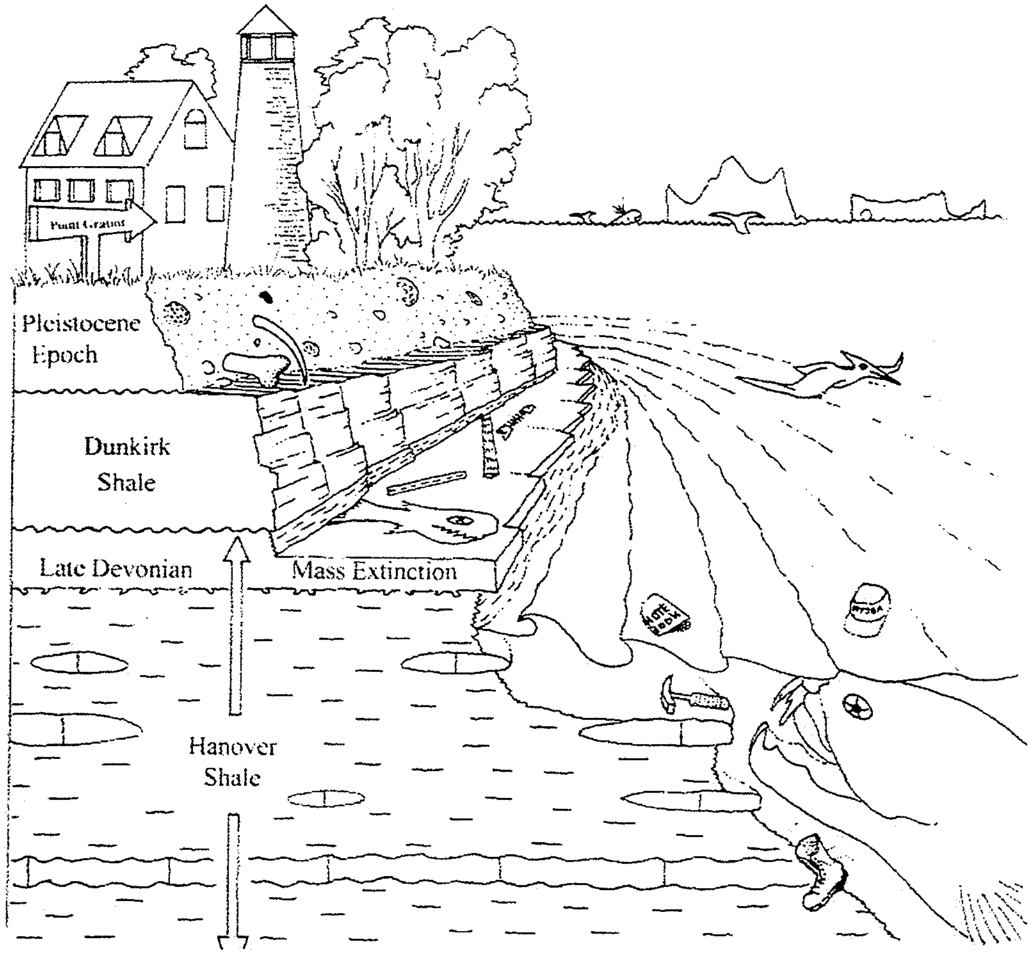
NEW YORK STATE GEOLOGICAL ASSOCIATION

71ST Annual Meeting
October 1-3, 1999

Field Trip Guidebook



SUNY College at Fredonia

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FIELD TRIP GUIDEBOOK

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Errata

Due to the insertion of superfluous pages in the original guidebook, removed from this edition, pages *Sat. F5* and *Sun C 24* appear to be missing herein. This is not the case. The text is intact.

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INTRODUCTION

The lower (sub-Ludlowville Formation) part of the Hamilton Group in western New York has received little attention by geologists owing to poor exposure and to the perception that it is composed essentially of drab, unfossiliferous deposits. Reexamination of numerous sections and several subsurface cores of Onondaga Group and lower Hamilton Group strata by Brett and Ver Straeten (1994) and Ver Straeten et al. (1994) has led to significant revisions of published correlational schemes (Rickard, 1975, 1984). In particular, the old formational division of the lower Hamilton Group (Marcellus Formation) has been elevated to subgroup status and is now understood to include two formational entities (Ver Straeten et al., 1994); the Union Springs Formation (Bakoven Member-Hurley Member-succession) comprises the lower part of the Marcellus subgroup and the Oatka Creek Formation (Cherry Valley Member through Chittenango Member-succession) represents the upper part (Fig. 1). The above terminology of Ver Straeten et al. (1994) is employed herein (Figs. 1, 2). Two of us (Baird, Brett) are involved in ongoing revision of the Union Springs-through-Skaneateles formational successions across central and western New York as, well as central Pennsylvania. Only a small portion of this work has yet been set in print; Meyer, working under supervision of Baird, revised the stratigraphy of the Stafford Member (basal Skaneateles Formation) and elucidated its relationship with the Mottville Member (Meyer, 1985). A spectacular erosionally furrowed discontinuity surface (see STOP 6) has been described from the lower medial part of the Levanna Member in Erie County (Brett and Baird, 1990; Baird and Brett, 1991). The stratigraphic relationships of basinal Chittenango Member and Levanna Member facies in western New York with coarser, shoreward deposits in central New York are the subject of detailed scrutiny by Brett and Baird.

The present paper advances an overview of the stratigraphy of the topmost Onondaga Group and sub-Centerfield Hamilton interval between the Seneca Lake meridian and Lake Erie noting revisions to date. We also tentatively explain vertical and lateral lithologic changes in terms of an inferred sea level curve and the sequence stratigraphy paradigm. Key background sources on the stratigraphy of this interval by earlier workers include: Cooper (1930); Smith (1935); Rickard (1975, 1984); Grasso (1986); Linsley (1991); Brower and Nye (1991); Brett and Ver Straeten (1994); and Ver Straeten et al. (1994). Because the Union Springs, Oatka Creek, and, especially, the Skaneateles

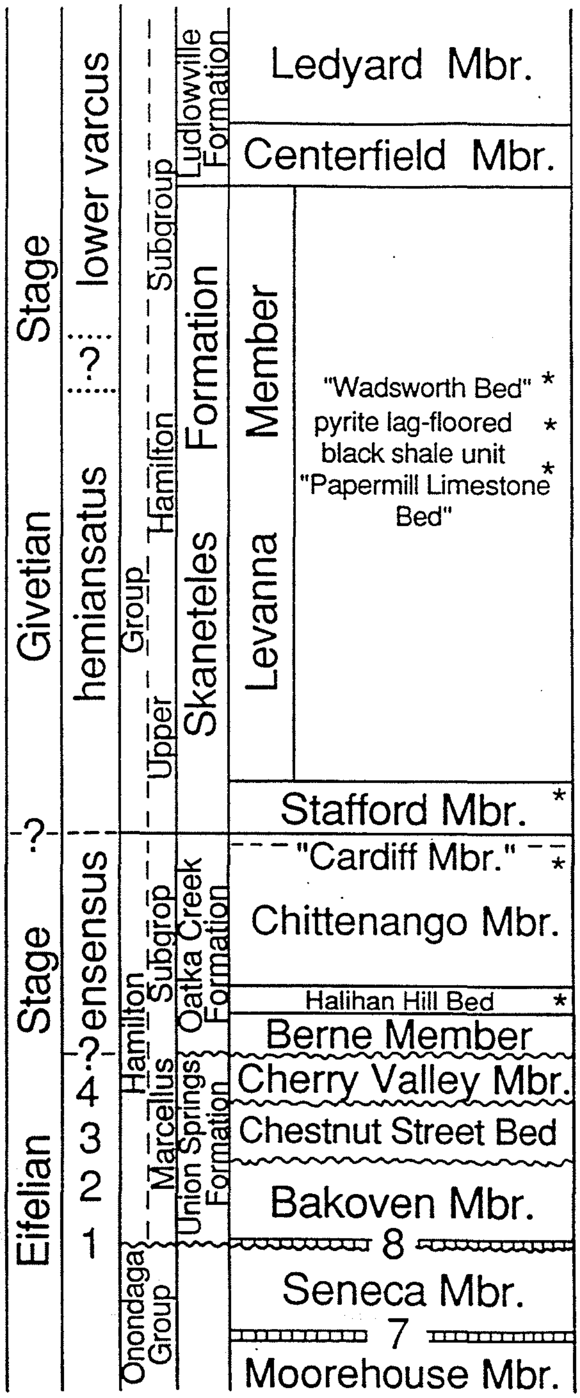


Figure 1. Generalized succession of lithologic and zonal units in the uppermost Onondaga Formation-through-basal Ludlowville Formation interval in western New York. Numbers denote: 1, base-Bakoven Member discontinuity; 2, *Cabrieroceras plebieforme* zone; 3, *Haplocrinites* zone; 4, *Agoniatites vanuxemi* zone; 7, Onondaga Indian Nation (OIN) K-bentonite; 8, Tioga "F" K-bentonite.

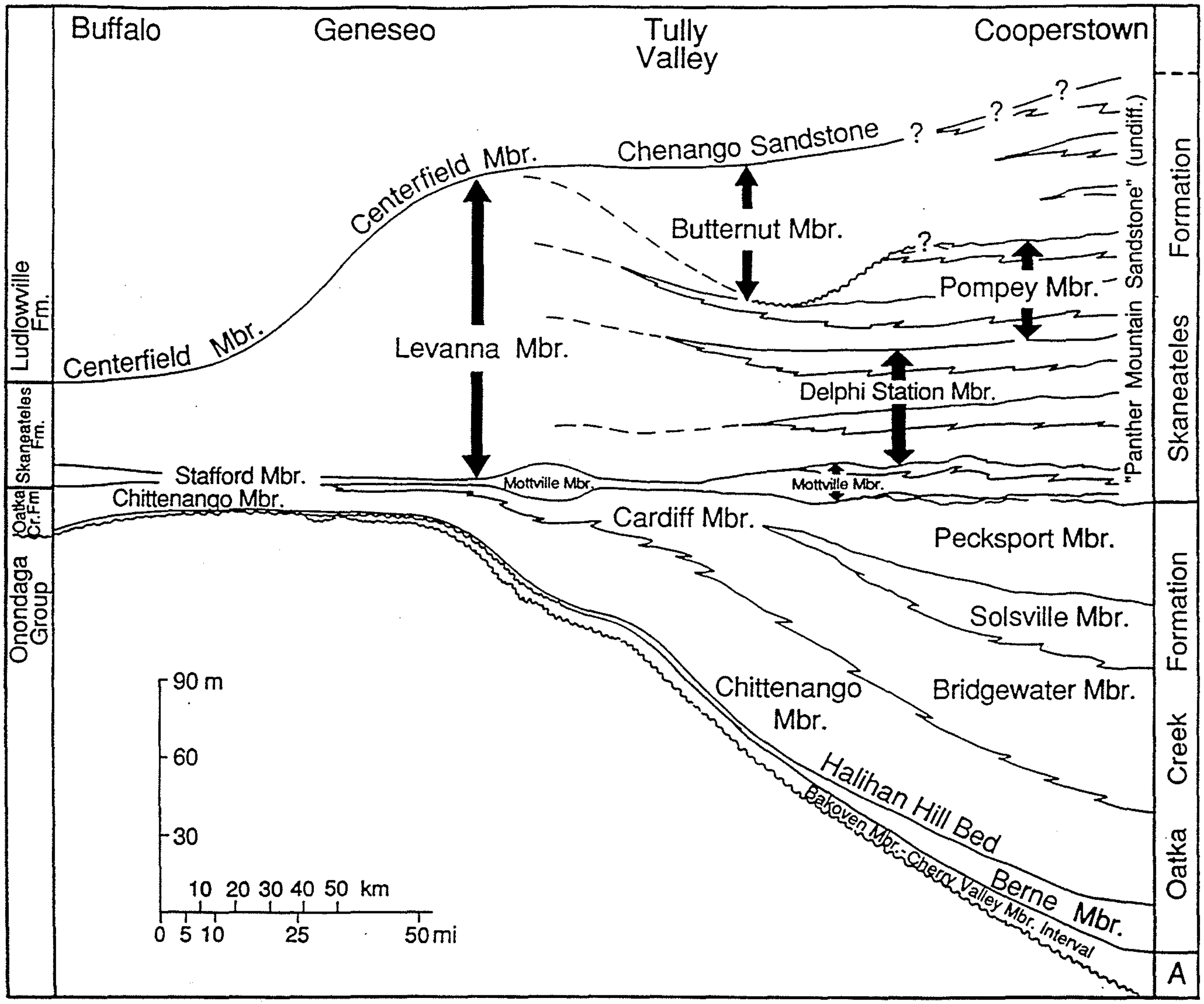


Figure 2. Generalized stratigraphy and unit relationships in the lower part of the Hamilton Group along the east-west outcrop belt across New York State. Conspicuous eastward thickening of units reflects major clastic influxes associated with the second tectophase of the Acadian Orogeny and coincident deepening of the Devonian foreland basin.

formational successions are poorly exposed, we can only focus on a few key beds and distinctive intervals in the present report.

STRATIGRAPHIC-HISTORICAL OVERVIEW

Onondaga Group and Union Springs Formation

The uppermost Emsian?-Eifelian Onondaga Group records a subtidal carbonate shelf supportive of a variably diverse open marine biota comprising the "Onondaga Fauna" (see Oliver, 1956, Koch, 1981; Brett and Ver Straeten, 1994). Epeirogenic processes, presumably linked to the ongoing Acadian Orogeny in New England (Ver Straeten et al. 1994) explain a pattern of an eastwardly migrating backbulge basin within the medial Onondaga Limestone across western New York (Brett and Ver Straeten, 1995). In Pennsylvania, to the south of the Finger Lakes, Onondaga deposits accumulated in a carbonate-starved deeper part of the foreland basin under conditions that were more decidedly dysoxic (Koch, 1981; Brett and Ver Straeten, 1994).

The end of Onondaga carbonate deposition, marked by packstone to lime mudstone facies of the Seneca Member, signaled the onset of a major deepening event within the Appalachian Basin, designated the "second tectophase" by Ettensohn, 1985, 1987; widespread deposition of organic-rich shales and ribbon limestones of the Bakoven Member of the Union Springs Formation marks the presumed collapse of the carbonate platform due to a major thrust loading pulse associated with terrain collision to the east. This was closely associated with the progradation of clastics from orogenic source areas to the east; the developing foreland basin was filled with sediment as it subsided and expanded leading to the long-recognized pattern of eastwardly thickening clastic wedges within the Hamilton Group (Fig. 2). Significantly, the post-Onondaga deepening event is closely associated with the "Tioga" cluster of k-bentonites that occur both within the upper Onondaga and basal Union Springs successions. Rapid eastward-southeastward thickening of the Bakoven shale in the vicinity of the Hudson Valley attests to initial development of foreland basin conditions timed with earliest Hamilton Group deposition (Ver Straeten et al., 1994).

The Union Springs Formation marks an initial major flooding pulse partly of tectonic and partly of eustatic origin (see Ettensohn, 1985, 1987; Ver Straeten et al., 1994). Above the Bakoven Member interval, however, is evidence of a regression marked by the Stony Hollow Member-Chestnut Street Bed-interval (Ver Straeten et al., 1994) which is mostly eustatic origin but is influenced by the first coarse clastic pulse of the Hamilton succession. The thin Chestnut Street Limestone submember ("proetid bed") of the Hurley Member originally lumped within the Cherry Valley Member (Rickard, 1975; Cottrell, 1972), is now observed to be a distinct unit from the overlying Cherry Valley (Fig. 1). This bed, is the condensed cratonward equivalent of the much thicker, siliciclastic succession of the Stony Hollow Member in the Hudson Valley (Ver Straeten et al., 1994). Moreover, the Cherry Valley Member, "*Agoniatites* Limestone" of early workers, is observed to be a thin (condensed) transgressive drape over the top of the Stony Hollow Member in eastern Mohawk Valley and Hudson Valley sections (Ver

Straeten et al., 1994). Thus the Bakoven-Stony Hollow-Chestnut Street succession respectively correspond to late highstand-regressive parts of the first great Hamilton sedimentary cycle, while the Cherry Valley marks the basal transgressive deposit of the second major cycle.

The Union springs cycle also marks an incursion of a new faunal association that replaces the long-standing "Onondaga Fauna". This faunal change was part of a global or near-global series of bioevents termed "Kacak-otomari" events by Chlupac and Kukal, 1986; Walliser, 1986; Truyols-Massoni et al., 1990 which are believed to be linked to a sea level highstand event timed with the late Eifelian. Distinctive taxa including: *Variatrypa arctica*, *Pentamerella winteri*, *Schizophoria* Sp., and *Emmanuella* Sp. characterize the Union Springs Formation. Kacak-Otomari immigrants are believed to be linked to warmer tropical water sources, perhaps in paleoenvironments recorded in deposits in present day arctic Canada.

Oatka Creek Formation

The Oatka Creek Formation, dominated by organic-rich basinal facies in central and western New York, records expansion of the foreland basin during the earliest Givetian. (Figs 1,2). A brief but widespread incursion of globally important cephalopods and dacryoconariids (Chlupac and Kukal, 1986; Walliser, 1986; Ver Straeten et al., 1994; Griffing and Ver Straeten, 1991) is reflected in the transgessive Cherry Valley facies. The Eifelian-Givetian zonal boundary probably lies slightly above the Cherry Valley Member-Berne Shale Member contact across the study area. The Berne Member, marked by a very thin, condensed interval of black, styliolinid-dacryoconariid-rich black shale in central and western New York, records a major highstand event (Ver Straeten et al., 1994). In western New York it is only 0.3-1.5 m-thick but thickens dramatically in Hudson Valley localities attesting to a depocenter in that region.

The Berne Member is succeeded by the widespread thin (0.5-1.0 m-thick) Halihan Hill Bed which marks the dramatic appearance of the long-standing "Hamilton fauna," an endemic "cooler water" biota characteristic of much of the Appalachian basin Givetian succession (Ver Straeten et al., 1994. The Halihan Hill Bed, originally discovered by Clelland (1903) and termed the "first *Meristella* Bed" in the Cayuga Valley and later rediscovered in several western New York localities, but not formally named, by Baird during the 1980s, is named for an occurrence 100 m above the base of the Berne Member at Halihan Hill near Kingston (Griffing and Ver Straeten, 1991; Ver Straeten et al., 1994). The Halihan Hill Bed, marking a major regression, yields a diverse biota locally characterized by large corals in the Hudson Valley. Key first appearances of the Hamilton fauna include: *Phacops rana, Microcyclus, Mediospirifer, Tropidoleptus*, and *Meristella;* in addition a number of Onondaga lineages reappear, e.g., *Heliophyllum, Heterophrentis*, and *Athyris*. This unit abruptly overlies the Berne Member and is herein defined as the base of the Chittenango Member in western and central New York and the equivalent Otsego Member in eastern New York. The condensed nature of the Halihan Hill Bed is widespread and striking.

Examination of Cooper's (1930) Chittenango type section, near Cazenovia, NY demonstrated that the lowest well exposed beds are styliolinid-rich limestones associated with the Halihan Hill bed. Thus, we define the term "Chittenango" as including the Halihan Hill bed and all overlying black, organic-rich shale up to the gray Cardiff beds; we also extend the member name into western New York where the Chittenango encompasses most of the Oatka Creek formation.

