# BATHYMETRY AND PALEOECOLOGY OF SILURIAN BENTHIC ASSEMBLAGES, LATE LLANDOVERIAN, NEW YORK STATE

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#### Abstract

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Late Llandoverian marine shales in New York State are highly fossiliferous and provide an opportunity to examine gradients of biofacies. The Williamson and Willowvale formations (Llandoverian  $C_6$ ) were deposited during a major transgressive episode in and adjacent to the axis of a narrow NE-SW trending, central Appalachian foreland basin. The Williamson Shale is a black to dark green, graptolite-bearing unit of the upper Clinton Group of western New York State. It grades eastward into gray fossiliferous shales and coquinoid limestones of the Willowvale Formation. Orientation analysis of graptolites (*Monograptus clintonensis*) indicates paleocurrents dominantly from the northeast to east.

The presence of rippled, cross-laminated sandstone beds (tempestites) within dark gray, graptolitic facies of the lower Williamson indicates that the dark shale facies was deposited in dysaerobic to marginally aerobic water slightly below storm wave base. Poorly fossiliferous green shales, higher in the Williamson, appear to reflect slow deposition in dysaerobic water and suggest a gradual deepening. Graded brachiopod coquinoid limestones, interpreted as storm layers, occur near the middle and top of the Williamson and in the Willowvale Shale, and indicate deposition of these sediments above maximum storm wave base.

The faunas of the Williamson and Willowvale shales are subdivisible into five vertically and laterally adjacent associations as follows: (a) Ichnofossil (Chondrites), (b) Monograptid-"Chonetes" cornutus, (c) Eoplectodonta-Atrypa, (d) Palaeocyclus-bryozoan, and (e) Eocoelia-"Chonetes" cornutus associations. This spectrum of fossil associations appears to parallel the increasing frequency of bottom disturbance by waves and currents from deeper basinal areas to higher-energy outer and low energy inner shallow, shelf settings. The fossil associations of the Williamson (a-c) probably belong to the deeper benthic assemblages 4-5, but developed in environments within to slightly below storm wave base, (about 50-80 m deep). The Willowvale fauna (c, d) representing benthic assemblages 3-4, inhabited somewhat shallower, better oxygenated environments of the photic zone, probably at depths of approximately 20-50 m. The easternmost to slightly southeastward, equivalent of Williamson-Willowvale fauna (e) evidently represents shallow water benthic assemblages 3-5; a new interpretation of approximate depths for this range is presented herein.

#### Introduction

Early Silurian fossil assemblages in the Welsh Borderland provided important models for understanding the distributional ecology of paleocommunities (Ziegler, 1965; Ziegler et al., 1968). However, numerous problems remain unsolved with regard to the paleobathymetric relationships of the "classic" Silurian depthrelated communities. For example, communities assigned to the benthic assemblage 4-5

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range (e.g. *Clorinda* and *Dicoelosia*) are generally accepted to represent offshore or relatively deep water settings. But does this mean the subphotic zone, "shelf break", or below maximum storm wave base? Does "deep water" imply 50 m, 100 m, 200 m (see Boucot, 1975; Cocks and McKerrow, 1984; Johnson, 1987; Wang et al., 1987)?

The well known Silurian strata of New York State have received relatively little paleoenvironmental study, until recently. In this paper we present the results of our detailed paleoecological study of the late Llandoverian interval in New York State, in order to interpret paleoenvironments and place this sequence into the context of better-studied assemblages from the Welsh Basin. This study presents a revised view of the bathymetric relationships of these classic benthic assemblages.

The Williamson and Willowvale formations of New York State (Fig.1) comprise dark gray, black and greenish shales and thin carbonates and sandstones deposited in the northern end of the Appalachian foreland basin during a major late Llandoverian transgression (see Gillette, 1947; Lin and Brett, 1988, for detailed discussion of stratigraphy and facies relationships).

The green clay shale lithofacies of the Williamson very closely resembles that of certain Lower Silurian units (e.g. Sodus and Maplewood shales) which display evidence of shallow water deposition and this may have caused problems in interpretation of the Williamson and Willowvale shales. By analogy to these facies and on the basis of graptolite communities, the assignment of both the Williamson and Willowvale to the Eocoelia biofacies of benthic assemblage 2 has been implied, though not explicitly stated (Berry and Boucot, 1972, p. 61; Boucot, 1975; see especially Boucot's fig.13 in which the word Williamson apparently should be replaced by Willowvale). However, the Williamson sedimentary setting and fauna indicate deposition in considerably deeper water. By examining evidence for storm deposition, photic zone indicators, and regional relationships, we provide more objective criteria for the depositional environments and relative depths involved in these deposits.

Abundant aligned specimens of the graptolite *Monograptus* in the Williamson permit paleocurrent analysis. Oriented samples from five major outcrops (Fig.2) of the Williamson have been used to determine circulatory dynamics in the upper Clinton sea. The distribu-



Fig.1. General stratigraphic relationships of late Llandoverian to earliest Wenlockian in New York State; W' and Hem. = Westmoreland Hematite (after Lin and Brett, 1988).



Fig.2. Locality map of the Williamson and Willowvale shales. Localities include: 1=Genesee Gorge West; 2=Genesee Gorge East; 3=Tryon Park (Palmer's Glen); 4=Salmon Creek West; 5=Second Creek; 6=Little Wolcott Creek; 7=Phoenix; 8=Brewerton; 9=Verona Station; 10=Lairdsville; 11=Dawes Quarry Creek; 12=Willowvale Glen; 13=Chadwicks; 14=Ohisa Creek; 15=Van Hornesville. Oriented Monograptus samples were collected from localities 1 to 5.

tion of lithofacies, and taphonomic features in the Williamson and Willowvale shales, together with paleocurrent data, permit reconstruction of the depositional environment and paleogeography of the late Llandoverian strata. Additionally, the distribution of brachiopods and other fossils has been recorded for all measured sections (Lin, 1987); this has permitted recognition of several distinctive associations which can be related to other facies criteria and compared with the classic onshore-offshore gradient established for the Silurian in the Welsh Basin (Ziegler, 1965; Ziegler et al., 1968; McKerrow, 1978).

#### General geological setting

The Lower Silurian Clinton Group of New York State was deposited in a tectonic setting transitional between orogeny and extreme quiescence (Hunter, 1970). Terrigenous sediments derived from the Taconic orogenic belt were deposited near the northeast end of the central Appalachian foreland basin (Johnson, 1987). Marine faunas of pelagic graptolites, brachiopods, trilobites, echinoderms and others were abundant near the margins of the basin.

Most paleogeographic reconstructions of North America during the Silurian (Ziegler et al., 1977; Bambach et al., 1980; Johnson, 1987; Van der Voo, 1988) indicate that New York lay in a subtropical climate belt about 25-30° S of the paleoequator, which would have placed the epeiric seas in the pathway of tropical storms, equatorial currents, and trade winds. Conversely, the reconstructions of Boucot and Gray (1983) and Boucot (1985) would place New York in mid-southern latitudes, or in a zone of winter storms (Marsaglia and Klein, 1983). In any case, the Williamson-Willowvale shales provide evidence for storm-influenced shelf sedimentation, as has been noted previously for the slightly younger Rochester Shale (Brett, 1983).

The Williamson-Willowvale shales represent the initial deposition of a widespread latest Llandoverian ( $C_6$ ) marine transgression (Johnson et al., 1985; Johnson, 1987) and overlie a widespread, regionally angular erosion surface (Lin and Brett, 1988). According to Johnson et al. (1985) this sea level peak was the last of three Early Silurian large scale transgressions which occurred with a periodicity about 2.5 million years.

# Williamson-Willowvale paleoenvironment and facies

#### Paleogeography and paleocurrent analysis

General facies geometry suggests that during deposition of the Williamson Shale the axis of maximum subsidence of the central Appalachian Basin lay in western New York and western Pennsylvania. This basin extended southward into western Pennsylvania and Ohio, where the Williamson grades into the upper Rose Hill and Estill shales (Hunter, 1970; Brett and Goodman, 1988) (Fig.3). Closure or at least shallowing of the north end of the basin (Johnson, 1987), north of the present outcrop belt is suggested by E-W trending facies belts with evidence for deeper water deposits in the New York subsurface in many Silurian units (Rickard, 1969; Belak, 1980; Brett, 1983), as well as evidence for minor siliciclastic sediment input from the north (Muskatt, 1972; Crowley, 1973), and the absence of Silurian deposits at Montreal (Boucot et al., 1987). The eastern shoreline during latest Llandoverian probably lay somewhat to the east of Herkimer County, N.Y. area where the Willowvale Shale is now bevelled due to a Late Silurian erosion interval (Rickard and Zenger, 1964). Easternmost outcrops of the Willowvale yield a distinctive nearshore (BA-2) fossil assemblage dominated by the Eocoelia brachiopods.

Analysis of aligned graptolites suggests a NE-SW orientation of the eastern paleoshoreline during the deposition of the Williamson-Willowvale shales (Lin, 1987). Fossil orientation has been widely used as a paleocurrent

![](_page_3_Figure_5.jpeg)

Fig.3. Depositional setting of the late Llandoverian Williamson and Willowvale shales. Eastward gradation from black and sparsely fossiliferous green shales at the type section eastward into thicker, grayish shales with coquinites indicates that the basin axis was in west-central New York, with water shallowing eastward. This pattern is also indicated by paleocurrent and fossil community studies.

indicator (Nagel, 1967; Jones and Dennison, 1970; Potter and Pettijohn, 1977). Graptolites are light and elongate; their rhabdosomes probably responded to the most gentle of currents, aligning with the long axes of stipes parallel to the flow direction; as a result, they provide sensitive indicators of paleocurrent systems (Ruedemann, 1897; Schleiger, 1968).

