TIDAL CURRENTS, BIOGENIC ACTIVITY AND PYCNOCLINAL FLUCTUATION ON A LOWER DEVONIAN RAMP: BECRAFT, ALSEN, AND PORT EWEN FORMATIONS, CENTRAL HUDSON VALLEY

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INTRODUCTION

The Helderberg Group (Lower Devonian) of New York State includes eight thin, but extensive formations that comprise two transgressive cycles separated by a minor regression (Rickard, 1962; Head, 1969; Laporte, 1969; Ebert, 1982, 1983). The lower cycle exhibits the classic deepening upward sequence of formations: Rondout, Manlius, Coeymans, Kalkberg, New Scotland (Table 1; Rickard, 1962; Laporte, 1967, 1969) that has been widely cited as an example of epeiric sea (ramp) sedimentation. The regression is recorded by an upper tongue of the Kalkberg Formation and the lower portion of the Becraft Formation (Head, 1969; Arif, 1973; Ebert, 1982, 1983). The upper transgressive cycle is comprised of the Becraft, Alsen and Port Ewen formations and has been assumed to represent a repetition of Coeymans, Kalkberg and New Scotland lithologies and environments (Rickard, 1962; Laporte, 1967). Gross similarity in outcrop appearance had been the only basis for this assumption. Recent descriptions of the upper cycle (Ebert, 1982, 1983, 1985, 1986; Mazzo, 1981, Mazzo and LaFleur, 1984) have indicated significant departures from the characteristics of the lower formations. Comparison of upper and lower cycles (Ebert, 1982, 1983, 1985) has resulted in improved understanding of the processes that operated on the Helderberg ramp.

Tidal sand waves are recognized in the Becraft Formation. This formation and other skeletal grainstone units have previously been interpreted as shoal deposits that accumulated above wave base. The predominance of wave action has always been assumed in these interpretations; however, analysis of sedimentary structures clearly indicates the dominance of tidal currents.

Tidal sand waves occur in a variety of modern environments, from estuarine channels to the open shelf. The simplistic, and possibly erroneous, interpretation of wave dominance in many coarse carbonates probably has led to inaccurate reconstructions

SYSTEM	SERIES	STAGE	GROUP	FORMATION	MEMBER
LOWER DEVONIAN	ULSTERIAN	SAWKILL	TRISTATES	BOIS BLANC/SCHOHARIE	
				CARLISLE CENTER	
				ESOPUS	
		DEERPARK		ORISKANY/CONNELLY/ GLENERIE	
				PORT JERVIS	
		HELDERBERGIAN	HELDERBERG	PORT EWEN	
				ALSEN	
				BECRAFT	
				KALKBERG/NEW SCOTLAND	
				KALKBERG	
				COEYMANS	DEANSBORO
					DAYVILLE/RAVENA
				MANLIUS	JAMESVILLE
					CLARK RESERVATION
					ELMWOOD
					OLNEY
					THACHER
				RONDOUT	CHRYSLER/WHITEPORT
U.SIL.		CAYUGAN	SALINA		CHRYSLER
					AKRON/COBLESKILL
				BERTIE, CAMILLUS, SYRACUSE and VERNON	

TABLE 1

Lower Devonian Stratigraphy of New York state. After Rickard (1975).

of environments and paleogeography, especially when adjacent facies are poorly exposed.

The occurrence of tidal sand waves in a sequence that has been interpreted as representing sedimentation in an epeiric sea (Laporte, 1969) raises important questions about the processes that operate in such seas. Traditional epeiric sea models (Shaw, 1964; Irwin, 1965; Ahr, 1973) have treated these seas as being tideless (Hallam, 1981). These models regard the position of wave base as the primary factor governing the distribution of facies. Tides are considered to be absent or of negligible effect.

Significant tidal exchange in epeiric seas has been disregarded because of the supposed frictional difficulty of moving the tidal prism across such wide, shallow shelves (Shaw, 1964; Irwin, 1965; Mazzullo and Friedman, 1975; Hallam, 1981). Despite this bias, a tidal origin has been demonstrated for many quartz arenites from epeiric sea settings (e.g. Klein, 1970, 1971, 1975, 1977; Thompson, 1975; Johnson, 1975; Swett, Klein and Smit, 1971; Chafetz, 1977; Barwis and Makurath, 1978; Recently, Slingerland (1986) has developed a numerical model that supports the hypothesis (Klein, 1977; Klein and Ryer, 1978) that some epeiric seas could have been tide-dominated. This model for the Upper Devonian Catskill epeiric sea includes the geographic area of the present study. Tidal sand waves of the Becraft Formation and the model of Slingerland suggest that, at least, the shallow portions of the northern Appalachian Basin may have been tidally dominated throughout the Devonian. It should be pointed out, however, that deeper portions of the basin, especially during the Middle Devonian, were storm-dominated (for examples, see Brett, 1986).

Biogenic processes played an important role in the Helderberg sea, as well. The Alsen Formation displays a predominance of biogenically-disrupted fabrics, although remnants of physical structures are also preserved. The overlying Port Ewen Formation also shows evidence of the importance of biogenic activity. A variety of ichnofossils are present in this unit. These traces provide a detailed record of subtle changes in water oxygenation on the deeper portions of the Helderberg ramp. Of particular interest are the cyclic variations in the distribution of Zoophycos, Chondrites and Helminthoida and associated lithologies. These cycles record fluctuations in the position of the pycnocline and its intersection with the sediment-water interface. These fluctuations occurred in response to regional transgression and record the shoreward shift in the location of the pycnoclinal intersection. Both symmetric and asymmetric cycles are recorded. Although PAC-like in scale, these cycles do not seem to fit the PAC motif of shallowing upward. Deepening upward and shallowing followed by deepening seem to be the more typical pattern for these cycles.

PREVIOUS WORK

New York's Helderberg carbonates have been studied since the 1840's; however, few of these works have been sedimentologic in nature. The vast majority of early research was concerned with paleontology and biostratigraphy. Research prior to 1962 has been succinctly summarized by Rickard (1962).

The detailed stratigraphic analysis of Rickard (1962) has provided an excellent standard for evaluation of earlier paleontologic and biostratigraphic efforts. It has also served as the framework upon which all subsequent work is based. Outcrop designations in this report follow Rickard (Fig. 1; e.g. R-44 = Rickard's section 44). Most subsequent study of the Helderberg Group has concentrated upon the lower formations. Significant contributions include Laporte (1967, 1969); Anderson (1967, 1971, 1972, 1974), Head, Harper, Laporte and Andersen (1969), Belak (1978, 1980) and Epstein (1968, 1969, 1971). Numerous detailed stratigraphic studies have also been undertaken by E. J. Anderson and P. W. Goodwin and their students in the development and testing of the hypothesis of Punctuated Aggradational Cycles (PACs).

Paleogeographic reconstructions of the northern Appalachian Basin during Helderberg time (Laporte, 1967; Head, 1969, 1974) show the bathymetric axis of the basin trending northeast-southwest and intersecting the New York outcrop belt in the vicinity of Kingston (Rickard's section 24 and STOP 3 of this trip). These maps also demonstrate the near coincidence of Lower Devonian depositional strike and the trend of the modern outcrop belt through most of New York State.

Upper Helderberg units have received considerably less attention. A cursory account of the Becraft Formation is included in Anderson (1972). Arif (1973) studied Becraft petrology. Mazzo (1981) and Mazzo and LaFleur (1984) described lithologies and cyclicity in the Port Ewen Formation. Ebert (1983) is the only comprehensive treatment of the upper units.