The Chittenango Shale Member comprises the bulk of the Oatka Creek Formation thickness across western and west central New York (Fig. 2). This unit is remarkable for its elevated (up to 18%) total organic carbon content (Ver Straeten pers. comm.). Both the Bakoven and Chittenango members display high T.O.C. levels and are highly radioactive markers on gamma ray logs (Rickard, 1984). In fact, these units display the highest geochemical signals for anoxia known for the Devonian of eastern North America. In the area of the field trip excursion the Chittenango Member averages 10 m-thickness. In eastern New York, this interval expands to 500 m or more in thickness as the black shale facies passes laterally to gray mudstone, nearshore sandstone facies and red beds.

The uppermost 1-3 m of the Chittenango interval below the Stafford Member of the Skaneateles Formation in the field trip area is composed of fissile medium gray to dark gray mudstone yielding a sparse biota of small *Eumetabolotoechia* ("*Leiorhynchus*") *limitare*, flattened orthoconic nautiloids, the bellerophontid *Retispira* and styliolines. This division, is believed to be equivalent to the Cardiff Member in central New York. It records dysoxic, outer shelf conditions intermediate between the anoxic Chittenango Member and the overlying Stafford Member.

Skaneateles Formation

The laterally equivalent and coextensive Stafford Member (western New York) and Mottville Member (central New York) successions mark a regressive interval at the base of the Skaneateles Formation. The Stafford succession in Genesee, Livingston, and Ontario County, consists of a single 20-50 cm-thick falls-capping limestone bed underlain by approximately 0.5 m of calcareous dark gray shell-rich, fissile shale and overlain by about a meter of calcareous dark gray mudrock with sparse fauna. The basal shale interval abounds in the brachiopods *Ambocoelia umbonata, Longispina, Productella,* and *Truncalosia truncata*, flattened orthoconic nautiloids and small benthic molluscs. The hard limestone contains small rugose and auloporid corals, the gastropod *Bembexia sulcomarginata*, three-dimensional orthocones, *Ambocoelia*, and small benthic molluscs. The upper shales contain *Ambocoelia*, orthocones and small molluscs.

In Erie County, the Stafford thickens to 4 m total thickness at Como Park (STOP 5) and acquires minor lentils of chert in its upper part (Meyer, 1985; Brett and Baird, 1990). Further west, at Buffalo Creek, the Stafford continues to thicken and it becomes distinctly cherty. In this region, the main limestone portion of the Stafford yields abundant small *Phacops rana*, scattered pelmatozoan columnals and molluscan debris (Meyer, 1985). Throughout western New York, the fauna of the main limestone bed is of only moderate diversity, recording minimally oxic conditions. The higher shale unit marks an upward transition to anoxia recorded in the basal part of the Levanna Shale Member.

Across Cayuga and Onondaga counties, the Stafford thickens eastward as it grades laterally into the Mottville Member (Meyer, 1985; Grasso, 1986). In the Skaneateles area, the Mottville is expressed largely as a 10 m-thick calcareous mudstone unit recording higher sedimentation rates under minimally oxic conditions. Both at and east of the Otisco Lake meridian, the Mottville dramatically thins and changes eastward to calcareous silty mudstone and siltstone beds yielding a diverse brachiopod and coral-rich fauna (Grasso, 1986). We believe that the Stafford central limestone ledge may link directly to the lower of two Mottville coral-rich silty limestone ledges at the Syracuse meridian. Clearly, the westernmost Mottville and Stafford members represent deeper water conditions than are indicated for the Syracuse-area Mottville.

The overwhelming balance of the Skaneateles Formation between the Stafford-Mottville interval and the Centerfield Member of the basal Ludlowville Formation is represented by the Levanna Shale Member. In the field trip area this 35-70 m thick unit is generally composed of dark gray fissile shale yielding a dysoxic, outer shelf fauna of small brachiopods, diminutive molluscs, occasional trilobites and flattened orthoconic cephalopods. However, our observations show that the Levanna is not monotonous, but subdivisable into traceable units, some of which are associated with significant erosional bounding surfaces (see below).

Both at and east of the Syracuse meridian the post-Mottville Skaneateles succession can be vertically subdivided into units each characterized by an upward (regressive) gradation from fissile shale into siltstone facies which is, in turn, bounded by an abrupt, transgressive change to shale (Cooper, 1930; Smith, 1935; Grasso, 1986). These divisions, including in respective ascending order: the Cole Hill, upper Delphi Station, "lower Pompey," "upper Pompey," (or Marietta) and Butternut-Chenango cycles, are collectively correlative to the Levanna Member with the exception of the Chenango Member which is correlative with the lower half of the Centerfield Member (Grasso, 1986; Gray, 1984, 1991). Westward correlation of regressive tongues and bounding surfaces of these cycles into the Levanna is the subject of ongoing STATEMAP work (Figs. 2, 3), but relevant new developments are reviewed below. The most important observations to date include: a) identification of the top-Cole Hill horizon as a condensed, shell-auloporid-rich bed or discontinuity westward of the Seneca Lake meridian; b) linkage of the top-Delphi Station cycle interval with a distinctive cluster of limestones and shell beds within the medial Levanna in the Genesee Valley-Batavia region (see below); c) linkage of the lower Pompey cycle cap to an erosion surface in the Genesee Valley-Buffalo region (see below); linkage of the upper Pompey cycle cap to a cluster of shell beds and concretionary layers that can be traced as far west as the Batavia meridian. Our observations show that most of the upper Levanna Member (corresponding to the Pompey and Butternut members in central New York) grades into black, fissile shale in Erie County and is, as yet, not subdivided into lithologic or cyclic units.

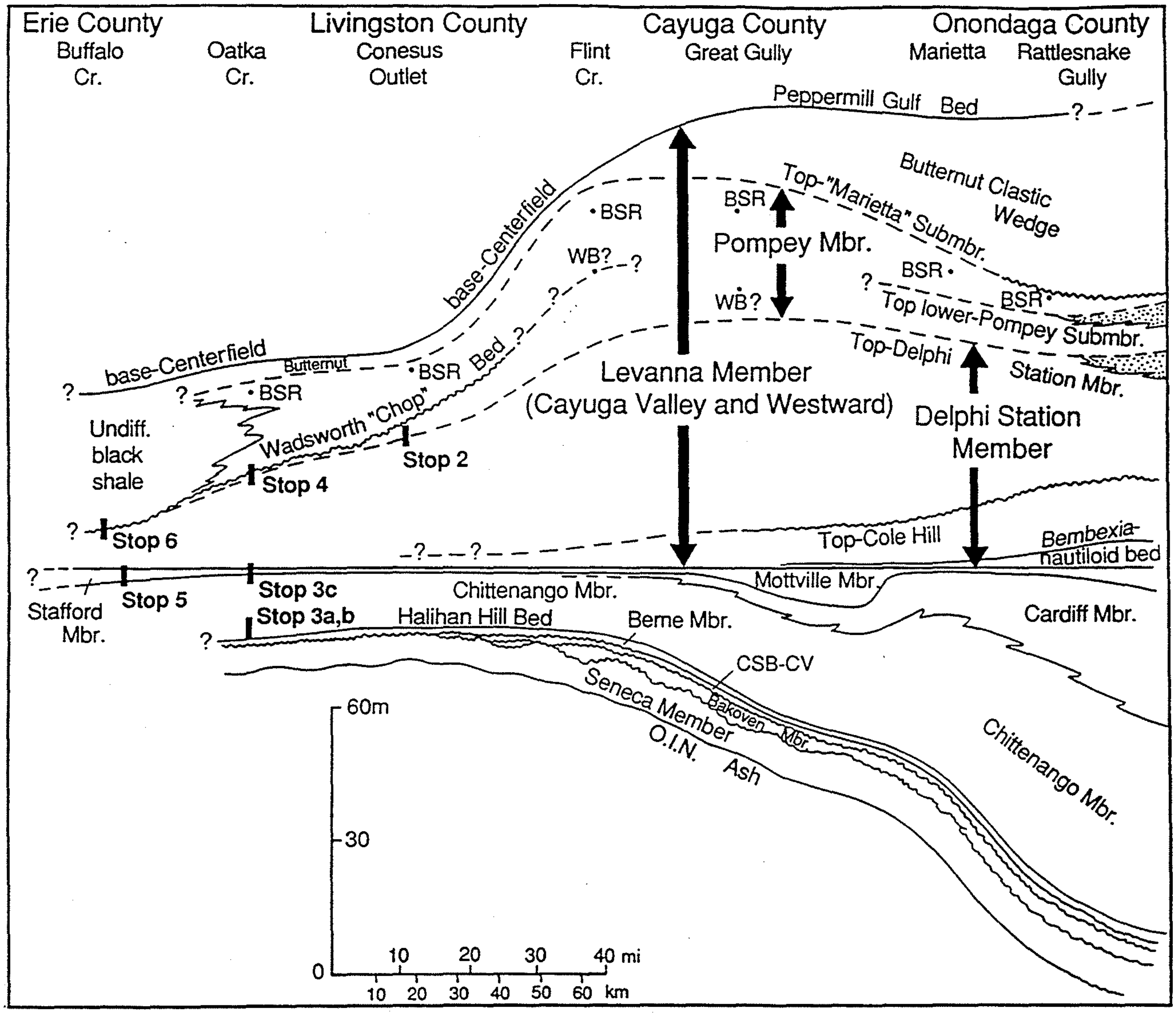


Figure 3. Regional stratigraphy of uppermost Onondaga Formation and lower part of Hamilton Group in western New York. Note that basal Hamilton divisions (Union Springs Formation, basal Oatka Creek Formation) are extremely thin compared to younger units. Dashed lines show tentative correlations of central New York Skaneateles divisions to key Levanna markers (see text).

DESCRIPTION AND DISCUSSION OF KEY UNITS AND CONTACTS

Seneca Member-Union Springs Formation unit relationships

In the study area the Seneca Member of the Onondaga Formation is underlain by the Onondaga Indian Nation K-bentonite, an isochron that has yielded a precise K-Ar age of 390. M.Y. (Fig. 4). The succeeding Seneca Limestone is moderately fossiliferous in the LeRoy-Stafford region, but grades eastward into sparsely fossiliferous lime mudstone facies in a more basinal setting centered in the Cayuga Valley (Ver Straeten et al., 1994). Immediately below the level of a higher ash bed ("Tioga restricted" K-bentonite) Onondaga carbonates give way to black shale and bituminous limestones of the Bakoven Member of the Union Springs Formation (Fig. 4). A minor disconformity marks the top of the Seneca Member at the Honeoye Falls Quarry (STOP 1) near Lima and nearly directly underlies the Tioga Restricted Ash. Just above the "Tioga restricted" ash, however, is a thin bone-styliolinid bed which is locally spectacular as in the Jamesville Quarry near Syracuse.

Key Union Springs Formation Units

Bakoven Member (STOP 1) – The Bakoven Member consists of interbedded sooty black shale and bituminous concretionary limestone beds and styliolinid concentrations. This unit is marked by bone beds and the "Tioga Restricted" (Tioga "13") K-bentonite both at and near the base. The Bakoven fauna is extremely depauperate, yielding *Eumetabolotoechia* ("*Leiorhynchus*") *limitare*, very large *Panenka* bivalves, *Styliolina* and zonally important goniatites. The Bakoven thickness ranges from 0-4 m, but it is highly variable.

Chestnut Street Submember (STOP 1) – This unit is a thin (15-30 cm-thick) partly truncated gray limestone bed rich in pelmatozoan debris, brachiopods, trilobites, and small corals. Distinctive fossils include ambocoeliid and atrypoid brachiopods, common proetid trilobite exuviae and the microcrinoid *Haplocrinites*. The base of this unit marks a discontinuity. The Cherry Valley Limestone variably truncates the Chestnut Street Bed across western New York (Fig. 4).

At the Rochester meridian, the Bakoven is nearly absent due to beveling beneath the Cherry Valley Limestone (Figs. 3-5). In a new drill core, obtained from the site of the new American Rock Salt Mine at Hampton Corners south of Geneseo, 0.7-1.3 m of Bakoven Member is observed below the Cherry Valley Member. Similarly, 2.6 m of Bakoven Member was observed in the Livonia Salt Shaft as suggested by lithologic descriptions of Luther and Clarke (1893) and Clarke (1901).

To the west of the Honeoye Falls quarry and the new American Rock Salt core site, no Bakoven beds have been observed to date. In two older AKZO cores obtained from the area of the now flooded AKZO mine at Greigsville, the Berne Member of the Oatka Creek Formation directly overlies a conspicuous pyrite-coated discontinuity surface developed on the Seneca Member (Baird and Brett, 1991: Fig. 6, p.244). Similarly, the

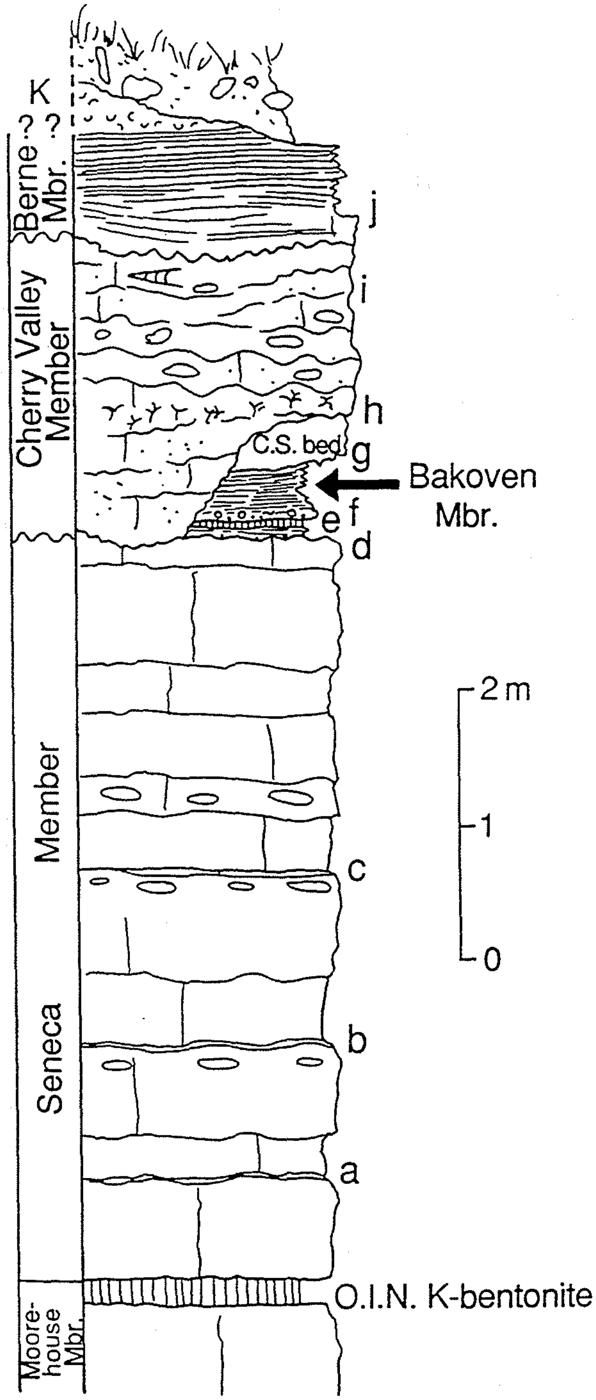


Figure 4. Uppermost Onondaga Formation-through-lower part of Oatka Creek Formation succession exposed in General Crushed Stone Quarry near Honeoye Falls (STOP 1). Lettered units include: a-c, thin K-bentonite beds in Seneca Member; d, diastemic erosion surface at top of Seneca Member; e, Tioga "F" K-bentonite bed; f, bone bed in lower part of Bakoven Member; g, Chestnut Street Bed; h, channeled disconformity surface at base of Cherry Valley Member; I, cephalopod-bearing interval in upper part of Cherry Valley; j, top-Cherry Valley corrosional discontinuity overlain by Berne Member.

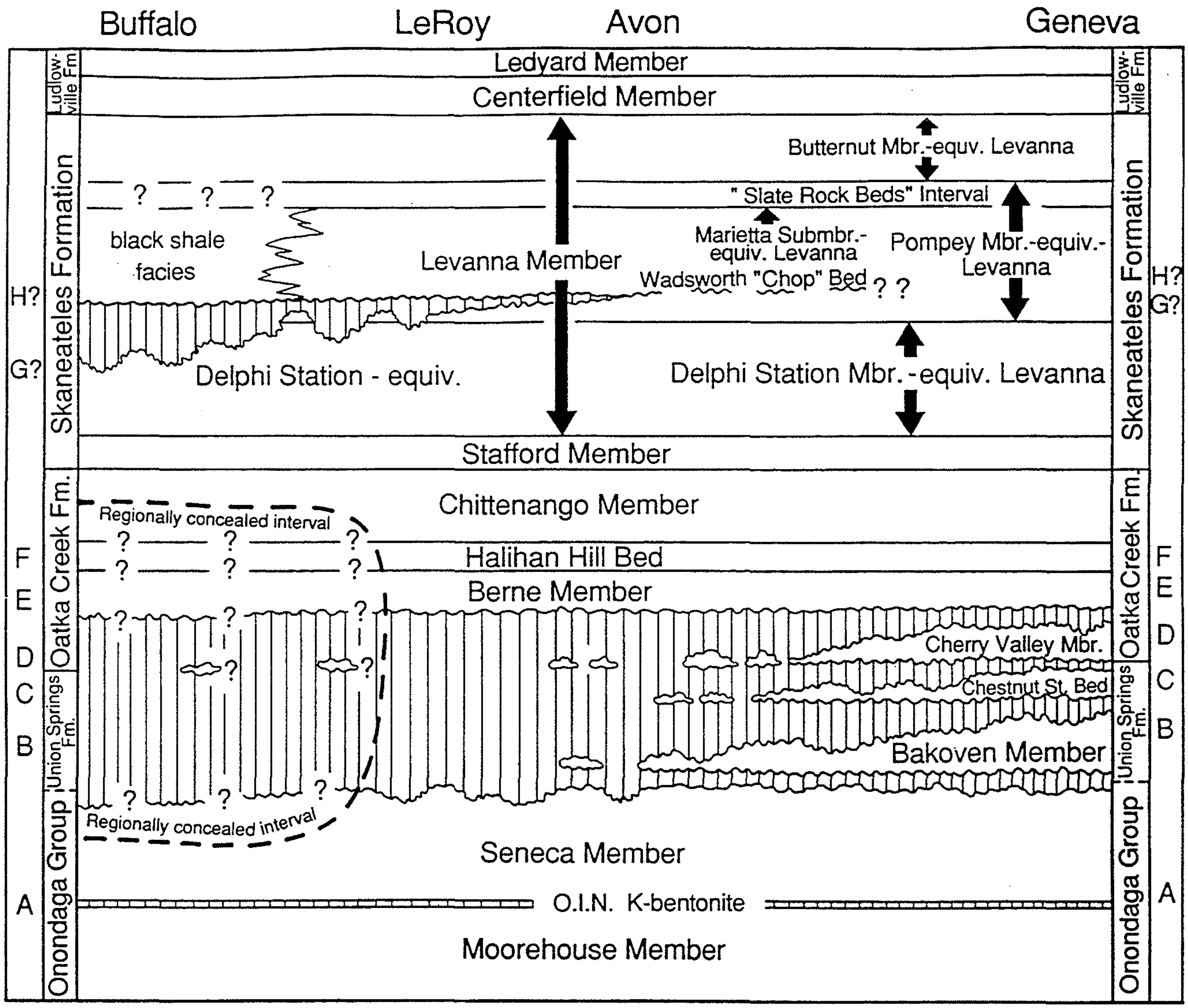


Figure 5. Time-rock relationships of sedimentary divisions in the uppermost Onondaga Formation and in the lower half of the Hamilton Group across western New York. Note development of composite disconformity below Berne Member west of the Genesee Valley and development of medial Levanna disconformity mainly west of the LeRoy meridian. Heavy dashed line encloses part of diagram where strata are concealed and reconstruction is conjectural. Lettered units include: A, Onondaga Indian Nation K-bentonite; B, *Cabrieroceras_plebieforme* zone; C, *Haplocrinites* level; D, *Agoniatites vanuxemi* level; E, styliolinid-dacryoconariid-bearing black shale (Berne Member); F, lowest level of Hamilton macrofauna; G?-H?, possible *ensensis*-lower *varcus* zonal conodont boundary.