Flow directions during deposition of the Williamson Shale were inferred from aligned graptolites (*Monograptus*, *Retiolites*) and sole marks. Computer-aided analysis of over 1200 oriented *Monograptus* rhabdosomes from black shales at five localities indicates rather consistent current alignment. Approximately equal proportions of *Monograptus* rhabdosomes are oriented with the thecae pointing to the left or to the right. Graptolites on bedding planes show significant to highly significant preferred long axis orientations (*R* values ranging from 0.63 to 0.95); the null hypothesis (random orientation) was rejected with a Chi-squared test in 11 of 12 sampled horizons. Orientation is typically in the range of N 20°E to due north. As a rule, long rhabdosomes (4 cm or longer) show a higher degree of preferred orientation than do shorter rhabdosomes, which apparently were subjected to reworking and fragmentation (Fig. 4). Some variation in orientation is evident between localities and from horizon to horizon at each locality. Furthermore, a few bedding plants preserve graptolites oriented mainly at approximately right angles to the dominant trend displayed at most horizons. This seems to indicate a current flow approximately perpendicular to the dominant flow.

Aligned graptolite rhabdosomes display orientations consistent with those of sedimentary structures (cross laminae, ripples, sole marks) and were produced by the same unidirectional paleocurrents. Sole marks preserved at the bases of graptolitic horizons at Tryon Park

![](_page_4_Figure_2.jpeg)

Fig.4. Size frequency analysis of *Monograptus* graptolites of the Williamson Shale for several localities. The leftskewed pattern of the *Monograptus* rhabdosomes indicates that the rhabdosomes probably underwent some transportation, reworking and fragmentation.

(Loc. 3) and Second Creek (Loc. 5) reveal a dominant northeast to southwest or north to south flow direction.

Concretions in the Williamson at Genesee Gorge East (Loc. 2A) also display aligned long axes oriented N 50°E, a direction consistent with the aligned *Monograptus* (see Fig.8B). These concretions occur in a discrete horizon immediately above a thin, laminated siltstone and were probably formed by selective cementation along zones of high permeability. Colton (1967) and Craig and Walton (1962) previously have noted that elongate concretions commonly parallel transport directions within turbidites.

The paleocurrents were probably dominantly gradient currents, approximately perpendicular to the margins of the basin but a minority were parallel to the basin contours. One interpretation is that most currents in western New York flowed approximately N to S, indicating a gentle paleoslope toward the S. A regional trend of current orientations displays minor change from consistently SSW at Alton (Loc. 5), to more due S or even SE in the Rochester area. This suggests that, from E to W, the contours of the basin margin might have curved gently from NW to more due W or even slightly SW (Figs.5 and 6). The fact that both SE and SW orientations occur in equal abundance at Salmon Creek is consistent with other indications that this section lay near the basin axis. No graptolite orientation data were obtained from rocks east of Alton. However, previous paleocurrent studies based on ripples and cross beds from the middle Clinton Group near Utica, indicate E to W or NW-flowing currents (mean composite cross-bedding dip azimuth for Clinton sandstones: 284° ± 64°; Muskatt, 1972). This may indicate a general SE to NW orientation of the eastern side of the basin. Our interpretation of the variation of graptolite orientation from Alton to Williamson to Rochester is that the Williamson basin formed a narrow trough trending roughly NE-SW (Figs.3 and 6); the northwest rim of this basin trended ENE to WSW, approximately parallel to the present Silurian outcrop belt from Rochester westward. This pattern is

![](_page_5_Figure_1.jpeg)

Fig.5. Azimuthal rose diagram indicates general trends in graptolite orientation; note NE-SW orientations at several localities. GG-L (Genesee Gorge West, unit 16); GGE (Genesee Gorge East, Location A; unit 7); GGE2 (Genesee Gorge East, Location B; unit 1); TP-U, TP-M, TP-L (Tryon Park; units 18, 16, 9), SAM-U, SAM-L (Salmon Creek West, unit 1; upper and lower horizons), SC-U, SC-M, SC-L, SC-L1 (Second Creek, units 16, 3, 2) (see Lin, 1987, for detailed measurement of sections and description of methods).

consistent with basin geometries, previously noted, that suggest closure of the basin and shallowing to the north.

#### Lithofacies and cyclicity

Eastward thickening of the Williamson Shale and gradation into slightly coarser grained, fully aerobic facies of the Willowvale Shale indicate a clastic provenance and general shallowing to the east. The aggregate thickness of the quartzose sandstone, siltstone and coquinoid limestones and thickness of individual beds of these lithologies increase toward the east side of basin. The Williamson is extremely thin, or is absent in western New York (Lin and Brett, 1988), suggesting that the northwestern side of the basin was sedimentstarved. Maximum development of the dark gray to black graptolitic facies occurs in a narrow area between Williamson and Tryon Park, and this region is inferred to represent the basin center.

In more easterly localities, olive to greenish gray clay shales and coquinoid limestone with abundant fossils dominate the upper part of Williamson. These greenish gray shales facies pass eastward into gray slightly silty shales of the Willowvale Formation.

Phosphatic and quartzose conglomerate beds (Second Creek Bed) 2-5 cm thick in the basal 30 cm of the Williamson at most of the localities and represent a transgressive lag deposit associated with the basal unconformity (see Lin and Brett, 1988); they are immediately overlain by dark gray to black shales with abundant Monograptus. The Williamson is coarsest at the base and gradually fines upwards into fine, greenish gray clay shales. These beds, in turn, pass upward into a middle minor interval with minor black shales and sandy coquinite. The Williamson terminates at a phosphatic and quartz pebble-bearing, dolomitic limestone bed which marks the base of the Irondequoit Formation. Greenish gray clay shales with a few poorly preserved brachiopods and trilobites and typically lacking Monograptus form the bulk of the upper part of the Williamson Formation, with recurrent black beds in the upper third of the unit at some localities.

On the basis of provenance studies, Muskatt (1972) concluded that sediments comprising the upper Clinton Group were derived dominantly from source areas to the east or southeast, composed of low grade metamorphic rocks with abundant quartz veins as should be typical of Taconic terranes. However, he also notes the presence of some grains derived from sedimentary rocks, gneiss, pegmatite and possible granite and basalt (Muskatt, 1972, p. A27). Abundance of sand- and silt-sized siliciclastic grains at the base of the William-

![](_page_6_Figure_0.jpeg)

Fig.6. Map showing average orientations of graptolites at various locations and inferred basin contours (relative). In general, graptolites are oriented mainly N-S in Rochester area, but show a major distinctly NE-SW orientation in more easterly samples. These orientations were probably produced by storm-generated currents flowing perpendicular to the basin contours; hypothetical basin contour lines are shown in dotted lines; orientation is approximately perpendicular to mean vectors for graptolite azimuths. These same currents probably transported sand into the basin.

son indicates that the basin center was receiving sediment from reworking of an eroded emergent terrain, probably near the eastern and perhaps northern borders of the basin.

While the water was still relatively shallow, some coarser sediments were transported into the basin probably by intermittent stormgenerated gradient currents (see below). With gradual deepening, and transgression of shorelines the western side of the basin was cut off from receipt of coarse siliciclastics.

The frequency pattern of storm-generated beds (tempestites) during deposition of the Williamson also suggests a central minor regression. Locally phosphatic brachiopod coquinoid limestones and sandstones occur within the middle of the Willowvale Formation. Sparsely fossiliferous green shales, between shell rich intervals, appear to reflect slow deposition in dysaerobic water and suggest a gradual deepening. A shallowing episode at the end of the Williamson-Willowvale interval is recorded by the recurrent quartz granule-phosphatic bed (Salmon Creek Bed; Lin and Brett, 1988). Hence, the Williamson-Willowvale interval, as a whole, constitutes two subsymmetrical transgressive-regressive cycles.

## Biofacies and paleoecology of the Williamson-Willowvale shales

Fossil associations, as defined herein, are recurrent groupings of fossil taxa; they may or may not represent true communities; for example the *Monograptus-"Chonetes" cornutus* association contains a mixture of benthic elements and pelagic graptolites. Consequently we avoid the term "communities" and use the broader and less genetic term associations.

# Chondrites association: greenish gray shale facies

### (1) Fossils

Beds displaying abundant small-diameter Chondrites, alternate with laminated layers in

![](_page_7_Figure_1.jpeg)

the basal Williamson Shale at Genesee Gorge West (Loc. 1) and Tryon Park (Loc. 3). A polished core of the Williamson Shale also revealed abundant, small diameter, flattened burrows throughout much of the upper green shales (Fig.7C). Body fossils are quite uncommon in most horizons, although some bedding planes contain poorly preserved molds of brachiopod valves which apparently dissolved prior to compaction.

#### (2) Sedimentology and taphonomy

This facies is composed of platy greenish gray (5GY 4/1), clay shales generally lacking interbeds. Pyrite occurs only rarely as thin linings of thread-like burrows. Burrows are generally not apparent but very fine *Chondrites* occur as vague, buff colored areas on some weathered portions of the shales.

#### (3) Paleoautecology

Chondrites may represent endichnial-mining traces (fodinichnia), that show repetitive, systematic and branched patterns. Alternately, Bottjer et al. (in press) argue that some *Chondrites* may represent tubes produced to pump anaerobic bacteria from pore waters.

