Ironstones, condensed beds, and sequence stratigraphy of the Clinton Group (Lower Silurian) in its type area, central New York

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ABSTRACT

The fossiliferous and oolitic ironstones of the Clinton Group (Silurian, late Llandovery to early Wenlock) in central New York have inspired considerable interest since the early surveys of Eaton in the 1820s. Although these ores have never been mined on industrial scales, they were processed extensively up to the mid 1900s for oxides used in red paints. Three of these horizons, Westmoreland, "basal Dawes" or Salmon Creek, and Kirkland, will be examined and discussed on this excursion, with emphasis placed on their sedimentology, taphonomy, correlation, and regional significance in the context of depositional cycles.

Recent work has recast these classic deposits in the context of sequence stratigraphy, wherein ironstones and related phosphatic and shelly deposits are viewed as condensed facies: the product of siliciclastic sediment starvation during periods of rapid transgression at the bases of small- and large -scale depositional sequences. These strata and the environmental conditions they represent will also be considered in the context of recently collected geochemical and geophysical data, which have implications for the correlation of these sections and their importance with regard to regional and global environmental changes and bioevents.

1. INTRODUCTION

Although iron rich horizons in the sedimentary record are the subject of numerous studies, many critical questions remain concerning the processes of their formation (see Van Houten and Bhattacharyya, 1982; Kimberley, 1994 and references therein). Ferruginous strata of the lower Silurian (Aeronian-Sheinwoodian) Clinton Group in east central New York State feature prominently in this debate, owing to many excellent exposures and a rich history of study (e. g. Eaton, 1824; Vanuxem, 1839, James Hall, 1852, Smyth, 1918). These ores, commonly referred to as the "Clinton Ironstones", have never been mined on industrial scales, but they were processed extensively up to the mid 1900s as a source of red paint pigment (for a more comprehensive history see also Van Houten, 1991; Williams, 1998). Eight named ironstones are recognized within the Clinton Group; although these strata are of little economic importance today, they hold considerable stratigraphic, paleoecological, taphonomic, and sedimentological interest (e. g. Smyth, 1918; Gillette, 1947; Schoen, 1964; Brett et al., 1998; see Van Houten, 1991 for a detailed review). Three of the aforementioned eight ironstones will be featured in this field excursion through the classic type area of the Clinton Group, with considerations given to their history, stratigraphic significance, depositional conditions, and sedimentological features.

2. GEOLOGIC SETTING

2.1 Regional Structure

The regional architecture of Paleozoic sedimentary rock in the eastern United States is the product of several orogenic events occurring along the eastern margin of the Laurentian plate throughout the Phanerozoic (Root and Onasch, 1999; Ettensohn, 2008). Much of this bedrock is contained within the Appalachian Foreland Basin, a large structural and depositional province bounded by the Cincinnati, Findlay, and Algonquin Arches to the west and the Appalachian Highlands to the east (Figure 1a; Colton, 1970). In central and western New York, Silurian strata are exposed along a roughly east-west trending outcrop belt, running between Niagara and Schoharie Counties (Figure 1b), which marks the northern margin of the Appalachian Foreland Basin.

2.2 Early Silurian Tectonics and Paleogeography

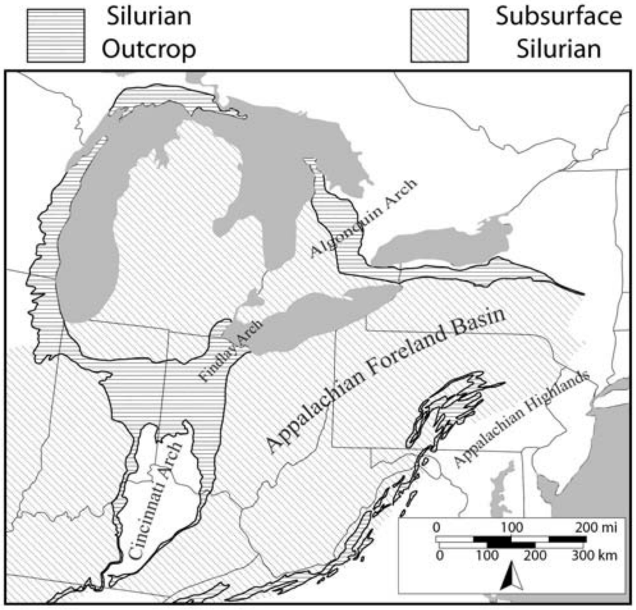

Figure 1a – Regional geographic map of the northeastern United States. Major structural features are labeled. Silurian outcrop is highlighted with horizontal lines; subsurface distribution of Silurian strata is highlighted in diagonal lines. Modified from Berry and Boucot, 1970.

Accretion of one or more island arcs onto the eastern margin of the paleocontinent Laurentia produced several episodes of mountain building during the Late Ordovician into the Early Silurian (Rodgers, 1970; Waldron and van Staal., 2001; Ettensohn and Brett, 2002; van Staal et al., 2007). These episodes of uplift, referred to collectively as the Taconic Orogeny, resulted in structural loading and subsidence in the Appalachian Basin, which was rapidly filled with clastics flushed off the newly formed mountain ranges (Beaumont et al., 1988; Ettensohn and Brett, 1998; Ettensohn, 2008). However, toward the end of the Rhuddanian, local orogenic activity had begun to taper off, commencing a period of relative tectonic quiescence that lasted until the end of the Telychian.

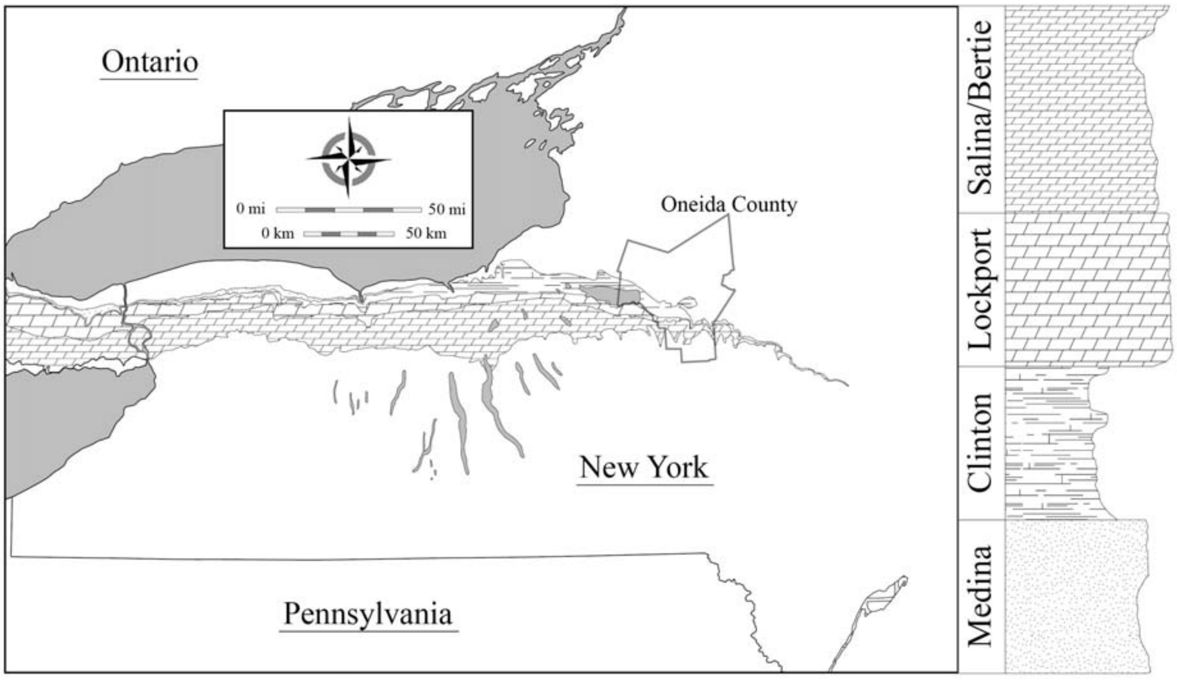

Figure 1b – Geologic map of upstate New York with Medina, Clinton, Lockport, and Salina/Bertie Groups highlighted (modified from Fisher et al., 1970). The outcrops featured in this excursion are located in Oneida County, which is outlined in black on this map.

At this time renewed tectonic loading caused the basin axis to migrate and form a new forebulge in the Appalachian Basin (Goodman and Brett, 1994; Ettensohn and Brett, 1998). This minor episode of uplift and erosion, termed the Salinic Disturbance, is recorded by the thick siliciclastic successions of the Upper Clinton Group in New York and the Shawangunk Conglomerate of southeast New York (Goodman and Brett, 1994; Ettensohn and Brett, 1998; Brett et al., 1998). These recurrent pulses of tectonic activity, followed by episodes of quiescence occurred lock-step with a lateral migration of the basin depocenter, a phenomenon that reflected the repeated flexure and relaxation of the crust (Goodman and Brett, 1994; Ettensohn and Brett, 1998).

The Clinton Ironstones were deposited in the Appalachian Foreland Basin starting in the Early Silurian following the end of the Taconic Orogeny; they were deposited sporadically at discrete time intervals up to, and during, the time of the Salinic Disturbance (see Brett et al., 1998). During this time, the Appalachian Foreland Basin was a topographic low within an epicratonic sea that covered the paleocontinent of Laurentia (Figure 2; Scotese and McKerrow, 1990; Cocks and Scotese, 1991). This depositional basin was bounded to the northwest by a carbonate bank and to the southeast by the much beveled Taconic Highlands (Figure 2; Scotese and McKerrow, 1990; Brett and Ray, 2005); strata now exposed in upstate New York were deposited in this region at approximately 20-30° south latitude (Cocks and Scotese, 1991). The internal architecture of the Appalachian Basin is inferred on the basis of widely traceable facies belts that show coarse siliciclastic dominated successions to the east, which grade westward into depositional environments dominated progressively by fine grained sediments and carbonates (Hunter, 1970; Brett et al., 1990; 1998).

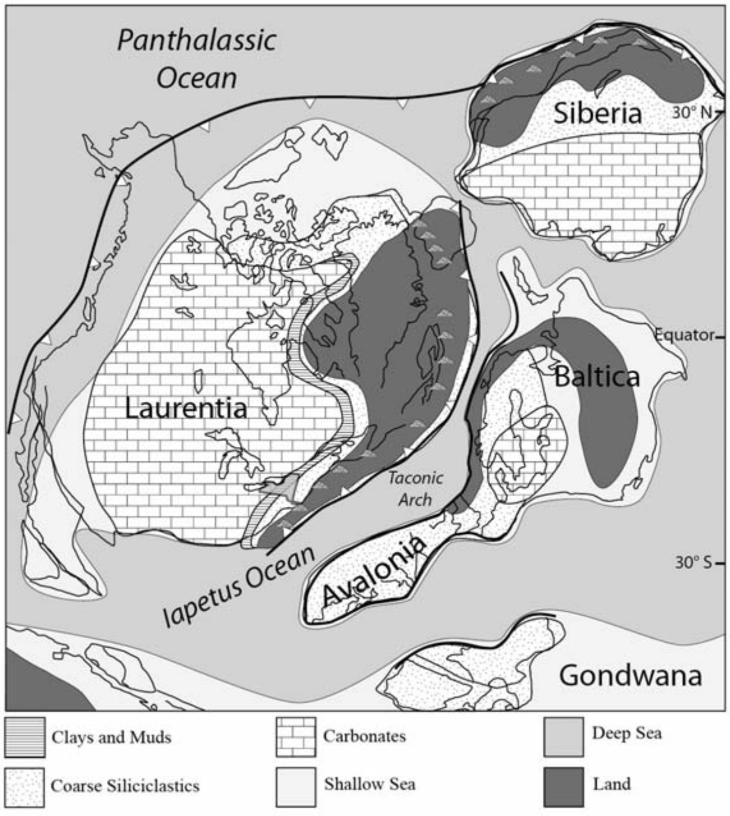

Figure 2 – Paleogeographic map of Laurentia during the Silurian with New York State highlighted. Modified from Scotese (1990), Cocks and Scotese (1991), and Brett and Ray (2005).