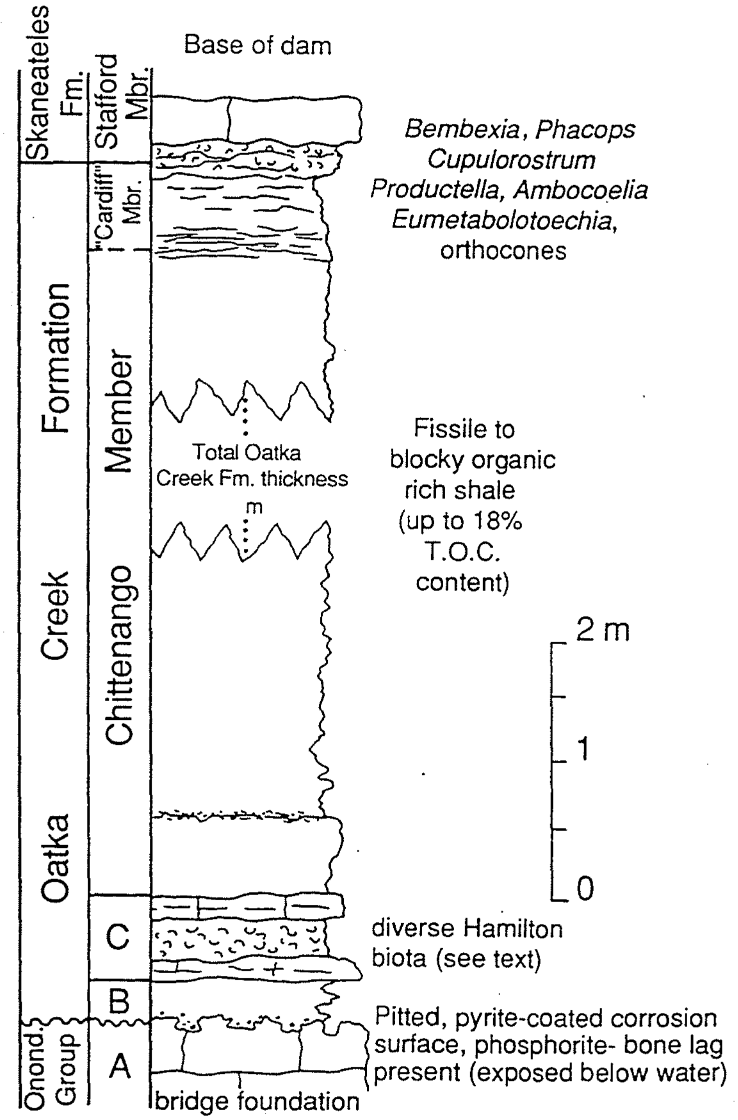


Figure 6. Section flooring Oatka Creek in town of LeRoy, Genesee County (STOP 3a-c). Key units include: A, top of Seneca Member of Onondaga Formation; B, black shale representing condensed Berne Member section; C, richly fossiliferous gray mudstone deposits of Halihan Hill Member.

Berne rests on an irregular pitted, pyrite mineralized top-Seneca contact along Oatka Creek (STOP 3a) in LeRoy. This discontinuity is also visible in the Honeoye Falls Quarry (STOP 1) but it is of smaller magnitude in that area given that the subjacent Bakoven and Cherry Valley members are present there (Figs. 4, 5). In essence, no less than four discontinuities: the base-Bakoven diastem, a lower Bakoven bone-bed contact, a major base-Cherry Valley contact, and the base-Berne discontinuity are collectively cutting out portions of the overall section in the vicinity of Lima and the new American Rock Salt mine. To the northwest, sub-Berne corrosional overstep is such that a composite disconformity is developed and the entire Union Springs Formation is absent (Figs. 3, 5, and 6). At Oatka Creek (STOP 3a), the Seneca Member-Berne Member contact is below water and can be accessed only with difficulty.

Key Oatka Creek Formation Units

Cherry Valley Member (STOP 1) – This is the well known "Agoniatites Limestone" of early workers. In western New York the Cherry Valley is a thin (0.2.0 m-thick) brown, petroliferous and nodular limestone composed largely of *Styliolina fissurella* tests. The Cherry Valley limestone is particularly distinctive for abundant auloporid thickets and cephalopod conchs. *Agoniatites vanuxemi* is locally abundant; this goniatite occurs in association with orthocones in vast cephalopod pavements within the upper part of the unit (see Cottrell, 1972; Baird and Brett, 1986; Griffing and Ver Straeten, 1991; Ver Straeten et al., 1994). The Cherry Valley Member is a rare example of a "cephalopod limestone" (cephalopodenkalk) in the New York Devonian section. Such units are believed to reflect conditions of sediment starvation in offshore and/or deeper water settings. The Cherry Valley represents a transgressive systems tract associated with sea level-rise following deposition of the Stony Hollow-Chestnut Street Bed Interval (Ver Straeten et al., 1994). We will see the Cherry Valley Member at its westernmost accessible locality at STOP 1 (Fig. 4). West of the Genesee Valley, both it and the underlying Union Spring Formation divisions are missing due to erosion in most areas (Figs. 5, 6).

Berne Member (accessible at STOP 1) – This is a 30 cm-thick interval of black shale, rich in styliolinids and dacryoconariids. As noted above, it is the thin condensed equivalent of a much thicker shale succession in eastern New York. This unit, marking the zonal base of the Givetian Stage overlies a regional, corrosional discontinuity. At Oatka Creek (STOP 3a) it is erosionally juxtaposed onto the Seneca Member (Fig. 6).

Halihan Hill Bed (STOP 3a) – As noted above, the temporal debut of the Hamilton Evolutionary-Ecological Biota appears to be very sudden and dramatic. Overlying a 40 cm-thick condensed Berne section on Oatka Creek (STOP 3a) is a profusely fossiliferous interval of shell-rich, soft, gray mudstone which is exposed in the floor of the creek (Fig. 6). This 30 cm-thick unit yields small rugose corals, *Mediospirifer, Tropidoleptus, Meristella, Phacops,* encrusting and fenestrate bryozoans as well as many other taxa. Near Schoharie, this bed yielded the distinctive button coral *Microcyclus*. Larger corals, including *Heterophrentis, Heliophyllum*, and *Cystiphylloides* are observed in localities near Kingston. The Halihan Hill Bed, is widespread and regressive relative to synjacent black shale facies, and is everywhere thin. Unlike similar recurrent facies higher within the Hamilton Group, the Halihan Hill Bed does not appear to thicken eastward (and shoreward). This unit displays the shallowest water facies encountered in the Oatka Creek and Skaneateles formations in western New York.

Chittenango Member (STOP 3a-c) – Above the Halihan Hill Bed is a 10 m-thick interval of massive, well jointed, hard black shale that records maximum development of Devonian anoxia in this region (Fig. 6). This shale, yielding up to 18% T.O.C., is uniformly thin across the study area attesting to early highstand conditions with very low siliciclastic sediment supply. Because this unit is highly radioactive, it is a major marker in geophysical logs. Below the Stafford Member is a thin interval of calcareous shale that is less organic-rich than that of the typical underlying Chittenango. *Eumetabolotoechia* (“*Leiorhynchus*”) *limitare* and orthocones attest to minimally dysoxic bottom conditions. Although thin and poorly defined on Oatka Creek, this interval does grade eastward into a thicker, gray shale division identified as the Cardiff Member in central New York (Figs. 2, 3).

Oatka Creek Formation Unit Relationships

In the present field trip area few lateral lithologic and thickness changes are noted within the Oatka Creek Formation interval. The stratigraphy is rather of a “layer cake” nature and all component units apparently accumulated in a sediment-starved setting (Figs. 2, 3). Unfortunately the lower part of the Oatka Creek Formation is concealed west of LeRoy and the nature of the Cherry Valley Member-Halihan Hill interval in Erie County is poorly known (see below).

Regionally, the Cherry Valley Limestone extends from the Hudson Valley, where it overlies the Stony Hollow Member (Griffing and Ver Straeten, 1991; Ver Straeten et al., 1994) westward to the Genesee Valley where it is unconformably overlain by black shale deposits of the Berne Member (Figs. 2, 3). Beginning approximately at the Genesee Valley meridian, the Cherry Valley is regionally beveled and is clearly absent, both in drill cores from the old AKZO mine near Griegsville and at LeRoy (STOP 3a). As noted above, the sub-Berne corrosional disconformity is responsible for this erosion (Figs. 5, 6). Clarke (1901) claimed to have found the “*Agoniatites* limestone” (Cherry Valley Member) on Little Conesus Creek south of Avon, New York. Recent examination of Little Conesus Creek suggests that Clarkes’ “*Agoniatites* limestone,” which was supposed to be present above the Erie Railroad overpass, is actually the Stafford Member. Ironically, the sub-Berne disconformity was found further downstream on this creek. However, the poor quality of the exposure preclude positive identification of the sub-Berne carbonate as Seneca Member or Cherry Valley Member. Clarke (1901) indicated that “*Agoniatites*” was observed at the base of the “Marcellus Shale” section in a borehole section at Stony Point on Lake Erie. Similarly, carbonate yielding *Agoniatites* has been reported from the vicinity of Lime Rock east of LeRoy. In essence, outliers of uneroded Cherry Valley may underlie western New York in many areas (Fig. 5).

In the Honeoye Falls Quarry, the Cherry Valley displays a channeled lower surface and overlies variable thicknesses of Bakoven Shale and even a small remnant of Chestnut Street submember; (Fig. 4). In the Livonia salt shaft, south of the Honeoye Falls Quarry, 2.6 m of Bakoven shale and approximately 1.3 m of Cherry Valley? limestone were reported (Clarke, 1901). Similarly, 2 m of Bakoven is reported in cores taken from the new American Rock Salt mine site at Hampton Corners south of Geneseo (Brett and Ver Straeten, pers. comm.). As noted above, the old AKZO cores from Griegsville, 12 km to the northwest of the new mine and 5 km southwest of Little Conesus Creak, show complete removal of Bakoven, Chestnut Street and Cherry Valley deposits by sub-Berne erosion.

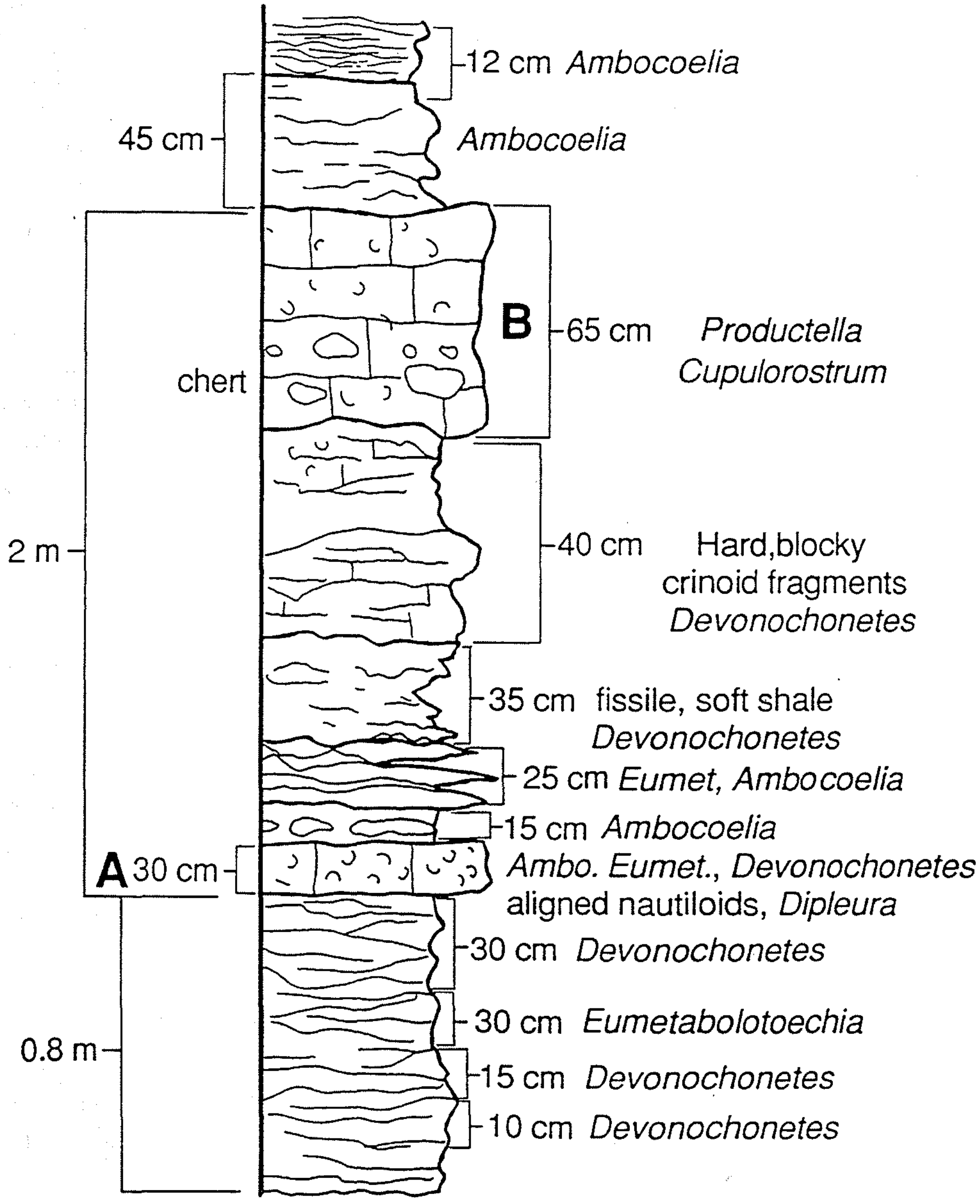
With the exception of the Halihan Hill Bed, the paleoenvironment of the post-Cherry Valley-Oatka Creek succession was that of a deep water, anoxic basin (Baird and Brett, 1986, 1991); two discrete highstand events (Berne, Chittenango Members), however, are separated by the problematic, major regional lowstand/transgressive facies interval of the Halihan Hill Bed. The widespread nature of the Halihan Hill Bed strongly indicates that the regression event recorded in it was of an eustatic origin.

Key Skaneateles Formation Units (see STOPS 2-6)

Stafford Member (STOPS 3c, 5) – In the Genesee Valley-Oatka Creek area, the Stafford member is a thin, 1.5-2.0 m-thick interval centered on a resistant limestone bed which is 0.25-0.6 m in thickness (Fig. 6). Beneath the limestone ledge, dark gray calcareous shale beds of the basal Stafford yield numerous small brachiopods, diminutive gastropods and bivalves, and flattened cephalopods. Brachiopods include *Crurispira nana, Truncalosia truncata*, and *Eumetabolotoechia ("Leiorhynchus") limitare*. Many of the flattened orthocones display current-aligned colonies of the problematic organism *Reptaria stolonifera* (Baird et al., 1989); these encrusters appear to have encrusted the shells of live orthocone hosts, responding rheotrophically to the host's motion.

The Stafford Limestone ledge, conformably overlying the calcareous shale interval, yields a slightly richer, but still modest faunal assemblage. Notable are the occurrences of numerous gastropods and orthoconic cephalopods that are preserved three dimensionally as spar filled natural casts or as coarse black calcite replacements of aragonite. The limestone is gray brown in color and is petroliferous. Generally the skeletal fabric is that of a wackestone except where fossils are locally concentrated in burrow fillings. Key taxa include the brachiopods *Longispina* and *Cupulorostrum sappho*, sparse small rugosans, the gastropod *Bembexia sulcomarginata*, nuculoid bivalves and orthocones. The fauna reflects minimally oxic conditions in an outer shelf setting. The upper Stafford transition into the Levanna Member is not exposed on Oatka Creek, but where seen, consists of calcareous, dark gray, petroliferous shale with a sparse dysoxic fauna.

In Erie County (STOP 5) the Stafford is thicker and more differentiated lithologically (Fig. 7). In Lancaster (Plumbottom Creek and Cayuga Creek (STOP 5)), it is 2.5 m-thick starting with an 19 cm-thick basal limestone ledge rich in *Ambocoelia, Emanuella*, and



Lancaster,NY Composite
Stafford Section

Figure 7. Composite Stafford Member section based on sections at Como Park, Lancaster, New York (STOP 5) and on Plum Bottom Creek, also in Lancaster. Unit A is *Ambocoelia* and *Devonochonetes*-rich limestone bed which is probably correlative with the basal Mottville "sub-A" interval in central New York (see text). Unit B is chert-rich limestone bed that probably correlates to the Mottville "B" ledge (Case Hill coral bed) of central New York sections (see text).

orthocones as well as an unusual occurrence of the trilobite *Dipleura*. This shell-rich unit ("Sub-A Bed") is succeeded by a 18 cm-thick calcareous shale unit yielding *Emanuella*, large *Aulocystis* and abundant *Phacops*. Above this interval is an 18 cm-thick hard limestone rich in crinoidal debris at the base and a sparse molluscan fauna above. This unit may correlate to the "A Bed" of the Mottville in central New York localities. Above the second limestone bed is 0.7 m of impure, lenticular to nodular concretionary limestone yielding a sparse fauna. The top of the Erie County Stafford, visible on Plum bottom and Buffalo Creeks, is increasingly characterized by buff to brown weathering (dolomitic?) impure cherty nodules (Fig. 7). Above the concretionary zone is a 0.3-0.5 m-thick unit ("B Bed") consisting of hard limestone with widely scattered chert nodules. Fossils are sparse in this unit, but include small favositid and auloporid corals, as well as the brachiopods *Meristella, Camarotoechia*, and *Productella*. Still further west, on Buffalo Creek, the Stafford thickens to 3 m overall and becomes distinctly more cherty in the upper ("B Bed") part.