#### (4) Interpretation

Chondrites and pyrite stringers, alternate with laminated beds of dark gray graptolitebearing shales in the basal beds of the Williamson. Burrows in light green matrix are commonly darker than surrounding shale; those in dark matrix are typically lighter. This contrast appears to reflect piping or backfilling of later sediment into older muds. However, strongly

The color of these shales indicates a low content of organic carbon and of iron sulfides relative to the dark gray shales (Potter et al., 1980). The greenish shale facies of the Williamson is usually devoid of body fossils, although this may partly reflect early dissolution (see below). Moreover an abundance of minute Chondrites (Figs.7C and 8C) in these shale layers indicates low oxygen (dysaerobic) conditions near the substrate (Bromley and Ekdale, 1984: Savrda and Bottier, 1987a). Horizons with Chondrites in otherwise unburrowed shales indicate temporary slight oxygenation of the seafloor. As a whole, the trace fossils within the Williamson represent offshore environments probably in depth ranges well below wave base and rarely affected by storms. The absence of Chondrites in laminated shales containing well-preserved graptolites may reflect anoxic conditions or very rapid suspension and redeposition of sediments which obliterated traces and laid down layers that were too thick to be later penetrated by burrows. Pervasive burrowing of the upper Williamson beds indicates relatively slow deposition which allowed fairly thorough bioturbation.

Teichichnus and indeterminate pyritic burrows occur in thin (2 cm thick) beds of pale greenish sandstone within greenish shales (Fig.7A, B). Small pyrite nodules and pyritic

Fig.7. Stratification and trace fossils of the Williamson Shale. A. *Teichichnus* trace fossil from unit 11 at Genesee Gorge East (Loc. 2A). B. Polished slab contains *Teichichnus* associated with pale greenish sandstone with green shale partings from unit 11 at Genesee Gorge East (Loc. 2A). C. Polished drill core displays distinctly compacted trace fossils; upper part of the Williamson Shale from Rochester area. D. Polished slab of concretion displays internal lamination; surrounding shales exhibit approximately two-fold differential compaction relative to concretion; unit 5 at Genesee Gorge East (Loc. 2A). E. Sharp base of the coquinoid limestones with gutter casts or scour marks; unit 38; Second Creek (Loc. 5). F. Polished core displays intimately interbedded greenish clay shales and black, laminated shales. (arrow indicates sharp contact; note convex down shell of brachiopod); Rochester area. G. Polished slab of fine-grained sandstones and laminated siltstones, unit 33; Second Creek (Loc. 5). H. Basal conglomerate bed at Second Creek (Loc. 5); arrow shows the contact of Williamson Shale and Wolcott Furnace Shales.

![](_page_9_Figure_1.jpeg)

![](_page_9_Picture_2.jpeg)

![](_page_9_Picture_3.jpeg)

![](_page_9_Picture_4.jpeg)

burrows are associated with the *Teichichnus* occurrences. The distribution of these facies was probably controlled by greater oxygenation and/or the deposition of coarser sand substrates.

Monograptid-"Chonetes" cornutus association: dark gray to black shale facies

# (1) Fossils

The Monograptid-"Chonetes" cornutus association contains abundant Monograptus clintonensis and a few Retiolites graptolites, brachiopods, including small specimens of Eoplectodonta transversalis, Atrypa reticularis, and Leptaena "rhomboidalis", "Chonetes" cornutus, Skenidioides pyramidale, Whitfieldella? sp. (one bed only), the ostracodes Beyrichia, Mastigobolbina typus and Dibolbina (Table I). Orthoconic nautiloids and tentaculitids are found immediately below the graptolite-bearing shales in the Genesee Gorge but maybe reworked from the underlying Lower Sodus Shale in which they are abundant (Fig.8D; Table I). Very abundant individuals of the brachiopod "Chonetes" cornutus, are found in some of the graptolite-bearing layers. Gillette (1947) also reports Clorinda fornicata and Chaetetes lycoperdon at Rochester, but these reports could not be confirmed.

### (2) Sedimentology and taphonomy

The Monograptid-"Chonetes" cornutus association occurs in dark gray to nearly black (N3-N1) or rarely dark greenish gray (5GY 5/1), fissile to platy, laminated shales. This facies ranges from smooth clay shale to slightly silty shale. Dark bands within the Williamson tend to be somewhat more resistant than the green clay shales and may weather from the bank as ledges. Bases of the dark bands are commonly sharp and display evidence of erosion of the underlying units (Fig.7H). Individual black bands are correlatable for distances of tens of kilometers (see Lin and Brett, 1988). The dark shales contain minor pyrite aggregates in the form of small (usually 1-2 mm) spheroids, as drusy coatings on bedding planes, or rarely as infillings of fossil nautiloids and graptolite rhabdosomes.

Dark shales are commonly interbedded with thin (0.5-1.0 cm) to very thinly-laminated, finegrained quartz arenites (Fig.7G). Thin sections of these sandstones and siltstones show thin quartz sand/silt laminae (<2 mm thick), alternating with layers of muds containing bioclasts (<1 mm in diameter) possessing abundant pyrite coatings (Fig.9A). Laminated beds from Tryon Park display reworked, aligned pyritized burrow fillings and brachiopod valves on lower surfaces (Fig.8A), immediately overlying graptolitic shales. Abundant disseminated late diagenetic pyrite is present.

Graptolites vary in completeness from nearly entire pyritized rhabdosomes to carbonized fragments. They are typically found in dense aggregations displaying preferred orientation of individuals with dominantly unimodal distributions (see above). Bedding planes commonly bear abundant fossil debris including small specimens (<1 cm) of *Eoplectodonta*, Atrypa and chonetid brachiopods that may be partly or wholly replaced by pyrite. Thin, pyritic, threadlike burrows (less than 2 mm in thickness) occur in the basal 2 cm thick, dark, graptolite-bearing shales; larger pyritic burrows in the dark gray shales are restricted to higher horizons.

Fig.8. Sediments and fossils in the Williamson Shale. A. Dark gray shale with *Eoplectodonta* brachiopods (a), reworked pyrite burrows (b), and tentaculitids; lower Williamson Shale, Tryon Park (Loc. 3). B. Thin layer displays convex upward *Whitfieldella* (?) brachiopod valves (a), with lunate scour marks around their margins (b), unit 6; Genesee Gorge East (Loc. 2A). It indicates the probable southwest flowing currents; penny gives scale. C. Slab shows small *Chondrites* burrows associated with *Monograptus* graptolites; lower Williamson Shale, Tryon Park (Loc. 3). D. Slab shows oriented tentaculitids (a), ostracodes (b), and *Eoplectodonta* brachiopods (c); Lower Williamson Shale, Genesee Gorge West (Loc. 1). E. Monograptid-"*Chonetes*" association. Slab displays oriented *Monograptus* (a) *Retiolites* (b); Lower Williamson Shale, Second Creek (Loc. 5).

#### TABLE I

Fossil distribution in the Late Llandoverian Williamson and Willowvale shales of New York and upper Rose Hill Formation of Pennsylvania. Symbols: M-"C": Monograptid-"Chonetes", E-A: Eoplectodonta-Atrypa, P-b: Palaeocyclus-bryozoan, E-"C": Eocoelia-"Chonetes". g: report by Gillette (1947), c: common, cc: abundant, s: report by Swartz (1934), x: present, z: report by Rickard and Zenger (1964). \* probably reworked from Lower Sodus Shale into the basal beds of Williamson. RC: drill core, Rochester; GG: Genesee Gorge, Rochester; SM: Salmon Creek west, Williamson; SC: Second Creek, Sodus; LW: Little Wolcott Creek, Wolcott; PH: Phoenix, Schroeppel; BR: Brewerton, Cicero; VR: Verona Station (Thruway cut), Verona; DQ: Dawes Quarry Creek, Kirkland; WV1: Willowvale Glen (upper), New Hartford; WV2: Willowvale Glen (lower), New Hartford; OH: Ohisa Creek, Stark; VH: Van Hornesville, Stark; PA: Rose Hill Formation (Mastigobolbina typus zone), Pennsylvania.

Fossils	Benthic assemblages													
	(BA-	-5)			(BA-	4)				(BA-3)	)		(BA-	2)
	Associations M-"C"			E-A				<i>Р</i> -ь			<i>E-"C"</i>			
Location	RC	GG/	SM	SC	LW	PH	BR	VR/	DQ	WV1	WV2/	OH	VH	PA
Algae? (Receptaculitida) Ischadites planoconvexum			1			x		x						
Porifera (Sclerospongidae)														
Chaetetes lycoperdon		?g			g			x		g				
Cnidaria (Rugosa)														
Enterolasma caliculum			g	х	x	g	g	х						
Palaeocyclus rotuloides							g	g	с	с	g			
(Tabulata)														
Favosites								x	x					?
Bryozoa														
Acanthoclema asperum								x		g				
Ceramopora imbricata								x		g				
Eridotrypa striata								x		g				
Fenestella elegans								cc	х	g				
Mesotrypa nummiformis								?			g			
Phylloporina asperato-striata								x	x					
Rhinopora verrucosa								x		g				
Semicoscinium tenuiceps								с	x	g				
Brachiopoda														
Atrypa reticularis	x	x	g	с	с	с		c	x	g	g	x		s
Atrypina disparilis				g	g	g		x	g					
"Chonetes" cornutus	x	с	x	g	g	g	g	?	g	g		с	c	S
Clorinda fornicata		g?												
Coolinia subplana			g?				g	x	g	g	g	x	x	
Costistricklandia lirata								x						
Cyrtia meta			g	g		g	g	x	g					
Dalejina hybrida					g	-		x	x					x
Dicoelosia biloba	x	g	?			g	g	x		g	g			
Dolerorthis flabella		-		g		-	-	x		-	-			
Eocoelia sulcata				-		g?	g?	x	g	g	g	cc	cc	cc
Eoplectodonta transversalis	x	x	g	c	c	c	c	cc	x	g	g			s
Eospirifer radiatus			g	x	g	x	g	c	g	g	g			
Hedeina eudora			1		g									s
Leptaena rhomboidalis		g	g	x	x	g	g	с	g	g	g	x	x	s
Lingula lamellata							g	?	g					
L. perovata												z	z	
Nucleospira pisiformis										g?	g?			
"Orthis" tenuidens				g		g				g	g			
Pholidops squammiformis			g	x	x	x		x	g	<del>-</del>	77	z	z	
Plectatrypa nodostriata					g	g		x		g				
Protomegastrophia profunda					Ť				g	g				