2.3 Climate and Oceanographic Conditions

The Early Silurian has traditionally been characterized as a period of climatic stability marked by high sea levels, extensive reef buildups, and widespread greenhouse climates (Copper and Brunton, 1991; Brenchley et al., 1994; Brunton et al., 1998; Veizer et al., 2000; Copper, 2002; Miller et al., 2005). However, a recent and ongoing resurgence of interest and study in the Silurian has characterized the time period as one of exceptional and unusual climatic, oceanic, and biotic trends (e. g. Jeppsson, 1990; 1997; Munnecke et al., 2003; McLaughlin et al., 2008; Cramer et al., 2011; McLaughlin et al., in review). Several short-lived episodes of cooling and glaciations have been documented through this interval on the basis of oxygen isotopes (Lehnert et al., 2010) and regional mapping of diamictites in South America (Caputo, 1998). Related to these climatic changes are widely documented oscillations in relative sea-level, which appear to reflect eustatic fluctuations (Johnson et al., 1998; Loydell, 1998; Brett et al., 2009). These sea level changes, together with tectonic uplift and subsidence, have produced widespread depositional sequences, which form a major theme of this trip.

Over the past few decades, high-resolution biostratigraphic studies of the Silurian have revealed widespread and severe biotic crises affecting a broad range of taxa around the world (Jeppsson et al., 1995; Jeppsson, 1997; Gelsthorpe, 2004; Eriksson, 2006; Manda et al., 2011). Many of these biotic events are closely coupled with strong shifts in the ratios of stable carbon isotopes (i. e. $\delta^{13}C$) recorded in marine carbonate rocks, which is thought to reflect dramatic and widespread fluctuations in marine circulation patterns, rates of primary productivity, and the efficiency of nutrient recycling (see Cramer and Saltzman, 2007 for a more detailed review). During this time, New York State was situated in the subtropics, where the shallow seas would likely have been subjected to consistently warm weather, with sharp annual variation in precipitation and powerful tropical storms. These warm, shallow waters were home to a rich and diverse fauna of epibenthic suspension feeders such as brachiopods, favositid and rugosan corals, bryozoans and echinoderms, which are present in great abundance throughout lower Silurian strata (e. g. Hall, 1852; Foerste, 1931; Gillette, 1947).

3. STRATIGRAPHY OF THE CLINTON GROUP

3.1 Overview

The Lower Silurian Clinton Group in east central New York is bounded at its base by the coarse siliciclastic successions of the Medina Group and at its upper contact by the carbonate dominated Lockport Group (Fisher et al., 1970; Rickard, 1975). The name Clinton Group was proposed by Lardner Vanuxem in 1842, though Amos Eaton, working in 1824 made reference to "ferriferous slates" distributed throughout east central and western New York. The Clinton Group received numerous revisions and refinements from several authors working in the early twentieth century, notably Hartnagel (1907), Chadwick (1918), Goldring (1931), and Sanford (1935). Working primarily in Maryland, Ulrich and Bassler (1923) developed a detailed ostracod biozonation for lower Silurian strata of the Appalachian Basin. Given the relative paucity of zonally significant conodonts and graptolites in these successions, Ulrich and Bassler's zonation remains a primary standard for interregional correlation of Clinton Group strata to this day.

The lithostratigraphic nomenclature proposed by workers in New York and the ostracod biozonation of Ulrich and Bassler (1923) was integrated by Tracy Gillette in his 1947 publication *The Clinton of Western and Central New York*, a work of considerable scope. Gillette (1947) subdivided the Clinton Group into Lower, Middle and Upper subdivisions on the basis of lithology and ostracod faunas (Figure 3). He argued that an unconformity beneath the Upper Clinton

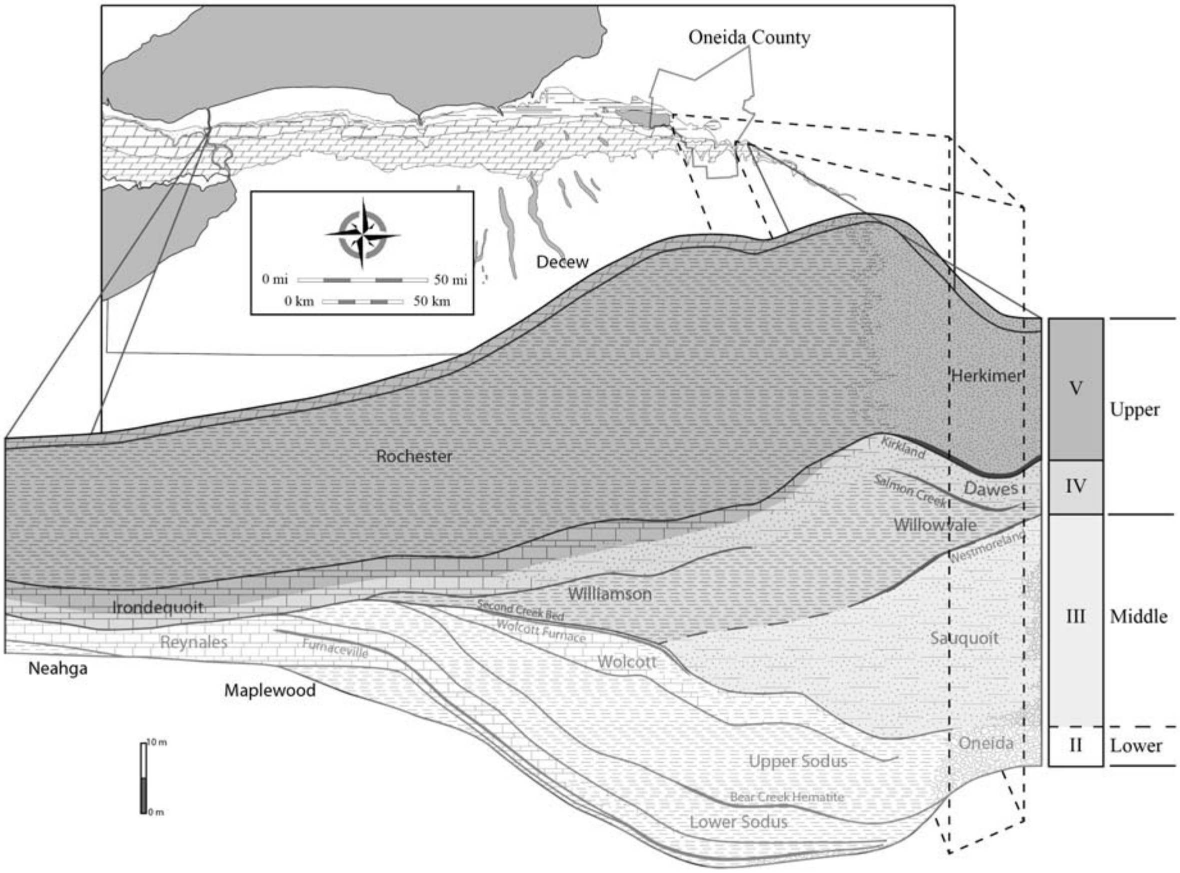

Figure 3 – Regional cross section, showing litho– and sequence stratigraphic relationships of the Clinton Group. Cross section modified from Gillette (1947) and Brett and others (1998). Map modified from Fisher and others (1970).

progressively truncates strata to the west; in the vicinity of Niagara Falls, much of the Lower Clinton and all of the Middle Clinton are missing (Gillette, 1947). Hunter (1970) further refined this stratigraphy, correlated strata to this reference standard along the Appalachian Basin as far as eastern Kentucky and Virginia, and emphasized the importance of ironstones as regional markers.

A sequence stratigraphic framework was erected for the Clinton Group by Brett and others (1990, 1998) who divided the unit into four unconformity-bound packages of genetically linked strata (Figure 3). They argued that many the ironstones distributed throughout the Clinton Group represent transgressive units overlying regionally angular unconformities (Brett et al., 1990). As such, they would represent deposition during times of sea-level transgression, when landward migration of depocenters, and sequestration of siliciclastic sediments in coastal area, caused a decrease in the amount of sediment reaching the basin and offshore sediment starvation. Brett and others (1990, 1998) subdivided the Silurian strata of New York State into seven or eight major, third -order sequences, termed S-I to S-VIII. Sequences S-III (the Sauquoit Formation of the Middle Clinton), S-IV (the Willowvale and Dawes Formations of the Upper Clinton), and S-V (the Kirkland Iron Ore and Herkimer Formations of the Upper Clinton) will be the focus of this trip.

3.2. Overview of Stratigraphic Units Exposed in the Type Clinton Area

Eight named rock units will be observed and discussed during this excursion. These units collectively comprise the Clinton Group as it is expressed in Oneida County; an idealized representation of this succession is shown in Figure 4. Each named unit is described briefly herein.

Oneida Conglomerate

Definition and Type Area - Defined by Vanuxem (1842) as the conglomeratic unit exposed in Oneida County

Thickness and Extent - The Oneida Conglomerate has been traced as far west as the Oswego River; to the east, it grades into thick undifferentiated siliciclastic successions. In the vicinity of Oneida County, it attains a maximum thickness of approximately 10 meters (30 feet)

Age - Late Aeronian to Middle Telychian (Brett et al., 1990)

Sequence Stratigraphy - S-II to lower S-III lowstand and transgressive systems tract (Brett et al., 1998)

Facies and Deposition Environment - Massive quartz pebble conglomerates are typical of the Oneida, but these are commonly interbedded with light grey sandstones and dark, clay shales. The coarser beds are generally cemented with silica.

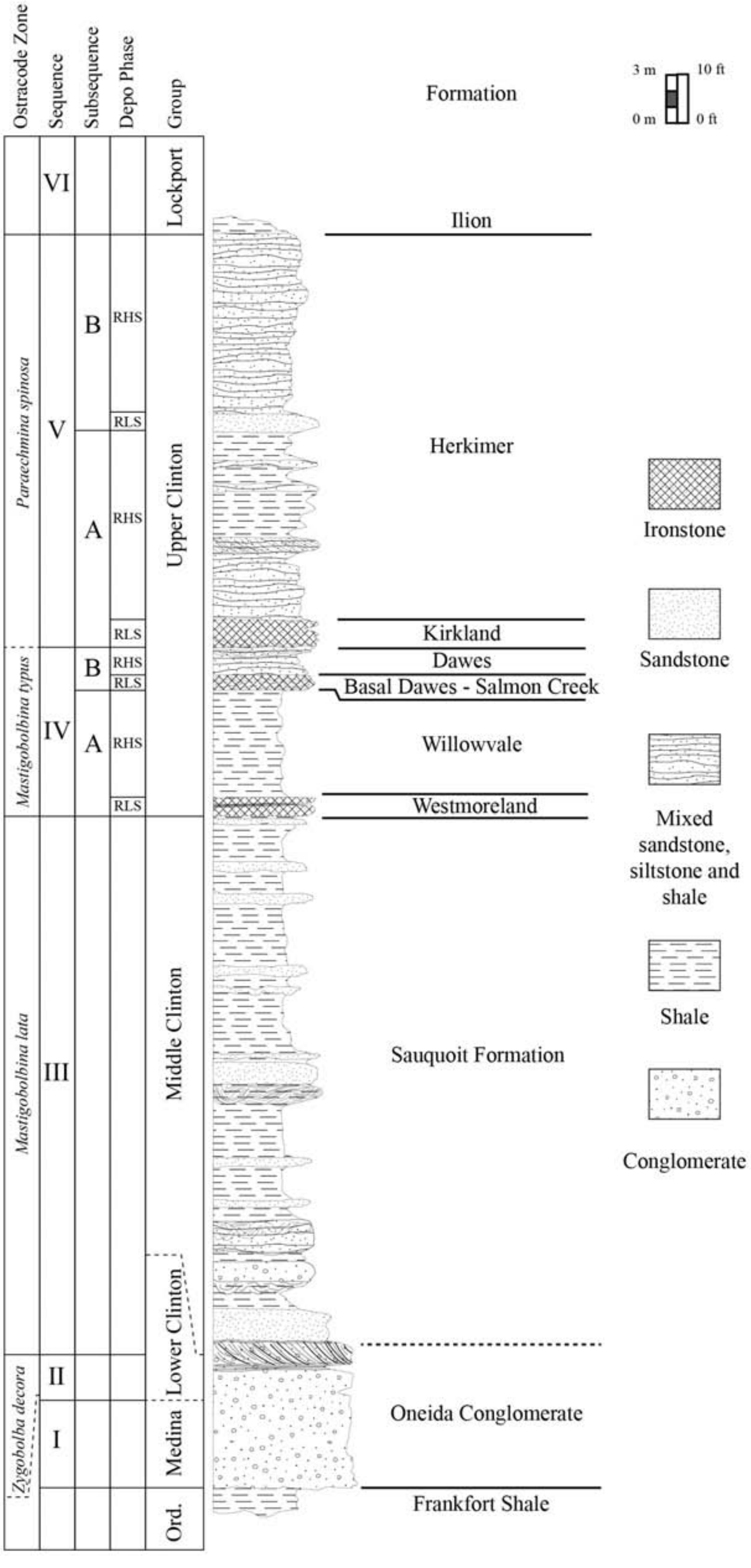

Figure 4 – Generalized stratigraphic column for the Clinton Group in east central New York with biozonations plotted (modified from Muskatt, 1972; Brett and Goodman, 1996).