Regionally, the Stafford is thin and stratigraphically condensed in the Waterloo-Stafford region but thickens both to the east and west of this area (Fig. 3). As noted above, it thickens westward to 3 m in Erie County and is marked by an ambocoeliid-rich limestone ("Sub-A Bed") near its base and a somewhat thicker limey zone with chert nodules ("B Bed") near its top. However, the Stafford Member thickens eastward from 0.5 m south of Waterloo to 2.7 m at Great Gully east of Cayuga Lake and 3 m near Half Acre southwest of Auburn. In this area, a 20-25 cm-thick "Sub-A" bed rich in ambocoeliids is succeeded by 2.3 m of calcareous, slightly silty mudstone and nodular limestone layers with a sparse fauna. The lower part of this interval displays impure concretionary, lenticular limey beds whereas the top third of the interval displays dolomitic? and variably siliceous nodules. The top "B Bed" ledge is a 30-35 cm-thick layer of hard impure, unfossiliferous limestone rich in siliceous and dolomitic nodules. Meyer (1985) noted the striking physical similarity of the Great Gulf and Lancaster sections despite the notable thinness of intervening sections. The present authors, noting the similarity of the Lancaster and Half Acre (Auburn) sections, conclude that the "sub-A", "A", and "B" units mark eustatic signals that may be widespread.

Eastward from the Great Gulf and Half Acre sections, we observe continued thickening of the overall section to maximum values of 8 m-thickness near Skaneateles (Fig. 3). Here, the Stafford has transformed into a mud-dominated unit represented by the type-Mottville section (Meyer, 1985; Grasso, 1986). Recent work by the present authors, shows that the thick Skaneateles Mottville sections are clearly subdivisable into units that can be correlated to the east and west of there. This work is still in progress.

Levanna Member (STOPS 2, 4, 6)

Overview – As noted above, this division is stratigraphically thick and poorly exposed. Parts of it cannot be easily measured since it is often exposed on floors of swampy, low gradient creeks. However, we believe that the lower half of the Levanna corresponds to the undifferentiated basinward equivalents of the siltstone-capped Delphi Station Member in central New York (see Grasso, 1986; Linsley, 1991: see Figs. 3, 5). We presently recognize the top Cole Hill horizon (lower Delphi Station Member) west to the Phelps meridian and tentatively to the Genesee Valley as a thin, small brachiopod, small mollusc and auloporid-bearing layer approximately 4 m above the top of the Stafford. However, much of the lower Levanna succession both below and above the Cole Hill position is sparsely fossiliferous dark gray to nearly black shale. The succession becomes progressively more calcareous and fossil-rich as one proceeds upward through the lower half of the Levanna. This regressive trend culminates in the Papermill and Pole Bridge limestone beds which are conspicuous falls-capping units in the Genesee Valley. These apparently link eastward respectively to two siltstone beds at the top of the Delphi Station Member in the Syracuse-Cazenovia area (Figs 3, 5).

Above the Pole Bridge marker is a return to shale-dominated facies which is, in turn, capped by two separate sets of concretionary limestone layers (Wadsworth beds and Slate Rock beds) yielding small brachiopods and some auloporid corals. The lower pair of limestones (Wadsworth beds) are believed to link to siltstones capping Cooper's (1930) Pompey Member, and the upper bundle of shell-rich-beds (Slate Rock beds) marks the top of a second siltstone-capped interval in central New York that we provisionally named the "Marietta submember" (Fig. 3).

The topmost 3-4 m of the Levanna below the Centerfield Member consists of organic-rich, fissile black shale. This is believed to be correlative with the Butternut Member in central New York (Figs. 3, 5).

Key Levanna Markers

Molluscan debris layer near base of Levanna – On Flint Creek near Phelps 4 m above the base of the Levanna we observe a 12 cm-thick layer of auloporid-rich mudstone yielding numerous nuculoid bivalves and gastropods. We believe that this unit may be the westernmost observed expression of the Cole Hill Cycle regression event that produced a prominent fossil-rich sandstone unit in central New York (Linsley, 1991), Fig. 3).

Papermill Limestone Bed – 0.5-8 m below the top of the Delphi-Station-equivalent part of the Levanna in the Geneva-LeRoy area we observe a resistant, 0.6-0.85 m-thick limestone bed that holds up waterfalls on Conesus and Little Conesus Creeks near Avon (see STOPS 2, 4). We herein informally designate this unit the Papermill Limestone Bed for an excellent exposure on Conesus Creek (STOP 2) where it caps a falls below Papermill Road southeast of Ashantee, Livingston County (Genesee 7.5' Quad.). This unit has been mistaken for Stafford by early workers. It yields a sparse fauna of auloporids, small bivalves and gastropods. It is really the most prominent ledge of several impure limestone layers in the lower medial part of the Levanna Member (Figs. 8, 9). West of Oatka Creek (STOP 4) this unit has not been observed to date; it may grade westward into less resistant shalier carbonate or it may be erosionally overstepped by the "Union Road disconformity" (Fig. 9). East of the Avon area, the Papermill gradually becomes less resistant, changing to several stacked concretionary limestone beds on Flint Creek at Orleans. It is last seen on a small creek near the Rose Hill mansion east of

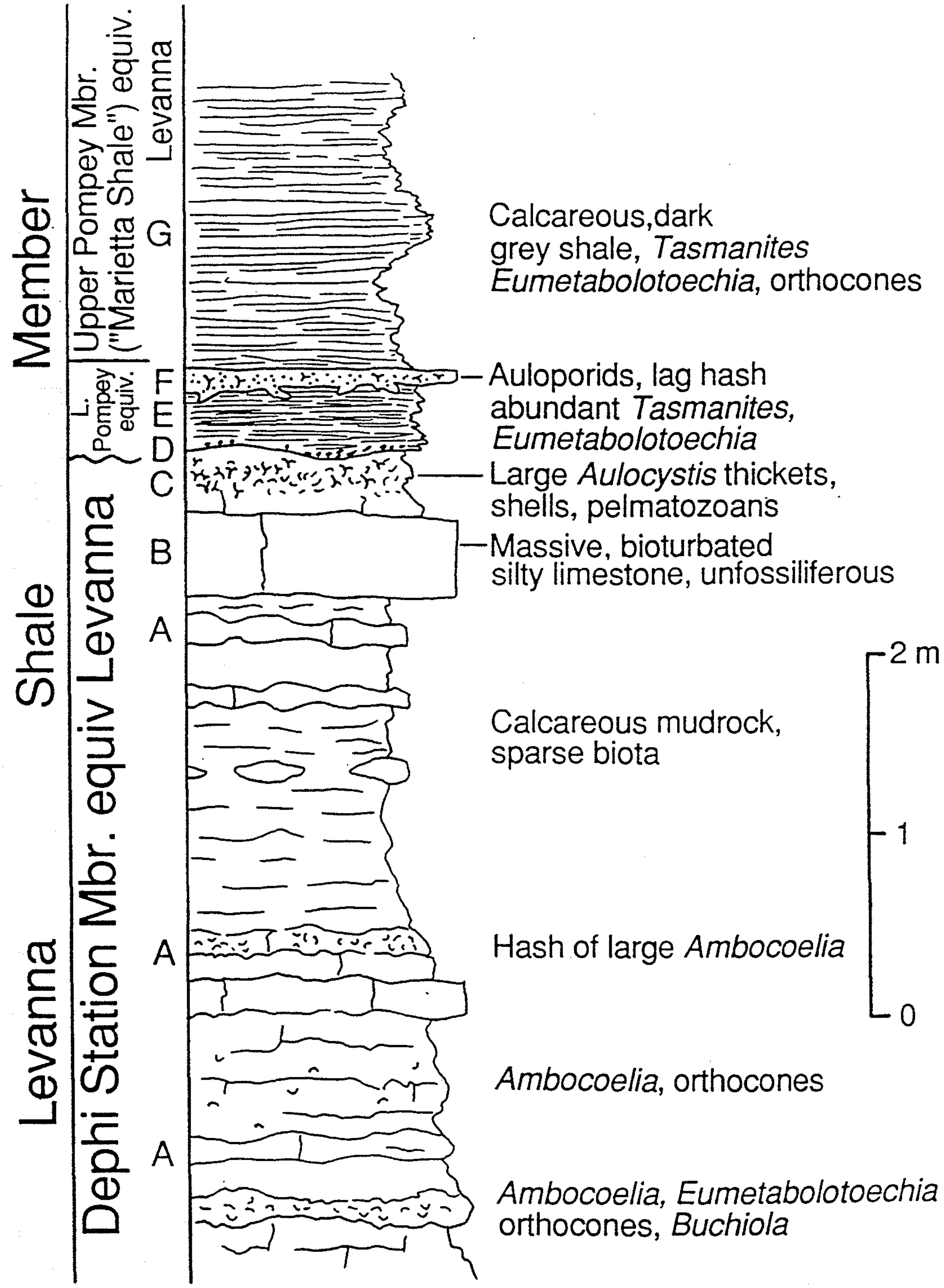


Figure 8. Section flooring Oatka Creek downstream from Covell Road overpass southeast of Roanoke, Genesee County (STOP 4). Lettered units include: A, concretionary impure limestone beds with minor shell beds; B, Papermill Limestone Bed; C, auloporid thicket interval of Roanoke Bed; D, black shale-roofed discontinuity marked by lag of reworked pyrite and fish bones; E, *Tasmanites*-rich "highstand" black shale unit; F, Wadsworth Bed characterized by comminuted shell hash, conodonts and fish bones that fill *Thallasinoides* burrow prods into underlying shale; G, dark, fissile shale yielding *Devonochonetes* and flattened rhynchonellids.

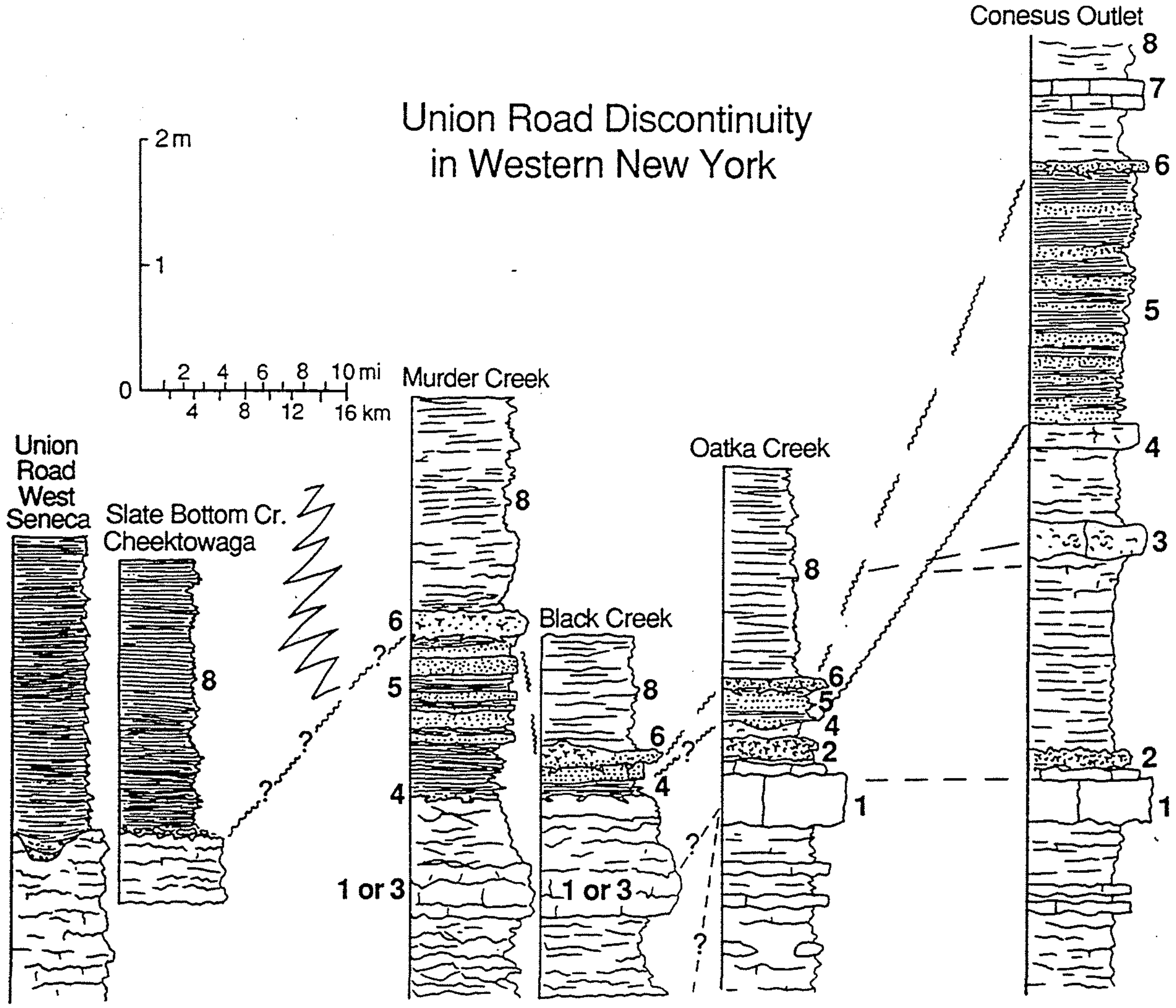


Figure 9. Tentative correlation scheme for key marker beds in the medial Levanna Member in western New York. It shows provisional westward correlation of inferred top-"Delphi Station"-base "Pompay" contact within the Levanna Member in the Genesee Valley to the Union Road disconformity in Erie County (see text). Numbered units include: 1, Papermill Bed; 2, Roanoke Bed; 3, lower Pole Bridge Bed; 4, upper Pole Bridge Bed; 5, dark fissile shale unit with abundant *Tasmanites* and flattened rhynchonellids; 6, lower (main) Wadsworth Bed; 7, upper (minor) Wadsworth Bed; 8, dark gray, fissile shale (correlative? With "Marietta Shale" in central New York).

Seneca Lake where it is represented by a 1.5 m-thick bundle of thin, barren ribbon limestones in an otherwise shaley succession. East of the Rose Hill locality in the Cayuga Valley this unit becomes shyly and nonresistant. Further east, we believe that it corresponds to the lower of two prominent siltstone beds that mark the top of the Delphi Station Member in the Syracuse area.

Roanoke Bed – Capping the Papermill Bed in Genesee Valley localities and also along Oatka Creek (STOP 4) is a 9-20 cm-thick layer that is profusely fossiliferous (Figs. 8, 9). We herein name this bed the Roanoke Bed for its occurrence on Oatka Creek downstream from the overpass southeast of the hamlet of Roanoke, Genesee County (Stafford 7.5' Quad: STOP 4), where it is best developed. At this locality it reaches peak development. The Roanoke Bed is characterized by colonial thicket growths of a large species of *Aulocystis* in association with brachiopods, trilobites and pelmatozoans. Occasional *Pseudoatrypa* and *Rhipidomella* occur in this layer, as does *Phacops rana* and the crinoid *Arthracantha*. Fossils are densely concentrated both in and around the thickets, but are more scattered in a thin overlying interval of soft, gray fossiliferous shale. At Conesus and Little Conesus Creeks near Avon this unit is thinner, but still rich in fossils (Figs. 8, 9). On Flint Creek at Orleans, the Papermill Bed is capped by a thin fossil debris layer yielding *Ambocaelia* and small auloporid debris that is the apparent expression of this bed in the vicinity of Phelps.

Pole Bridge Beds – We herein informally designate two 20 cm-thick shell-rich limestone layers, occurring respectively 1.4 and 2.3 m above the Roanoke Bed in the Genesee Valley region as the Pole Bridge bed for exposures on Little Conesus Creek below Pole Bridge Road near Avon, Livingston County (Rush 7.5' Quad.). At this section and on the adjacent Conesus Creek the lower Pole Bridge Limestone Bed is characterized by abundant *Ambocoelia umbonata* and rare specimens of the small rugose coral *Stereolasma*. The upper Pole Bridge Bed, occurring 0.75 m above the lower bed is less resistant and internally more complex. In addition to *Ambocoelia*, and *Devonochonetes* it contains abundant flattened rhynchonellids and profuse concentrations of *Tasmanites*, such that the beds appear granular and "oolitic". On Flint Creek at Orleans and near the Rose Hill mansion east of Seneca Lake, the Pole Bridge Beds are expressed as dense *Ambocoelia* concentrations in shale. East of Rose Hill these layers apparently persist into Onondaga County where they occur as mollusc-dominated shell beds above prominent siltstone beds at the top of the Delphi Station Member. West of the Genesee Valley these beds have not been found (Fig. 9).

Tasmanites–rich black shale unit – Commencing above the second Pole Bridge Bed on Conesus Creek is a change to black fissile to platy shale abounding in the algal phycoma organ *Tasmanites* and flattened-fragmented rhynchonellids. Beds at the base of this 3.0 m-thick interval display bedding planes so rich in *Tasmanites* as to appear granular; cysts are particularly concentrated in *Planolites* burrows. East of the Genesee Valley the *Tasmanites*-rich zone has not been identified with any certainty. However, it appears to be present on Oatka, Black, and Murder creeks in Genesee County (Fig. 9). On Oatka Creek (STOP 4), the Roanoke Bed is unconformably overlain by a 33 cm-thick, fissile black shale unit yielding abundant flattened rhynchonellids and *Tasmanites* (Fig. 8). This discontinuity is marked by a thin discontinuous lag deposit of reworked pyrite similar to other black shale-roofed detrital pyrite beds (Leicester Pyrite, Skinner Run Pyrite Bed) described by Baird and Brett (1991). Conodonts from this lag may belong to either the uppermost *ensensis* zone or the lowest part of the *varcus* zone as this zonal boundary may be near this level. At Conesus, Black and Murder Creeks, however, the base of this shale unit appears to be non-erosional and conformable.

Wadsworth Bed – On Conesus Creek, the *Tasmanites*-rich shale unit is abruptly overlain by a 8-10 cm-thick bed abounding in *Ambocoelia,* crinoid debris and auloporid coral thickets. We herein designate this unit the Wadsworth Bed owing to its proximity to the Wadsworth Boy Scout Camp along Conesus Creek. This bed occurs only a short distance south of (upstream from) the Paper Mill Road overpass and the Papermill bed type section on Conesus Creek south of Avon (Geneseo 7.5' Quad.). In addition to auloporids and small brachiopods, this bed contains abundant conodonts and occasional fish bone debris indicating that this layer is, at least, partly erosional in origin.

We believe that this bed is present in several sections to the west and can be seen as far west as Erie County (Figs. 8-10). At all Genesee County sections (Oatka Creek, Black Creek, Murder Creek) it is lithologically similar to the type section occurrence and it has yielded fish bones and conodonts. Moreover, the Wadsworth Bed overlies variable thicknesses of black, fissile, *Tasmanites*-rich shale suggesting differential erosion of underlying beds. On Oatka Creek (STOP 4), it occurs only 33 cm above the unconformable base of the *Tasmanites*-rich black shale (Fig. 8). In Erie County, the top of the Delphi-Station-equivalent part of the Levanna is marked by a conspicuous disconformity (see below). We believe that the Wadsworth Bed may correlate to this discontinuity surface (Fig. 9). To the east, the Wadsworth Bed may connect to shell beds at the top of the Pompey Member in central New York but this correlation is, as yet, unproven.

