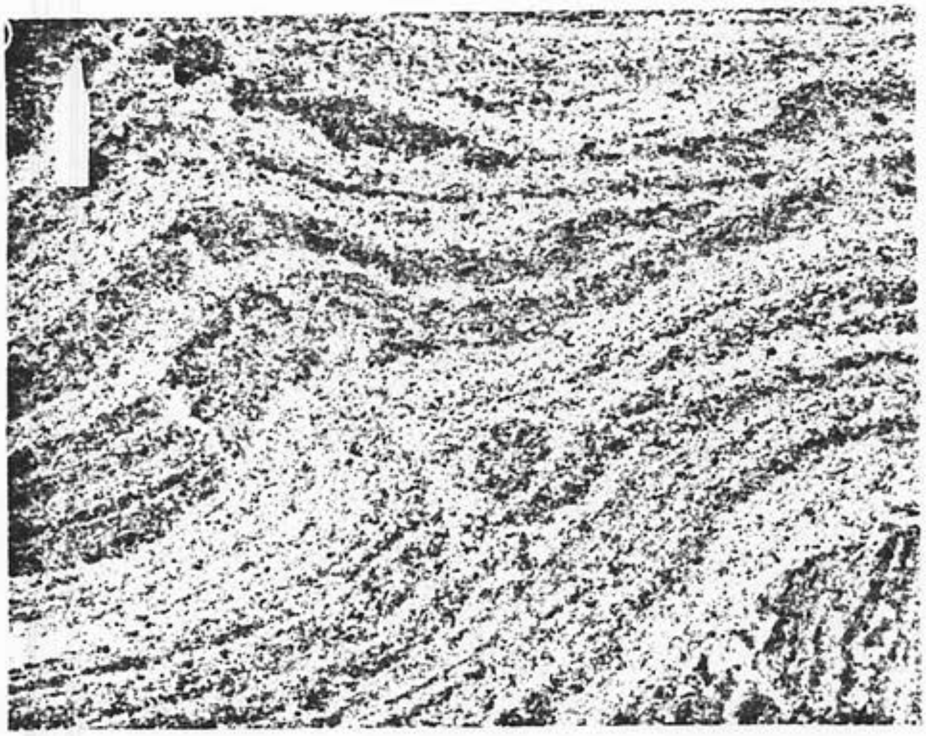


Figure 11-C. Top of Cycle B.