Biostratigraphy -

Mastigobolbina lata Zone (Gillette, 1947)

Paleoecology - The Oneida Conglomerate is typically unfossiliferous. However, several shale and sandstone beds occurring near the top of the formation in the Clinton Area may yield a typical normal marine fossil assemblage that includes bivalves, brachiopods, and ostracodes.

Correlations

Thorold Sandstone of western New York (in part; Gillette, 1947)

Shawangunk Formation of southeastern New York (Willard, 1928)

Possibly much of the Lower Clinton Group in western New York (Brett et al., 1990)

Sauquoit (Shale) Formation

Definition and Type Area – Defined as all sandstone and shale beds between the Oneida conglomerate and the Westmoreland Hematite at Swift Creek, the type section, which is just north of the hamlet of Sauquoit (Chadwick, 1918)

Thickness and Extent – The Sauquoit attains its maximum thickness of approximately 27 m (90 feet) near Verona Station; the Sauquoit thins dramatically to the west and pinches out somewhere between the towns of Fulton and Wolcott, NY (Gillette, 1947)

Age – middle Telychian (C-5 of Berry and Boucot, 1970; see Brett et al., 1998)

Sequence Stratigraphy - Sequence III highstand (Brett et al., 1998)

Facies and Depositional Environment – The Sauquoit Formation is predominantly greenish to bluish gray shales with interbedded sandy limestones, calcareous sandstones, and conglomeratic horizons.

Biostratigraphy –

Eocoelia sulcata brachiopod Zone (Gillette, 1947; Brett et al., 1998)

Mastigobolbina lata ostracod Zone (Gillette, 1947)

Pterospathodus amorphognathoides conodont Zone (Rexroad and Richard, 1965)

Pterospathodus celloni Zone (Kleffner, pers. comm. in Brett et al., 1998)

Pterospathodus amorphognathoides Zone conodonts were reported by Kleffner (pers. comm. in Brett et al., 1998) from dolomitic sandstones at the base the Westmoreland Formation.

Paleoecology – The fossil assemblages of the Sauquoit formation are distinct from those of over- and underlying units (Gillette, 1947). Bivalves are the dominant macrofossils, though brachiopods and gastropods are also common. Ostracodes are also present in great abundance and many of them are biostratigraphically useful, at least within the Appalachian Basin. The lower Sauquoit contains fine- to medium- grained interbedded sandstones and conglomerates that display hummocky cross stratification, well defined sole marks, and hummocky to symmetrical ripples (Muskatt, 1972). These indicate deposition within shallow storm wave base, at perhaps 10 to 30 m depths; sands and well rounded quartz pebbles were transported offshore from proximal sources, perhaps Taconic terranes re-uplifted in early phases of the Salinic Orogeny. The mixture of quartz pebbles with phosphatic nodules including fossil steinkerns at three or more levels within the Sauquoit indicates that some of these pebbly beds reflect remaining sediments associated with prolonged periods of sediment starvation. Abundant phosphates may reflect inputs from fluvial sources or possibly upwelling in the narrow Sauquoit foreland basin. The Sauquoit passes eastward gradationally with red sandstones and conglomerates of the Otsquago Formation within about 60-70 km of the study area; the latter reflect near-shore, possibly tidal deltas to non-marine sediments. The presence of abundant *Eocoelia* brachiopods in some beds of the Sauquoit suggests a BA-2 (*Eocoelia* community of Ziegler, Cocks and Bambach (1968). However, some portions of the Sauquoit contain more typical offshore biotas, including dalmanitid trilobites, suggesting possibly deeper water conditions.

Correlations –

Otsquago Sandstone of central New York (Gillette, 1947; Brett et al., 1998)
Center Member of the Rose Hill Formation of Pennsylvania (Brett et al., 1998)

Westmoreland Iron Ore

Definition and Type Area – The dark red, oolitic, hematitic iron ore exposed at Roaring Brook, which is the informal name given to a small tributary of Oriskany Creek approximately half a mile east of Lairdsville in the town of Westmoreland, Oneida County (Gillette, 1947).

Thickness and Extent – The Westmoreland Iron Ore is approximately 70 centimeters thick at its type section, it reaches its maximum thickness in the vicinity of Clinton, where it may reach up to 80 centimeters in thickness. Exposures of this unit are scarce outside of Oneida County though a thin phosphatic and glauconitic zone containing some hematite has been recognized at the top of the Sauquoit Formation in drill cores taken east of Oneida Lake (Gillette, 1947).

Age – Late Telychian (Rickard, 1975; Brett et al., 1998); Early Sheinwoodian (McLaughlin et al., in review)

Sequence Stratigraphy - Relative lowstand (=lowstand to early transgressive systems tract) of subsequence IV-A (Brett et al., 1998)

Facies and Depositional Environment – The Westmoreland Iron Ore is a dark red ironstone composed primarily of rounded, sand sized grains that display concentric laminae, textures that have been characterized as oolitic (Smyth, 1918; Gillette, 1947). The lower contact of the Westmoreland is sharp, and the upper contact contains large, symmetrical ripple marks. The unit may also contain rip-up clasts, apparently derived from underlying strata. At some sections, the Westmoreland Iron Ore contains a thin tongue of dark gray shale. The latter contains fossils, including brachiopods and graptolites. This juxtaposition of evidently high energy and low energy, dysoxic facies is difficult to reconcile. Baird and Brett (1986) reported similar ripple-like features interbedded with black shale in the Leicester Pyrite, another transgressive lag deposit but in that case conditions were evidently dysoxic to anoxic. In the case of the Westmoreland, the presence of hematitic ooids indicates well oxygnated conditions at least episodically on the seafloor. It is possible that the ooids were originally chamosite and thus represent mildly reducing conditions in the sediment. However, the presence of large ripple forms in red hematite indicates that these ooids were subsequently reworked and concentrated under fully oxic and intermittently high-energy conditions, possibly forming submarine shoals or bars. The interbedded dark shale could record preservation of dysoxic lagoonal or intershoal muds. However, the fauna, including monograptid graptolites, suggests an offshore setting (BA 3 to 4). It is possible that the dark shale represents a remnant of highstand muds associated with a small scale (high frequency) depositional sequence; in this case true deepening to muddy out shelf conditions occurred following the initiation of the larger scale (3rd order) transgression. A second lowering of base level may have removed much of the shale and stacked a younger, transgressive oolitic hematite onto the erosion surface.

Biostratigraphy –

Stimulograptus clintonensis (formerly assigned to *Monograptus clintonensis*) was reported by Gillette (1947); however, this report has not been confirmed. All specimens studied by Loydell et al. (2007) from the overlying Willowvale Shale turned out to be the long-ranging *Monograptus priodon.*

Retiolites geinitzianus venosus, a graptolite typical of the Williamson Shale and characteristic of late Llandovery faunas, was reported by Gillette (1947) from the

Westmoreland shale tongue.

Palaeocyclus rotuloides (Gillette, 1947)

Mastigobolbina typus Zone (Gillette, 1947)

Paleoecology – In contrast to the other ironstones in the region, the Westmoreland Iron Ore is sparsely fossiliferous. Nearly all fossils reported from the unit are found within the black shale interbed described above. This fossil assemblage is noted for its similarity to that of the overlying Willowvale (Gillette, 1947).

Correlations –

Second Creek Phosphate Bed of west-central New York State on the basis of similar faunas and seemingly transitional phosphatic nodule beds underlying the Williamson in drill cores recovered from near Syracuse (Gillette, 1947; Lin and Brett, 1988; Eckert and Brett, 1989; Brett et al., 1998). However, this correlation has not been substantiated by subsequent biostratigraphic work (see Kleffner, pers. comm. in Brett et al., 1998; Loydell et al., 2007).

Merritton Limestone of Ontario (Brett et al., 1998). However, this unit underlies the Second Creek Phosphate Bed, making this correlation unlikely for the reasons described above.

Ferruginous limestones bearing *Palaeocyclus* at the base of the Upper Shaly Member of the Rose Hill Shale in Pennsylvania (Brett et al., 1998).

Willowvale Shale

Definition and Type Area – The term Willowvale was introduced by Gillette (1947) to include the blue grey shales between the Westmoreland and the Kirkland Iron ores, or the base of the Dawes Sandstone where it is present. As a type locality he designated a small, east-flowing tributary of Sauquoit Creek, informally referred to as “The Glen” or “Willowvale Creek” in the town of Willowvale, New York (Gillette, 1947).

Thickness and Extent – The Willowvale Shale is approximately 6.7 m (22 feet) thick at its type section, a value that remains consistent where typical Willowvale is exposed (Gillette, 1947). The unit is not found west of Oneida County, though its proposed lateral equivalent, the Williamson Formation, has been traced as far as Niagara County (Gillette, 1947; Brett et al., 1990). The Willowvale grades eastward into large, undifferentiated sections of coarse clastics (Gillette, 1947).

Age – Late Telychian (Brett et al., 1998), Early Sheinwoodian (McLaughlin et al., in review)

Sequence Stratigraphy – Relative highstand of subsequence IV-A (Brett et al., 1998)

Facies and Depositional Environment – The Willowvale Formation is predominantly dark gray to purple, thin bedded shales with calcareous sandstone and argillaceous, shelly limestone interbeds. The unit is interpreted as the product of proximal deposition in relatively shallow and well oxygenated environments (Eckert and Brett, 1989). The presence of siltstones and silty carbonates with small scale hummocky cross lamination and tool marks suggests at position near storm wave base.

Biostratigraphy –

Ancyrochitina gutinica (Loydell et al., 2007)

Conochitina proboscifera (Loydell et al., 2007)

Mastigobolbina typus Zone (Gillette, 1947)

Monograptus priodon (Loydell et al., 2007), reported as *Monograptus clintonensis* (Gillette, 1947)

Palaeocyclus rotuloides (Gillette, 1947)

Pterospathodus amorphognathoides Zone (Kleffner, pers. comm. reported in Brett et al., 1998)

Paleoecology – The Willowvale Shale has a rich and varied fossil fauna that is noted for its unusual co-occurrence of disparate taxa not known to inhabit similar depositional environments; graptolites, cephalopods, bryozoans, corals, and brachiopods are all commonly found (Gillette, 1947). Eckert and Brett (1989) characterized the Willowvale fauna in easternmost outcrops as a near-shore benthic assemblage (BA-2 to 3 of their terminology) dominated by *Eocoelia.* However, in the Clinton area, the occurrence of a diverse fauna with *Dicoelosia, Skenidioides, Eoplectodonta* and rare *Costisticklandia* indicate a BA 4-5 position (Eckert and Brett, 1989). This fauna shows affinities with that of the Williamson Formation to the west, a relationship also noted by Gillette (1947). The lower part of this unit and the underlying Westmoreland Iron Ore contain abundant specimens of the solitary coral *Palaeocyclus rotuloides,* an unusual, button-shaped coral found in coeval sections worldwide (Duncan, 1867; Gillette, 1947; Ehlers, 1973; Munnecke et al., 2003). The widespread, but stratigraphically narrow occurrence constitutes a useful marker, representing a global epibole of this unusual organism. Rare *Palaeocyclus* have been found in what appear to be transitional facies the lower Williamson-Westmoreland as far west as Syracuse, NY. The near-simultaneous invasion of what may have been a deep-water coral into shallow seas on several continents may reflect a response to elevated sea level and incursion of cool and perhaps dysoxic water masses onto the craton during the strong and rapid late Telychian transgression (locally Sequence IV TST).

Correlations –

Williamson Formation of west-central New York has been correlated with the lower Willowvale Shale and both units have yielded diagnostic *Mastigobolbina typus* Zone ostracodes (Gillette, 1947; Lin and Brett, 1988; Eckert and Brett, 1989; Brett et al., 1990; 1998). However, graptolite and conodont work suggests that the basal Williamson may actually be older than the lower Willowvale, belonging to the *Pt. amorphognathoides angulatus* Zone (Rexroad and Richard, 1965; Loydell et al., 2007).