#### TABLE I (continued)

Fossils	Benthic assemblages													
		-5)			(BA-	4)				(BA-3)	)		(BA-	2)
		Associations M-"C"			E-A				P-b			E-"C"		
Location	RC	GG/	SM	SC	LW	PH	BR	VR/	DQ	WV1	WV2/	OH	VH	PA
Strophodonta corrugata				g	g	g		x						
Resserella elegantula			g	g		g		x	g	g	g			
Rhynchonella bidens			g			g		x		g		Z	Z	S
Skenidioides pyramidalis		g	g	g	g	g	g	?	g					
Stegerhynchus acinus							g	x	g	g				
S. neglectum								х		g	g	х	x	
"Strophodonta" corrugata				g	g	g		x						
Strophoprion patenta										g	g	z	Z	с
Whitfieldella intermedia										g	g	x	x	
W. ?sp. cf. W. oblata		x	x	x										
W. oblata														s
Bivalvia									~					
Cornellites emaceratum				~		~	g		g	C	~	*	x	5
Cienoaonia macirijormis				g		g	B		B	S	B	*	A	
Leptodesma rhomboidea							a		σ	c		x	x	
Pyrenomoeus cuneatus							ь		ъ	ø	ø	x	x	
Gastronoda										0	0			
Cyclonema varicosum							g	x	g	g	g	x	x	
Hormotoma subulata (sulcatum)		g		g		g	?	x		g	2	x	x	
Strophostylus cancellatus		0		0							g			
Cephalopoda (Nautiloidea)											200			
Dawsonoceras annulatum								x	g	g				
Orthoceras bassleri		x	g			g		x	g	?			x	
Trilobites														
Dalmanites limulurus				g		g	g	?	g	g	g			S
Liocalymene clintoni			g	g	g	g	g	x	g	g	g	Z	z	s
L. niagarensis									g			Z	Z	
Ostracodes						. de				1.00	1.1			
Beyrichia aff. lakemontensis		g	g	g	g	g	g	•	g	g	g	•	•	s
Diboloina n. sp.		g	g	g	g	g	g		g		~	•		
Mastigoooloina punciala		g	g	g	g	g	s		g	s	8	•		e
M. tritooata		s	g	~	g	B	g	•	5	8	6		. 7	e
Plathoholbing tunicalis		5	8	6	5	5	5	•	5	8	5	7	7	s
Zygosella cf vallata												Z	Z	s
Grantolithina (Grantoloidea)													- 5	
Monograptus clintonensis	с	с	с	с	с	x	x	x	g	g				
Retiolites venosus		x	x	x	x	g	g		g	g				
(Dendroidea)							~							
Dictyonema gracilis			g			g	g		g	g				
Reticulograptus retiforme			g			g	g		g	g				
Incertae sedis														
Conularia niagarensis				g										
Tentaculites sp.		c*									x	x	x	c
Crinoidea														
Periechocrinitid sp.														
(Large root system)								x	x	x	x			
Protaxocrinus n. sp.								x		x				
Asteroidea														
Faleaster : sp.				x										

![](_page_13_Picture_1.jpeg)

Fig.9. Thin sections of coquinoid limestone and quartzose sandstones of the Williamson Shale. A. Quartzose sandstone, unit 33; Second Creek (Loc. 5). B. Coquinite bed shown in Fig.7C displays a winnowed accumulation of chaotically oriented brachiopod shells with calcite cement between the shells, Second Creek (Loc. 5).

As noted, light olive gray (5Y 5/2), ellipsoidal, carbonate concretions with aligned long axes up to 10 cm long and up to 2 cm in thickness are found in the lower part of the Williamson Formation of Genesee Gorge East (Loc. 2A). They occur within laminated, dark gray, silty shales with a layer of *Whitfieldella* (?) brachiopods and very abundant specimens of *Monograptus* at the top, and small (0.5 cm) pyrite nodules at the base. Concretions display alternating dark gray to black laminae, continuous with those in the surrounding shales (Fig.7D). However, the laminae are more widely spaced within the concretions and converge toward the margins indicating approximately two-fold differential compaction of shales relative to concretions.

#### (3) Paleoautecology

Life habits of *Monograptus* are essentially unknown, but graptoloids are believed to have been epiplanktonic, or weakly nektonic. *Monograptus* rhabdosomes, though occasionally quite long (more than 20 cm), are invariably incomplete. Floats or holdfast attachments were not observed in this study. Most of the associated brachiopods e.g. "*Chonetes*" cornutus and Eoplectodonta were reclining epifaunal suspension feeders (see below).

#### (4) Interpretation

The dark gray to black beds of the Williamson appear to have been deposited mainly in restricted, oxygen deficient environments, with minor fluctuations into better oxygenated or anoxic conditions. The laminated, nonbioturbated nature of the lower dark beds indicates anoxic conditions within the sediment to near the sediment-water interface. Certain beds also yield a low diversity benthic assemblage consisting mostly of small, lowlevel suspension feeding brachiopods. This fauna indicates that minimally aerobic conditions prevailed in the bottom water. The general absence of infauna suggests exaerobic conditions (Savrda and Bottjer, 1987b; cf. also the "bituminous" facies of Morris, 1979, 1980). A pelagic fauna of graptolites and perhaps nautiloids lived much higher in the water column.

Dark gray to black shales of the basal Williamson display beds containing *Chondrites* that alternate with laminated sandy sediments (Fig.7C, F). The *Chondrites* layers represent temporary oxygenation of the sea floor (0.1– 1.0 ml oxygen/l, dysaerobic environment; Savrda and Bottjer, 1987a,b) and commonly supercede graptolitic shales deposited under conditions of rapid sedimentation. Such storm layers may have been selectively colonized by the trace-makers (cf. Vossler and Pemberton, 1988).

At least some graptolitic horizons may represent storm-generated sand/mud layers. Association of graptolites with coarser sediments could have resulted from sudden importation and burial of rhabdosomes.

The clustered distribution of well preserved graptolite rhabdosomes (Fig.8E) suggests mass mortality, which could have resulted from overturn or upwelling of anoxic water during storms. Graptolites then sank to the bottom, were subject to varying degrees of transportation, reworking, and concentration and were subsequently buried.

Alignment of graptolite rhabdosomes suggests that mass mortality and rapid burial were accompanied by moderate current action on the seafloor. Fragmentation of graptolites in some beds may indicate brief periods of reworking of skeletons on the seafloor. Erosion of the seafloor by the same currents is indicated by scour marks and the presence of reworked pyrite clasts derived from underlying muds. This evidence indicates that the quartzose sandstones and siltstones and interlaminated graptolitic shales were deposited by episodic strong currents in otherwise low energy anaerobic to dysaerobic environments. Consistent long axis alignments of graptolites parallel to basal tool marks indicate that the entire bed of interlaminated fine sand and mud was laid down during a single current emanating from the N to NE. Evidence for differential compaction around concretions suggests that dark gray muds and silts were originally waterrich.

Occurrence of abundant graptolites, in part, certainly reflects a preservational bias. The organic-walled rhabdosomes of graptolites may have been disintegrated by scavenging and possibly bacterial action; they are rarely found in fully oxic sediments. The preservation of graptolites was considerably enhanced by burial in anoxic, organic-rich sediment. Early pyrite diagenesis also aided in preservation of some Williamson graptolites. Such pyritization may have resulted from burial of rhabdosomes with intact soft tissue which provided a reductant for sulfate-reducing bacteria.

Geochemical studies demonstrate that much pyrite forms in the upper few meters of sediment in direct contact with sea water (Fisher and Hudson, 1985; Raiswell and Berner, 1985). Graptolites infilled with pyrite are inflated and robust in contrast to other coalified specimens which are highly compressed; similarly the pyritized nautiloids show lesser degrees of compaction than nonpyritic specimens and display brittle fracturing of pyrite linings. Moreover, there is evidence for reworking of pyritic burrow tubes on the seafloor. Thus pyritization within this facies probably developed very early, prior to compaction (burial of about 5 m; Allison, 1988), in response to local, organic-rich microenvironments in otherwise anoxic but organic-poor, nonsulfidic sediments (see Brett and Baird, 1986; Allison, 1988 for discussion).