Description of the sedimentology of the upper units with a revised model for epeiric sea sedimentation and a slightly revised stratigraphy are included in Ebert (1983). Significant aspects of the revised stratigraphy include: 1) recognition of the upper tongue of the Kalkberg Formation between the New Scotland and Becraft Formations in the Hudson Valley, 2) demonstration of partial temporal equivalence of the Kalkberg and lower Becraft Formation in the east-west portion of the outcrop belt, 3) demonstration of stratigraphic convergence of the Becraft Formation with lower units toward the western end of the Becraft outcrop belt, 4) recognition of four distinctive subfacies within the Becraft Formation, 5) amplification upon earlier correlations of the Minisink Formation of eastern Pennsylvania, and 6) description of a clear exposure of the Port Ewen-Glenerie contact at Bloomington, New York. This work is summarized in Ebert (1982, 1985) and details of Becraft sedi-

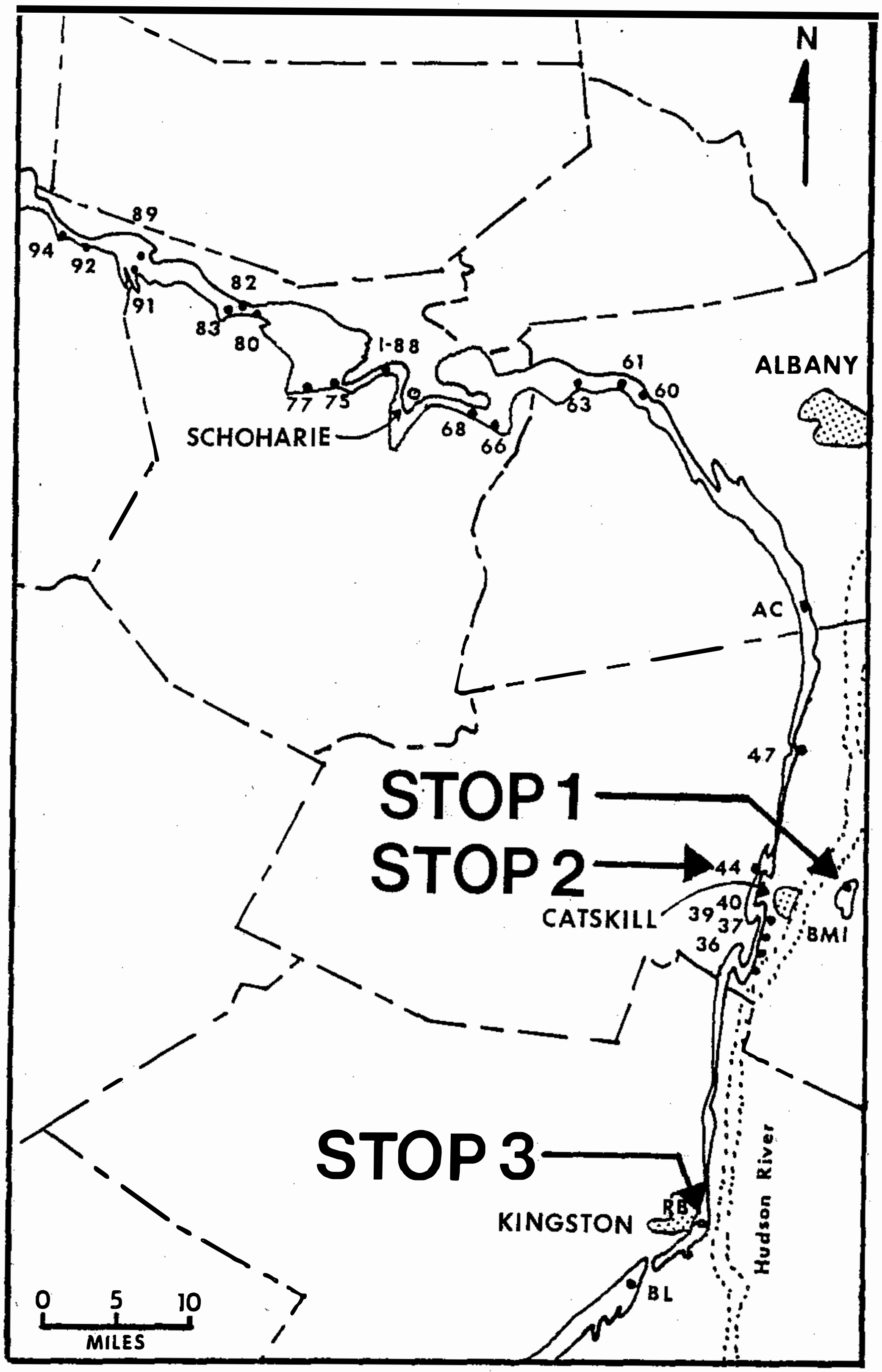

FIGURE 1. - Portion of Helderberg outcrop belt in eastern New York and location of stops. Upper Helderberg formations occur from R-92(?) through Section BL (Bloomington). I-88 = roadcut on interstate, AC = Atlantic Cement quarry at Ravena, BMI = Becraft Mountain Independent Cement quarry, RB = Rhinecliff Bridge, Rt. 199 roadcut. Modified from Rickard (1962).

mentology are presented in Ebert (1986). This paper illustrates some of the major aspects of the sedimentology of the upper Helderberg Formations.

BECRAFT FORMATION

Sand waves are common bedforms in modern, siliciclastic, estuarine and shelf-sea environments. In recent years, sand waves have been widely documented in ancient siliciclastic rocks (e.g. Allen and Narayan, 1964; DeRaaf and Boersma, 1971; Narayan, 1971; Pryor and Amarel, 1971; Johnson, 1975; Anderton, 1976; Nio, 1976; Button and Vos, 1977; Hobday and Tankard, 1978; Lovell, 1980; Visser, 1980; Allen, 1981a, b, 1982; Homewood and Allen, 1981; Allen and Homewood, 1984; Kreisa and Moiola, 1986). These sandstone examples commonly display meter-scale or larger cross-bedding that is arranged in sigmoidal tidal bundles (Boersma and Terwindt, 1981) as defined by silt or mud drapes. Erosional reactivation surfaces and ripples or small scale (<0.04m) cross-stratification produced by the subordinate flow are also common features. Paleocurrents tend to be nearly unidirectional, which Allen (1980) attributes to strong tidal asymmetry.

Tidal sand waves are also common bedforms in modern carbonate environments, especially in oolitic facies and one would suspect that they should be common in ancient carbonates, as well. Tidal sand waves have only recently been reported from ancient carbonate rocks (Ebert, 1983, 1986; DeMicco, 1986). This field trip will examine features of tidal sand waves from a skeletal limestone, the Becraft Formation. The interpretation of this unit as a complex of sand waves is based upon an assemblage of sedimentary structures that is similar to those reported from modern oolitic sand waves (Hine, 1977) and similar to the theoretical suite of structures modelled by Allen (1980). Many structures reported from siliciclastic rocks are present as well. The suite of structures described implies a greater degree of tidal symmetry for these carbonate sand waves than is typically indicated in the siliciclastic examples cited above.

Internal stratigraphy of the Becraft Formation

Four distinct subfacies are recognized within the skeletal grainstones of the Becraft Formation (Fig. 2; Ebert, 1983). Subfacies 1 and 2 comprise the tidal sand waves that will be examined on this trip. Subfacies 1 makes up the lower half of the formation in the central Hudson Valley and is absent west of Ravena, N.Y. as a result of thinning and facies change. Thickness ranges from 0 to 7.5 meters (24.6 feet). This unit was originally recognized by Rickard (1962) and used by Arif (1973).

Subfacies 2 is present throughout the outcrop belt of the Becraft. This subfacies thins from 9.2 meters (30.2 feet) in the Hudson Valley (sections R-44, R-47) to disappearance just east of Cherry Valley (R-94) via truncation along the pre-Oriskany disconformity. Rickard and Arif also noted the occurrence of this unit. Subfacies 1 and 2 will be examined at several stops on this field trip.