Upper Shaly Member of the Rose Hill Formation of Pennsylvania, which contains the diagnostic ostracod *Mastigobolbina typus* (Brett et al., 1998)

Salmon Creek ("Basal Dawes") Bed

Definition and Type Area – The term "Salmon Creek Bed" was proposed by Lin and Brett (1988), who established the type section at Salmon Creek West, approximately 50 meters south of NY route 104 in the town of Williamson, Wayne County, New York. In its type area, the Salmon Creek Bed is a phosphatic, quartz bearing conglomeratic bed that separates the Irondequoit Formation from the underlying Williamson (Lin and Brett, 1988). However, this unit was correlated eastward to a cross-bedded, impure hematitic sandy carbonate referred to in some publications as the "basal Dawes bed" (Lin and Brett, 1988; Eckert and Brett, 1989; Brett et al., 1998).

Thickness and Extent – The Salmon Creek Bed has been traced from Tryon Park in Rochester New York, to the Clinton Type Area (Lin and Brett, 1988). Although this unit is only a few centimeters thick at its type locality in northern Wayne County, it reaches a thickness of 80 centimeters in Oneida County. The Salmon Creek Bed has been traced eastward at least to Ohisa Creek in Herkimer County (Zenger, 1971; Brett, pers. observation)

Age – Late Telychian (Brett et al., 1998); Late Llandovery to early Wenlock (Lin and Brett, 1988); Early Sheinwoodian (McLaughlin et al., in review)

Sequence Stratigraphy – Relative lowstand (LST to early TST) of subsequence IV-B (Brett et al., 1998).

Facies and Depositional Environment – The Salmon Creek Bed in the Clinton type area is characterized as a crossbedded, sandy dolostone with locally abundant stringers of hematite and phosphate nodules (Brett and Goodman, 1996). The unit has a sharp base, which is interpreted as an erosive contact.

Biostratigraphy –

Upper *Mastigobolbina typus* Zone (Gillette, 1947)

Pterospathodus amorphognathoides amorphognathoides Zone (Loydell et al., 2007)

Paleoecology – Stalked echinoderm fragments are the dominant component of the Salmon Creek Bed. This, coupled with observations of sedimentary structures such as cross stratification, suggest the bed was deposited in a relatively high energy, well oxygenated environment similar to the Kirkland Formation (see below).

Correlations –

Basal bed of the Keefer Sandstone in Pennsylvania, Maryland, Virginia, and Tennessee (Brett et al., 1998)

Salmon Creek Phosphate Bed of central-western New York (Lin and Brett, 1988)

Dawes Formation

Definition and Type Area – The Dawes Formation is defined as the dolomitic sandstones, siltstones, and shales found between the top of the Willowvale Shale and the base of the Kirkland Iron Ore; the designated type locality is Dawes Quarry creek, a westward flowing stream in the village of Clinton (Gillette, 1947).

Thickness and Extent – In his original description of the Dawes Sandstone, Gillette (1947) suggested that it was restricted to the area between College Hill Creek in Clinton and the unit's type locality at Dawes Quarry Creek, where it is approximately 2.5 meters thick. At localities further to the east, the overlying Kirkland Iron Ore rests directly on mudstones that have been referred to as the upper Willowvale Shale (Gillette, 1947). However, at localities to the west, other authors have recognized the position of the Dawes-Rockway interval based on the presence of a basal hematitic, pyritic and phosphatic carbonate bed, the Salmon Creek equivalent (Lin and Brett, 1988).

Age – Late Telychian (Brett et al., 1998); Late Telychian to Early Sheinwoodian (Brett and Goodman, 1996); Early Wenlock (Lin and Brett, 1988), Early Sheinwoodian (McLaughlin et al., in review)

Sequence Stratigraphy – Relative highstand of subsequence IV-B (Brett et al., 1998); late highstand to falling stage of third-order Sequence IV.

Facies and Depositional Environment – The Dawes Sandstone is predominantly light gray, slightly calcareous sandstones. Gillette (1947) describes the bed as irregularly bedded, and very cross-bedded, though finely laminated siltstones and sandstones characterize the unit at some localities (e. g., Theime Gulf). On the basis of these sedimentary structures, the rarity of normal marine fossil assemblages, and the limited extent of this unit, Gillette (1947) hypothesized that this unit may represent a small delta deposit. Several sections of the Dawes Sandstone contain a zone of deformed calcareous sandstones and shales just below the overlying hematitic unit. These beds are interpreted as the product of soft sediment deformation, possibly formed by seismic activity.

***Biostratigraphy* –**

Mastigobolbina typus Zone (inferred by Brett et al., 1998; though no ostracodes have been reported directly from this unit)

Pterospathodus amorphognathoides Zone (inferred by Brett et al., 1998; though no conodonts have been reported directly from this unit)

***Paleoecology* –** In contrast to the hematitic beds that bracket this unit, the Dawes Sandstone contains very few fossils, though occasional, fragmentary remains of brachiopods, gastropods, and cephalopods have been reported (Brett and Goodman, 1996). Like the Sauquoit, the Dawes Sandstone shows evidence of deposition in shallow, storm influenced waters. Fossils, other than burrows are generally scarce but some bedding planes are covered with *Strophochonetes cornutus*, which is viewed as an opportunistic shallow water species. The lenticular fine sandstones of the Dawes may represent offshore sandbars. Their rapid accumulation on mud may have produced substrate instability that, in the presence of seismic shocks may have resulted in extensive foundering of ball and pillow masses (seismites). The presence of abundant small brachiopod *Clorinda*, together with *Skenidioides* and *Dicoelosia* suggests BA-4 to 5 positions. However, the occurrence of small ischaditid algae within these beds at Second Creek and bedding planes covered with these algal thalli near Verona suggest that water depths were still relatively shallow and well within the photic zone.

***Correlations* –**

Rockway Dolostone (or Rockway Member of the Irondequoit Formation) of west-central New York (Eckert and Brett, 1989; Brett et al., 1998)

Lower Keefer Sandstone of Pennsylvania, Virginia, and Maryland (Brett et al., 1998; McLaughlin et al., in review)

Kirkland Iron Ore

***Definition and Type Area* –** The Kirkland Iron Ore was defined by Chadwick (1918) as the fossiliferous hematitic bed well exposed in the vicinity of Kirkland in Oneida County, New York. Also referred to as the upper iron ore of Vanuxem (1842) and the red-flux ore of Smyth (1895), the Kirkland sharply overlies the Willowvale Shale or the Dawes Sandstone where it is present. Its upper contact with the Herkimer Sandstone is gradational (Gillette, 1947).

Thickness and Extent – The Kirkland Iron Ore is highly variable in thickness, reaching up to two meters at sections near Lairdsville, New York. Within the Clinton Type area, the Kirkland serves as an important stratigraphic marker. However, like many of the other Clinton Ironstones, the Kirkland cannot be easily traced in surface exposures outside of Oneida County (Gillette, 1947).

Age – Sheinwoodian (Brett and Goodman, 1996; Brett et al., 1998; McLaughlin et al., in review)

Sequence Stratigraphy – Relative lowstand (LST to early TST) of subsequence V-A (Brett et al., 1998)

Facies and Depositional Environment – The Kirkland is a fossiliferous, hematitic grainstone with highly variable concentrations of iron and several cross-stratified horizons. The beds also have high concentrations of carbonate which made this unit it a valuable target for miners and smelters as a self-fluxing ore (Van Houten, 1991). It is composed primarily of crinoid-dominated packstones and grainstones, indicative of relatively shallow water and moderate- to high energy transgressive shoal conditions.

Biostratigraphy –

Kockelella ranuliformis Zone (Kleffner pers. comm. reported in Brett et al., 1998)

Paraechmina spinosa Zone (Gillette, 1947)

Paleoecology – Like the Salmon Creek Bed, the Kirkland contains abundant remains of rather large pelmatozoans (stalked echinoderms), though bryozoans and brachiopods are also common. The preservational state of these organisms is highly variable, and a taphonomic gradient of ferruginization has been noted by previous workers (Gillette, 1947) suggesting strong reworking and time-averaging the Kirkland with preferential preservation of more robust skeletal elements. The presence of moderately large brachiopods including *Meristina* (=*Cryptothyrella*) *cylindrica*, *Coolinia* and *Leptaena* suggests a BA-3 open shelf, shoal position.

Correlations –

Upper Irondequoit Formation of west-central New York and Ontario (Lin and Brett, 1988; Brett et al., 1998)

Upper Keefer Of Pennsylvania, Maryland, and Virginia (Brett et al., 1998)

Lower Keefer of Pennsylvania (McLaughlin et al., in review)

Herkimer Sandstone

Definition and Type Area – The Herkimer Sandstone was defined by Chadwick (1918) as the upper sandstones of the Clinton Group as they are exposed in southern Herkimer County.

Thickness and Extent – In the Clinton Type Area, the Herkimer Formation is approximately 22 meters in thickness. The unit expands to the west; in the vicinity of Verona, New York, the unit is up to 28 meters in thickness. The unit is widely traceable, but to the west of Oneida Lake it becomes increasingly shaly and interfingers with the Rochester Shale (Gillette, 1947).

Age – Sheinwoodian (Brett and Goodman, 1996), Middle to Late Wenlock (Berry and Boucot, 1970)

Sequence Stratigraphy – Relative highstand of subsequence V-A and subsequence V-B (Brett et al., 1998)

Facies and Depositional Environment – The lower part of the western or Joslin Hill facies of the Herkimer Sandstone (Zenger, 1971) is composed of interbedded dark gray fossiliferous shales and coarse, calcareous sandstones, many of which display ripple marks. The unit becomes increasingly sandy toward its upper contact with several prominent reddish hematitic, sandy horizons (Gillette, 1947). Trace fossils, including excellent *Rusophycus* (trilobite resting traces) are present as hypichnia on the bases of some sandstone beds. The depositional setting of the Herkimer in central New York State is thought to be similar to that of the Willowvale and Dawes and the unit shows four major o coarsening- upward cycles of, dark gray mudstone and shale to fine hummocky bedded sandstone and quartz granule to fine pebble conglomerates with some open marine brachiopod faunas. These beds are abruptly overlain by calcareous, pebbly sandstones and sandy, hematitic crinoidal pack- and grainstones, resembling the Kirkland Formation, with relatively diverse fossil assemblages (possibly BA-3) of rhynchonellid and strophomenid brachiopods. These beds have been interpreted as the relatively siliciclastic starved transgressive deposits. The Joslin Hill passes westward into dark gray mudstones and thin dolomitic siltstones of the Rochester formation and eastward into the unfossiliferous massive, cross bedded quartz arenites of the Jordanville facies. The latter record offshore muddy shelf settings with BA 4 faunas while the Jordanville represents near-shore high-energy sand bar and shoal complexes. The absence of body fossils and presence of *Skolithos* traces suggests strong reworking of sands in high energy very shallow subtidal to intertidal conditions. Overall, the increased input of siliciclastic sediments into the foreland basin during Rochester-Herkimer depositions suggests an increased pulse of uplift and erosion associated with a second Salinic tectophase.

Biostratigraphy –

Paraechmina spinosa Zone (Gillette, 1947)

Paleoecology – Fossil assemblage reported in the Herkimer Sandstone are indicative of normal marine deposition. The sandstone beds of the lower Herkimer Sandstone are sparsely fossiliferous. However the shales yield fairly common brachiopods, bivalves, and ostracodes.

Correlations –

Rochester Shale of west-central New York (Gillette, 1947; Berry and Boucot, 1970; Brett et al., 1998).

Upper Rochester Shale of west-central New York (McLaughlin et al., in review)

Upper Keefer of Pennsylvania (McLaughlin et al., in review)

4. THE NATURE OF IRONSTONES

4.1 Mineralogy and Sedimentology

Phanerozoic ironstones are a heterogeneous mixture of various iron-bearing and non-ferruginous minerals. The predominant iron oxide mineral found within the Clinton Ironstones is hematite, which gives the horizons their characteristic dark red color (Schoen, 1962). Although the predominance of these oxides within the Clinton Ironstones suggests an oxic depositional environment, the presence of reduced iron minerals such as chamosite and berthierine indicates a complex history of redox conditions. Small, but ubiquitous crystals of pyrite are also present, and in nearly all cases show a late-stage mineral replacement history. Other common minerals within the Clinton Ironstones are illite, calcite, and quartz.

Iron bearing minerals in the Clinton Ironstones are commonly manifested as intergranular cements, cavity fillings, or concentric laminae accreted around a nucleus (Cotter and Link, 1993). Beds composed primarily of sand-sized quartz grains surrounded by concentric, ferruginous laminae have been characterized as having an "oolitic" texture (Smyth, 1892; 1919), though in contrast to carbonate ooids, these grains typically have an elliptical flax-seed shape (Chowns, 1996). Fossiliferous ironstones are similar to oolitic ironstones in many ways, though bioclasts commonly form the nucleus for accreted rinds of iron minerals in these beds. Fossils in ironstone horizons may be tinted bright red where carbonate minerals have been impregnated or replaced by iron oxides.