Berry and Boucot (1972) considered the Monograptus priodon-Retiolites genitzianus association to be a shallower water graptolite biofacies-probably belonging to BA-2 or BA-3 (i.e. inner shelf muds associated with Eocoelia biofacies); they cited the Williamson and Willowvale shales as a typical example of this type of occurrence. However, all evidence presented in this paper (including brachiopod biofacies) indicates that the Williamson was deposited in deeper, offshore settings, probably near the center of a density-stratified basin; the associated brachiopods-(Eoplectodonta, "Chonetes", Dicoelosia, Skenidioides) would favor a BA-4 to BA-5 assignment, comparable to many graptolitic shales of the Welsh Basin. Sedimentological evidence also indicates that these sediments accumulated in environments episodically affected by storm-generated gradient currents, but not directly by storm waves.

We do not mean to imply that *Monograptus* and *Retiolites* represent deep water graptolites. The shallow water occurrence of these graptolites has been further confirmed by Mu et al. (1986); and, as noted below, they do occur in relatively nearshore, shallow water facies of the Willowvale as well as the offshore William-

![](_page_15_Picture_0.jpeg)

![](_page_15_Picture_1.jpeg)

son beds. This is the expected distribution pattern of a shallow-floating pelagic organism; the rhabdosomes probably settled after death uniformly to shallow as well as deeper water seafloors. The abundance of the monograptid-"Chonetes" cornutus association in offshore, dark gray Williamson facies probably reflects primarily favorable circumstances. Unexplained at present is the absence of deeper water graptolites from the Williamson, and all other Silurian offshore facies in the central Appalachian Basin. Possibly the larvae of these graptolites floated deeply and were excluded from entering the Appalachian Basin by surrounding shallow water platforms; in contrast shallow floating larvae of monograptids and various brachiopods were not excluded (see also Boucot, 1975).

# *Eoplectodonta-Atrypa* association: gray shale facies

#### (1) Fossils

This is primarily a brachiopod-dominated association, with moderate diversity assemblages (species richness 20-25 species in richest beds: Table I). The brachiopods Pholidops squammiformis, Eoplectodonta transversalis, Atrypa reticularis, Leptaena rhomboidalis, Coolinia sp. and "Orthis" tenuidens are locally very abundant. Less common species include Atrypina disparilis, Cyrtia meta, Eospirifer radiatus, "Chonetes" cornutus, "Strophodonta" corrugata, Resserella elegantula and Rhynchonella bidens (see Gilette, 1947). Gillette (1947) reports abundant Dicoeosla biloba and Skenidioides pyramidalis, although these minute orthid brachiopods appear to be confined to thin layers in the uppermost beds of the Williamson Shale associated with Eoplectodonta and Atrypa. Associated fossils include the trilobite Liocalymene clintoni (Fig.10D), poorly preserved bivalves and nautiloids, the ostracodes Beyrichia, Dibolbina and Mastigobolbina, and rare specimens of the solitary rugose coral Enterolasma; a single articulated starfish was found in the uppermost part of Williamson (Table I). Thin dark layers with abundant, mostly fragmented Monograptus are interbedded with the Eoplectodonta-Atrypa association. Slabs of olive gray shale identified as "Willowvale Shale from Verona Station, N.Y." in the New York State Museum, display bedding planes covered with the receptaculitid Ischadites planoconvexa (see Nitecki, 1972). Associated brachiopods on these slabs suggest the Eoplectodonta-Atrypa association. We have recently discovered specimens of Ischadites from a similar litho- and biofacies in blocks of probable upper Williamson Shale and in the lower beds of the Irondequoit Formation, which overlies the Williamson, and contains a Plectodonta and Clorinda dominated fauna.

#### (2) Sedimentology and taphonomy

The Eoplectodonta-Atrypa association occurs mainly in the olive gray (5Y 4/1) to blueish gray (5B 5/1) shales, and in interbedded shellsupported coquinoid limestones (Fig.11A-C). Brachiopods from dark greenish gray shales are commonly moldic or partially dissolved. They are predominantly in convex-down orientations (56-85%) (see Appendix I) and the valves contain mud consistent with surrounding matrix. The high percentage of convex down orientation of brachiopod valves suggests burial in life position, or by settlement after stirring from the bottom by waves. Coquinites are scattered, commonly lenticular, bluish gray (5B 5/1) beds, 2-4 cm in thickness, mainly composed of the brachiopods Atrypa and Eoplectodonta. Elongate lenses of bra-

Fig.10. Fossil associations of the Williamson-Willowvale shales. A-D. Eoplectodonta-Atrypa association; unit 39, Second Creek, Alton, N.Y. (Loc. 5). A. Note abundant Atrypa sp. (a) and Eoplectodonta transversalis (b) brachiopods. B. Shows reclined Atrypa with extensive frills (a), Eoplectodonta (b), and small orthid brachiopods (c). C. Leptaena rhomboidalis brachiopod. D. Articulated trilobite Liocalymene clintoni. E. Palaeocyclus-bryozoan association; Palaeocyclus corals (a), and fenestellid and ramose bryozoans (b); Willowvale Shale, The Glen, Chadwicks, N.Y. (Loc. 12). F. Specimen of the large brachiopod Costistricklandia lirata; Willowvale Shale, Verona Station, N.Y. (Loc. 9), white bar=4 cm.

![](_page_17_Figure_1.jpeg)

Fig.11. Coquinite beds of the Williamson Shale. A,B. Polished coquinoid limestone slabs from the Williamson Shale at Little Wolcott Creek (Loc. 6). A. Shows fining upward with brachiopod coquinite grading upward into laminated to cross-laminated calcisiltites; note predominance of convex-downward orientations in concave-convex *Eoplectodonta* brachiopods. B. Displays well-preserved *Eoplectodonta* and *Atrypa* brachiopods, note geopetal structures in shales. C. Polished coquinoid limestone slab of the Williamson Shale from Second Creek (Loc. 5) displays a partly winnowed, dense accumulation of brachiopod shells; note spar filling areas between brachiopods.

chiopod coquinite appear to represent gutter casts.

Fine grained cross-laminated calcisiltites gradationally overlie some of the brachiopodsupported limestone layers (Fig.11A, B). Coquinoid limestone beds often have sharp bases (Fig.7E), and contain abundant greenish gray mudstone intraclasts (Fig.11C). Thin sections reveal abundant pyrite coatings on disarticulated brachiopods within the coquinoid limestones (Fig.9B). Pyritic burrows are also found in greenish gray shales associated with these coquinoid limestones.

#### (3) Paleoautecology

This association is dominated by low-level epifaunal to semi-infaunal brachiopods (Fig.10A-C). Atrypa reticularis, which is commonly the dominant species, probably reclined on its pedicle valve; the presence of broad, marginal frills on specimens in the upper Williamson suggests an adaptation for increased bearing area, in response to soft substrates. Eoplectodonta, Leptaena and Coolinia were also adapted to a very low epifaunal to semiinfaunal mode of life and probably rested on their convex pedicle valves. These brachiopods were well adapted to soft plastic muds; evidently they were able to cope with relatively low oxygen levels, as they also occur in the dark gray nonbioturbated shales of the Williamson.

High level suspension feeders, such as bryozoans and crinoids, generally are very rare in this association, perhaps reflecting paucity of suspended food or low oxygen levels and/or absence of sufficient turbulence for passive suspension feeding. Vagrant epifauna, possibly detritus feeders, are represented by calymenid trilobites, rare starfish and *Cyclonema* gastropods. The receptaculitid *Ischadites* was most probably a photoautotrophic alga. Although the affinities of receptaculitids are still enigmatic, most recent studies of these fossils suggest that they were a type of heavily calcified algae (see Beadle and Johnson, 1986; Beadle, 1988 for recent reviews).

#### (4) Interpretation

The lithological characteristics of olive gray to medium bluish gray shales and moderately diverse benthic fauna suggest better bottom oxygenation than in the deeper Monograptid-"Chonetes" cornutus or Chondrites associations. Brachiopods display greater average size than those in the Monograptid-"Chonetes" *cornutus* association. However, interfingering with the latter association indicates a similar, probably adjacent, bathymetric position.

Predominant convex down brachiopod orientations in shales suggests undisturbed burial in low energy environments (Appendix I). Articulated specimens of *Liocalymene*, ostracodes and other delicate fossils point to episodes of very rapid mud sedimentation.

The coquinites from Second Creek and Little Wolcott Creek closely resemble graded storm lag deposits described by Kreisa (1981), Kreisa and Bambach (1982), Aigner (1982, 1985), and others. Williamson coquinites display abundant evidence of episodic scouring of the seafloor by storm waves and redeposition including sharply demarcated bases with sole marks, brachiopod valves with evidence of mud sheltering and/or sediment screening, and upward gradation into laminated to crosslaminated siltstone with hummocky ripples. Shell beds at Second Creek and Phoenix, also display elongated gutter casts on their bases resembling those described by Aigner (1982). Coquinoid limestones and gutter casts in this Williamson biofacies are interpreted as tempestites resulting from the combined action of storm waves which scoured the seafloor and aggregated shells, and basinward directed gradient currents that deposited fine sands and silts transported from shoreward areas.

The great abundance of brachiopod shells in these coquinites as compared to background shales may reflect varied processes. The relatively thick, persistent coquinites may record periods of low net deposition during which shells grew and accumulated on the seafloor by event condensation (cf. Fürsich, 1982). However, the difference may also reflect taphonomic bias; there is evidence for partial solution of shells within greenish shales. Sepkoski (1978, 1982) and Kreisa and Bambach (1982) note that shells in aggregations are better buffered against acidity and may be well preserved, while those in carbonate-poor muds were subject to dissolution.