Slate Rock Beds – Below Slate Rock Falls on Wilson Creek west of Seneca Lake (Ontario County, 7.5' Quad.) is an occurrence of a prominent tabular shell-rich limestone layer 3 m below the top of the Levanna and two to three associated concretionary layers in the underlying 2.5 m of section. The name Slate Rock beds is proposed to denote this widespread bundle of shell beds and concretionary layers which can be mapped within the upper Levanna from the Batavia meridian eastward into central New York. It marks the top of a medium to dark gray shale succession above the Wadsworth Bed and it conformably floors a fissile black shale unit (Butternut Member-equivalent) in all observed sections (Figs. 3, 5).

On Wilson Creek and at other sections where this unit occurs, there are usually two to three thin beds rich in *Devonochonetes scitulus, Ambocoelia umbonata, mucroclipeus,* and *Mucrospirifer mucronotus* that occur within a 2.5 m interval. Other fossils in these beds include auloporid corals and occasional *Stereolasma,* nuculoid bivalves, numerous *Phacops* exuviae, and orthoconic cephalopods. These organisms suggest upper dysoxic to minimally oxic conditions over a broad area. This fauna improves both in diversity and preservation as these beds are traced eastward into the Skaneateles-Tully Valley

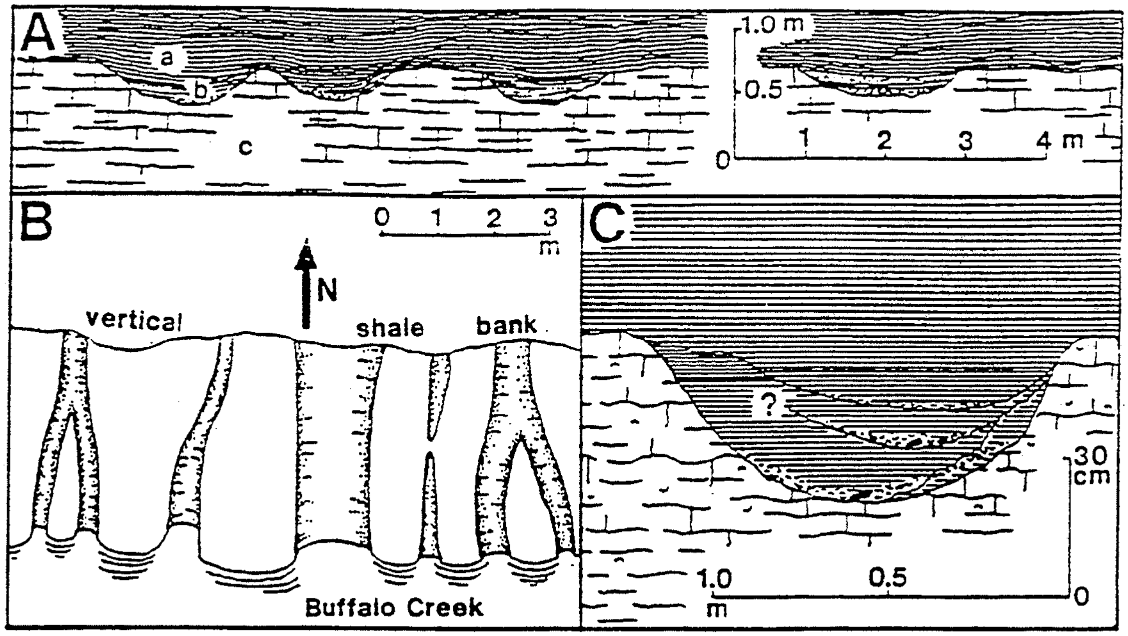


Figure 10. Submarine discontinuity within Levanna Shale Member on Buffalo Creek at Union Road (see STOP 6). A) along-bank profile of a series of erosional runnels (troughs) into calcareous mudstone that are filled with brownish-black shale of upper unit; B) vertical ("map") view of channels on exposed creek bed bordering shale bank. Note southward bifurcation of some channels suggestive of southward current-flow; C) complex history of episodic scouring and filling of mud within channels. Sharp scoured contacts with associated lag debris of fish bones and shells grade laterally to extinction (continuity) over very short distances. Lettered units include: a) black, laminated shale with flattened rhynchoneilids, *Styliolina*, and palynomorphs; b) brown-black shale filling in troughs with associated scoured contacts and brachiopod-trilobite fish bone lag debris; c) calcareous gray to dark gray blocky to chippy mudstone with *Ambocoelia, Devonochonetes,* and *Phacops rana.* From Brett and Baird (1990), Baird and Brett (1991).

region. In that area they cap a sedimentary interval that is distinct from the underlying Pompey Member and the overlying Butternut Member (Fig. 3). This unit, tentatively designated the "Marietta Member", is a subject of ongoing study.

West of the "East Bethany" (Francis Road) Centerfield Member locality in Genesee County, the Slate Rock beds interval is nowhere exposed. It is apparently hidden in the short covered interval on Buffalo Creek between Transit Road (US 20) and the Centerfield Member exposure upstream at Blossom.

Butternut Member–equivalent Levanna – West of Cayuga Lake the uppermost part of the Levanna Member is represented by a 3-5 m interval of hard, black, fissile shale that is characteristically jointed and characterized by flattened rhynchonellids and tasmanitids at many levels. This unit, separating the Slate Rock beds interval from the overlying Centerfield Member, is the thin lateral equivalent of the much thicker Butternut Member in central New York. Between Cayuga Lake and the Skaneateles Valley this part of the Levanna thickens from approximately 5 m to 35 m and, as formal Butternut Member, thickens further eastward to approximately 58 m in Madison County (Linsley, 1991, Fig. 3). Though notably thinner than the typical Butternut Member, this top-Levanna division is easily identified as Butternut as far west as the Francis Road Centerfield locality south of Batavia. Although not formally advanced in the present publication as Butternut Member, as distinct from Levanna Member, we believe that Butternut Member will eventually be extended westward to the Batavia Meridian. Since the Slate Rock bed interval is not seen west of the Francis Road locality, there is no way to distinguish Butternut-equivalent strata from underlying basinal facies in Erie County, it seems less likely that this term can be extended to that region (Fig. 5). However, black shale deposits observed below the Centerfield Member at Blossom on Buffalo Creek are almost certainly part of the Butternut-equivalent succession.

Levanna Divisions Erie County.

Lower calcareous mudrock division – Along Spring Creek south of Wende, Cayuga Creek in Lancaster, Slate Bottom Creek in Cheektowaga, Buffalo Creek by Indian Church Road, Cheektowaga, and Cazenovia Creek in West Seneca, is an interval of variably calcareous shale-mudstone facies with several concretionary limestone beds in the upper part. Along Buffalo Creek where this unit can be seen in its entirety, it includes 8.5 m of strata (Fig. 3). Fossils in this division are usually sparse but include auloporid corals, *Ambocoelia* and exuviae and occasional whole individuals of *Phacops rana*. We believe that this interval is the condensed, carbonate-enriched, cratonward equivalent of the Delphi Station Member minus an unknown thickness of strata eroded from the top (see below). The upper part of this unit will be seen at Buffalo Creek (STOP 6: Fig. 10).

Union Road disconformity – At Buffalo Creek and Slate Bottom Creek, the lower Levanna calcareous mudrock interval is abruptly overlain by a submarine disconformity (see Fig. 10: STOP 6). On Buffalo Creek, both beneath and immediately upstream from the Union Road overpass, this discontinuity separates underlying, gray calcareous mudrock facies from overlying fissile black to dark gray shale deposits. A significant transgression is indicated by the lithologic change, but the character of the contact itself is remarkable (Fig. 10). At Union Road, this discontinuity is characterized by numerous, parallel to subparallel, north-south-trending erosional runnels (Fig. 10). These 1.0-2.0 m side and 25 cm-50 cm-deep erosional channels are complexly filled with dark shale deposits which, in turn, may contain smaller nested channels. The bottoms of the larger channels contain lag concentrations of ambocoeliid brachiopods, *Phacops* exuviae and fish bones. Baird and Brett (1991) concluded that these channels represent ancient examples of submarine furrows, which are produced by sustained, unidirectional current erosion (Flood, 1983). Furrows occur in a variety of modern settings, but they are particularly common on the outer parts of continental shelves, often near the continental slope break. STOP 6, thus, affords a rare three-dimensional view of submarine erosive processes associated with transgressive onset of anoxic or minimally dysoxic conditions. At Slate Bottom Creek, this same contact is visible, except that no furrows are observed there (Fig. 9).

Undifferentiated medial and upper Levanna black shale division – Above the Union Road discontinuity on Buffalo Creek is approximately 27 m of very dark gray to black fissile shale which is overlain by the Centerfield Member (Figs. 3, 5, 10). From the Wende-Alden meridian westward to Lackawanna the medial and upper parts of the Levanna are represented by a facies succession that is distinctly more basinal than that further east; we believe that all of the Levanna succession above the Wadsworth Bed (and possibly above the base of the *Tasmanites*-rich shale unit) in the Genesee Valley grades westward into black shale (Figs. 5, 9). It is possible, if not probable, that the Slate Rock beds interval may persist into Erie County as a non-black facies unit, but no exposures of it exists there (Fig. 5). Thus, in Erie County, the Levanna is effectively two lithologic units, a lower calcareous mudstone division (Delphi Station Member-equivalent) and a higher division (Pompey Member-through-Butternut Member-equivalent succession).

Skaneateles Formation Unit Relationships: Central-Western New York Region

The Skaneateles Formation containing regionally mappable subdivisions represents a succession of outer shelf paleoenvironments ranging from near-anoxic and lower dysoxic (*Tasmanites*-rich shale unit, Butternut Member-equivalent black shale unit, medial-upper Levanna succession in Erie County) to fully oxic (parts of Stafford Member, Roanoke Bed, possibly Wadsworth Bed). It records stable outer shelf conditions, generally shallower than those indicated by the Union Springs and Oatka Creek formation-succession. Generally, there is an overall upward-deepening trend, starting with the relatively regressive Stafford Member and culminating with the top-Levanna (Butternut Member-equivalent) shale unit. Regionally, the Skaneateles Formation displays relatively shallower oxic and upper dysoxic facies at the Syracuse meridian, dysoxic to near-anoxic depocenter facies at the Cayuga Lake meridian, variably dysoxic to minimally oxic facies in Genesee Valley localities, and predominantly lower dysoxic to near-anoxic facies in Erie County.

The most prominent internal feature of the Levanna Member is the Union Road discontinuity which may represent significant erosional down cutting in Erie County

(Figs. 5, 9). This discontinuity may correlate with the Wadsworth Bed in the Genesee Valley-Batavia region. Further east, it may correlate with the "*Nyassa* Bed" (*Nyassa arguta*-rich siltstone layer recognized as the top of the Pompey Member by Cooper (1930) at the Pompey Member type section at Pratts' Falls near Pompey, New York) in central New York, but this is still unproven (Fig. 3). As seen with other contacts associated with black shale units, it appears to be most prominent where the overlying deposits become maximally basinal in character as in Erie County. This may be due to the effects of sediment-starvation and a combination of abrasive and corrosive bottom conditions associated with the base-Pompey Member-age transgression in that area.

TECTONIC AND EUSTATIC QUESTIONS

The various facies of the uppermost Onondaga Group-through Skaneateles Formation succession in western New York are most likely the result of eustatic rather than tectonic controls given the overall distance from the Acadian Orogeny, except for the great inferred regional deepening associated with onset of Bakoven black mud deposition which may be a partial result of viscoelastic lithosphere relaxation ("second tectophase") associated with thrust loading (see Ettensohn, 1985, 1987).

In this tectonic scenario, the Devonian foreland basin expands and deepens substantially accounting for the development of the Bakoven-through-Chittenango black shale succession. However, the enigmatic Halihan Hill Bed with its rich Hamilton fauna is observed to neatly separate the Berne Member (black shale) from the Chittenango Member (black shale) across almost the whole length of the State (Figs. 2, 3). Moreover, this bed yields a large-coral fauna in Hudson Valley localities and moderately shallow water taxa (*Tropidoleptus, Pseudoatrypa, Mediospirifer*, fenestrates, stereolasmatid rugosans) in localities to the west of there. As noted above, this thin unit produces the shallowest-water fossils observed between Onondaga and Centerfield strata in western New York, yet it is stratigraphically sandwiched within one of the most organic-rich black shale intervals in the east.

This pattern appears to contradict the concept of a thrust-loaded depression which should have relegated all associated basal Hamilton facies to a basinal anoxic-dysoxic facies range spectrum. Moreover, if the tectophase model were to apply here, one would perhaps expect that the Halihan Hill Bed might be a shallow water unit in western New York but be represented by significantly deeper water facies and thicker deposits in eastern New York more proximal to thrusts. If tectonic loading was truly operating at that time, thrust loading would have been essentially restricted to the New England and Hudson Valley regions with the foreland basin constrained to an area largely east of New York State. This would better explain the lack of major sediment input during the Halihan Hill eustatic lowstand. Otherwise, the significant eustatic lowstand, suggested by Halihan Hill Bed facies, would have produced a major progradational pulse timed with this unit if the thrust-load basin was centered west of the Catskill front at this time.

Applying the terminology of sequence stratigraphy to divisions discussed here, it can be argued that the upper Onondaga Group generally comprises a transgressive systems tract with development of high energy, proximal facies (Moorehouse Member) in the middle Onondaga and mid to outer-shelf deposits (Seneca Member) at the top (see Brett and Ver Straeten, 1994). The Bakoven black shale deposit, marks a major eustatic (and partially tectonic?) highstand event with the top-Seneca Member corrosional discontinuity marking a maximum flooding surface (Brett and Ver Straeten, 1994; Ver Straeten, et al., 1994). Most of the Stony Hollow Member constitutes a regressive or late highstand systems tract while the Cherry Valley Member marks the transgressive systems tract of the next major sequence. The Chestnut Street submember, correlative to the uppermost part of the Stony Hollow, is believed to rest on a regional (4th order) sequence boundary unconformity (Ver Straeten et al., 1994). The Cherry Valley-Berne contact, marked by a corrosional discontinuity in western New York is a maximum flooding surface contact overlain by early highstand facies of the Berne Member.

The Berne-Halihan Hill contact apparently represents another major (4th order) sequence boundary, though no obvious erosional lag features (phosphatic pebbles, reworked concretions, scour channels) are observed at its base. In essence, the Halihan Hill Bed may be a rare example of condensed proximal facies in a sediment-starved regime. Major southeastward thickening and moderate coarsening of the Berne Member in eastern New York suggests that the Halihan Hill Bed may have "ridden over" a major progradational regressive systems tract succession east of the current Devonian outcrop limit. If so, it would constitute an initial transgressive systems tract succession. Black Chittenango facies above the Halihan Hill Bed represent early highstand deposits, perhaps accentuated by tectonic thrust loading. A 1 cm-thick shell hash layer rich in orbiculoid shell fragments within the lower Chittenango (0.8 m above the Halihan Hill Bed on Oatka Creek, STOP 3b) may represent a maximum flooding surface or a separate event.

The Stafford –Mottville succession marks the end of another widespread regression perhaps comparable to but not as prominent as that of the Halihan Hill. Recent examination of Mottville sections near Syracuse by the present authors show that the actual regression and progradation event is represented by the Mottville "sub-A" deposit. An erosional sequence boundary unconformity is present beneath the Mottville "A Bed" encrinite of Grasso (1986). Hence, the Mottville "A: and all higher Mottville layers are part of a transgressive systems tract succession. Although the exact position of the "A" Bed is somewhat uncertain for western New York Stafford sections, we believe it is at or near the base of the Stafford main limestone bed at LeRoy (Stop 3c).

The Levanna Member records a succession of transgressive-regressive cycles. As noted above, the Cole Hill cycle, Delphi Station cycle, the Pompey and "Marietta" cycles and the Butternut-Chenango cycle of central New York (Grasso, 1986; Linsley, 1991) all connect to various beds and intervals in the western New York Levanna succession. As of this writing, maximum flooding events associated with the basal Pompey ("*Tasmanites* Shale" interval), top-Pompey (Wadsworth Bed and Union Road disconformity), and base-Butternut contact are the most conspicuous tie lines observed in the Levanna. Confirmation of correlation of these and lesser markers to central New York coarsening-up cycles is the goal of our ongoing work.

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ROAD LOG

Leave SUNY Fredonia and proceed to I-90 Dunkirk interchange. Proceed east on I-90 (NYS Thruway) past Buffalo towards Rochester. We begin the field trip road log at the junction of I-90 and I-390 south of Rochester where we exit I-90 (NYS Thruway) onto I-390 and proceed south.

0.0	0.0	Enter I-390 (southbound)
0.15	0.15	Cross I-90
3.2	3.05	Exit I-390 onto U.S. Route 15 Southbound
7.25	4.05	Route 15 passes over I-390
7.45	0.2	Intersection (yellow blinking light) of Route 15 and Honeoye Fall #6 Road. Turn left (east) onto Honeoye Fall #6 Road
7.6	0.15	Cross over I-390; view of three drumlins to the right (south)
9.3	1.7	Five Points Road on left; continue straight ahead
10.2	0.9	Cross Works Road; small outcrop of Onondaga Limestone on right along Works Road.
10.9	0.7	Entrance to General Crushed Stone Corporation, Honeoye Falls quarry, at Town of Mendon line; turn right into entrance and bear right.
11.1	0.2	Quarry Office: stop and check in General Crushed Stone Quarry, Honeoye Falls Plant (Five Points Quarry).
11.1	0.0	Turn left (south) onto main quarry road and proceed past high tanks towards old equipment area onto narrow road along north rim of quarry.
11.7	0.6	Fork of lower and higher quarry roads.
11.75	0.05	Enter higher road onto top of Onondaga Limestone and park.

STOP 1: General Crushed Stone Quarry, Honeoye Falls Plant. Quarry north-northwest of Lima, New York (RUSH 7.5' Quadrangle). Pit is located on south side of Honeoye Falls #6 Road, 6 km (3.4 mi) east of the Honeoye Falls #6 Road/Route 15 intersection. PERMISSION TO ENTER QUARRY MUST BE OBTAINED BEFORE ENTERING. Hardhats required!!!

This is a classic exposure of the Onondaga Limestone and the basal portion of the Hamilton Group (see extensive treatment by Brett and Ver Straeten, 1994; Ver Straeten et al. 1994). We will proceed southeastward on foot from the quarry road terminus at the southwest edge of the pit along the conspicuously sloped next-to-top riser. Note the exceptional jointing of the limestone at various quarry levels and the southward dip throughout which is steeper than the 0.5° average for the region. The riser on which we walk is developed on the top-contact of the Moorehouse Member of the Onondaga; choice of this horizon as a staging surface in the quarry probably relates to the position of the soft Onondaga Indian Nation (OIN) K-bentonite which allowed for easy peel-back of overlying beds. This ash is 25 cm-thick at this locality. The OIN K-bentonite is the thickest of a series of closely-spaced ash beds known as the "Tioga Ash Complex" in literature (Conkin, J.E. and B.M. Conkin, 1984; Rickard, 1984). Dennison and Textoris (1978) believe that "Tioga" tuffs originated in what is now northern Virginia and the prevailing paleowinds carried the volcanic products predominately westward (in the present sense) into the U.S. midwest. Several higher, thinner K-bentonites can be seen in the Seneca Member (quarry wall above OIN position) as reentrants. Some of these are associated with chert bands (see discussion of Ver Straeten et al., 1994) of detailed ash succession (Fig. 4).