4.2 Genetic Models

The ubiquity of ferric iron bearing minerals in many types of ironstones suggests that they were deposited in environments that experienced oxidizing conditions at least sporadically, yet it is widely acknowledged that iron is highly immobile in oxic environments (Kimberley, 1989, Boggs, 2001). This apparent contradiction is referred to as the "ironstone paradox" or the "oxidation-reduction paradox", which has been the subject of numerous studies (Maynard, 1986; Cotter, 1992; Kimberley, 1994; McLaughlin et al., in review).

Ironstones occur non-randomly within the Phanerozoic, and are particularly common within the Ordovician through Devonian and Jurassic through Early Cenozoic (Van Houten and Bhattacharrya, 1982; Van Houten and Arthur, 1989). These intervals of earth's history are traditionally associated with greenhouse climates and subdued tectonism, leading to the conclusion that deep weathering of continental bedrock would provide a ready source of iron, favoring the deposition of ironstones (Van Houten and Bhattacharrya, 1982). However, Van Houten and Arthur (1989), citing a close temporal relationship between ironstones and black shales, suggested a common cause in poorly circulated anoxic water masses, which have the capacity to transport large quantities of dissolved iron in its reduced, ferrous state. Cotter and Link (1993) expanded on this idea suggesting that ironstones could form along the pycnocline, where dysoxic deeper waters came into contact with more oxygenated shallow waters. Under these mildly reducing conditions, ferrous iron dissolved in the dysoxic water mass could have precipitated near the sediment water interface as iron rich clays such as chamosite and berthierine, which may occur as intergranular cements, oolitic coatings, or cavity fillings, possibly mediated by microbial activity (Cotter and Link, 1993; Chowns, 1996). They argue that these minerals could then be altered to ferric oxide during later diagenesis (Cotter and Link, 1993).

However, Silurian ironstones are commonly associated with diverse open marine fossil assemblages (Gillette, 1947) and *in situ* bioturbating organisms (Chowns, 1996) indicating oxic conditions at the site of deposition. Regional stratigraphic studies traced many of these ironstones laterally into thin, pyrite and phosphate rich conglomeratic horizons, suggesting a genetic link between them (Lin and Brett, 1988). The position of some ironstones and coeval phosphatic horizons upon unconformities, created during global lowstands of sea level, indicate that deposition occurred during times of sea level rise (transgression) and siliciclastic sediment starvation. As such, ironstones were interpreted to represent highly condensed beds that represent much more time per unit thickness than the shales and sandstones that bracket them (Brett et al., 1990; 1998; McLaughlin, Brett, and Wilson 2008). However, because the iron transported into the Appalachian Basin was in the form of grain coatings on clay particles and silt and sand grains under background conditions, siliciclastic sediment starvation would stop the influx of iron into the basin during transgression, thus requiring mobilization of iron from out of the preexisting basin sediments or from a source outside the basin.

Recent carbon isotope analysis across the Appalachian Basin indicates synchrony between the timing of globally recognized positive carbon isotope excursions and the occurrence of ironstones (Figure 5; McLaughlin and others, in review). The large positive shifts in carbon isotopes reflect burial of massive amounts of light organic carbon globally. The incredible increase in primary productivity and burial required to drive such enormous fractionation (up to 10 per mil in the late Ludlow) required oceanic anoxia. The presence of widespread anoxic conditions is supported by proxy data from geochemical studies and the shift to black, laminated shales in basin-center deposits during these events around the world. Within the Appalachian Basin a shift from red and green shales to olive, gray and black shales records this change in organic carbon burial. Ironstones and phosphorites are coincident with this shift in sediment color. Where ironstones are traced down-ramp into phosphorites, the position of this facies transition reflects the original position of a redox interface within the basin. Geochemical analysis of tens of meters of strata below the ironstones shows an iron concentration typical of marine rocks (several orders of magnitude lower than the ironstones) and no significant stratigraphic variation in iron concentration. Thus, there is no evidence that the iron that makes up the ironstones was leached from the underlying strata. Thus, without a sufficient source of iron from riverine input (as predicted during transgressive siliciclastic sediment starvation) or from the underlying sediments, it follows that the primary source of iron was extra-basinal. It is likely therefore that advance of an anoxic water mass into the Appalachian during global organic carbon burial events provided the medium for delivery of massive amounts of dissolved iron. The ironstones and iron-rich carbonates were deposited at a water mass boundary as indicated by their "bath tub ring" distribution around the margins of the basin. The composition and distribution of the ironstones indicates that this water mass boundary was somewhat diffuse and fluctuated between oxic conditions prevalent above and the anoxic conditions present below.

No clear consensus has emerged among the scientific community regarding the origin of ironstones; it may well be that several models or a combination thereof may be responsible for their genesis. Several of the classic "Clinton Ironstones" will be examined through the course of this excursion in the context of these models.

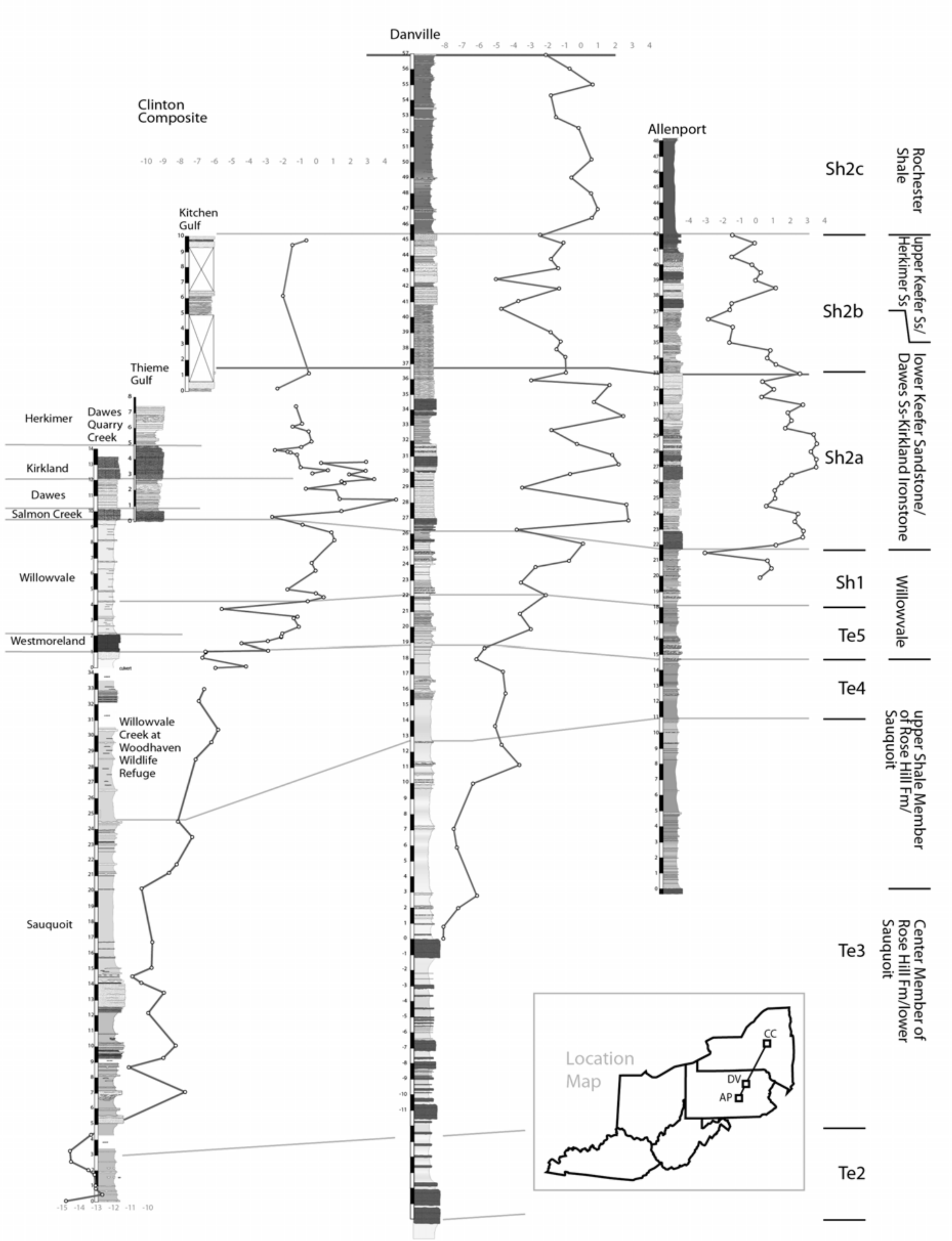

Figure 5 - A regional cross section of Lower Silurian strata in the eastern Appalachian Basin showing regional correlations and the interrelationships between $\delta^{13}C$ values and the stratigraphic distribution of ironstones, which are shaded dark grey in this figure. Modified from McLaughlin and others (in review).

4. CONCLUSIONS

Dramatic and dynamic global patterns of climatic, biotic, and oceanographic change in the Silurian are now thoroughly documented and the equally vivid record of these patterns are well represented in the ironstone bearing stratigraphic successions of Oneida County. Considerable progress has been made in constraining the depositional setting of Phanerozoic sedimentary ironstones such as these, though much remains to be done. For example, ironstones appear to be preferentially associated with basal lowstand to early transgressive lag deposits of depositional sequence; sediment starvation appears to have allowed buildup of early diagenetic minerals without dilution. However, ironstones are also restricted to particular time intervals (McLaughlin et al., in press) and the source of the iron, whether intra- or extrabasinal, and the process of concentration remain a source of discussion. As this debate and others evolve, the Silurian successions of east central New York will continue to play an important role in our understanding in this pivotal episode of earth's history.

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STOP DESCRIPTIONS

This field excursion features three well-known exposures of the Clinton Group: Roaring Brook at Lairdsville (Type Westmoreland), Theime Gulf, and the Woodhaven Wildlife Refuge (also called Willowvale Creek, or the Glen). All three sections are exposed in the beds of small streams and glens running through Oneida County in the Vicinity of the town of Clinton (Figure 6). A fourth locality, the Forever Wild Nature Preserve, is also included here as an optional stop. This is the first published description of the strata exposed at this last section.

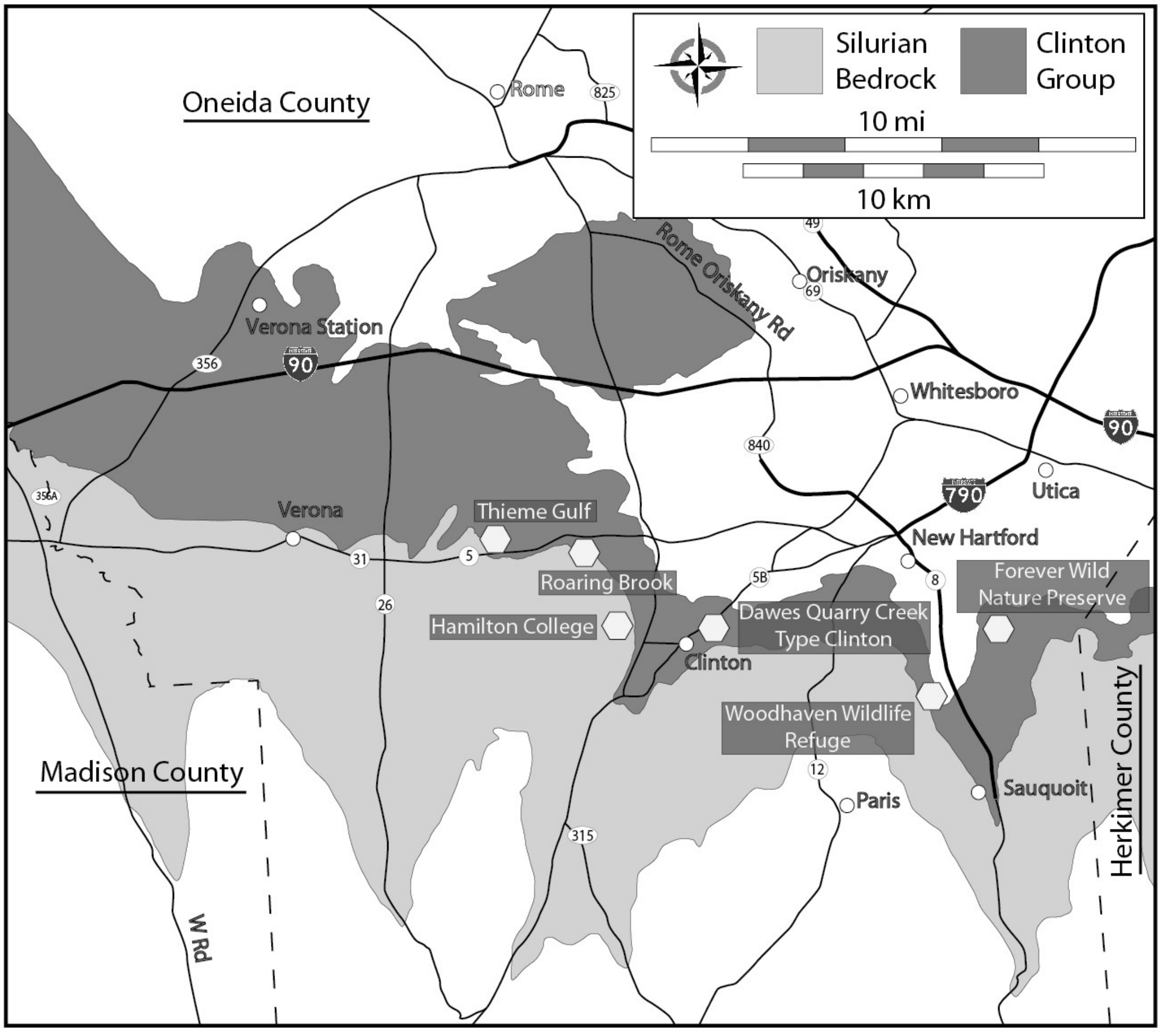

Figure 6 – Map of the Clinton Type Area with all sections mentioned in this write up plotted. Modified from Fisher and others (1970).