Poorly preserved molds of the brachiopods Atrypa, Eoplectodonta, and Coolinia are found

in dark greenish shales at Little Wolcott Creek (Loc. 6). In some cases only thicker portions of the brachiopod valves remain calcified; atrypids from the upper Williamson show decalcification of their thin frills whereas the thicker portions of their shells remain calcified but perhaps somewhat reduced in thickness. Molds of Atrypa frills display deformation and apparently underwent early dissolution prior to compaction of the muds. It is notable that shells are commonly better preserved in black or dark gray than in green bioturbated shales. This is consistent with observations of shell dissolution in modern marine muds (Aller, 1982; Reaves, 1986). Fluctuating oxidation states within bioturbated muds of dysaerobic settings enhance dissolution of carbonates. In some modern environments iron sulfides precipitated in near surface anoxic muds are periodically oxidized (either by storm disturbances or bioturbation) forming sulfuric acid. which lowers pH and causes carbonate dissolution (Aller, 1982).

The moderate diversity of benthic invertebrates in the *Eoplectodonta-Atrypa* association suggests near-normal oxygen levels, at the sediment-water interface. Occurrence of *Dicoelosia* and rare *Skenidioides* but absence of *Clorinda* in the *Eoplectodonta-Atrypa* association indicates that this association belongs to an offshore benthic assemblage (BA-4 to BA-5, see Ziegler, 1965; Boucot, 1975). The coquinoid limestones suggest that, at least in part, the *Eoplectodonta-Atrypa* association lived above storm wave base, probably in less than about 50-60 m of water.

The discovery of receptaculitids from the Willowvale-Irondequoit interval is also of considerable importance. Although the exact affinities of receptaculitids are debated, they probably represent a problematic calcareous algae (Nitecki, 1972; Beadle and Johnson, 1986; Beadle, 1988). [see Brett et al., in press for more detailed discussion of the problems involved in interpreting absolute depth from algae]. Therefore, their occurrence in the *Eoplectodonta-Atrypa* association may indicate that, at least parts of this association occurred in the

in the Willowvale Shale indicates that this association belongs partly to Boucot's (1975) BA-4. Much of the Willowvale Shale was deposited in moderately shallow marine environment that supported a diverse fauna. This facies should probably be assigned to BA-3 to 4 despite the lack of diagnostic brachiopods, because of the abundant bryozoans and by analogy to Rochester Shale bryozoan beds (Brett, in press). As in the previously discussed Eoplectodonta-Atrypa association, abundant winnowed coquinoid limestones occur within this association. This indicates that the Palaeocyclus-bryozoan association existed in water depths of between normal and average storm wave base (probably about 20-50 m). It is probably somewhat shallower than the Eoplectodonta-Atrypa association as it contains a greater abundance of coquinoid limestones and, in eastern sections, more fine grained sandstone and siltstone layers. It also lies shoreward of the latter assemblage (Fig.12), and offshore of the Eocoelia-"Chonetes" cornutus association. Association of Palaeocyclus with *Costistricklandia* in the Willowvale Shale indicates that this association belongs partly to Boucot's (1975) BA-4.

Eocoelia sulcata-"Chonetes" cornutus association: olive gray shale facies

#### (1) Fossils

Low diversity assemblages (richness=10-15 species, Table I), strongly dominated by brachiopods and bivalves, characterize Willowvale outcrops east of Utica area in eastern N.Y. They also typify correlative beds in the upper Willowvale Shale of Pennsylvania. Brachiopods form mono- or paucispecific assemblages on bedding planes including Eocoelia sulcata, Chonetes cornutus, Atrypa reticularis and Leptaena rhomboidalis. Poorly preserved bivalves (Ctenodonta, Cornellites, Leptodesma, Pyrenomoeus) and the ostracodes Dibolbina and Mastigobolbina are abundant on many bedding planes; others are barren or with only obscure burrows. Graptolites have not been found.

![](_page_19_Figure_6.jpeg)

Fig.12. Bathymetry and paleoecology of late Llandoverian (Silurian) benthic assemblages. GG = Genesee Gorge, Rochester, SM = Salmon Creek West, Williamson, SC = Second Creek, Alton, BR = Brewerton, Cicero, VR = Verona Station, (Thruway cut), Verona, VH = Van Hornesville, Stark.

### (2) Sedimentology and taphonomy

Fossils occur on bedding planes within yellowish weathering olive to greenish gray crumbly shales. Most brachiopods are disarticulated and commonly fragmented. Shells typically occur in convex up pavements of single valves. As in other beds of the Williamson-Willowvale, shells display partial dissolution and are preserved as molds.

Thin beds of laminated fine-grained greenish gray sandstone with sharply defined soles displaying convex up shells and are interbedded with the shales.

Brachiopods, mainly *Eocoelia*, may occur in densely packed, lenticular coquinites 1-10 cm in maximum thickness. These beds display sharp bases and chaotic internal arrangement of shells, such coquinite lenses are very abundant in the equivalent upper beds (*Mastigobolbina typus* zone) of the Rose Hill Formation in Pennsylvania (Swartz and Swartz, 1931; Swartz, 1934) but rare in the equivalent Willowvale in eastern New York.

#### (3) Interpretation

This association is very similar to previously described Eocoelia communities (Ziegler, 1965; Ziegler et al., 1968; Cocks and McKerrow, 1984). As with the latter, we infer that the eastern Willowvale Shale and its counterpart in the upper few meters of the Rose Hill Shale in Pennsylvania, were deposited in shallow, inner shelf muddy seafloors. Assignment to benthic assemblage 2 seems reasonable; see Berry and Boucot (1972). In New York State, the eastern shoreline facies are not seen because the Willowvale Shale is truncated by a later (late Silurian, Salinic?) erosion surface beneath the Syracuse Formation (Rickard and Zenger, 1964). However, in Pennsylvania, the upper Rose Hill, bearing the Eocoelia sulcata-"Chonetes" association grades eastward into purplish shale with distinct coarsening upward sandstone cycles; a few kilometers to the east, this passes into the Lizard Creek Sandstone Member of the Shawangunk Formation (Swartz and Swartz, 1931). However, Eocoelia communities in the upper Sauquoit beds, which underlie the Willowvale in eastern New York, grade into reddish marginal marine sandstone (Otsquago facies) within a distance of about 15-30 km E of the Verona-Willowvale area of optimal development. All of this suggests that the *Eocoelia sulcata-"Chonetes" cornutus* association existed only a few tens of kilometers offshore. The background sediments consisted of muds indicating generally low energy conditions apparently reflective of a quiet water nearshore belt ("Z" zone of Irwin, 1965).

Thin sandstones and coquinites display wave-formed ripples and evidence for multiple winnowing indicating episodic turbulence events on the seafloor. Low diversity-very high dominance associations of brachiopods and small bivalves that typify this biofacies appear to reflect hardy, opportunistic species that existed in local dense populations in a stressed shallow water environment. It is notable that one of the species, "Chonetes" cornutus, also occurred in prolific assemblages in offshore areas stressed by oxygen deficient conditions.

In the eastern Willowvale Formation and, particularly in the Rose Hill Formation, evidence suggests that stress factors may have included high turbidity, episodic and rapid deposition, and, perhaps, slight fluctuations in salinity. This physically stressed environment apparently was unfavorable to most high level suspension feeders. Crinoids and bryozoans decline markedly in the transition from the *Palaeocyclus*-bryozoan association. In contrast, infaunal bivalves (*Ctenodonta, Pyrenomoeus, Modiolopsis*) were much more abundant than in the western biofacies.

A curious anomaly of the Willowvale biofacies is the near absence of typical BA-3 pentamerid assemblages, at least as a "high energy" or "shoal type" fauna. Rather, the shales bearing *Palaeocyclus*-bryozoan biofacies appear to grade directly into seemingly similar shales containing the BA-2 *Eocoelia*-"Chonetes" cornutus associations.

The crinoidal, *Palaeocyclus* and bryozoan bearing limestones appear to be a hint of the high energy offshore belt. Also, the Willowvale and overlying Dawes Formation contain the greatest frequency of sandstone beds near Clinton, New York; while both units consist predominantly of shale in a eastern (shoreward) direction. This may indicate the presence of a zone of wave dissipation ("Y" zone of Irwin, 1965) offshore of low energy inner shelf muds (BA-2-Eocoelia biofacies).