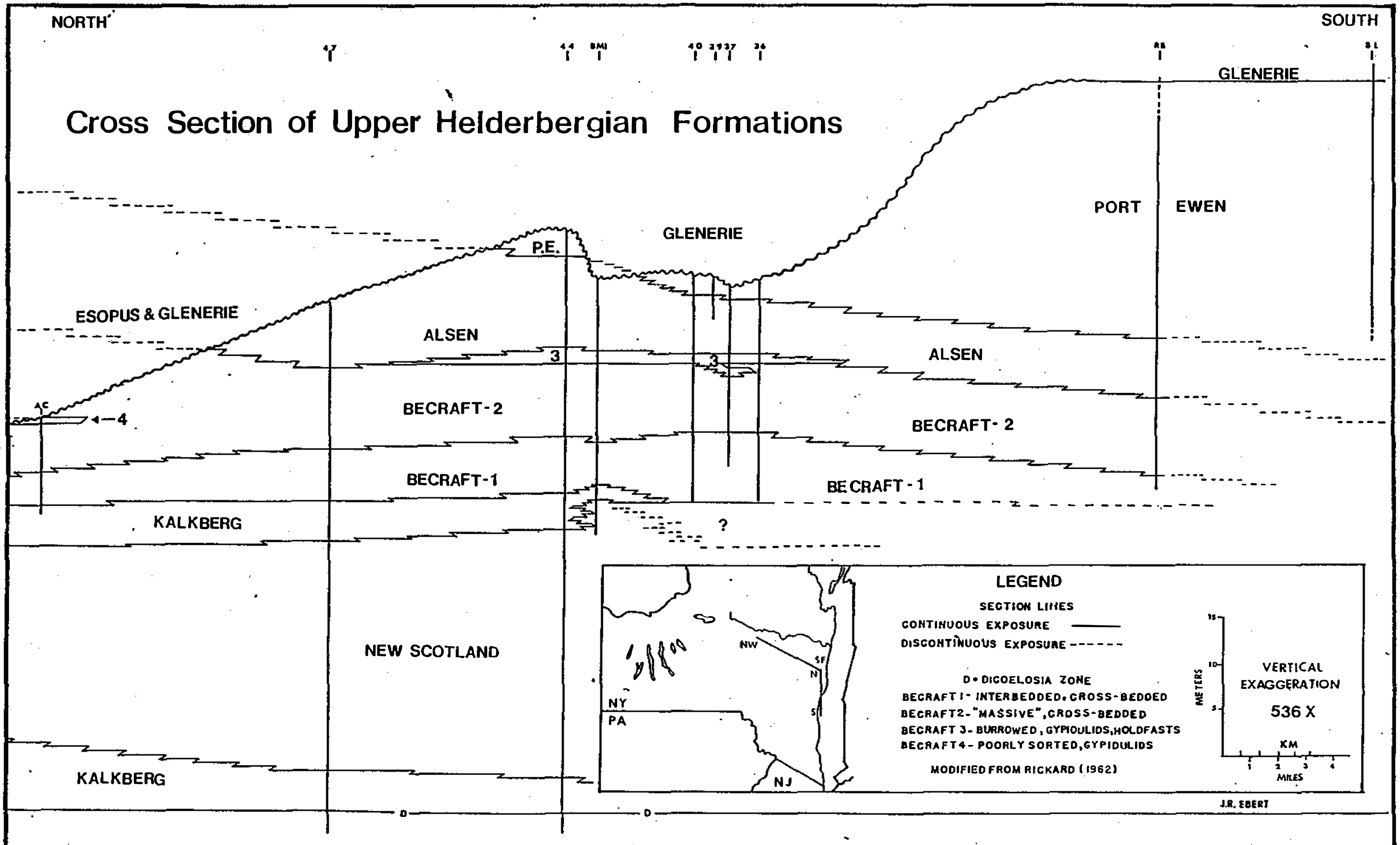

FIGURE 2. - Cross section of upper Helderberg formations and subfacies in the central Hudson Valley. Modified from Rickard (1962) and Ebert (1983).

Subfacies 3 and 4 are thin (<1.6m, 5.2 ft.) and more limited in distribution than subfacies 1 and 2. Subfacies 3 occurs at the top of the formation in the central Hudson Valley only between Catskill Creek and Cementon (Fig. 2) and will be seen at stops 1 and 2. It is comprised of well-sorted, subrounded, medium-to-coarse skeletal grainstone (crinoidal debris - 34%, brachiopod values - 23%, bryozoans - 16%, micritized grains - 16%). This unit is readily recognized by an abundance of disarticulated valves of the pentamerid brachiopod Gypidula pseudogaleata and root-like holdfasts of the crinoid Clonocrinus(?). Planar erosional surfaces separate beds that show few physical sedimentary structures. Asymmetrical ripples and herringbone cross-lamination are present, but are not common. Bioturbate fabrics predominate. Subfacies 3 represents inactive sand waves that were transitional between the active sand waves of subfacies 1 and 2 and the open shelf (Alsen Formation).

Subfacies 4 overlies and interfingers with subfacies 2 at sections I-88, R-66 and AC and is not present in the field trip area. Subfacies 4 of the Becraft has been regarded in the past as Port Ewen (see references in Rickard, 1962, p. 91) and outliers of the Alsen Formation (Rickard, 1962, 1975). Textural and faunal criteria indicate strong similarity to the Becraft and marked differences from the Alsen and should, therefore, be regarded as a subdivision of the Becraft (Ebert, 1983). This unit consists of very poorly-sorted, cross-bedded crinoidal grainstones interbedded with bioturbated skeletal packstones. Gypidula is again abundant. Peloids are common and rare ooids are present. Subfacies 4 occupies a more shoreward position and is interpreted as lagoonal sediments (packstones) interbedded with washovers (grainstones) derived from the sand waves of subfacies 2.

SEDIMENTOLOGY OF BECRAFT SAND WAVES

SUBFACIES 1 AND 2

Becraft sand waves are recorded by two distinctive subfacies (1 and 2) of skeletal grainstone. Both subfacies record nearly symmetrical tidal regimes; however, slight variations in tidal dominance and symmetry occur between subfacies. Most exposures of these subfacies are essentially two-dimentional; so detailed study of paleocurrents was not possible. Estimations of tidal directions, dominance and symmetry are based upon apparent dip data from these two-dimensional exposures and are regarded as representing general trends.

Both subfacies are subtidal in origin as suggested by the presence of a normal marine fauna (e.g. echinoderms, brachiopods, bryozoans and rare corals) and paired silt drapes, a sedimentologic criteria of subtidal deposition (Visser, 1980). Depositional and diagenetic features of intertidal or supratidal origin are absent from both subfacies.

Subfacies 1

The lower subfacies (1) is a heterolithic sequence comprising the following lithologies: a) very coarse, crinoid and brachiopod grainstones to rudstones, b) medium quartz siltstones to very fine sandstones, and c) fine peloidal grainstones. Crinoidal debris (35%), disarticulated brachiopod valves (25%), and bryozoan fragments (24%) are the major particles in grainstones and rudstones. The distinctive holdfast of <u>Aspidocrinus scuteliformis</u> is abundant and diagnostic of this unit at most locations. All grains are sub-angular and poorly to moderately sorted. Finer-grained lithologies display a complete range of compositions from nearly pure quartzose siltstones and very fine sandstones to nearly pure peloidal grainstones. Quartz grains are angular to sub-angular. Peloids are typically sub-spherical to slightly ovoid and average 0.001 m in diameter (very fine sand). These finer grains are typically moderately- to well-sorted.

Skeletal grainstones and rudstones occur as tabular beds, 0.05-0.35 m in thickness or as lenses defined by the finer-grained lithologies. Siltstones and peloidal grainstones occur as thin (0.005-0.05 m) interbeds that separate beds of skeletal grainstone or as sigmoidal drapes (Kreisa and Moiola, 1986) that define the forms of dunes in skeletal grainstones (Fig. 3). Preserved duneforms in this subfacies are typically 0.2-0.3 m in amplitude, with wavelengths of 1.3-3.0 m. Drapes commonly split into pairs along dune foresets. The lateral spacing of drapes in the downcurrent direction may define neap-spring tidal bundles (Fig. 3), however this is difficult to determine because of the limited width of most exposures.

Skeletal grainstones exhibit herringbone and unidirectional cross-bedding in decimenter scale cosets. A slight majority of the sets are generally oriented toward the southwest. Individual sets overlie planar or undulose erosional surfaces or thin interbeds of the finer-grained lithologies. Within cross-sets, single and paired drapes of the finer lithologies are common. These drapes define the duneforms described above.

Interbeds of siltstone and peloidal grainstone are commonly cross-laminated. Asymmetrical ripples are less commonly preserved. Ripples and/or cross-lamination that ascend foresets in grainstones have been noted; however, these structures are rare. These structures indicate apparent paleoflow that was opposite to that recorded by cross-bedding in underlying and overlying grainstones. Cross-laminations without reversal of paleoflow have also been observed. Some interbeds appear to be structureless or vaguely laminated.

Subfacies 1 represents slightly asymmetrical, subtidal sand waves. The tidal regime was slightly ebb-dominant, toward the southwest. Heterolithic bedding records unsteady flow and deposition from both bedload and suspension. Drapes were

FIGURE 3. - Sketch of duneform and silty/peloidal drapes and interbeds in Becraft subfacies 1 from field photograph, taken at R-44 (STOP 2). Paired drapes occur at A and B. Drapes are separated by thin lenses of skeletal grainstone that may represent ripples. Lateral spacing from A to B may define a neap-spring-neap tidal bundle. Note also ripples at the crest of the dune that indicate paleocurrent reversal. Scale bar = 0.1 meters.

deposited from suspension during slack water periods. Paired drapes record two slack water periods which can only occur in a completely subtidal setting (Visser, 1980). Ripples and cross-lamination in fine-grained lithologies indicate current reversal and reworking by the subordinate tide.

Subfacies 2

Very coarse skeletal grainstones and rudstones make up subfacies 2. The distinctive fine-grained drapes and interbeds of the subfacies 1 are absent from this unit. However, some fine quartz and peloids are present as geopetal sediment in shelter pores. Crinoidal debris (40%)and brachiopods valves (30%) are the dominant particles. Both are slightly more abundant than in subfacies 1. Bryozoan fragments are common (14%), but less abundant than in the lower unit. Skeletal grains are sub-angular to sub-rounded. Sorting is moderate to poor. Grainstones of subfacies 2 exhibit improved sorting and roundness relative to subfacies 1.