Route Description	**Number of Miles**	**Cumulative mileage**
Starting Point **Taylor Science Center,** Hamilton College, Clinton, NY 13323	Depart	
Head **north** toward **Campus Rd/County Rd 77**	0.08	0.08
Turn left onto **Campus Rd/County Rd 77**	1.1	1.2
Turn left onto **County Rd 15A/Norton Ave**	1.1	2.3
Turn right onto **NY-5 E/Seneca Turnpike**	0.6	2.9
Stop 1 **Roaring Brook - Type Section of the Westmoreland** 7041 NY Rte. 5 (Seneca Turnpike), Clinton, NY 13323	Arrive	

Stop #1. Roaring Brook - Type Section of the Westmoreland Iron Ore
Coordinates: N 43° 04' 48.30", W 75° 25' 16.79"

Roaring Brook is the informal name given to a small, south flowing tributary of Oriskany Creek found in Lairdsville, a small Hamlet of Clinton, New York, in Oneida County. This locality was designated by Gillette (1947; p. 91-93) as the type section for the Westmoreland Hematite, though no detailed description of the outcrop was given. This section is located on private property and those wishing to view it must first obtain permission from the residents of 7012 NY Rte. 5 (Seneca Turnpike), in Lairdsville, NY. The most straightforward way of accessing the stream bed is by walking down the western slope of the valley cut by the stream where several paths provide relatively easy access to the section. A large (3-4 meter) waterfall, capped by the Westmoreland Iron Ore is a notable feature of this locality. A smaller falls, upstream and closer to the road, is capped by the Salmon Creek Bed.

This section has been featured previously as stop 13 of Brett and Goodman (1996). Five named rock units are exposed here; they are described and illustrated in ascending order herein (Figure 7).

Unit 1 - Sauquoit Formation

All strata exposed below the large waterfall at this locality are assigned to the Sauquoit Formation of the Middle Clinton Group (Sequence S-III of Brett et al, 1990). The Sauquoit Formation is reported to be approximately 30 meters thick in this area; the upper 6-7 meters of the unit is relatively well exposed along an approximately 0.25 kilometer stretch of creek bed extending downstream from the large waterfall.

Here, the Sauquoit Formation is dominantly greenish grey clay shale with thin interbeds of varying lithology that include planar to cross laminated, fine- to medium-grained calcareous quartzose sandstone and phosphatic, quartz pebble conglomerates. Many of these interbeds display numerous sedimentary structures, including sole marks, gutter casts, and asymmetrical, symmetrical,

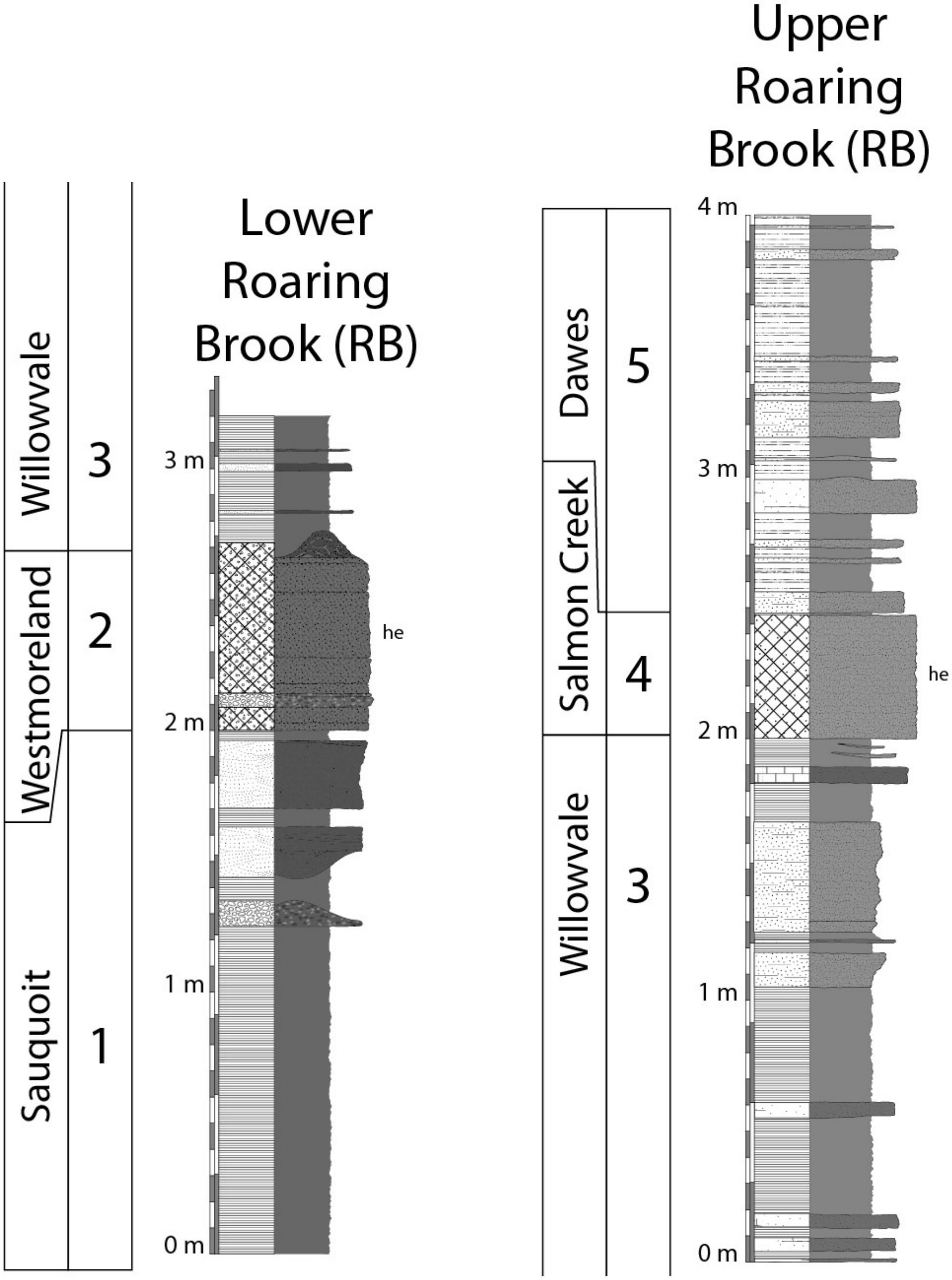

Figure 7 - Stratigraphic columns for outcrops at Roaring Brook, in Lairdsville New York.

and interference ripple marks. Several thick, cross bedded sandstone interbeds occur near the top of the Sauquoit Formation at this locality, which contain abundant phosphatic shell fragments tentatively interpreted as lingulid remains. Below these upper sandstone beds is a locally present, rippled quartz phosphate pebble conglomerate.

Macrofossils are relatively sparse, though bedding planes may contain abundant bivalves and brachiopods. The brachiopods *Strophochonetes* (?) *cornutus, Leptaena rhomboidalis,* and *Eocoelia sulcata* are all relatively common, suggesting assignment to Boucot's (1975) benthic assemblage 2. Bivalves are also quite common on some bedding planes, and very rare large trilobites have been found here as well. The presence of Ostracodes belonging to the *Mastigobolbina typus* Zone suggest a mid Telychian (C-5) age for these beds.

Unit 2 - Westmoreland Iron Ore

The large waterfall at Roaring Brook is capped by a 70-80 centimeter thick interval of bright red hematitic beds assigned to the Westmoreland Iron Ore. This horizon has been mined extensively here, and large portions of this unit are removed.

The bed is composed primarily of small, sand sized "oolitic" sediments composed of concentric laminae of hematite, chamosite, and berthierine surrounding a nucleus that is usually composed of a rounded quartz grain (Schoen, 1962). Several conglomeratic horizons are also found in the Westmoreland Iron Ore at this locality, composed primarily of quartz and phosphatic pebbles surrounded by a matrix of oolitic, hematitic grains. Brett and Goodman (1996) reported centimeter wide rectilinear cracks infilled with quartz and phosphate grains underlying the Westmoreland, which they interpreted as sedimentation within emergent mudcracks forming in the underlying Sauquoit. The upper surface of the unit displays large (~10 cm high) symmetrical ripple marks.

The Westmoreland is sparsely fossiliferous here, though conodonts of the *Pterospathodus celloni* to *Pterospathodus amorphognathoides* Zones have been reported from the unit here (M. Kleffner, pers. comm. 1990 *in* Brett and Goodman, 1996). Brett and Goodman (1996) also report *Eocoelia sulcata*, *Eospirifer radiatus,* and *Eoplectodonta transversalis,* suggesting a late Telychian age for this unit. The thin, fossiliferous black shale bed reported in the Westmoreland Iron Ore at other sections by Gillette (1947) is not present here.

Unit 3 - Willowvale Shale

Sharply overlying the Westmoreland Iron Ore is the Willowvale Shale, which is approximately 6.1-7.6 meters thick in this area. At Roaring Brook, the unit is primarily gray to olive grey shaly mudstone with minor interbeds of light colored, sandy fossiliferous dolostones.

The Willowvale Shale yields a diverse marine fossil assemblage interpreted as the remnants of a relatively deepwater fauna (Eckert and Brett, 1989). The lower 0.3 to 0.75 meters of the Willowvale Shale contains several dolostone interbeds, which contain abundant specimens of a small discoidal rugose coral identified as *Palaeocyclus rotuloides* a fossil that appears in equivalent late Telychian strata throughout the world.

Unit 4 - Salmon Creek - Basal Dawes Bed

Upstream from the Willowvale bank exposures, the stream takes a sharp bend that leads up to a second, small falls just below the culvert under NY Route 5. This small falls is capped by a 40-50 centimeter thick, pinkish, blocky, sandy dolostone, which contains numerous small stringers of hematite; in the past this unit has been misidentified as Kirkland iron ore at some sections. This bed is interpreted as the basal bed of the Dawes, also referred to as the Salmon Creek Bed. The dominant fossils found in this unit are fragments of stalked echinoderms, primarily crinoids which are highly disarticulated and often impregnated with hematite.

Unit 5 - Dawes Sandstone

Above Unit 4 are a few meters of interbedded siltstones, sandstones and shales assigned to the Dawes Sandstone, which is the highest stratigraphic unit observed in Roaring Brook on the south side of NY Route 5. The unit is not fossiliferous and it is poorly exposed, being largely covered by soil and rip-rap sitting below the culvert under the road. Better exposures of this unit and some of the underlying beds can be viewed at the next stop.