#### Discussion

### General bathymetric model for upper Clinton Group biofacies

Williamson-Willowvale fossil assemblages can be subdivided into five recurring associations (Figs.12 and 13), as follows: (a) Chondrites association, (b) Monograptid-"Chonetes" cornutus association, (c) Eoplectodonta-Atrypa association, (d) Palaeocyclus-bryozoan association, and (e) Eocoelia sulcata-"Chonetes" cornutus association. The spectrum of fossil

		WILLIAMSON- WILLOWVALE ASSOCIATIONS	SILURIAN COMMUNITY EQUIVALENTS	ICHNO- FACIES	OXYGEN	DEPTH	S TORM BED
	<b>BA-2</b>	EOCOELIA- "CHONETES"	EOCOELIA	ITES VUS	YC	E BASE NE	! t
MBLAGES	BA-3	PALAEOCYCLUS- Bryozoan	STRICKLANDIA- ISORTHIS	PLANOL	AEROI	ORM WAVE	OQUINITE
ASSE	BA - 4	EOPLECTODONTA- ATRYPA	CLORINDA- DICOELOSIA	HTES	LOWER	ABOVE ST EUP)	LAVER
BENTHIC	BA - 5	MONOGRAPTID- "CHONETES"	VISBYELLA	CHONDE	ROBIC	LOW M W.B.	FINES
			GRAPTOLITE	NO	DYSAE	BESTOR	

Fig.13. Biofacies and bathymetry of the Williamson-Willowvale interval. The Monograptid-"Chonetes" and Chondrites associations represent deeper water condition and forms are similar to the Visbyella communities of the Welsh Borderland (cf. McKerrow, 1978); the Eoplectodonta-Atrypa and Palaeocyclus-bryozoan associations are successively shallower water and closely resemble the Dicoelosia and Stricklandia communities of the Welsh Borderland. Evidence of storm-generated deposits in all biofacies also suggests the waters were not very deep, instead they represent dysaerobic to fully aerobic settings, with water depths of about 50-80 m, at the deepest.

associations appears to parallel increasing frequency of bottom disturbance by waves and currents from deeper basinal areas to a higherenergy, shallow shelf setting; this is again replaced, eastward, by low energy facies. In general the biofacies appear to have been elongate parallel belts along the onshoreoffshore gradients of the Williamson-Willowvale sea. The monotonous green platy shales of the Chondrites association were deposited in low energy settings rarely disturbed by storm event deposition. These probably accumulated below deep storm wave base. The Monograptid-"Chonetes" cornutus association of the Williamson probably represents relatively deep water, normally low energy dysaerobic settings, episodically influenced by storm induced gradient currents, about 50-80 m deep. The more diverse Eoplectodonta-Atrypa association intergrades with the Monograptid-"Chonetes" cornutus association but apparently represents slightly better oxygenation, as evidenced by increased brachiopod size, faunal diversity and the blueish to greenish gray coloration of shales. This environment was probably also slightly shallower, as indicated by a higher frequency of graded coquinites. These beds suggest occasional effects of deep storm waves directly on the bottom. In addition the occurrence of probable algal fossils (receptaculitids) probably demonstrates deposition in lit waters. The Palaeocyclus-bryozoan association developed in relatively shallow water frequently affected by storm waves and within the euphotic zone. Finally, the Eocoelia sulcata-"Chonetes" association represents a shallow water but relatively low energy inner shelf mud belt.

#### Comparison with other communities

Williamson-Willowvale fossil assemblages contain many genera in common with other Silurian assemblages and thus permit direct comparison with previously described communities.

Studies of the Rochester Shale fauna (Silurian; Wenlockian) and depositional environ-

ments in western New York (Brett, 1983) vielded six intergrading fossil associations as follows: (1) Chondrites, (2) Amphistrophia-Dalmanites, (3) Striispirifer, (4) Atrypa-bryozoan patch, (5) encrinites, and (6) fistuliporoid bioherms. The Chondrites association is common to both. Apparently, the Monograptid-"Chonetes" association of the Williamson Shale has no counterpart in the Rochester Shale and thus may record unique environments more dysaerobic and/or deeper than those of the Rochester Shale. Conversely, the Amphistrophia-Dalmanites and Striispirifer associations of the Rochester are absent or poorly developed in the Williamson-Willowvale interval. These assemblages may have been adapted to higher turbidity areas unrepresented in the Williamson.

Recently, Brett (in press) further subdivided the five generalized Rochester Shale associations into a series of 12 communities, several of which are loosely comparable to the Williamson-Willowvale associations described herein. In particular, the broadly defined Atrypa bryozoan patch association (Brett, 1983) has been subdivided into the diverse ramose bryozoan-dominated Atrypa-Dicoelosia and Howellella-Striispirifer communities, typical of lower Rochester shelly mudstones in western New York: brachiopod-dominated Eoplectodonta-Dicoelosia, and Whitfieldella-Dalejina communities occupy analog stratigraphic positions in central New York. These are normally mudsupported skeletal accumulations with minor evidence for storm-winnowed layers interpreted by Brett (in press) as belonging to BA-4 to BA-5.

The strongly brachiopod-dominated Eoplectodonta-Atrypa association of the Williamson Shale is very similar to the slightly higher diversity Eoplectodonta-Dicoelosia community of the lower Rochester Shale; all species of brachiopods found in the former are also present in the latter community and the dominance of Eoplectodonta and, in some beds, Dicoelosia is typical of both associations. Brett (in press) considers the Eoplectodonta-Atrypa association to be a subcommunity of the Eoplectodonta-Dicoelosia community. A Howellella-Leptaena-fenestrate bryozoan community was proposed for diverse assemblages of bryozoan-rich pack- and grainstones in the middle beds of the Rochester Shale; this was interpreted as a BA-3, moderately high energy environment (Brett, in press). Stormgenerated calcarenites and calcirudites of bryozoans in the Rochester Shale display mixtures of well preserved and broken, abraded, and corroded fossils indicating multiple episodes of reworking and condensation of proximal tempestites; these are very similar in lithology and fauna to coquinites in the Palaeocyclusbryozoan association of the Willowvale Shale.

Thus, portions of the Willowvale and the Williamson were deposited in environments similar to those of the Rochester Shale, and, as in that unit, may have accumulated partly above storm wave base.

Calef and Hancock (1974) studied Wenlockian and Ludlovian marine communities in Wales and the Welsh Borderland and described a set of five major Silurian communities offshore from the *Lingula* community, *Salopina*, *Homoeospira* / *Sphaerirhynchia*, *Isorthis*, *Dicoelosia*, and the deepest water Visbyella community. The depth-related environmental factors determining the distribution of Silurian benthic marine communities probably included substrate, water turbulence and food supply. Increasing size of brachiopod lophophores with depth apparently reflects a limited food supply (Fürsich and Hurst, 1974).

Similarly, Hurst (1975) studied Wenlockian carbonate, level bottom, brachiopod-dominated communities from Wales and the Welsh Borderland and again recognized four basic benthic marine communities: Sphaerirhynchia wilsoni (argillaceous micrite and biomicrite phases), Isorthis clivosa, Eoplectodonta duvalii, and Visbyella trewerwa. He considered rates of sedimentation, turbulence and substrate type to be primary factors controlling distribution of brachiopods in shallow water environments.

These British communities bear many similarities to those of the New York sequence. The Monograptid-"Chonetes" cornutus association of the Williamson Shale is somewhat similar to the Visbyella association in containing a dominance of pelagic graptolites and nautiloids. In both associations, the benthic fauna is dominated by small reclining brachiopods; common taxa include chonetids, and small specimens of Eoplectodonta and Atrypa. The nominal taxa of each association, however, do not occur in the other. The Eoplectodonta-Atrypa association of the Williamson-Willowvale interval shares many characteristics with the Dicoelosia communities of Fürsich and Hurst (1974) and the very similar Eoplectodonta duvalii community of Hurst (1975). These three associations share several closely related taxa including Eoplectodonta, Atrypa, Dicoelosia, and Coolinia. Similarities between the Palaeocyclus-bryozoan association and the Isorthis communities include high diversity of brachiopods and abundant crinoid and bryozoan debris.

# Implications of late Llandoverian benthic assemblage model

Ziegler et al. (1968) studied the composition and structure of Early Silurian (Llandoverian) marine communities and described five benthic brachiopod communities in detail: (1) Lingula, (2) Eocoelia, (3) Pentamerus, (4) Stricklandia, (5) Clorinda. These communities occupied shelf regions of the British Isles, Norway, and North America in the late Llandoverian, and are thought to represent a spectrum of marine environments ranging from the coast to the limit of the shelf (Johnson, 1987). Subsequent studies of Silurian fossil communities in Britain and elsewhere have confirmed this general pattern, though the paleoecological interpretations differ (Ziegler et al., 1968; Calef and Hancock, 1974; Fürsich and Hurst, 1974; Hurst, 1975; see Boucot, 1975; Cocks and McKerrow, 1984, for a review).

In summarizing earlier Silurian studies, Boucot (1975) classified Silurian brachiopod communities into five "benthic assemblages" (BA-1 to BA-5) corresponding to Ziegler's original broadly defined "communities". As interpreted by Boucot, benthic assemblage 3 (BA-3) occurs in subtidal areas between normal wave base and the lower limit of active photosynthesis (< 80m), BA-4 and BA-5 represent areas within the subtidal zone and below the lower limit for active photosynthesis and reef-building (<150-200 m).

The Williamson-Willowvale fossil associations appear to fall in Boucot's BA-2 to BA-5 categories based on taxonomic comparison. Some portions of the Chondrites and Monograptid-"Chonetes" cornutus association bear comparison with the Visbyella community of the Welsh Borderland. Hence, these associations belong to BA-5. The main Williamson brachiopod association (Eoplectodonta-Atrypa) is clearly related to the British Dicoelosia or Clorinda communities, and in the case of the Willowvale there are hints of the Costistricklandia community. Hence, all Williamson biofacies reflect offshore communities. while the Willowvale includes the shallow shelf Palaeocyclus-bryozoan and nearshore Eocoelia associations.

The relative onshore-offshore order of these communities or benthic assemblages, first recognized by Ziegler (1965), is strongly corroborated by the results of this study of New York Llandoverian fossil associations; there does appear to be a bathymetrically related pattern, at least in the distribution of Williamson-Willowvale brachiopod associations. In that any given brachiopod association may occur in varied lithologies, from siliciclastic to carbonate, there appears to be less dependence on substrate composition. In the case of bryozoans and pelmatozoans, however, there does appear to be an association with more calcareous facies, while bivalves clearly predominate in silty mudstones and siltstones and are much less abundant in calcareous facies. As noted above, sedimentological evidence suggests that none of these facies were deposited in extremely deep water.