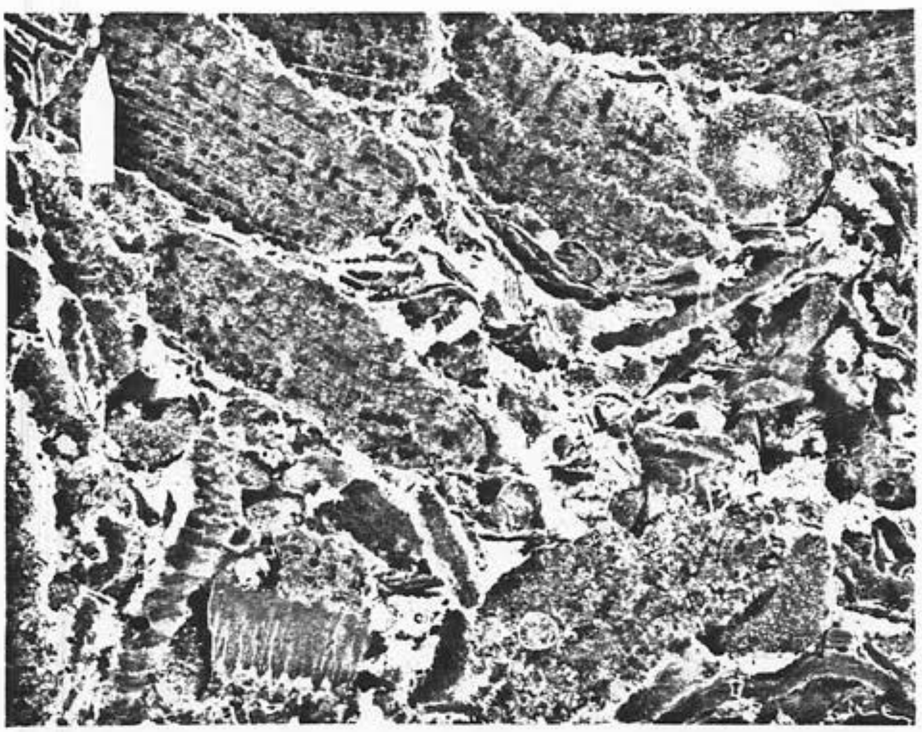


Figure 11-D. Base of overlying cycle.

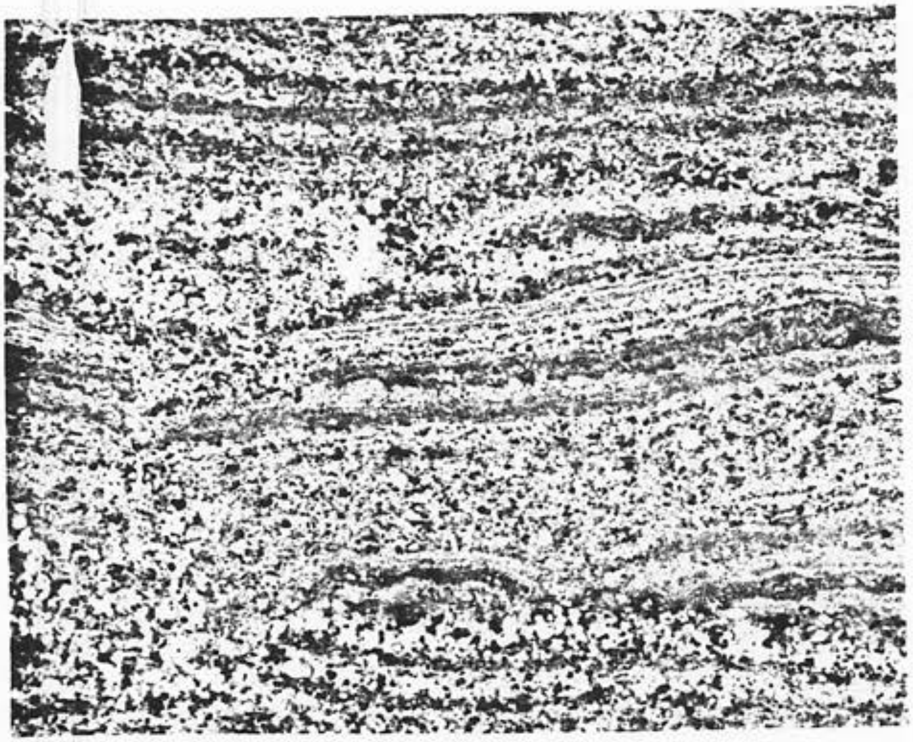


Figure 12-A. Top of underlying cycle.

Figure 12-B. Base of Cycle C.

Figure 12 - Photonegative prints surrounding and within Cycle C. Arrow = 1.0 mm. in length.