Route Description	**Number of Miles**	**Cumulative mileage**
Stop 1 **Roaring Brook - Type Section of the Westmoreland** 7012 NY Rte. 5 (Seneca Turnpike), Clinton, NY 13323	Depart	
Head **west** on **NY-5 W/Seneca Turnpike** toward **County Rd 15A/ Norton Ave**	0.8	3.7
Take the 1st right onto **Theime Gulf Rd**	0.2	3.9
Stop 2 **Theime Gulf** 4486 Theime Gulf Rd, Clinton NY 13323	Arrive	

Stop #2. Theime Gulf

Coordinates: N 43° 04' 48.17", W 75° 26' 10.80"

The outcrops exposed at Theime Gulf are found in the banks of a small, northwest flowing tributary of Oriskany Creek. Five named stratigraphic units are featured at this stop, which partially overlap the section exposed in Roaring Brook at Stop # 2 (See Figure 8). These outcrops are located on a private residence at 4486 Theime Gulf Road, in Clinton New York; visitors must obtain permission before entering. This section has been featured previously as Stop 14 of Brett and Goodman (1996).

Unit 1 - Willowvale Shale

The lowest exposed strata at Theime Gulf are assigned to the upper part of the Willowvale Shale. Here the unit is primarily a dark grey shaly mudstone with very few interbeds. Only the upper few meters of the Willowvale Formation are exposed here, and these can only be accessed with some excavation. A single interbed was observed, approximately 15 centimeters below the base of Unit 2. This bed was a dark grey, orange-brown weathering dolomitic carbonate containing abundant fossils, particularly the high spired gastropod *Murchisonia*, which is commonly infilled by a black mineral interpreted as phosphate.

Unit 2 - Salmon Creek - Basal Dawes

Overlying the Unit 1 is an 80-90 centimeter, reddish pink sandy carbonate grainstone horizon interpreted as the Salmon Creek, or Basal Dawes Bed which supports a small falls near the bottom of this section. This horizon appears to be much more ferruginous at this locality than at Roaring Brook (Stop 2). The unit is blocky and heavily cross stratified. Its upper and lower contacts are sharp, and small rip-up clasts are observed at several horizons. In contrast to the overlying beds, the Salmon Creek Bed is fairly fossiliferous. Stalked echinoderm columnals are the primary constituent of this assemblage, many of which are stained dark red with hematite.

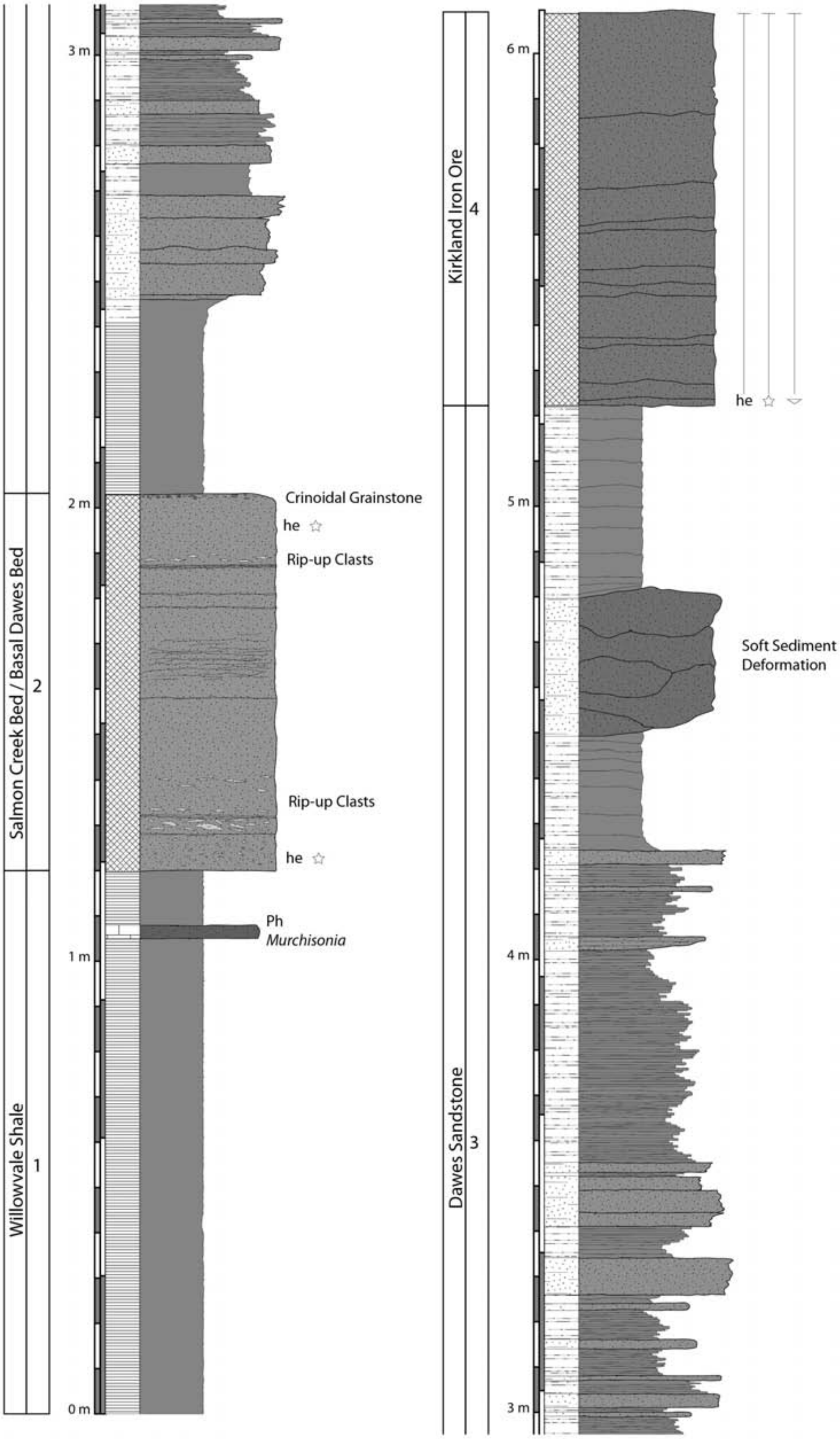

Figure 8 - Stratigraphic column showing the units exposed at Theime Gulf.

Unit 3 - Dawes Sandstone

Overlying Unit 2 are approximately 3.2 meters of dark grey shales, siltstones and sandstones assigned to the Dawes. Fine grained shales and siltstones are the predominant lithology this interval, in contrast to the coarser beds observed at Dawes Quarry Creek. These units are generally finely laminated, though the numerous 5-25 centimeter sandstone interbeds are often massive, with ripples on their upper surfaces. Near the top of this unit is an approximately half meter interval of sandstone and shale showing extensive deformation and ball and pillow structures, which are interpreted as post depositional soft-sediment deformation.

Unit 4- Kirkland Iron Ore

Approximately two meters of massive, dark red dolomitic carbonates overlie Unit 3; these beds are assigned to the Kirkland Iron Ore. The unit is a highly fossiliferous crinoidal, pack- to grainstone with hematitic cement. Although crinoids are the dominant component of the Kirkland's fossil assemblage, bryozoans such as *Acanthoclema* and *Eridotrypa* are also important components. Several beds of the Kirkland are display prominent cross stratification. The basal contact of the unit is sharp, but its upper boundary with the overlying unit is gradational.

Route Description	**Number of Miles**	**Cumulative mileage**
Stop 2 **Theime Gulf** 4486 Theime Gulf Rd, Clinton NY 13323	Depart	
Head **south** on **Theime Gulf Rd** toward **NY-5 W/Seneca Turnpike**	0.2	4.1
Turn left onto **NY-5 E/Seneca Turnpike** Continue to follow NY-5 E	6.8	10.9
Continue onto **NY-12 N**	0.6	11.5
Take the exit toward **NY-8 S/New Hartford**	0.2	11.7
Merge onto **Campion Rd**	0.4	12.1
Continue onto **Oxford Rd**	2.6	14.7
Turn right onto **Oneida St**	0.6	15.3
Stop 3. **Willowvale Creek at Woodhaven Wildlife Refuge** Woodhaven Lane and Oneida Street, Chadwicks, NY, 13319	Arrive	

Stop #3. Willowvale Creek at Woodhaven Wildlife Refuge

Coordinates: N 43° 01' 50.02, W 75° 16' 44.42"

The Woodhaven Wildlife Refuge is a privately owned nature preserve occupying the site of a former picnic area in Chadwicks, New York. At this locality several tens of meters of section can be observed in the bed of Willowvale Creek, a small east-flowing stream which eventually passes under Oneida Street in Chadwicks. This section was described in detail by Gillette (1947; Section 34), and it represents perhaps the most complete, and best exposed outcrop of the Clinton Group in its Type Area. However, only thin, ironstone bearing excerpts of this entire section have been drafted here. Those interested in a more detailed and comprehensive descriptions of the outcrop are referred to Gillette (1947).

The creek was dammed in three places, forming small artificial ponds along the creek. At least two ironstone horizons are located some distance upstream; they may be accessed by a short walk through the scenic preserve. All outcrops described herein are on private land, visitors must first obtain permission from the administrators of the Woodhaven Wildlife Refuge.

Unit 1 – Sauquoit Formation

Unit 1, assigned to the Sauquoit Formation, is at least 35 meters thick at this locality, consisting primarily of blue grey to green gray shales and mudstones with many interbeds composed of calcareous sandstone, siltstone, and quartz-phosphate pebble conglomerates. The unit is abundantly fossiliferous; bivalves, ostracodes, and brachiopods predominate though some trilobites have been reported here as well. Intervals containing ball-and-pillow structures have been observed in shales at several intervals of the Sauquoit at this locality, which are interpreted as the post depositional soft sediment deformation of units, possibly due to seismic activity. The upper few meters of the Sauquoit Formation at this locality are difficult to access, though a relatively complete reconstruction can be compiled through a comparison of creek bed and gully wall outcrops.

Unit 2 – The Westmoreland Hematite

Numerous fragments of oolitic ironstone litter the creek bed, where their bright red color makes them easy to pick out. Many of these fragments are believed to originate from Unit 2, which is assigned to the Westmoreland Hematite. The only outcrop of this bed is located at N 43° 01' 47.39", W 75° 16' 49.25", this is within a very steep gully above the lake formed behind the lowest of the three Willowvale dams (Figure 9). Accessing the outcrop is quite difficult.

The unit is composed primarily of sand sized, iron coated grains which are deeply weathered

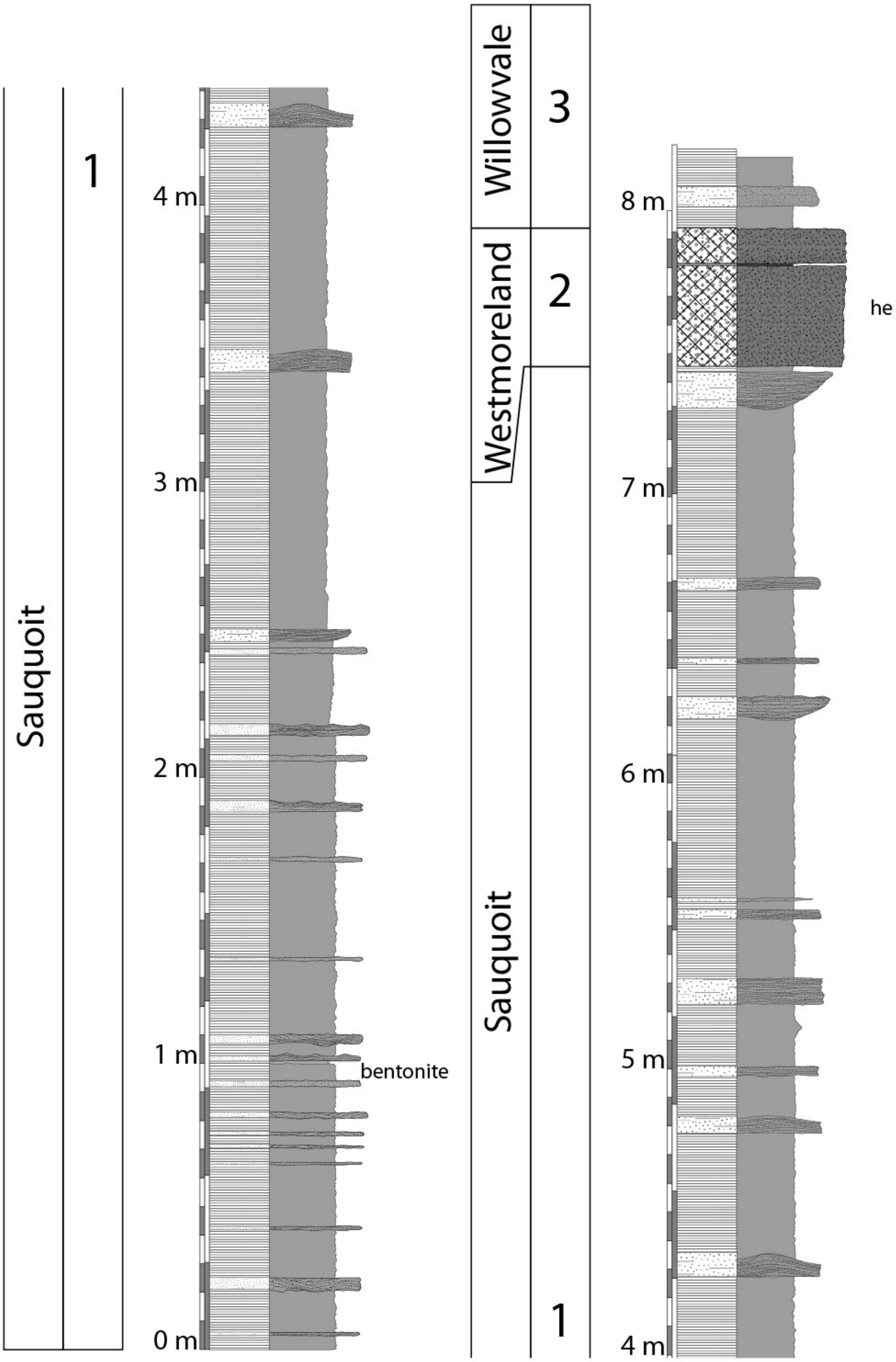

Figure 9 – Stratigraphic column of the upper Sauquoit Formation, Westmoreland Hematite, and Willowvale Shale exposed within the steep gully above the lake formed by the lowest dam on Willowvale Creek.

in the outcrop. These are bright red in color, and unfossiliferous. A black shale lens within the hematite was observed here, similar to the ones described by Gillette (1947), but no fossils were observed in this horizon either.