Crinoidal, brachiopod-rich limestone marking the top of the Seneca Member is abruptly succeeded by the Bakoven Member where a 2-3 mm-thick black shale bed is draped upon a minor discontinuity at the top of the Onondaga (Fig. 4). This is, in turn succeeded by a 15 cm-thick K-bentonite layer (Tioga F Ash) and platy styliolinid-rich limestones that overlie the ash. Within the interval of styliolinid limestones is a bone bed rich in onychodid teeth, arthrodire dermal armor and conodonts. Very large specimens of *Panenka*, a bivalve typical of dysoxic facies, occur within the styliolinid limestone interval as well. Succeeding Bakoven strata are composed of platy black shale facies (Fig. 4). In this quarry, the Bakoven Member ranges from1.7 m to as little as 7 cm in thickness due to variable truncation below the sub-Cherry Valley unconformity (Ver Straeten et al., 1994).

The Chestnut Street submember of the Hurley Member is only locally exposed in this quarry (Fig. 4); it is expressed as a light weathering richly fossiliferous limestone bed at the eastern end of the exposure. The proetid trilobite *Dechenella haldemanni*, auloporids, sponge spicules and diminutive calyces of the crinoid *Haplocrinites* are characteristic fossils. Removal of almost all of the Chestnut Street bed and all post-Chestnut Street Bed Hurley strata reflects channelized downcutting associated with a disconformity at the base of the Cherry Valley Limestone (Ver Straeten et al., 1994).

The Cherry Valley Member of the Oatka Creek Formation is represented by 0.4 to 3.0+ meters of crinoidal pack-and grainstone carbonate containing lesser amounts of styliolinid and fenestrate allochems. Major variation in Cherry Valley thickness at this locality apparently reflects paleorelief at the base of the unit owing to the presence of paleochannels associated with differential erosion of the Bakoven Shale (Ver Straeten et al., 1994). Sparse conchs of the characteristic goniatite *Agoniatites* and the orthoconic cephalopod *Striacoceras* have been found at this locality. A pyrite coated corrosional discontinuity marks the contact between the Cherry Valley limestone and overlying black shale facies of the Berne Member of the Oatka Creek formation (Fig. 4). At last visit about 1.5 m of this shale was exposed below till at the uppermost bedrock limit; to date, the Halihan Hill Bed has not been uncovered in this section.

The Honeoye Falls quarry section is significant in that it displays the westernmost occurrences of the Bakoven Shale, Chestnut Street submember, and Cherry Valley Limestone that can be seen in outcrop (Figs. 4, 5). At STOP 3a, the Berne Member is juxtaposed directly onto the Seneca Member with development of a composite unconformity between them (Figs. 5, 6). STOP 1 is significant in showing no less than four discontinuities: base-Bakoven, lower-Bakoven, sub-Cherry Valley, and sub-Berne contacts that ultimately contribute to the large composite hiatus at LeRoy.

Return to cars and retrace route to quarry entrance.

12.6	0.85	Turn left (west) onto Honeoye Falls #6 Road. Retrace route back to Honeoye Falls #6/Route 15 intersection.
16.05	3.45	Turn left (south) onto Route 15 at yellow blinking light.
16.55	0.5	Enter Livingston County
18.8	2.25	Intersection of Route 15 and U.S. Route 20 in Village of East Avon. Continue straight (south).
21.4	2.6	Junction of Route 15 with Ager Road. Turn right (west) onto Ager Road.
22.75	1.35	Junction of Ager Road and Pole Bridge Road. Turn left (south) onto Pole Bridge Road (we will be on this only momentarily).
22.8	0.05	Junction of Pole Bridge Road and Paper Mill Road. Turn right (west) onto Paper Mill Road.
24.0	1.2	Cross over Conesus Creek and make immediate right turn into small park at creek.

STOP 2: Levanna Shale Member. Type section of Papermill Limestone and associated beds of uppermost part of Delphi Station-equivalent Levanna (see Fig. 9).

The footbridge over the creek near the parking area, provides a good look at the resistant limestone ledge of the Papermill Bid. This unit was misidentified as Stafford in early literature. At this locality, the Papermill is composed of bioturbated mudstone characterized by few fossils. The most notable bed content consists of three-dimensional barite infilled orthoconic cepholopods and infrequent clumps and masses of barite. The top of the Papermill Bed near the foundation of the Paper Mill Road overpass is marked by a thin bed of auloporid corals and other fossils (Fig. 9); this is the Roanoke Bed which is better developed at STOP 4 (Fig. 8). Upstream from the Paper Mill Road bridge are good exposures of both Pole Bridge Limestone layers and still further upstream is good development of the Wadsworth Bed (see text). The upward succession of Papermill Bed-lower Pole Bridge Bed-upper Pole Bridge Bed-"*Tasmanites* Shale" interval marks a stepwise overall marine deepening that marks the change from upper Delphi Station lowstand conditions to basal Pompey cycle highstand facies (see text).

		Return to cars and exit park. Turn right (west) onto Paper Mill Road.
24.4	0.4	Junction of Paper Mill Road and Route 39. Turn right (north) onto Route 39.
26.2	1.8	Cross Conesus Creek at Ashantee. Onondaga Limestone (Seneca Member) is exposed both below and above Route 39 bridge.
27.5	1.3	Route 39 intersection with combined Routes 5 and 20 in Avon. Turn left (west) onto Route 20.
27.9	0.4	Leave Village of Avon.
28.0	0.1	Bridge over Genesee River
28.4	0.4	U.S. Route 20 forks from Route 5. Bear right on Route 5 and proceed northwest to Caledonia.
29.1	0.7	Leave Genesee River floodplain.
33.8	4.7	Enter Village of Caledonia
34.5	0.7	Center of Caledonia; Route 36 merges in from the right; turn left (west).
34.7	0.2	Route 36 splits off from Route 5. Continue on Route 5.
35.35	0.65	Leave Village of Caledonia.
37.35	2.0	Leave Livingston County; enter Genesee County.
38.45	1.1	Pass through Limerock. Proceed towards LeRoy; route passes south of 5 to six large quarries developed into the Onondaga Limestone.
40.65	2.2	Enter Village of LeRoy.
41.45	0.8	Cross over Oatka Creek; falls over Stafford Limestone immediately north of bridge.
41.5	0.05	Turn right (north) onto Mill Street from Route 5.

41.95 0.45 Turn right from Mill Street into parking pull off by Oatka Creek immediately north of railroad overpass and where Mill Street turns west. Proceed on foot to creek edge.

STOP 3: Bed of Oatka Creek north of (downstream from) Route 5 in town of LeRoy (LeRoy 7.5' Quadrangle). Creek parallels small park along Mill Street. Outcrop floors creek between falls over Stafford Member near dam and railway bridge to the north of a park footbridge over creek (Fig. 6).

This section offers a variably accessible but nearly continuous section from the uppermost Seneca Member up to the Stafford Limestone (Fig. 6). We will first park in the northernmost parking area where Mill Street turns west immediately north of the railroad overpass (STOP 3a). We will then drive south past two houses and a footbridge to the next park pull-off to the south of STOP 3a (STOP 3b) and finally to the main parking area near the southern end of Mill Street (STOP 3c). Proceed on foot from 3a pull off to edge of creek.

STOP 3a: Halihan Hill Bed and basal Chittenango Member of the Oatka Creek Formation.

Although the Seneca Member-Berne Member composite unconformity was excavated by Baird on this creek in the mid 1980s, the contact is currently concealed by debris. However, one can sample richly fossiliferous Seneca facies just below the contact level on this creek at the present time. The sub-Berne disconformity is expressed as a pyrite-coated irregular, pitted surface with phosphatic lag debris in depressions on the contact (Baird and Brett, 1991). The Berne Member is poorly exposed below water to the north of our access point (Fig. 6). This 40 cm-thick unit is composed of black shale rich in large styliolinids.

At this section, the Halihan Hill Bed is also exposed below water (Fig. 6). However, the upper part of this unit is within the reach of hammers if the water is not high. The 60 cm Halihan Hill interval is composed of very soft, gray shale which yields diverse and abundant fossils. Key brachiopods at this locality include *Mediospirifer audaculus, Athyris cora, Tropidoleptus sp., Devonochonetes sp., Ambocoelia umbonata, Pseudoatrypa devoniana*. Other fossils include stereolasmatid corals, encrusting, bifoliate and fenestrate bryozoans, pteriomorph bivalves, *Phacops* exuviae and pelmatozoan debris. The bed marks the dramatic appearance of the Hamilton macrofauna that holds sway in the study area for most of the Givetian Stage.

Return to vehicles. Turn left (south) and proceed along Mill Street.

42.05 0.1 Turn left onto park pull-off south of footbridge over Oatka Creek. Proceed on foot to creek.

STOP 3b: Black, organic-rich shale deposits of the Chittenango Member of the Oatka Creek Formation.

This brief stop serves to illustrate the exceptionally organic-rich facies of the Chittenango Member. Well jointed, very hard black shale is exposed in the creek bed. This part of the Chittenango displays T.O.C. values exceeding 15%. Although no macrofauna is observed in this facies, a thin (1 cm-thick) debris layer of orbiculoid fragments is observed in the lower Chittenango in the vicinity of the park pull-off.

Return to vehicles. Turn left (south) and proceed along Mill Street.

42.35 0.3 Turn left into large parking area near south end of street and proceed on foot to platform near falls.

STOP 3c: Stafford Limestone Member of Skaneateles Formation and uppermost strata (Chittenango Shale Member) of Oatka Creek Formation exposed in waterfall below dam. Section easily viewed from viewing platform by parking lot (Fig. 6).

Below the conspicuous Stafford limestone ledge are several feet of black to dark gray fissile shale assignable to the Chittenango Member. Some of the highest beds are not as black and organic rich as typical Chittenango. Moreover, they yield flattened rhynchonellids and orbiculoids below the base-Stafford contact. Although not formally used here, the term "Cardiff Shale" is marginally applicable to these beds (see above). Further east in the vicinity of Skaneateles, the upper part of the Chittenango transforms eastward into gray, fissile shale that has been formally assigned to Cardiff.

At this section 78 cm of Stafford Member, including a lower calcareous dark gray shale interval and 28 cm of resistant limestone, are present in the falls. The uppermost calcareous shale portion of Stafford is concealed here. As with other Stafford sections in the Waterloo-Stafford region, the member is thin and distinctly condensed. Unlike sections in Erie County (Meyer, 1985) and in Onondaga and Madison Counties (Grasso, 1986), where two prominent ledges ("A" and "B" beds) respectively characterize Stafford and Mottville sections, the LeRoy Stafford section is characterized by a single limestone unit underlain by a brachiopod-rich shale unit (Fig. 6). The shale interval below the limestone is typically characterized by abundant *Ambocoelia* and *Devonochoneaes*. The falls-capping limestone bed contains *Camarotoechia sappho, Bembexia sulcomarginata*, occasional small rugosans, auloporids and uncrushed orthoconic nautiloids. The matrix is a brownish gray wackestone lithology, fossils are typically three dimensional and mollusc shell is expressed as sparry black calcite.

Due to the thinness and minimal differentiation of the limestone part of the Stafford in this area, it is difficult to connect the "A" and "B" bed terminology of Meyer (1985) for Erie County and the "A" and "B" bed-usage of Grasso (1986) for Onondaga County (see text). We suspect that the regressive lowstand marked by a scour surface at the base of Grasso's "A" bed encrinite in Onondaga County roughly links to the base of the limestone bed at LeRoy, but this is, as yet, unproven.

Return to vehicles; turn left (south) out of parking lot.

42.4	0.05	Junction of Mill Street with Route 5; turn right (west) onto Route 5.
42.55	0.15	Junction of Route 5 and Route 19; continue straight.
43.25	0.7	Leave Village of LeRoy.
43.4	0.15	Junction of Route 5 and Bethany-LeRoy Road; turn left (south) onto Bethany-LeRoy Road.
46.2	2.8	Junction of Bethany-LeRoy Road with Covell Road. Turn left (south) onto Covell Road.
46.4	0.2	Cross Oatka Creek
46.42	0.02	Turn left into driveway immediately south of Covell Road bridge and proceed to house at end of driveway. This is PRIVATE PROPERTY. Permission to enter must be obtained from the owner.
46.55	0.13	Park vehicles and proceed to edge of creek.

STOP 4: Levanna Shale Member of Skaneateles Formation (Fig. 8).

This exposure shows Papermill Limestone Bed, Roanoke Bed, probable "*Tasmanites* Shale" with subjacent diastem, Wadsworth Bed, and an overlying unnamed shale unit in the upper Levanna (see text). The exposure is partly below water in bed of Oatka Creek 200-250 m east of (downstream from) Covell Road overpass (Stafford 7.5' Quadrangle). The outcrop is 6 km (3.5 mi) southwest of LeRoy, NY. We will access outcrop by entering through a private driveway exiting off of road immediately south of the creek that terminates at a residence near the exposure.

Several key Levanna beds occur in this section nearly juxtaposed on one another (Fig. 8). At the northeast (downstream) end of the section, is the Papermill Bed, a 0.7 m-thick massive limestone marker in the upper-middle part of the Levanna. This unit, yielding few fossils, marks one of the highest levels in that portion of Levanna that we believe is equivalent to the Delphi Station Member (see text: Fig. 8). Above the Papermill ledge is a 25 cm-thick interval of profusely fossiliferous, soft, gray mudstone yielding thicket growths of a large variety of *Aulocystis* (Fig. 8). This mudstone unit, herein designated the Roanoke Bed with this locality as its type section (see text), is mostly exposed below water. On Oatka Creek, this bed is thickest and best developed; the *Aulocystis* thicket layer yields brachiopods such as *Pseudoatrypa* and *Rhipidomella* and crinoid debris is abundant. Above the thicket layer is a 0-10 cm thick interval of soft gray mudstone yielding *Arthracantha* fragments and large *Phacops*. This unit marks the faunal acme of the entire Levanna in this region; it probably marks a sea level lowstand coincident with a maximally regressive part of the Delphi Station cycle in central New York (see text).

At STOP 4, the Roanoke Bed is abruptly and unconformably succeeded by a 40 cm-thick interval of fissile, dark gray to near black shale (Fig. 8). The Roanoke-black shale boundary is knife-sharp and it is marked by abundant reworked pyritic burrow tube fragments. These fragments, derived from in-situ pyritic burrow networks in the Roanoke Bed, locally show a weak current alignment. The tubes are identical to those observed in the Leicester Pyrite Member and in higher Genesee Formation levels; we believe that they were exhumed under dysoxic to near-anoxic conditions, most likely by bottom current processes or the shoaling of internal waves (Baird and Brett, 1991). Also significant is the scarcity of carbonate allochems associated with the tubes despite the abundance of carbonate fossils in the Roanoke. Baird and Brett (1991) argued that under lower dysoxic to near-anoxic bottom conditions, reworked pyrite could remain unoxidized when exposed to the sea bed while carbonate allochems would undergo dissolution. This reversal of the normal oxic situation could explain the lack of carbonate in detrital pyrite-dominated lags. The black shale above the discontinuity yields flattened rhynchonellids ("*Leiorcynchus*") and abundant *Tasmanites*. We believe that this unit is a beveled remnant of a thicker organic rich unit ("*Tasmanites* Shale") observed in the Genesee Valley (Fig. 9).

Above the dark shale unit is a 8-10 cm-thick bed marked by abundant fossils (Fig. 8). This is the Wadsworth Bed that is composed of a muddy hash of small brachiopods (*Devonochonetes, Ambocoelia*), minor pelmatozoan debris, auloporid thicket and debris fabric and *Tasmanites* set in a network of *Thallasinoides* burrows (see text). Conodonts and small fish bones and teeth are also present in this bed, though less conspicuous than at the base of the black shale. These are commonest in burrows at the base of the bed; their distribution suggests that the base of the unit is erosional and that this erosion explains the anomalous thinness of the underlying black "*Tasmanites*" Shale unit. This unit can be traced into the Genesee Valley, but only tentatively east of there (Fig. 9); it may correlate to the *Nyassa arguta*-rich sandstone at the top of the Pompey Member in central New York (see text). To the west it may connect to the Union Road discontinuity that we will see at STOP 6.

Above the Wadsworth Bed is a monotonous interval of dark gray fissile shale that is visible in the upstream, north-facing shale bank. These shales yield a sparse biota of *Devonochontes scitulus,* flattened rhynchonellids ("*Leiorhynchus*"), small Ambocoeliids and diminutive gastropods and bivalves. Based on correlations to date, we are involved in ongoing efforts to determine whether this unit is part of the Pompey or the next higher "Marietta Cycle" (see text).

Return to vehicles and retrace route back to Covell Road/Bethany-LeRoy Road intersection.

46.9 0.35 Turn left (west) onto Bethany-LeRoy Road.

47.55 0.65 Intersection of Roanoke Road and Bethany-LeRoy Road in Hamlet of Roanoke. Continue straight on Bethany-LeRoy Road.

50.15	2.6	Junction of Bethany-LeRoy Road and Route 63; turn left (southeast) onto Route 63.
50.4	0.25	Intersection of East Road and Route 63; turn right (west) onto East Road. East Road curves around to the south in a 0.25 mi distance.
51.65	1.25	Intersection of East Road and Jericho Road; continue straight (south) on East Road. Small exposure of Kashong Shale on East Road north of Intersection.
52.2	0.55	Intersection of East Road and U.S. Route 20. Turn right (west) on Route 20.
53.7	1.5	Exposure of Genundewa Limestone Member of the Genesee Formation (Upper Devonian: lower Frasnian) on left (south) side of Route 20 beneath Bethany Center Road overpass. The Genundewa is a styliolinid-rich limestone rich in cephalopod conchs at this locality and, along with the Cherry Valley Member is a classic cephalopod limestone.
		Proceed west on U.S. Route 20 through towns of Alexander, Darien, Darien Center and Alden. Not much geology is visible from Route 20 over this 25 mile distance, though numerous classic upper Hamilton Group localities occur near the read in this area.
79.2	25.5	Cross Bowen Road/Route 20 intersection near the approximate east edge of the Town of Lancaster, Erie County.
80.35	1.15	Turn left (south) off of Route 20 onto Church Street.
80.65	0.3	Cross Pardee Road into Como Park pull-off. Proceed on foot to outcrops on Cayuga Creek in park.

STOP 5 (optional): "A Bed" at base of Middle Devonian Stafford Limestone Member at Como Park (Fig. 7).

Along the banks and bed of Cayuga Creek between the dam and base of the small waterfalls lip at the Lake Avenue bridge are exposures of the Stafford Limestone Member, the basal division of the Skaneateles Formation (Fig. 7). Downstream from the waterfalls are intermittent exposures of the black, fissile, organic-rich Chittenango Member of the underlying Oatka Creek Formation which is mostly covered. Near the falls and bridge, the topmost few feet of the Chittenango Shale can be examined on the south side of the creek; these uppermost Oatka Creek beds are dark gray-brown in color and they yield a meager dysoxic biota consisting of flattened rhynchonellids ("*Leiorhynchus*"), *Styliolina*, and numerous flattened composite molds of an orthoconic nautiloid.