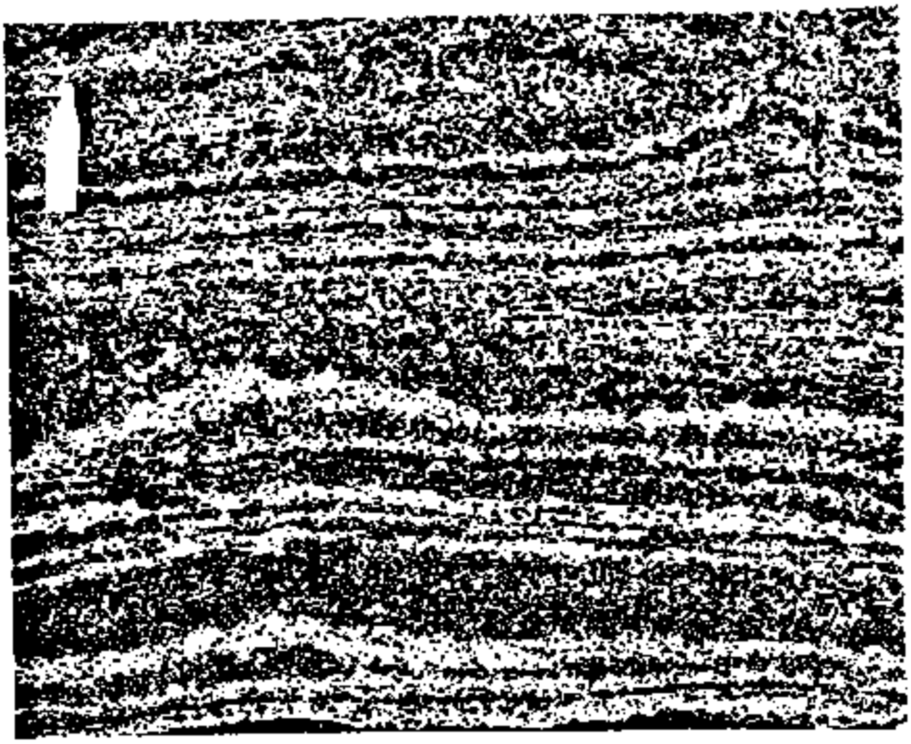


Figure 12-C. Middle of Cycle C.

Figure 12-D. Top of Cycle C.

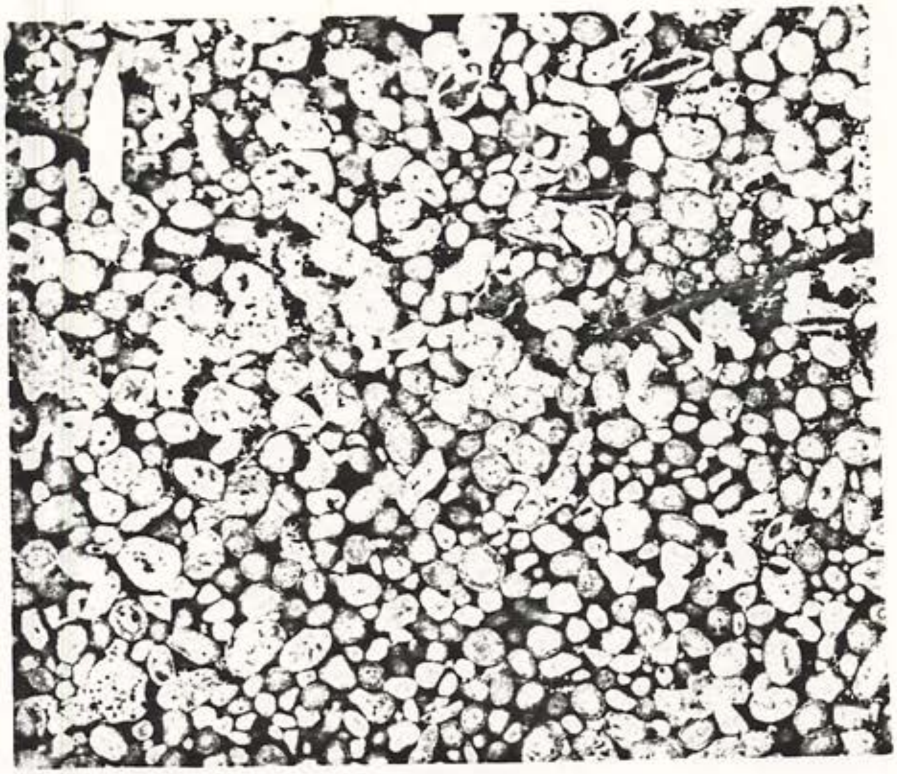


Figure 12-E. Base of overlying cycle in Clark Reservation Member.