Unit 3 – Willowvale Shale

Unit 3 constitutes the predominantly shaly unit between the ironstones represented by Units 2 and 4.This interval is interpreted as the Willowvale Shale which, like the Sauquoit Formation, consists of dark grey shales with occasional interbedded, fossiliferous calcareous sandstones. Unlike the Sauquoit, the shales of the Willowvale are dark to olive grey in color, and there are no conglomeratic horizons. The coral *Palaeocyclus* is abundant in the beds of the lower part of this horizon, though these can only be accessed with difficulty here. Other common fossils are brachiopods, bivalves, ostracodes, and graptolites.

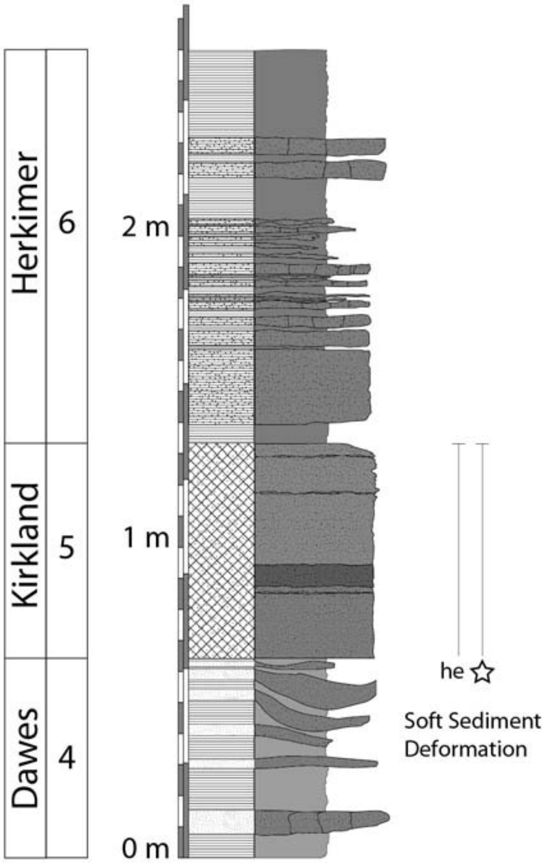

Figure 10– Stratigraphic column of the upper Willowvale Shale, Kirkland Hematite, and lower Herkimer Sandstone exposed at the waterfall just upstream from the lake formed by the middle Willowvale Creek dam.

Unit 4 - Dawes Sandstone

Unit 4 is a succession of relatively unfossiliferous blue grey shales with sandstone and siltstone interbeds. Although these beds were interpreted previously by Gillette, 1947, as the Willowvale Formation, we submit that this is a manifestation of the Dawes Sandstone. Although the Dawes is more shaly here than at Roaring Brook and Theime Gulf the zone of ball-and-pillow structures is similar to that of those and other successions of the Dawes.

Unit 5 - Kirkland Hematite

Unit 5 is a ferruginous limestone that forms the caprock of a small waterfall at approximately N 43° 01' 44.40", W 75°16' 57.31", just upstream from the lake formed by the middle Willowvale Dam. This bed is interpreted as the Kirkland hematite (or flux ore), a calcareous, fossiliferous hematitic ore overlying a zone of soft sediment deformation in the upper Dawes Formation (Figure

10). The unit contains abundant crinoids and stalked echinoderms, which are often stained dark red by hematite.

Unit 6 – Herkimer Sandstone

The Herkimer sandstone consists of orange brown sandstone horizons interbedded with very dark grey silty shales. Abundant ripple marks and cross beds indicate the unit was likely deposited in a relatively shallow environment close to normal wave base. The unit is fairly unfossiliferous, though large brachiopods and cephalopods have been found occasionally. Trace fossils, such as *Palaeophycus* and *Rusophycus* are relatively common.

Route Description	**Number of Miles**	**Cumulative mileage**
Stop 3. **Willowvale Creek at Woodhaven Wildlife Refuge** Woodhaven Lane and Oneida Street, Chadwicks, NY, 13319	Depart	
Head **northwest** on **Oneida St** toward **Bleachery Pl**	1.7	17.0
Turn right onto **Chapman Rd**	1.1	18.1
Take the 1st right onto **Meadowbrook Dr**	0.2	18.3
Take the 2nd right onto **Brookside Terrace**	0.05	18.3
Stop 4 (Optional) **Forever Wild Nature Preserve** Brookside Terrace, New Hartford, NY 13413	Arrive	

Stop #4. (Optional) Forever Wild Nature Preserve

Coordinates: N 43° 03' 07.54", W 75° 15' 05.28"

The Forever Wild Nature Preserve is a heavily forested area east of Washington Mills. The property is a privately owned and permission must be obtained before entering the property. Several excellent exposures of Lower Silurian strata may readily accessed from Brookside Terrace, a small, dead-end lane connected to Meadowbrook Drive in New Hartford New York. A well exposed section is exposed in the creek just south this road. These outcrops are described and illustrated herein (Figure 11), to our knowledge, for the first time in publication.

Unit 1 - Oneida Conglomerate

Strata exposed in the lower part of this creek section are predominantly unfossiliferous interbedded dark grey sandstones and quartz-phosphate pebble conglomerates assigned herein to the

Oneida Conglomerate. Several of the sandstone beds have rippled upper surfaces. A meter thick zone of cross bedded conglomerate occurs near the top of the unit; these beds are composed primarily gravel sized, rounded clasts of phosphate and quartz set within a matrix of dark red, hematitic sandstone. This zone is overlain by a 25 centimeter interval of blue grey shale, which is in turn overlain by a pair of hematitic, conglomeratic units with lithologies similar to the beds found in the cross bedded zone. The upper of these two beds contains very large, symmetrical ripple marks that have amplitudes up to 15 centimeters. The Oneida-Sauquoit contact is tentatively placed at the top of this unit.

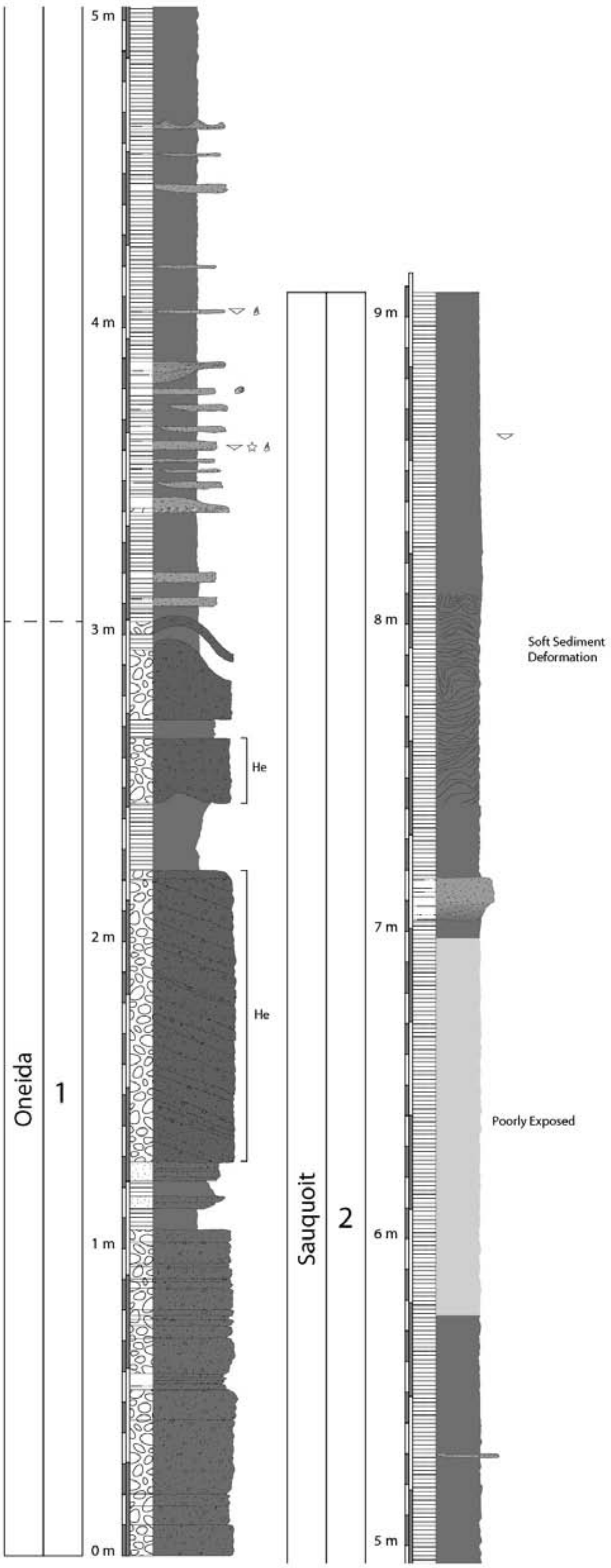

Figure 11 - Strata exposed in the small northwest flowing stream on the Forever Wild Nature Preserve, just south of Brookside Terrace.

Unit 2 - Sauquoit Formation

Overlying unit 1 is a succession of blue to greenish grey shales with interbedded calcareous sandstones assigned herein to the Sauquoit Formation. These calcareous sandstone interbeds often have ripple marks on their upper surfaces, and many display hummocky cross stratification. Several of these beds are fossiliferous, containing abundant gastropods, bivalves, brachiopods, and ostracodes. Near the top of the section illustrated in Figure 11, there is a zone of irregularly bedded shales interpreted as the product of post depositional, soft-sediment deformation, possibly as a result of seismicity.

Route Description	**Number of Miles**	**Cumulative mileage**
Stop 4 (Optional) **Forever Wild Nature Preserve** Brookside Terrace, New Hartford, NY 13413	Depart	
Head **northeast** on **Brookside Terrace** toward **Meadowbrook Dr**	0.05	18.4
Turn left onto **Meadowbrook Dr**	0.2	18.6
Take the 2nd left onto **Chapman Rd**	1.2	19.8
Turn right onto the **NY-8** ramp	0.3	20.1
Merge onto **New York 8 N**	1.8	21.9
Continue onto **NY-840 W**	0.2	22.1
Take the exit onto **NY-12 S/NY-5 W** toward **Syracuse/ Binghamton**	1.1	23.2
Turn left onto **New York 12B S/Clinton Rd**	4.1	27.3
Slight left onto **E Park Row**	0.1	27.4
Take the 2nd right onto **S Park Row**	0.05	27.4
Continue onto **College St**	0.9	28.3
Continue onto **College Hill Rd/County Rd 13**	0.5	28.8
Turn right onto **Campus Rd/County Rd 77**	0.3	29.1
Turn left	0.05	29.2
Ending Point **Taylor Science Center,** Hamilton College, Clinton, NY 13323	Arrive	