It is possible to place some constraints on the absolute depths of benthic assemblages 4 and 5, as they occur in the Llandoverian of New York. If these assemblages are to be based primarily on taxonomic composition, there

appear to be some fundamental problems with the bathymetric zonation, as proposed by Boucot (1975). Boucot interpreted the BA-3 to BA-4 boundary as the base of the euphotic zone. However, the occurrence of Ischadites in the Eoplectodonta-Atrypa association of the Williamson and in a Clorinda-dominated assemblage from the overlying Irondequoit Formation raises a possible problem for this interpretation. The receptaculitid fossils are well preserved and almost certainly were not transported into these assemblages. Unless previous interpretations of receptaculitids as photoautotrophic algae are incorrect, these occurrences indicate euphotic conditions for classic BA-4 to 5 associations (Clorinda, Dicoelosia). Much stronger evidence for a photic zone position of BA-4 assemblages is found elsewhere (e.g. Norway) where cyclocrinitids, almost certainly a type of dasycladacean algae, occur with stricklandiid communities (Beadle. 1988). Furthermore, abundant evidence for episodic storm wave impingement on the seafloor occurs within the Eoplectodonta-Atrypa association and, especially the Palaeocyclus-bryozoan association. This evidence includes occurrence of winnowed, sometimes graded shell beds, hummocky cross lamination, and erosional gutter casts.

Laminated fine-grained sandstones of the Monograptid-"Chonetes" association may have been deposited below storm wave base, perhaps by gradient currents. This indicates that maximum storm wave base may have coincided approximately with the BA-4 to 5 boundary. This evidence accords well with the algal evidence that these assemblages may represent approximately 20-80 m depths. In turn, this range is substantially shallower than earlier estimates of up to 200 m for analogous fossil assemblages. Based on evidence as mentioned above, the following revisions for benthic assemblage bathymetric zonation have been proposed.

The BA-3 to BA-4 boundary as defined taxonomically (e.g. *Pentamerus* to *Costistricklandia* association) does not correspond to the base of the euphotic zone, but rather should be interpreted as a shallow water zone approximately coinciding with normal or average storm wave base. Hence, BA-3 indicates a commonly high energy zone affected frequently by wave action. Assuming, as does Boucot (1975), that Dicoelosia and Clorinda associations belong to the transition zone of BA-4 to 5, this transition could be interpreted as approximately equivalent to the base of the euphotic zone. BA-4 would also represent environments affected by scouring of deep storm waves. BA-5 could be restricted to Visbyella-type communities, which were perhaps deposited below the photic zone and near the lower limit of deep storm wave effects. Because communities were controlled by many more factors than bathymetry, the benthic assemblage boundaries may not coincide in an absolute way with water depth. However, the model proposed here provides at least a first approximation of the depth zonation of benthic assemblages.

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Appendix I — Fauna census of the Williamson Shale from Little Wolcott Creek and Second Creek

I. Little Wolcott Creek (1) Dark greenish shale (5GY 4/1) Brachiopod	Disarti convex	culated convex	Articulated	
	up	down		
Atrypa reticularis	4	14	0	
Eoplectodonta transversalis	10	73	2	
Coolinia subplana	1	2	0	
Total	15	89	2	
	in the second			

Ratio for (disarticulated/articulated)=52.0 Ratio for (disarticulated convex down/total disarticulated)=89/104=0.856

(2) Coquinoid limestone Brachiopod	Disarti convex up	culated convex down	Articulated
Atrypa reticularis			11
Eoplectodonta transversalis	00	70	Ð
Total	125		16
Ratio for (disarticulated/artic Ratio for (disarticulated conv disarticulated) = 70/125 = 0.56	culated) vex down	= 125/16 = n/total	= 7.81
II. Second Creek (1) Light olive gray shale (5Y gray shale (5GY 5/1) (unit 37)	6 1) (un ]	it 36) and	d [greenish
Atrypa reticularis	1		1
Eoplectodonta transversalis Coolinia subplana	29[1] 2	[14] [3]	2[3]
Total	33	17	6
*Liocalymene clintoni **a few pyritized Monograptu	us clinto	nensis	1[1]
Ratio for (disarticulated/artic Ratio for (disarticulated conv disarticulated) = $17/50 = 0.34$	culated) vex dow	= 50/6 = 8 n/total	3.33
(2) Coquinoid limestones (unit Atrypa reticularis and	t 38)		
Eoplectodonta transversalis	34	56	4
Total	90		4
Ratio for (disarticulated/artic Ratio for (disarticulated conv disarticulated) = 56/90-0.62	culated) vex dow	=90/4=2 n/total	22.5
(3) Medium blueish gray (5B	5/1) (un	it 39)	
Atrypa reticularis	33		14
Eoplectodonta transversalis	332		26
Coolina subplana	27		
Leptaena rhomboidalis	3		
Pholidops squammiformis	2		
Total	397		40
*Liocalymene clintoni	3 (1 ce and	phalon 2 molds)	1
**Asteroidea (Paleaster ? sp.) ***a few Mastigobolbina pun	ctata		1
Ratio for (disarticulated/artic	culated =	= 397/40 =	= 9.925

Appendix II — Locality register (in order from west to east)

(1) Genesee Gorge West: Rocks exposed in north cliff of Maplewood Park, western side of Genesee River Gorge. Follow path north of Park about 50-100 m on terrace formed by Reynales Limestone, Rochester, Monroe County, New York (USGS, Rochester West 7.5' Quadrangle).

(2) Genesee Gorge East: A. Rocks exposed in south cliff at Maplewood Park, eastern side of Genesee River Gorge, near St. Paul Blvd., north of Scranton Street, about 20-50 m cliff formed by Rochester Shale and Irondequoit Limestone, Rochester, Monroe County, New York, (USGS, Rochester East 7.5' Quadrangle). B. Rocks exposed in east cliff, approximately 150 m south of Seth Green Drive, Rochester Gas Electric Access Road, Rochester, Monroe County, New York (USGS, Rochester East 7.5' Quadrangle).

(3) Tryon Park (Palmer's Glen): Palmer's Glen, exposure on north side of small tributary stream flowing into west side of Irondequoit Bay, just east of Route I-590 about 1 km north of Browncroft Blvd., and 150 km south of Tryon Park Road, Rochester, Monroe County, New York (USGS, Rochester East 7.5' Quadrangle).

(4) Salmon Creek West: Rock exposure along west Salmon Creek starts 50 m south of Route 104 and continue intermittently to the railroad bridge, Town of Williamson, Wayne County, New York (USGS, Williamson 7.5' Quadrangle).

(5) Second Creek: Williamson Shale exposure is located at 2250 m north of the bridge on Route 104 over Second Creek and extends from 100 to 400 m south of Red Mill Road, Hamlet of Alton, Town of Sodus, Wayne County, New York (USGS, Rose 7.5' Quadrangle).

(6) Little Wolcott Creek: Small bank Williamson Shale exposure on Little Wolcott Creek, approximately 300 m south of East Port Bay Road, Town of Wolcott, Wayne County, New York (USGS Wolcott 7.5' Quadrangle).

(7) Phoenix: Dumps of Williamson Shale along northeast banks of Oswego River, 950 m south of Route 57 and 300 m northwest of Town Line Road, Great Bear Springs, Town of Schroeppel, Oswego County, New York (USGS Pennellville 7.5' Quadrangle).

(8) Brewerton: Based on report of Gillette (1947), one of the best outcrops for collecting fossils is on United States Highway 11, approximately 150 m south of Oneida River, Town of Cicero, Onondaga County, New York. At present the outcrops are destroyed.

(9) Verona Station: Low ditch exposures along interchange no. 33 exit ramp from NY State Thruway onto Route 365, 350 m south of Thruway (I-90), 0.5 km east of Route 365, Verona, Oneida County, New York (USGS, Vernon 7.5' Quadrangle).

(10) Lairdsville: Exposures of Williamson Shale in banks of small north-flowing tributary of major east-flowing tributary of Oriskany Creek 50–200 m north of NY Route 5 (Seneca Turnpike) about 1.0 km east of hamlet of Lairdsville, Town of Westmoreland, Oneida County, New York (USGS, Clinton 7.5' Quadrangle).

(11) Dawes Quarry Creek: Exposures of Willowvale Shale on small tributary on north side of Sherman Brook (locally called Dawes Quarry Creek) about 500 m southeast of bridge of New Road over Dawes Quarry Creek, Village of Clinton, Town of Kirkland, Oneida County, New York (USGS, Utica West 7.5' Quadrangle).

(12) Willowvale Glen: The Glen, east-flowing tributary of

Sauquoit Creek at Willowvale, 2.5 km west of Bridgewater St., 1 km northwest of Chadwicks, Town of New Hartford, Oneida County, New York (USGS, Utica West 7.5' Quadrangle).

(13) Chadwicks: Exposures of Willowvale Shale along bed and south bank of Mallory Creek (west-flowing tributary of Sauquoit Creek) immediately south of Elm Street and 50-250 m west of North Road, Village of Chadwicks, Town of New Hartford, Oneida County, New York (USGS, Utica West 7.5' Quadrangle).

(14) Ohisa Creek: Exposures on banks of Ohisa Creek, 1000-1250 m northeast of bridge Travis Road over Ohisa Creek and 3.4 km southwest of Cramer Corners, Town of Stark, Herkimer County, New York (USGS, Van Hornesville 7.5' Quadrangle).

(15) Van Hornesville: Exposures in small south-flowing tributary of Otsquago Creek immediately west of Travis Road and north of Route 80, Village of Van Hornesville, Town of Stark, Herkimer County, New York (USGS, Van Hornesville 7.5' Quadrangle).

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