The Stafford, in Erie County, is a four-part member consisting of a basal, thin, shell-rich muddy limestone bed ("Sub-A" bed), a slightly higher limestone unit with encrinite at its base (probable "A" bed of central New York Mottville), a middle, shaley interval several feet thick which contains nodular, micritic, concretionary beds, and a fossiliferous upper cherty limestone division, termed the Stafford "B" bed, which is 0.6-1.3 m (2 to 4 feet) in thickness (see Meyer, 1985). In central New York, the equivalent Mottville Member starts with a fossiliferous, calcareous mudstone division ("sub-A" bed) followed by an encrinite-rich "A" bed limestone ledge, which is succeeded, in turn, by a variably-thick middle "shale" division followed by a micritic or siltstone regressive capping unit which corresponds to the Erie County, chert-rich ("B") micritic division visible by the Como Park dam (see text). The "sub-A" bed remains relatively thin, usually between 8 and 30 cm (0.2-1.0 feet) in thickness in this area, and it is typically a densely fossiliferous calcareous mudstone, both overlain and underlain by sparsely fossiliferous deposits (Fig. 7). The "sub-A" bed typically rests abruptly on dysoxic to anoxic dark shales. The "middle shale" usually grades upward into fossil-rich shaley micrites of the "B" bed.

At this locality the Stafford "sub-A" bed yields numerous small brachiopods, including *Crurispina nana, Truncalosia truncata, Devonochonetes scitulus*, and a small variety of *Tropidoleptus*. Other fossils include the large bivalve *Panenka*, occasional *Camarotoechia*, orthoconic nautiloids often encrusted by the reptate biserial tubular organism *Reptaria stolonifera*, which may have "hitchhiked" on the living cephalopod (see Baird et al., 1989), and wood debris. The diminutive brachiopod assemblage in the Stafford "sub-A" bed appears to represent only a slight increase in bottom oxygenation relative to the underlying Oatka Creek Shale. This assemblage falls between the "*Leiorhynchus*" and "*Ambocoelia*-chonetid" biofacies of Brett et al., 1986; Vogel et al., 1986; which is indicative of non-turbid upper dysoxic to minimally oxic bottom conditions (see text).

Return to vehicles. Turn left (west) on to Pardee Avenue.

80.7	0.05	Junction of Old Lake Avenue with Pardee Avenue. Bear right (northwest) onto Old Lake Avenue.
80.75	0.05	Junction of Lake Avenue with Old Lake Avenue. Turn right (north) on to Lake Avenue.
81.0	0.25	Junction of Route 20 and Lake Avenue. Turn left (west) onto Route 20.
81.3	0.3	Cross Cayuga Creek. Middle Devonian black and dark gray shales of the Chittenango Member are intermittently exposed along creek in this area.
81.8	0.5	Leave Town of Lancaster, NY.
81.9	0.1	Cross Cayuga Creek.
82.5	0.6	Junction of Transit Road (U.S. Route 20) with Broadway (Route 130).

		Continue straight (west) on Broadway (Route 130).
83.0	0.5	Junction of Broadway with Rowley Road (to left). Two excellent exposures of the upper part of the Onondaga Limestone with associated Tioga ash beds are respectively developed on Cayuga Creek adjacent to the road 0.5 and 1.5 miles west-southwest of the Broadway/Rowley Road intersection (Brett and Baird, 1990). We will continue west on Broadway.
84.1	1.1	Leave Town of Depew.
85.5	1.4	Junction of Union Road with Broadway; turn left (south) on to Union Road.
86.7	1.2	Cross Cayuga Creek. Middle Devonian Onondaga Limestone is exposed both below bridge and upstream from it.
88.0	1.3	Leave Town of Cheektowaga.
88.7	0.7	Cross Buffalo Creek. Excellent exposure of Levanna Member that we will examine is developed below bridge.
88.8	0.1	Turn left off of Union Road into small parking area immediately south of one-way exiting street. Park vehicles and proceed north across one-way road through area designated for a new town park (Burchfield Park) to edge of Buffalo Creek.

STOP 6. Submarine Discontinuity (Union Road disconformity) within Middle Devonian Levanna Shale Member along Buffalo Creek (Figs. 9, 10).

Along this cutbank exposure one can observe two key Levanna lithologic divisions which are currently unnamed. Just above water level is a calcareous, dark gray-shale division which yields the diminutive brachiopod *Ambocoelia* and specimens (many complete) of the trilobite *Phacops rana*. A submarine discontinuity (prominent undulatory outcrop reentrant) separates this lower unit from a fissile, black shale upper division, rich in flattened rhynchonellids ("*Leiorhynchus*") and *Styliolina*. This boundary is probably correlative with the Wadsworth Bed in the Black Creek-Conesus Creek area (Figs. 5, 9). The units in this section record oxygen-deficient outer shelf-to-basin conditions with the lower division recording dysoxic to minimally oxic conditions and the upper division recording lower dysoxic to near-anoxic conditions ("exaerobic" zone of Savrda and Bottjer, 1987) along the seabed.

This discontinuity is distinctive for its distinctly undulatory appearance; troughs between 0.5 and 2.0 m (1.5-6.5 feet) in width and between 12 and 45 cm (5 to 16 in) in depth alternate with intertrough ridges and platforms (Fig. 10). The troughs are erosional runnels cut into division 1 deposits which are aligned in a nearly north-south direction transverse to the creek channel (Fig. 10B). Some runnels bifurcate but most remain simple and linear. Trough bottom deposits often include calcareous brachiopods, *Phacops*, and *Styliolina* debris admixed with fish teeth and dermal plates. These lags are commonly at channel bottoms but they can occur in axial channel sediments above channel bottoms. Some troughs appear to have been repeatedly filled with sediment and scoured out by currents; these troughs display nested erosional scour surfaces with the sharpness of scour contacts varying from clear to diffuse (Fig. 10C). Evidently some episodes of scour removed only water-rich surface mud while others cut into firm muds.

Clearly, this section records a type of sedimentary condensation where repeated sediment accumulation and scour were dominant sedimentary processes. The overall upward-change across the disconformity appears to be transgressive with the consequent development of an erosional surface; the complex channel-fills appear to correspond to the interval of maximum sediment-starvation and sedimentary condensation which overlies the transgressive erosion surface.

These erosional runnels are probably submarine furrows (see Flood, 1983), which are rarely reported from the stratigraphic record. Furrows are believed to form through the action of abrasive horizontal, debris-laden current vortices which scour the bottom into linear runnels within a sustained unidirectional current regime (Flood, 1983). The complex "cut-and-fill" histories of the Levanna runnels is a testament to the unidirectional character of the currents which produced them. We are currently studying these features at this locality to establish which way the currents flowed and are also examining all other similar discontinuities to determine if similar runnels are distributed along them.

Return to vehicles. Turn right (north) onto Union Road and cross Buffalo Creek (traffic is heavy on Union Road; we will have to turn around at the intersection of Union Road and Route 354 just north of Buffalo Creek in Gardenville. The road log commences again at the Union Road bridge over Buffalo Creek once we have completed the U-turn).

89.05	0.25	Cross Buffalo Creek.
89.8	0.75	Entrance ramp to Route 400. Bear right on to ramp and proceed west on Route 400.
91.5	1.7	Entrance ramp to I-90 (southbound). Continue around cloverleaf and proceed to Fredonia.

END OF ROAD LOG

SILURIAN-EARLY DEVONIAN SEQUENCE STRATIGRAPHY, EVENTS, AND PALEOENVIRONMENTS OF WESTERN NEW YORK AND ONTARIO, CANADA

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INTRODUCTION

The Silurian rocks of the Appalachian Basin provide an excellent suite of strata for application of sequence, and event stratigraphic approaches. The strata are well exposed and display marked vertical changes in facies, commonly associated with distinctive condensed beds and/or discontinuities. The Niagara Escarpment in western New York and the Niagara Peninsula of Ontario represents a key reference area for the North American Silurian System. Indeed, the term "Niagaran," which has been variably applied to the "middle" or lower and middle portions of the Silurian, is still commonly used in North America. These rocks have been well documented by many researchers, beginning in the mid 1800s (Hall, 1852; Grabau, 1901; Williams 1919; Gillette, 1947; Bolton, 1957; Zenger, 1965, 1971; Sanford, 1969; Martini, 1971; Rickard, 1975; Brett, 1983 a,b; Brett et al., 1995; 1998).

A major theme of this report and field trip is the documentation and interpretation of Silurian facies and sequences along the northwestern rim of the Appalachian Basin. The larger scale ("third order") sequences described herein are unconformity bound stratal packages, ranging from less than a meter (where partially truncated or condensed) to about 50 m in thickness. Most display a generally deepening- shallowing pattern. They are divisible into smaller (fourth-order) sequence-like units that display similar patterns but are not separated by major unconformities; we have termed these units subsequences (see Brett et al., 1990a, b, 1995, 1998, for further details).

With its renewed emphasis on through-going discontinuities and condensed beds, the sequence approach has encouraged a broader, more regional view of stratigraphy and an attempt to understand the genetic significance of particular beds and surfaces. To some degree it vindicates the earlier "layer cake stratigraphy" approach. Sequence stratigraphy, originally developed from remote seismic studies of passive margin sediment wedges (Vail et al., 1977, 1991; Wilgus et al., 1988). is now being applied at an outcrop scale to diverse depositional settings including foreland basins such as the Appalachian (or Taconic) foreland basin of the Ordovician and Silurian (Brett et al., 1990 a,b; Witzke et al., 1996; Brett et al., 1998). Many distinct surfaces in the local stratigraphic record are interpretable as sequence boundaries or flooding surfaces. Moreover, a number of phenomena which occur non-randomly in the geologic record, from phosphatic nodule horizons to reefs fit in predictable ways into depositional sequences.

A secondary theme of this article is the recognition of widespread events, such as storm deposits (tempestites), rapidly buried fossil horizons (obrution deposits), and even seismically deformed beds (seismites). A variety of such catastrophic events are recorded in the Silurian rocks of the Niagara region and will be examined on this trip.

REGIONAL GEOLOGICAL SETTING

Silurian-Devonian strata of the Niagara Peninsula-western New York area were deposited along the northwestern rim of the Appalachian Basin, defined by the intermittently active Algonquin Arch, a presumed peripheral bulge (Figs. 1, 2). The Niagaran paleoenvironments were generally shallow, subtropical epeiric seas, situated 30-35° south of the paleoequator (Witzke, 1990).

Siliciclastic sediments were derived from eastern and, possibly, northeastern source terranes that were uplifted during the Taconic orogeny. Renewed uplift of tectonic terranes may have occurred during the medial- and Late Silurian in the Salinic Disturbance (see Ettensohn and Brett, 1998).

During the Early Silurian Medina Group siliciclastics accumulated in non-marine to shallow marine environments in western New York and extended with little or no break into the region of the Michigan Basin (Fig. 2A). However, by medial Silurian time (middle Llandovery), a broad carbonate platform (Algonquin Arch) appears to have existed in the area around Hamilton, Ontario northwest into the Bruce Peninsula (Fig. 2B). This platform was a region of shallow, epeiric seas, with little or no siliciclastic input, that accunulated a relatively thin succession of dolomitic carbonates. This arch formed a partial to nearly complete barrier between the Appalachian and Michigan Basins during the late Llandovery and Wenlock time (Fig. 2). During the early to medial Silurian (Llandovery-Wenlock Epochs) the axis of the foreland basin remained essentially northeast-southwest in its orientation but migrated laterally, first eastward and then starting in the latest Llandovery back to the west (Goodman and Brett, 1994; Figs. 2C,D, 14). In the Late Silurian Pridoli Epoch the basin again migrated eastward, such that its axis lay near the Hudson Valley by the Early Devonian.

The Algonquin Arch was probably emergent at times during the late Llandovery and late Wenlock when relative base level drops produced major unconformities within the carbonate succession. During Ludlow time, however, the Arch, appears to have subsided such that the area between Hamilton, Ontario and the northern Bruce Peninsula was the locus of deeper water environments than areas to the southeast or northwest. During this time reefy carbonates were widespread in the Appalachian Basin.

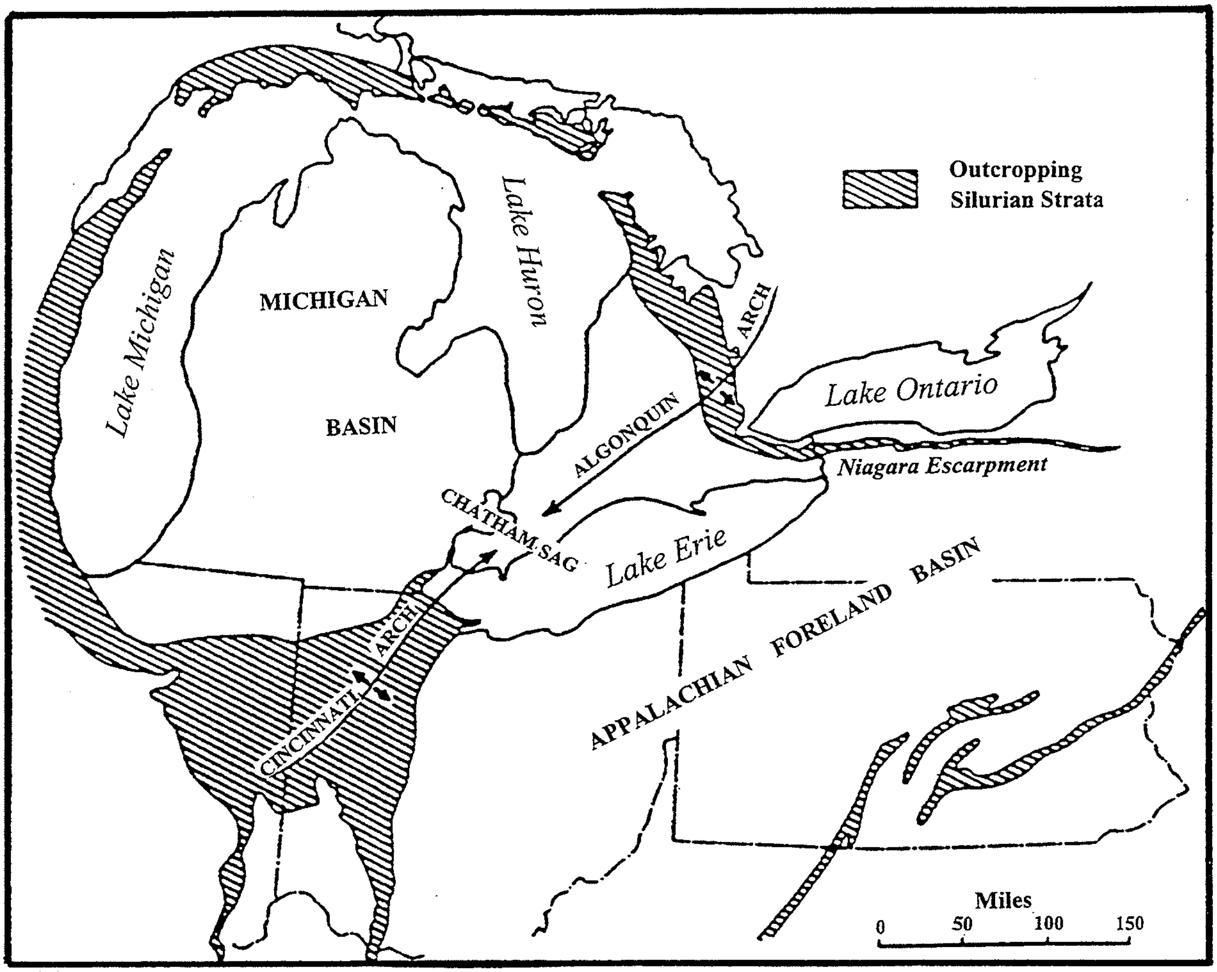

Figure 1. Geological setting of middle Silurian rocks in New York, Ontario, Michigan, and adjacent areas, showing position of the Algonquin-Cincinnati Arch system that separates Appalachian and Michigan basins; position of modern outcrop belt of mid Silurian rocks is shown in diagonal ruling. Modified from Telford (1978).

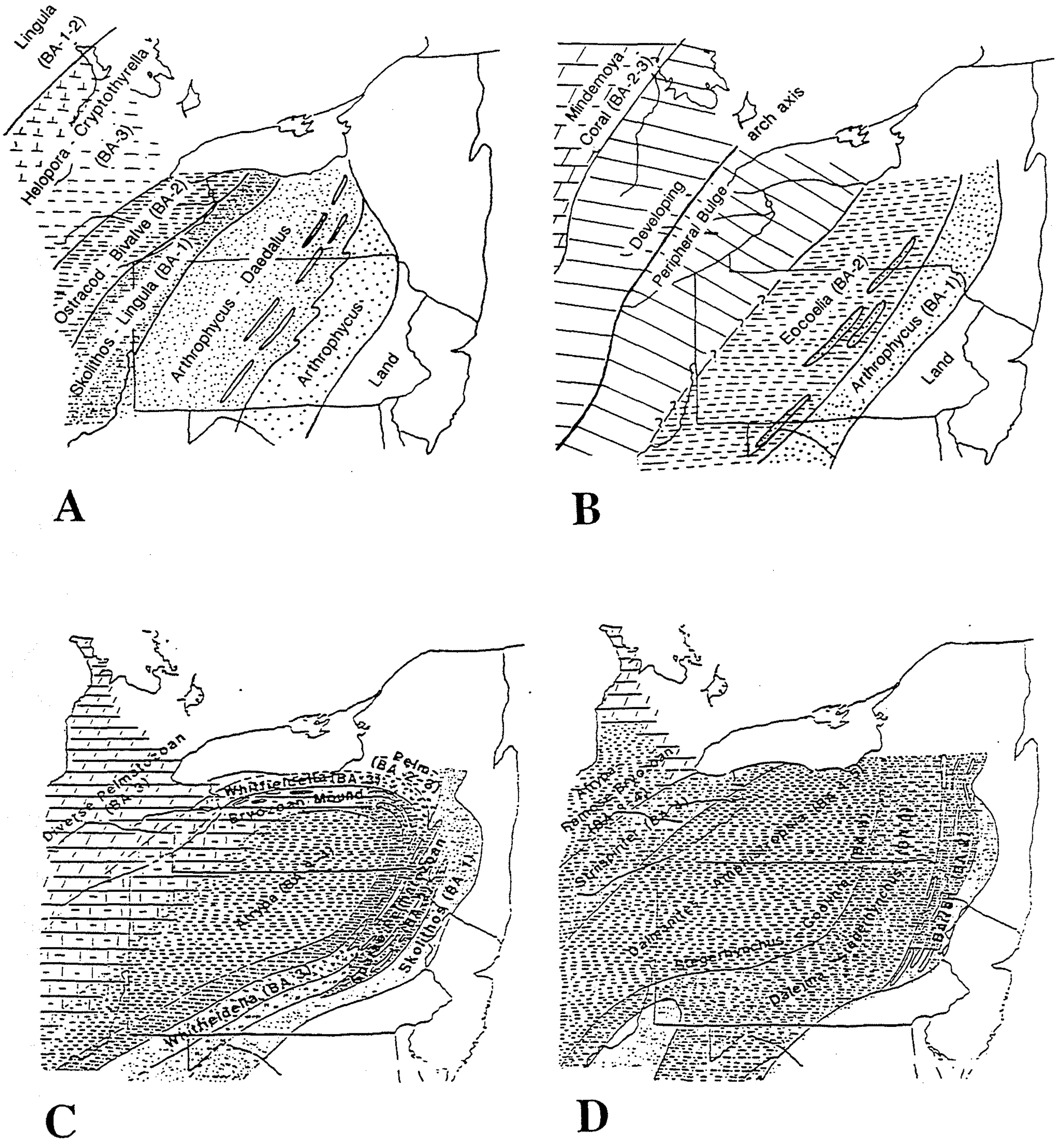

Figure 2. Paleogeographic map for Pennsylvania, New York, and Ontario during early and late Llandovery time. (A) Early Silurian (Rhudannian), Sequence I, Medina Group; note position of basin center in southern Ontario. (B) Mid Telychian time, during deposition of Sequence III, the Sauquoit-Otsquago-upper Rose Hill succession in central New York and Ontario. Note development of regional uplift (forebulge) along the Algonquin Arch (C) Early Wenlock time (Lower K. ranuliformis Zone), Note position of basin axis in western New York State during deposition of Irondequoit Limestone. (D) Mid Wenlock time (Low-mid K. ranuliformis Zone), relatively deep water occupies basin center during deposition of Rochester Shale.