Grainstone beds of subfacies 2 range from 0.05 to 1.0 m in thickness, but are typically 0.2-0.4 m. These beds are generally tabular or broadly lenticular. Duneforms have been observed and one locality (I-88) displays a train of three slightly climbing forms (Fig. 4). At this location, lenticularity of bedding can be attributed to the geometry of whole or partly preserved duneforms.

Planar and trough cross sets are the dominant type of internal stratification in subfacies 2. Herringbone and unidirectional cosets are present, with herringbone cosets being slightly more common (Fig. 4). Slightly more than half of these sets are oriented toward the northeast. Sets are erosively based by generally planar to very broadly undulose surfaces. Within sets, numerous low-angle, erosional reactivation surfaces are apparent (Fig. 4).

Horizontal or very gently inclined (<5 degrees) planar stratification is common throughout subfacies 2, but is most common in the upper third of the unit. Sets of planar stratification are typically underlain and overlain by nearly flat erosional surfaces. These beds occur in stacks up to 0.1 m thick or as composite sets with cross-stratified cosets. Most planar-stratified beds show uniform distribution of grain sizes, but normal and inverse grading have also been observed. Interbedding of relatively finer grainstones and coarser rudstones is one of the most conspicuous features of this type of stratification. Finer grainstones may display vague cross-lamination(?) in these interbedded associations; however, structures are difficult to recognize owing to the coarseness of the skeletal grains.

Asymmetric ripples and obvious ripple cross-lamination are relatively rare in subfacies 2. Ripples occur as distinctive caps on the crests of duneforms at the roadcut on I-88 near

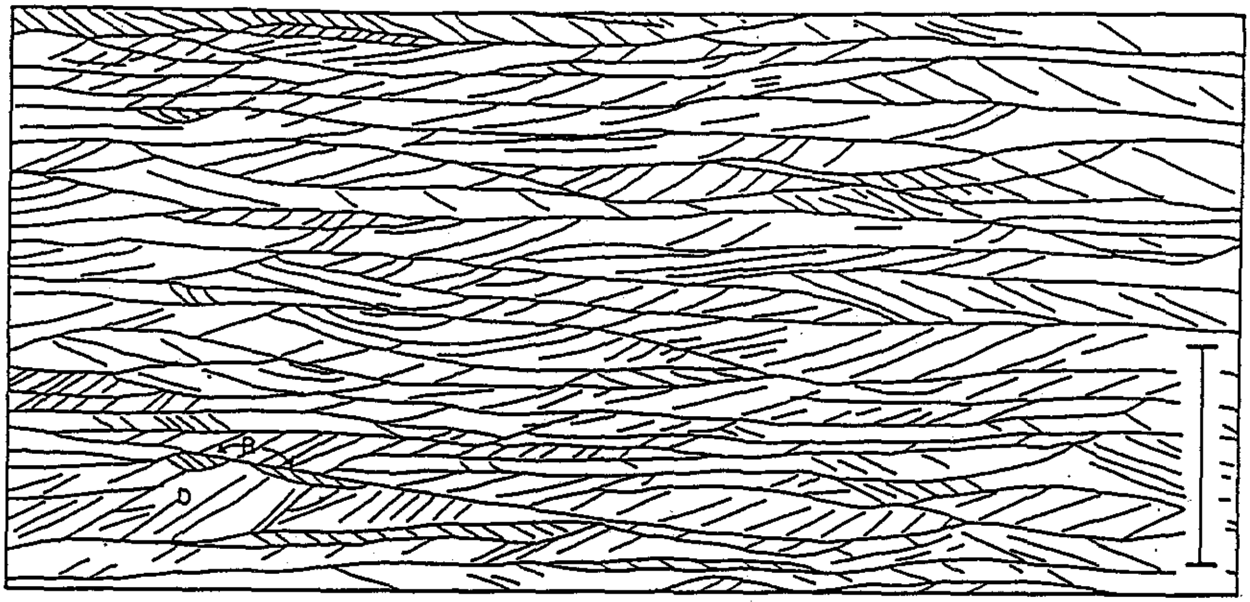

FIGURE 4. - Sketch of cross-stratification and bedforms in Becraft subfacies 2 from field photograph of weathered joint surface taken at the roadcut on I-88. Herringbone and unidirectional cosets are apparent, as are end-on views of troughs. Three, slightly climbing duneforms extend from D to the lower end of the scale bar. One duneform (D) exhibits several reactivation surfaces within its cross-stratification and a distinctive ripple cap (R). These features record a slightly subordinate, reversed tidal flow. A strikingly similar array of structures was modelled by Allen (1980) for nearly symmetrical and symmetrical sand waves. Scale bar = 0.5 meters.

Central Bridge (Fig. 4). Ripple caps exhibit opposed orientations to the paleoflow indicated by the underlying cross-stratification.

Biogenic structures are rare in subfacies 2. Minor biogenic disruption of fabric occurs near the top of the unit near the contact with subfacies 3 or the Alsen Formation.

Subfacies 2 records subtidal sand waves that were slightly flood-dominant toward the northeast and more symmetrical than the sand waves of subfacies 1. Herringbone cross-stratification indicates the near equality of flood and ebb tidal currents in this subfacies. Erosional reactivation surfaces and ripple caps record the reshaping of bedforms by opposed currents. Erosional reworking, rather than deposition of drapes, indicates the presence of a stronger subordinate tide and, therefore, increased tidal symmetry.

A strong subordinate flow is also indicated by the absence of the fine-grained drapes that were present in subfacies 1. The occurrence of fine internal sediment in shelter pores suggests that material capable of forming drapes was available during deposition of this subfacies. Fine sediment remained in suspension or was deposited and resuspended by the subordinate flow and was perhaps transported into adjacent deeper environments (e.g. Alsen Formation).

Coarse, planar-stratified grainstones and rudstones represent upper stage plane beds that formed during maximum velocity of the tidal flow. Interbedded finer grainstones may record flow reversal and/or accelerating and waning flow, especially if they are indeed cross-laminated. These planar- and cross-laminated(?) cosets are interpreted as vertically accreted tidal bundles (Kreisa and Moiola, 1986). Alternation of dominantly vertically accreted intervals with dominantly laterally accreted intervals may record neap-spring variations in tidal regime or variations in the rate of production of skeletal sediment relative to rates of reworking of this sediment by tidal currents.

ALSEN FORMATION

The Becraft Formation is overlain by the Alsen Formation (0-9.5m) in the central Hudson Valley. The Alsen thins to the north as a consequence of pre-Tristates beveling and is absent from Ravena westward. Skeletal grainstones and skeletal, peloidal grainstones are the dominant lithologies. Skeletal packstones with abundant peloids (average 11%) are locally common, especially at section RB (STOP 3). These packstones are typically more argillaceous than other lithologies. Particles are medium to coarse grained and moderately to poorly sorted. Skeletal grains are disarticulated, fragmented and highly micritized, but not rounded. Micritized grains constitute 22% of particles as a formational average. Peloidal lithologies are very fine to fine sands and include much coarser skeletal components.

Bedding in the Alsen is thin, discontinuous and irregular, commonly giving the appearance of a network of fitted nodules. These nodules probably originated through non-sutured seam pressure solution (Wanless, 1979) operating upon thin, vaguely rippled and bioturbated beds (Ebert, 1983). Physical sedimentary structures are rare in this unit owing to extensive bioturbation. Most fabrics consist of swirled or randomly oriented skeletal grains. Discrete burrows(0.5 to 2.0 mm diameter) are quite common and are usually filled with fine peloidal sediment, showing concentric, back-fill structures. Remnant physical structures include small-scale herringbone cross-lamination, asymmetric and symmetric ripples. Physical structures are more common in the base of the formation in close proximity to the Becraft Formation. These remnant structures and grainstone textures suggest the action of weak tidal currents (Ebert, 1983, 1985).

The fauna of the Alsen Formation is a diverse array of epifaunal suspension feeders and infaunal deposit feeders. Encrusting, ramose and fenestrate bryozoans are the dominant constituents. Brachiopods (11%) and crinoidal debris (19%) are also common. This fauna indicates ample oxygenation and relative stability of the substrate.

Textural, faunal, ichnofaunal and structural evidence suggest that Alsen deposition took place on an open shelf where water circulation was sufficient to maintain oxygenation and occasionally stir the substrate. Currents were sufficient to winnow the sediment periodically to produce grainstone textures and physical structures. However, the substrate was probably relatively stable and burrowing organisms were able to destroy most of the physical structures. The high percentage of micritized grains and the limited abrasion of these particles is additional evidence of substrate stability.

PORT EWEN FORMATION

The Port Ewen Formation overlies the Alsen Formation from Catskill Creek (R-44, STOP 2) south through the Hudson Valley. From Catskill Creek to Cementon (R-36) the Port Ewen is less than 2 meters thick as a result of pre-Tristates erosion. From Cementon to Kingston, the Port Ewen thickens rapidly, attaining a maximum thickness of roughly 24 meters (Fig. 2). The disconformable upper contact is clearly marked by phosphatic nodules at Catskill Creek (STOP 2). Elsewhere, the contact is poorly exposed or covered. However, at Bloomington, New York (section BL), the contact is reasonably well-exposed and appears to be conformable (see Ebert, 1983).

Five lithologies make up the Port Ewen Formation: 1) silty, argillaceous, skeletal packstone to wackestone, 2) silty, argillaceous, peloidal packstone to wackestone, 3) nodular to irregularly bedded peloidal grainstone, 4) dark grey to black shale, and 5) nodular to irregularly bedded chert.

Lithologies 1 and 2 comprise most of the formation. Bryozoans (12%), brachiopods (9%), ostracodes (6%), trilobites (5%), sponge spicules (2%) and crinoid fragments (2%) are present. Most skeletal grains are highly micritized and compacted, making them nearly unidentifiable (average 18% of grains). Skeletal particles are typically in the fine to medium sand range. Peloids are slightly ovoid in shape and average 0.1 mm in diameter. Quartz is present as medium to coarse silt.

Compactional and pressure solution fabrics are common in lithologies 1 and 2. Depositional textures and fabrics are difficult to assess and are further obscured by local development of structural cleavage. Primary structures are rare and poorly preserved. Fine lamination, rare, thin beds of graded packstone and burrows interpreted as *Helminthoida* are the only structures found in these lithologies.

Nodular and irregular beds of light grey, purer carbonate are one of the most striking features of the Port Ewen Formation. Nodules range from 0.02 m to 0.25 m in thickness and from 0.4 m to nearly 1.0 m in length. All nodules and irregular beds are comprised of peloidal grainstone with variable, minor quantities of skeletal debris. Microspar peloids, averaging 0.1 mm in diameter, show indistinct boundaries with the enclosing sparry cement. The skeletal elements within the nodules are slightly coarser than the fauna in surrounding lithologies, but are not different taxonomically.

Nodules are thoroughly burrow-mottled, except where recognizable ichnogenera are present, typically *Chondrites* and *Zoophycos*. Bioturbation is more intense within nodules than in the surrounding lithologies (1 and 2). Most nodules have sharp boundaries. However, some nodules have been observed that exhibit a gradual decrease in the degree of bioturbation into the surrounding lithologies.

The formation, geometry and distribution of nodules are the result of early cementation controlled by bioturbation and pelletization of sediment. Organisms responsible for *Chondrites* and *Zoophycos* pelleted the sediment in localized areas and thereby generated a more open fabric and greater permeability. These areas were cemented early, perhaps on the sea floor and thus preserved from subsequent compaction. Additional evidence for early cementation is provided by synsedimentary fractures in some nodules that are partially cement-filled, with sediment overlying cement.

Comparable relationships involving bioturbation, early cementation and differential compaction have been reported from chalks by Milliman (1966), Furisch (1972), Noble and Howells (1974), Hattin (1971, 1975, 1981), Bathurst (1975), and Garrison and Kennedy (1977). Nodules in some Cretaceous chalks, although smaller and less well-defined than Port Ewen nodules, display Chondrites, Planolites, and Zoophycos (Garrison and Kennedy, 1977).

Mazzo (1981) and Mazzo and LaFleur (1984) have suggested that nodules in the Port Ewen Formation are the result of soft-sediment deformation of allochthonous flows of carbonate sediment into the deeper portions of the basin. These workers have not noted any biogenic structures within nodules. Indeed, they suggest that burrowing infauna avoided these carbonate-rich horizons (Mazzo, 1981, p. 51). The geometry of nodules and the intimate association with clearly *in situ* ichnofossils argue against this interpretation. The present attitude of some nodules might possibly suggest transport or reorientation, but this is more likely the result of shearing and/or rotation during Acadian tectonism than synsedimentary processes.

Periodic exhumation of some nodular horizons and the development of patchy hardgrounds may have taken place, although the evidence is not conclusive. At several horizons, the upper surfaces of nodules are encrusted or replaced by fine pyrite. These pyritic zones contain sharp-sided biogenic structures that may be borings. Associated with these zones are pebbly, phosphatic and/or pyritic clasts that contain similar biogenic structures. Pyritic zones are most commonly overlain by dark, barren shales. This association of lithologies and structures collectively indicate low rates of sediment accumulation and quite probably non-depositional hiatuses.

Chert in the Port Ewen is present as rinds that centripetally replace nodules of peloidal grainstone and as continuous beds that were originally peloidal. These features tend to be more common in the upper five to eight meters of the formation. This distribution may reflect greater availability of silica in proximity to the quartz-rich lithologies of the Glenerie and Connelly formations.

Biogenic structures, in addition to those mentioned above, include Planolites and three rarer forms that are questionably identified as Paleodictyon, Teichichnus and Terebellina. The Port Ewen ichnofauna is assignable to the Nereites and Zoophycos associations (Seilacher, 1967, 1978) that define deep-water assemblages. These traces, coupled with the sparse shelly fauna, indicate dysaerobic conditions at or near the pycnocline in a stratified basin.

Cyclic distribution of lithologies and ichnofossils

Mazzo (1981) and Mazzo and LaFleur (1984) noted the presence of cyclic variation of lithologies in the Port Ewen Formation. They describe asymmetric cycles that are lighter colored and more nodular at the base and become progressively darker and shalier upward. Burrows (probably Helminthoida) are noted only in the top, shaly parts of cycles. Cycles are interpreted as recording fluctuations in the supply of allochthonous carbonate during regional transgression. Carbonate input is interpreted to have increased when the aerobic-dysaerobic pycnocline shifted basinward and decreased during shoreward shifts which would decrease upslope production of carbonate.

In addition to variations in lithologies and color, distribution of ichnofauna must be taken into consideration in any interpretation of Port Ewen cycles. Within cycles, ichnofossils vary in a regular fashion with lithology (Fig. 5). A typical asymmetric cycle consists of: 1) a sharp, but generally non-erosive basal surface overlain by thin (a few centimeters) dark shale. These horizons are commonly zones of bedding plane slip during deformation. 2) Thick, light grey, continuous beds or nodules of peloidal grainstone with abundant Zoophycos and/or Chondrites. 3) Smaller and sparser nodules of peloidal grainstone with greater amounts of skeletal wackestone or packstone between nodules. Chondrites and Zoophycos are less common than below and a few Helminthoida tubes are present. 4) Dark, laminated, highly argillaceous, skeletal wackestone and packstone. Helminthoida is the dominant trace. Planolites may be common and Chondrites are rare.

Symmetrical cycles also occur in the Port Ewen Formation (Fig. 5). In such cycles, the sequence described above is inverted in the lower half of the cycle and unit 2, the thick beds or nodules, occur in the center of the cycle.

In general, cycles tend to contain shallower water ichnofossils of the Zoophycos association at the base which are gradually replaced upward by deeper water forms of the Nereites association (Fig. 5). This progression is interpreted to represent abrupt shallowing (base of cycle) followed by gradual deepening in response to regional transgression. These variations occur as a response to shoreward shifts of the pycnocline during transgression. Variations in oxygenation at the sediment-water interface are recorded in a very detailed manner by the assemblages of trace fossils. During these shoreward shifts of the pycnocline, reduction in water oxygenation is responsible for reduced biogenic activity and hence there is little subsequent cementation and nodule formation. Although still a function of pycnoclinal shifts, this explanation of cyclicity differs significantly from that of Mazzo (1981) and Mazzo and LaFleur (1984).

It is interesting to note that Port Ewen cycles are of the same order of magnitude as PACs, yet they record deepening-upward rather than the universal shallowing predicted by the PAC hypothesis (Goodwin and Anderson, 1985). In the case of symmetrical cycles, gradual shallowing followed by gradual deepening are recorded. This symmetry and gradual variation are also at odds with the tenets of the PAC hypothesis.

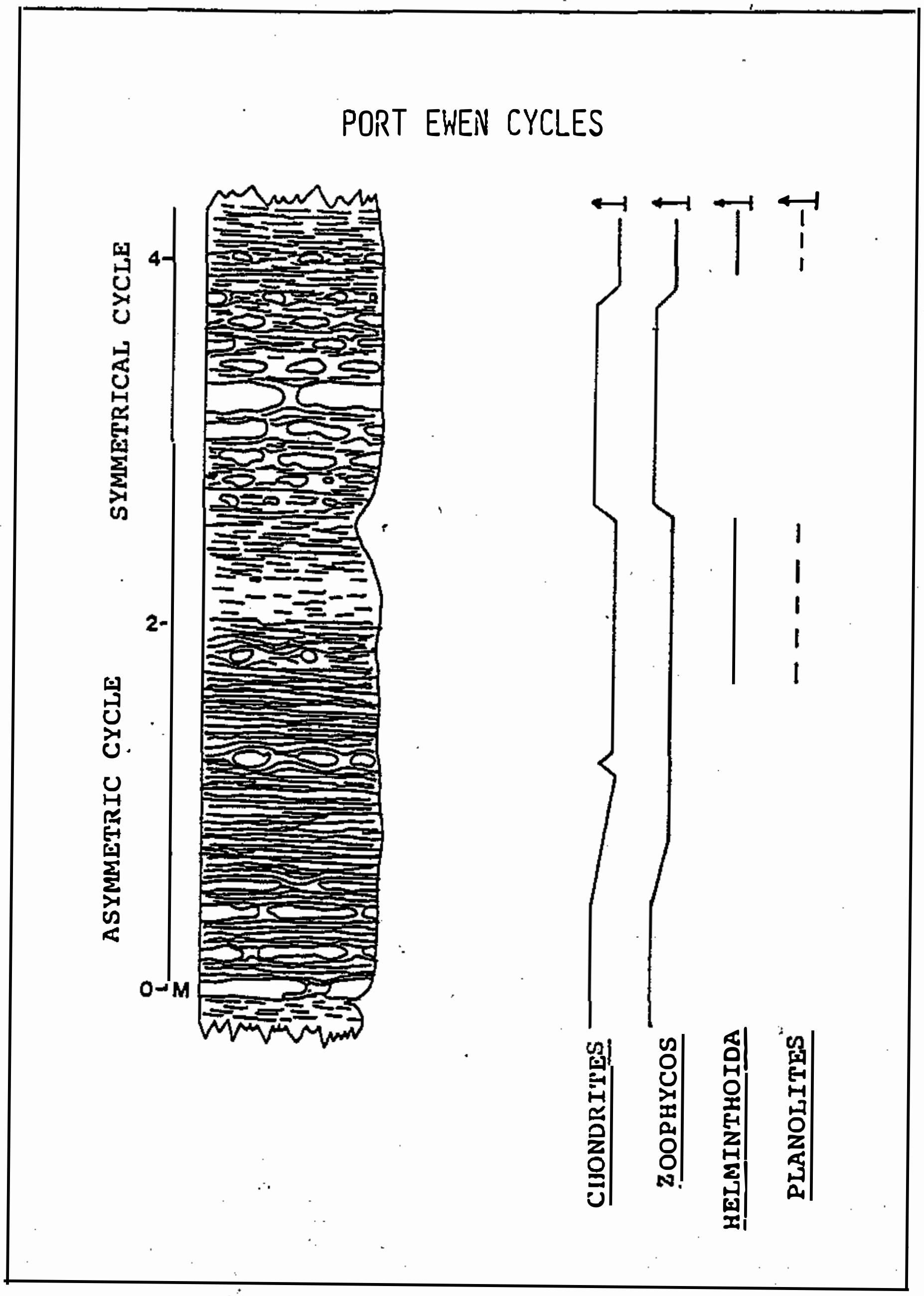

FIGURE 5. - Schematic representation of asymmetrical and symmetrical cycles in the Port Ewen Formation. Cyclicity is most apparent in the distribution of peloidal grainstone nodules. Detailed descriptions of lithologies are in text. Vertical lines show distribution and abundance of the four common ichnofossils of the Port Ewen. Arrows at the top of each column indicate relative abundance increasing to the left.

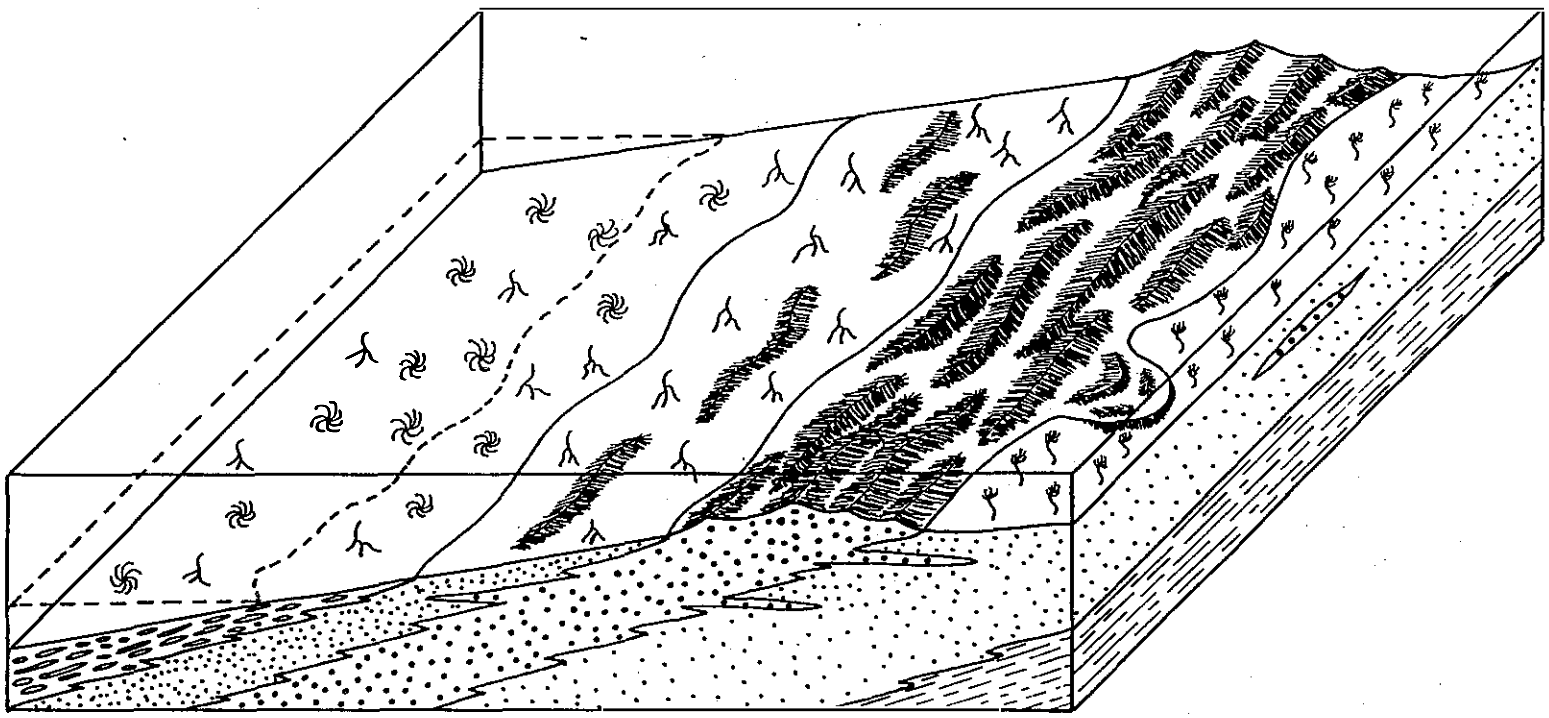

FIGURE 6. - Cartoon representation of upper Helderberg environments during the upper cycle transgression. From left to right environments are: deep, dysaerobic shelf (Port Ewen), open shelf (Alsen and Becraft-3), subtidal sand waves (Becraft-2), shelf lagoon (Becraft-4) and hypothetical tidal flat (lined pattern). Dashed line on left represents the pycnocline. Spirals = Zoophycos, branching symbol = general bioturbation, ovals in cross-section = burrow-generated nodules, brush-like symbol = crinoids. Nearshore environments (presumably similar to the Manlius Formation) have been removed by subsequent erosion.

ENVIRONMENTAL MODEL OF THE UPPER HELDERBERG RAMP

Figure 6 summarizes the distribution of environments on the upper Helderberg ramp. This ramp was characterized by an extremely low slope as in the traditional epeiric-sea models of Shaw (1964) and Irwin (1965). However, wave base was not the primary factor that governed the distribution of facies on the ramp. The depths at which tidal currents began to affect the bottom and the position of the aerobic - dysaerobic pynocline were the primary factors that controlled the nature and distribution of facies.

Subtidal sand waves were molded from loose skeletal debris in the shallow depths that were affected by tidal flow. Only robust brachiopods, crinoids, and a few bryozoans could tolerate this turbulent sand-wave environment. These organisms provided additional coarse sediment for the maintenance of the sand waves.

The sand-wave shoals dissipated much of the tidal flow and, therefore, reduced turbulence on their landward side. This facilitated the deposition of finer sediment in the more shoreward areas. Tidal flats similar to those of the Manlius Formation may have existed along the shoreline. Between the sand-wave shoals and the shore, a shallow shelf lagoon existed that supported a diverse assemblage of suspension feeders. Washovers or spillover lobes from the shoals periodically advanced over the finer sediments of the shelf lagoon.

A well-oxygenated, open shelf lay seaward of the sand-wave complexes. This open shelf supported an abundant and diverse assemblage of bryozoans, brachiopods, crinoids and abundant ichnofauna. Weak tidal currents aerated the shelf and occasionally winnowed the finer sediment or produced minor bedforms and perhaps low-amplitude sand waves. Substrate mobility was relatively infrequent and burrowers were able to destroy most physical sedimentary structures.

Deeper portions of the shelf were below the influence of tidal currents and waves. Micrite, clay and fine shelly debris were deposited on the deep shelf by dilute turbidity flows and by the settling of fine material that was winnowed from the sand waves and open shelf.

Bottom waters were poorly oxygenated and restricted the biota to a moderately diverse ichnofauna and sparse shelly fauna. Burrowers responded to subtle changes in water oxygenation on the deeper portions of the ramp and were thus influenced by the position of the aerobic - dysaerobic pycnocline.

The burrowing activity of organisms increased the porosity and permeability of the sediment in local areas. These areas experienced early cementation and became nodules of peloidal grainstone. The spatial and temporal distribution of organisms directly controlled the subsequent distribution of nodules.

Periodic exhumation of some nodular horizons by submarine erosion may have resulted in the existence of patchy hardgrounds on the sea floor.

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ROAD LOG FOR TIDAL CURRENTS, BIOGENIC ACTIVITY AND PYCNOCLINAL FLUCTUATION ON A LOWER DEVONIAN RAMP

CUMULATIVE MILEAGE	MILES FROM LAST POINT	ROUTE DESCRIPTION
0.0	0.0	Exit 21 toll plaza on I-87
0.1	0.1	Turn left on Old State Rt. 23
0.7	0.6	Turn east (left) on Rt. 23, outcrop on left displays Taconic unconformity
1.5	0.8	Jct. Rt. 9W south
1.8	0.3	Jct. Rt. 9W north
1.9	0.1	Steel deck bridge over tributary to Hans Vosen Kill
2.2	0.3	Jct. Rt. 385
2.5	0.3	Rip Van Winkle Bridge toll plaza, outcrops on both sides of road show chevron folds in the Austin Glen Formation, cross Hudson River $0.50 toll for passenger vehicles
3.6	1.1	Jct. Rt. 9G, Rts. 23 and 9G run concurrently, continue east on 23
4.1	0.5	Jct. Rt. 23B, continue east on 23
4.4	0.3	Entrance to Columbia - Greene Community College
6.25	1.85	Jct. Rt. 9, turn north (left) on Rt. 9, outcrop on corner is in Manlius Formation
6.5	0.25	Small outcrop of Normanskill Formation, the hill to the right of the road is Becraft Mountain, an outlier of the Helderberg Group
7.9	1.4	Entrance to inactive Independent Cement Corporation plant
8.0	0.1	Conveyor over road
8.1	0.1	Entrance to quarry, STOP 1, bus will park on opposite side of road.

STOP 1. BECRAFT MOUNTAIN

Location: Inactive quarry of the Independent Cement Corporation on Becraft Mountain outlier ("Becraft Hills"), located in northeast quarter of the Hudson South, New York 7.5 minute quadrangle, just east of Rt. 9, approximately 1 mile south of Hudson.

References: Grabau, 1903; Rickard, 1962

Description: A small pit in the Manlius and Coeymans formations can be seen to the left of the access road to the main quarry. Before entering the main quarry, exposures in the New Scotland Formation are visible along the access road. The main quarry is quite extensive; however, we will concentrate on the northern end. The lower Helderberg formations are largely submerged, but excellent exposures of the upper formations may be studied throughout the quarry.

The upper contact of the New Scotland Formation is clearly exposed in the northern wall of the quarry. Above the New Scotland is a thin (1.8 m) unit that I interpret as the easternmost extension of Rickard's (1962) upper tongue of the Kalkberg Formation. Slightly less than four meters of Becraft subfacies 1 overlie this unit. Subfacies 2 (8.5 m) and subfacies 3 (1.8 m) occur above subfacies 1. The Alsen Formation 2.5 m) is the highest unit present in the quarry.

The eastern position of the Becraft Mountain outlier places this exposure in a more shoreward position relative to localities in the main outcrop belt of the Helderberg Group. This is clearly reflected in the character of the upper formations. Subfacies 1, for example, exhibits fewer and thinner silty interbeds and drapes than at other localities in the central Hudson Valley, an indication of stronger current action in shallower water. Holdfasts of *Aspidocrinus scutelliformis* are usually sparse in this unit. Elsewhere, this holdfast is abundant in subfacies 1. These two factors combine to give subfacies 1 an overall appearance that is similar to that of subfacies 2 at other locations west of the Hudson. Erosional surfaces and silt drapes within sets of cross stratification are the major features to be observed in subfacies 1 at this stop.

Subfacies 2 is clearly exposed in the quarry, but access for large groups is difficult and potentially dangerous. For this reason, this unit will not be observed here. The general character of subfacies 2 can be seen from a distance, however. Thicker bedding, coarser textures and an abundance of *A. scutelliformis* and *Gypidula pseudogaleata* differentiate this unit from subfacies 1. The relative freshness of the exposure and the coarseness of subfacies 2 make observation of sedimentary structures difficult. Interbedding of rudstone and grainstone is the dominant structure. This interbedding is interpreted as vertically accreted tidal bundles. Unimodal cross stratification is common in the center of the unit, but may also be present elsewhere.

Subfacies 3 occurs just below the Alsen Formation. This unit is superficially similar to subfacies 2, but may be differentiated by the presence of bioturbate fabrics and the rootlike holdfast Clonocrinus(?). This unit is readily observable in the quarry, but is better studied at STOP 2, owing to the weathered character of that exposure.

By virtue of its position near the pre-quarry ground surface, the Alsen Formation is better weathered than other units in the quarry. Sedimentary structures and textures are highlighted by this weathering. Nodular chert also helps to differentiate this formation. Herringbone cross stratification, argillaceous interbeds, vague grading and bioturbate fabrics are the important features to note. Faunal differences from the underlying Becraft are evident in the decrease in crinoidal debris and brachiopods and the obvious increase in abundance and diversity of bryozoans. The Alsen Formation at this stop displays significantly more physical sedimentary structures than at other exposures. This is further evidence of a shallower position on the ramp for this location.

8.1	0.0	Return south on Rt. 9
9.85	1.75	Turn west (right) on Rt. 23
11.9	2.05	Jct. with Rts. 23B and 9B, view of Catskill Front across the Hudson
12.6	0.7	Rip Van Winkle Bridge, no toll in this direction
13.85	1.25	Jct. Rt. 385
14.2	0.35	Jct. Rt. 9W north
15.3	1.1	Jct. Rt. 23B, connector to I-87, excellent exposure of the Taconic unconformity on offramp
15.6	0.3	Large outcrop in Helderberg Group, these exposures continue for next half mile, units show complex deformation (see Marshak, 1986)
16.2	0.6	Bridge over Catskill Creek, STOP 2, bus will park on north side of road. CAUTION: TRAFFIC IS OFTEN HEAVY AND FAST-MOVING. CROSS TO SOUTH SIDE WITH EXTREME CARE.

STOP 2. CATSKILL CREEK IN AUSTIN GLEN.

Location: Waterfall and rapids on Catskill Creek, below and just south of the Rt. 23 bridge over the creek, approximately 0.35 miles northwest of the Rt. 23 bridge over I-87. The deep, narrow valley of Catskill Creek is known as Austin Glen or Leeds Gorge in this area. Northeast corner of Cementon, New York 7.5 minute quadrangle, 1980 photo revised.

References: Section 44 of Rickard (1962), Structural geology is described by Marshak (1986), STOP 2B, see also STOPS 1 and 2.

Description: The near vertical bedding at this location has created a natural dam across Catskill Creek. Resistant beds of the Glenerie Formation and the Upper Helderberg Becraft, Alsen and Port Ewen Formations form the dam and subsequent waterfall. Upstream from this dam, the creek has scoured out the less resistant Esopus Formation as it flows parallel to strike. In addition to these units, the top of the New Scotland Formation and the upper tongue of the Kalkberg Formation are also exposed just below the falls on the east bank of the creek.

The upper tongue of the Kalkberg Formation (4 m) and Becraft subfacies 1 (4.9 m) are strikingly similar at this location. The two are differentiated by the abundance of *Aspidocrinus* holdfasts in subfacies 1. This designation follows Rickard (1962). Duneforms, silty and peloidal interbeds and drapes are the essential features to note in this part of the section. Herringbone and unidirectional cross stratification are common, with end-on views of troughs less common. Ripples and cross lamination occur in some of the finer interbeds. The increased abundance and thickness of finer lithologies, relative to STOP 1, suggest that this location occupied a slightly more offshore or down ramp position.

Becraft subfacies 2 (approx. 9.5 m) is exposed in the falls and on the west bank of the creek. Thick to massive-appearing bedding and a nearly white weathered color set this unit apart from underlying and overlying units. As at STOP 1, the coarse texture of this unit makes observation of sedimentary structures difficult. Crude bedding is apparent in some crinoidal, *Gypidula* - *Concinnispirifer* rudstones. Planar stratification, grainstone - rudstone interbedding, normal and inverse grading are present. These features are interpreted as upper stage plane bedding and vertically accreted tidal bundles. Cross stratification is present, but is difficult to observe.

Subfacies 3 (1.6 m) is only subtly different from subfacies 2 in overall appearance. This unit is recognized by the abundance of *Gypidula* and *Concinnispirifer* and by the pink, root-like holdfasts of *Clonocrinus*(?). Finer textures and *in situ* holdfasts indicate reduced turbulence and increased stability of substrate relative to the underlying subfacies.

The Alsen Formation (approx. 11 m) is noticeably darker, finer-grained and chertier than the underlying Becraft Formation. The fauna is enriched in bryozoans relative to subfacies of the Becraft Formation. Crinoidal constituents are less abundant and finer and brachiopods tend to be thinner-shelled than in the Becraft.

Sedimentary structures have been largely destroyed by bioturbation. The increase in biogenically-disrupted fabrics and the paucity of physical structures, as compared to the Becraft Mountain exposure, also suggest a slightly more down ramp position for this exposure.

Approximately two meters of the Port Ewen Formation are exposed near the top of the section, just below the Glenerie Formation. The Port Ewen is a moderately fossiliferous, bioturbate wackestone to packstone at this section. Bryozoans dominate the fauna. Trilobites and ostracodes are also common. The Port Ewen is greatly thinned here by pre-Glenerie erosion. Large phosphatic and/or slightly pyritic cobbles in the base of the sandy Glenerie mark this disconformity. These features may be observed in the beds that make up the upstream portion of the "dam".

16.8	0.6	Jct. Cauterskill Rd. (Greene County Rt. 47), Sunoco station on right, Dairy Queen on left. Bus will turn here to return east on Rt. 23
17.3	0.5	Catskill Creek
18.0	0.7	Exit from Rt. 23 for Leeds and Jefferson Heights
18.2	0.2	Proceed left at bottom of ramp onto Old State Rt. 23
18.7	0.5	Turn right for entrance to Thruway, I-87
18.8	0.1	Toll plaza for interchange 21, starting point of road log. Take I-87 south. Note Helderberg outcrops on ramp. Outcrops of the Helderberg Group, Tristates Group, Onondaga Limestone and Hamilton Group may be seen along I-87 over the next 21.4 miles.
36.3	17.5	Ulster Service Area

40.9	4.6	Exit 19, Kingston, exit Thruway
41.5	0.6	Toll plaza
41.6	0.1	Traffic circle, follow Rt. 209 north (Pine Hill) for Rhinecliff Bridge
41.85	0.25	Traffic light on Rt. 28, proceed straight
41.95	0.1	Right turn onto ramp for Rt. 209, north
44.6	2.65	Bridge over Esopus Creek
45.3	0.7	Jct. Rt. 9W south, begin Rt. 199, continue east following Rt. 199
45.6	0.3	Outcrop in Tristates Group and Onondaga Limestone
46.0	0.4	STOP 3. Roadcut through anticline. Bus will continue east and turn around to park on north side of Rt. 199.
46.25	0.25	Outcrops in lower Helderberg Group
46.4	0.15	Exit for Rt. 32, Kingston and Saugerties
46.7	0.3	End of ramp, turn north (right) onto Rt. 32, under bridge
46.8	0.1	Turn right onto ramp leading to Rt. 199
46.9	0.1	Outcrops of Austin Glen Formation on ramp
47.3	0.4	Return to STOP 3.

STOP 3. ROADCUT ON ROUTE 199.

Location: Roadcut through anticline in the upper Helderberg Group on Rt. 199, the approach to the Kingston-Rhinecliff Bridge over the Hudson River. Exposure is 0.7 miles east of the junction of 199 with Rt. 9W and 0.35 miles west of the Rt. 32 overpass. Northwest quarter of Kingston East, New York 7.5 minute quadrangle.

<u>References</u>: STOP 1b of Waines and Hoar (1967); STOP 3 of Heyl and Salkind (1967); STOP 3 of Toots (1976); STOP 9b of Pederson, Sichko and Wolff (1976); STOP 7 of Marshak (1986).

<u>Description</u>: This exposure has been visited on several previous NYSGA field trips for the purposes of illustrating structural features or stratigraphic succession. This trip will examine the sedimentology of the Upper Helderberg Formations exposed in this popular roadcut.

The Becraft Formation (9.5 m) occupies the core of this anticlinal exposure. Slightly less than two meters of subfacies 1 are exposed at the base of the section. Subfacies 2 comprises the remaining 7.6 meters of the formation. Subfacies 3 is absent, although the uppermost parts of subfacies 2 are somewhat similar to subfacies 3. Minor silty interbeds may be found in places in the lower parts of subfacies 2. These interbeds are commonly cross laminated and some show paleocurrent reversals relative to adjacent cross-bedded grainstones. Structures in the grainstones are difficult to observe on this relatively fresh face.

The Alsen Formation (6.3 m) sharply overlies subfacies 2 of the Becraft Formation, although several beds of Becraft-like grainstones are interbedded throughout the lower few meters of the Alsen. Bioturbate fabrics predominate in the grainstones and packstones of this unit. The contact with the overlying Port Ewen Formation is readily recognized, but appears to be gradational.

All five lithologies that make up the Port Ewen Formation (24 m) are present in this exposure. Cyclicity is most noticeable in the distribution of the nodules and beds of peloidal grainstone. Asymmetrical and symmetrical cycles are present.

Nodules are thoroughly burrown-mottled, except where recognizable ichnogenera are present, typically <u>Chondrites</u> and <u>Zoophycos</u>. Bioturbation is more intense within nodules than in the surrounding lithologies. Most nodules have sharp boundaries. However, some nodules exhibit a gradual decrease in the degree of bioturbation into the surrounding lithologies. Differential compaction between nodular and non-nodular lithologies is readily apparent. Note the absence of evidence for soft-sediment deformation which Mazzo (1981) and Mazzo and LaFleur (1984) suggest should be ubiquitous.

The distribution of ichnofauna within cycles is such that <u>Zoophycos</u> and <u>Chondrites</u> are most abundant in the centers of symmetrical cycles. Deeper water forms are present in the upper and lower portions of these cycles. Several nodular beds exhibit pyrite impregnation of the upper surfaces. Borings (?) are associated with these surfaces, as are pebbly, phosphatic and/or pyritic clasts that contain similar biogenic structures.

Periodic exhumation of some nodular horizons and the development of patchy hardgrounds are suggested by these features. Additional evidence for early cementation is provided by synsedimentary fractures in some nodules that are partially cement-filled, with sediment overlying cement.

Chert is present as rinds that centripetally replace nodules of peloidal grainstone and as continuous beds that were originally peloidal. These features tend to be more common within five to eight meters of the contact with the Glenerie Formation.

Sandy, brachiopod-rich beds of the Glenerie Formation are present on the west limb of the fold. A covered interval of approximately 5 meters separates this formation from the Port Ewen below.

END OF ROAD LOG. CONTINUE ON RT. 199 WEST TO RT. 9W AND RETURN SOUTH TO KINGSTON.