As a broad generalization, Silurian strata in the northern Appalachian foreland display a trend from a) siliciclastic dominated units in the Early Silurian (Alexandrian or early Llandovery) Medina Group, to b) mixed siliciclastics and carbonates in the medial Silurian (lower Niagaran, upper Llandovery-Wenlock) Clinton Group, c) dolomitic carbonates in the Lockport Group (upper Niagaran; Wenlock-Ludlow), and d) mudrocks, dolostones and evaporites in the Upper Silurian (Cayugan, upper Ludlow-Pridoli) Salina-Bertie Groups (Fig. 3). These patterns reflect two major tectonic pulses: a late Taconic tectophase in earliest Silurian and the medial Silurian Salinic Orogeny; these times were dominated by prograding clastic wedges and westward migration of the foreland basin depocenter (Fig. 3; Goodman and Brett, 1994; Ettensohn and Brett, 1998). Intervening times of quiescence were marked by predominant carbonate deposition and eastward backstepping of the basin depocenters (Ettensohn and Brett, 1998).

PALEOECOLOGY

Throughout the Early to middle Silurian seas were of normal salinity and diverse marine invertebrate faunas formed a series of onshore-offshore biofacies. These biofacies formed extensive belts parallel to paleoshoreline that have been termed Benthic Assemblages (BAs; Fig. 2) by Boucot (1975). Benthic assemblages have been calibrated to approximate absolute depths by Brett et al. (1993). Following that model, Benthic Assemblage-1 (BA-1) constitutes peritidal biofacies typically dominated by lingulid brachiopods, bivalves, gastropods, or, in carbonates, stromatolites-thrombolites and ostracodes. BA-2 represents shallow, inner shelf sediments dominated by low diversity brachiopod associations (especially *Eocoelia* in the Early Silurian; Fig. 2), as well as tabulate coral and stromatoporoid biostromes and bioherms; tabulate -stromatoporoid patch reefs were particularly well developed in these settings during the Wenlock-early Ludlow of the Niagara region (Crowley, 1973; Armstrong and Johnson, 1990); BA-3 represents near-wave base environments, such as pelmatozoan shoals and pentamerid brachiopod banks; BA-4 encompasses shallow (30-60 m) outer shelf environments affected by storm wavebase and typified by diverse assemblages of brachiopods, bryozoans, trilobites, molluscs, and pelmatozoan echinoderms; BA-5 comprises deeper shelf settings below storm wavebase and is characterized by small brachiopods, a few bivalves, and, in some areas, graptolites. These benthic assemblages have proven to be widely mappable and useful in determining relative depths of the interior seas (Johnson, 1987). Events of storm-related deposition buried fossil assemblages intact producing spectacular obrution deposits of crinoids, rhombiferan cystoids, asteroids, and trilobites, especially in the Cabot Head and Rochester shales (Brett and Eckert, 1982; Taylor and Brett, 1996).

During Late Silurian (Cayugan or Pridoli) epeiric seas in the Appalachian and Michigan basins became restricted by barriers of the Bloomsburg clastic wedge (to the south) and barrier reef complexes (around the Michigan Basin) and developed hypersaline conditions under which evaporites formed and few organisms, other than rare ostracodes, occupied open shelf environments. In estuarine areas, where fresh water streams mixed with the hypersaline environments, distinctive brackish water biofacies developed (Clarke and

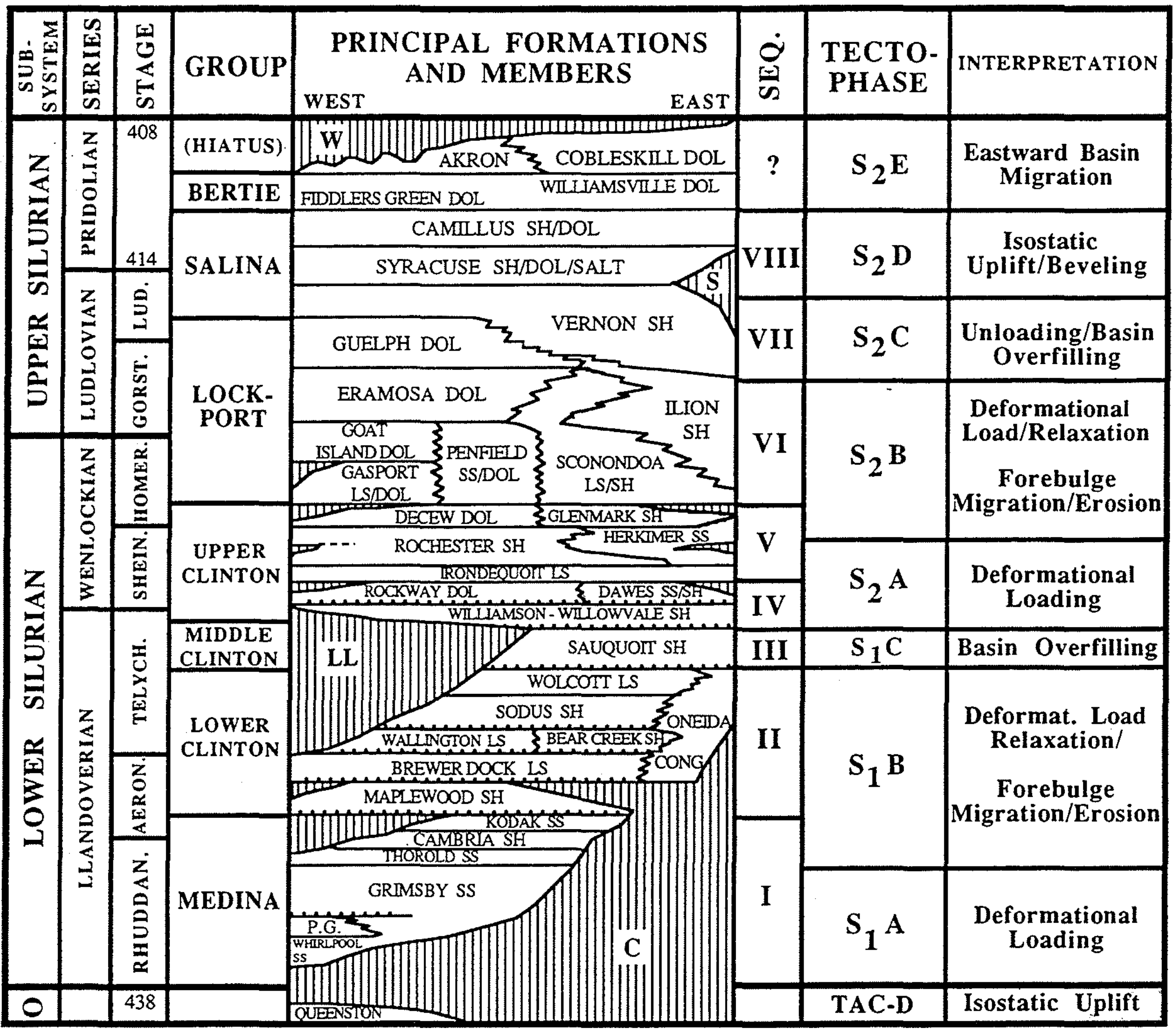

Figure 3. Generalized chronostratigraphic chart for the Silurian system along the east-west outcrop belt from Niagara Gorge to Utica, New York showing subdivision of stratigraphy into unconformity- bound sequences (I-VIII) and interpreted tectophases of the latest Taconic (S_1) and Salinic (S_2) orogenies. Symbols: dots indicate phosphatic/ironstone marker beds. Major unconformities indicated with letters: C: Cherokee; LL: late Llandovery ; S: Salinic; and W: Wallbridge unconformities. From Goodman and Brett (1994).

Ruedemann, 1912; Ciurca, 1973; 1990). These peritidal (BA-1 to 2) biofacies were dominated by eurypterids, and a few species of ostracodes, molluscs and algae. Only in the latest Silurian were normal marine salinities partially restored in the Appalachian Basin.

Silurian marine invertebrates and their biofacies exhibit long term concurrent evolutionary stability punctuated by abrupt intervals of extinction, immigration, evolution, and restructuring. Brett and Baird (1995) termed this pattern "coordinated stasis" and recognized distinctive stable faunas (or ecological evolutionary subunits) in the Silurian of the Appalachian Basin; these correspond very roughly to depositional sequences and were termed the: 1) Medina; 2) Lower Clinton: 3) Upper Clinton-Lockport; and 4) Salina faunas. The latest Silurian-Early Devonian E-E subunits are absent from the study area due to erosion at the Wallbridge Uncoformity. However, diverse coral and brachiopod faunas of the Scoharie (8) and Onondaga (9) stable faunas are well represented in the Bois Blanc and Onondaga formations in the study area of the Niagara Peninsula.

EVENT STRATIGRAPHY

A number of beds in the sedimentary record reflect single unique episodes of sediment deposition and/or deformation Where traceable, such beds provide not only evidence for catastrophic events but also form excellent time lines in local sections.

K-Bentonites

Altered volcanic ash beds provide some of the most valuable marker beds in the geologic record. In theory, these beds record single events of tephra deposition from explosive volcanic eruptions. Not only do they form excellent time lines but also many bentonites can be radiometrically dated. Few K-bentonites have been reported from the Silurian of the Niagara region. However, recently, thin clay layers that appear to be bentonites have been identified in the lower Lockport Group of western New York. These may correlate with probable K-bentonites that have been found in the medial Silurian on both eastern and western flanks of the Cincinnati Arch in Ohio, Kentucky, and Indiana (Brett and Algeo, 1999). Work on these beds is in very preliminary stages and will only be briefly discussed on this field trip.

Tempestites

Storms produce a distinctive suite of sedimentary deposits that range from coarse, amalgamated skeletal debris beds to hummocky laminated siltstones and sandstones, to distal mud layers. In some cases, particular conditions associated with a given storm bed may make it distinctive and usable for local or regional event correlation. Such applies to certain coarse skeletal debris layers, notably several bryozoan-rich horizons and a brachiopod bed in the Silurian Rochester Shale in the Niagara region.

Among more distal events, several other types of tempestites have proven to be regionally extensive and traceable. Particular thick calcisiltites with hummocky cross stratification have proven to be traceable in the Rochester Shale.

Obrution Deposits

Another type of tempestite related feature that provides very useful local markers are obrution or "smothered bottom", deposits. These are recognized taphonomically and may be traceable, at least locally. Excellent examples are provided by layers of beautifully preserved crinoids, trilobites, and other fossils (*Homocrinus* beds) that have been studied in detail from the lower Rochester Shale (Taylor and Brett, 1996). These rapidly buried surfaces have been correlated for tens of kilometers along outcrop strike of the Niagara Escarpment. The series of beds display much the same unusual characteristics over this area. Such evidence indicates that the smothering mud blanket was very extensive following a particular storm, resulting in mass mortality and burial on a regional scale.

LoDuca and Brett (1997) described laterally extensive horizons of extraordinarily preserved fossil green algae, annelid worms, and other non-skeletonized fossils from shaly dolostones in the base of the Goat Island Formation. Here rapid burial in organic-rich carbonate silts below an oxycline may have promoted preservation of soft bodied organisms as carbonized films.

Similar mass mortality beds of eurypterids are recorded in the Upper Silurian Bertie Group, especially in the upper Fiddlers Green and Williamsville formations (e.g. at Campbells Quarry; Ciurca, 1990; Batt, this volume; Stop 8, herein). Such beds appear to be persistent on a regional scale, although local areas, sometimes termed "pools" show greatly increased numbers of specimens. The eurypterids are sometimes associated with evidence of hypersalinity, such as salt hoppers, which suggest that the mass mortalities were associated with transport into hostile environments, such as hypersaline lagoons. Distributional data from eurypterids suggest that they actually lived in brackish water settings associated with estuaries. The "pools" may indicate proximity to such living sites. The briney condition of the sediments and pore waters may have aided in preservation of the chitinous exoskeletons by inhibiting chitinoclastic bacteria.

Seismites

Recently, a number of researchers have begun to recognize zones of widespread deformation that may be attributable to seismic shocking (e.g. Pope et al., 1997). These intervals are typified by beds of ball and pillow deformation that extend for tens to hundreds of square kilometers (Schumacher, 1992; Pope et al, 1997). Careful observation of these deformed intervals suggests, and that they resemble known seismically deformed sediments produced by liquefaction of muds and foundering of overlying coarser sediments, i.e. seismites. but detailed study of Pope et al. (1997) demonstrates that most deformed zones do not show consistent orientation of fold axes. Such evidence is consistent with a liquefaction triggered foundering as a opposed to slump model for the deformation.

Two excellent examples of possible seismites occur in the Silurian of the Niagara area. The first consists of a ball and pillow horizon in the reddish sandstones of the upper Grimsby Formation. The larger deformed masses up to 2 m across show overturned folds and flame structures; The deformation is not observed everywhere but seems to be concentrated in thicker areas of the sandstone bed that may represent shallow tidal channel fills (Duke et al., 1987). Basal surfaces of the pillows display small load casts, striations, deformed burrows and load crack casts indicating deformation of semiplastic muds by loading. To date, this horizon has been traced from Niagara Gorge near Lewiston, NY westward to Hamilton, Ontario.

The second example of a probable seismite horizon in the Niagara region is the well known "enterolithic" interval in the DeCew Dolostone. The DeCew consists of buff weathering, medium dark gray, hummocky laminated dolostone (originally fine calcarenite or calcisiltite) with scattered layers of small (1-4 cm) intraclasts. The lower 1 to 1.5 m of the DeCew displays extraordinary deformation that includes, ball and pillow style deformation and recumbent folds in the intraclasts beds. Overlying beds in the upper DeCew are unaffected. Again, preliminary study (Nairn, 1973) suggests that these folds do not show a consistent overturn direction. This suggests liquefaction possibly accompanied by some very local submarine sliding. A very similar, but much less extensive, bed of deformed dolostone in the upper Rochester Shale in the southern Niagara Gorge. The most impressive aspect of the DeCew deformed interval is its broad lateral extent. Similarly defomed dolostones are known to occur along nearly all Niagara Escarpment exposures from Penfield, east of Rochester, NY, to Hamilton, Ontario, where the DeCew has been erosionally truncated by erosion at the basal Lockport erosion surface (Sequence S-VI boundary). Similar deformation has been identified in a silty dolostone bed at the top of the Rochester Shale near Allenwood, Pennsylvania (Brett et al., 1990). Recently, a very similar zone of deformed dolostone has been identified in probably coeval strata mapped as upper Bisher or lower Lilly formation in southern Ohio (Brett and Algeo, 1999). This bed appears underlie the basal Sequence VI boundary at the base of the Lilly Formation (identified as upper Bisher Formation in some outcrops), At Hillsboro, Ohio it overlies a unit closely resembling, and probably equivalent to, the Rochester Shale. If the Pennsylvania and Ohio occurrences are indeed correlative with the DeCew, this would indicate and area of deformation of more than 200,000 km2, one of the most widespread deformed zones yet reported.

Detailed interpreatation of similar occurrences in the Upper Ordovician of Appalachian region by Pope et al. (1997) indicates that such widespread deformation over areas of a few tens of square kilometers would accompany large earthquakes with magnitudes in excess of 7 on the Richter scale. Pope et al. suggested that the ball and pillow horizons and related slumps might have been triggered by earthquakes in the Taconic Orogen or movements of local basement faults, In any case, these dramatically deformed intervals provide excellent stratigraphic markers. They also indicate that the Appalchian foreland basin was not tectonically quiescent through the Silurian (see Ettensohn and Brett, 1998).

Bioherms and Stromatolites

While not strictly examples of "event deposits", organic buildups, including small coral-stromatoporoid or algal mudmounds, thrombolites, stromatolites, and larger scale reef structures also appear to occur in very laterally extensive zones. For example, throughout western New York and Ontario, small fistuliporoid bryozoan-algal? mounds occur consistently near the top of the Irondequoit Limestone and project up to a meter into the overlying Rochester Shale (Cuffey and Hewitt, 1989). Similarly, stromatoporoid-tabulate bioherms occur at two horizons in the Lockport Group of western New York and Ontario: the top of the lower (Gothic Hill grainstone) member of the Gasport Limestone and extending upward up to 6 m into the overlying thin-bedded argillaceous Pekin Member (Crowley, 1973; Brett et al., 1995); and in possible channel fills on the top Gasport erosion surface and extending upward into thin bedded midle Goat Island formation (Brett et al., 1995). Not only are these horizons peristent over substantial distances in the New York-Ontario outcrop belt, similar thrombolitic mounds are present in probably corrrelative horizons in the McKenzie Shle in Pennsylvania to West Virginia (Brett et al., 1990). In a comparable way, small tabulate-rugosan bioherms in the Middle Devonian Onondaga Formation (see Stop 9) commence on top of a grainstone layer low in the Edgecliff Member and extend up into shaly, to cherty micritic limestones (Fig. 22). These bioherms also occur in this position consistently in the Niagara region and into central New York (Crowley and Poore, 1974; Woloscz, 1990).

Finally, very persistent zones of large stromatolites and thrombolites (non-laminated algal mounds) occur at several horizons, especially near the base of the Guelph Formation (Brett et al., 1990, 1995) and in the lower Fiddlers Green Formation of the Bertie Group (Ciurca, 1990).

Obviously these varied types of mounds have developed in very different environments. What these features appear to have in common is that they are in laterally persistent horizons and occur either immediately above unconformities or on the flooding surfaces at the tops of transgressive skeletal sands. We suggest that the non-random distribution of such organic buildups in the stratigraphic record reflects the dynamic interaction of sea-level and organism growth. Mounding commonly appears to be associated with transgressing or deepening successions. In particular, times of rapid deepening, as at maximum flooding surfaces. During these intervals rapid deepening created accomodation space and reef- or mound-forming organism built upward to keep pace with this increasing water depth. At the same time sequestering of sediments in coastal areas may have favored growth of algae and clonal organisms by reducing water turbiity and nutrient influx. Hence, widespread mound horizons are a signature of rising sea-level. In some cases the mounds were able to keep pace with deepening but in others they failed to keep up and were drowned. This explains the commonburial of bioherms by thin shaly sediments of deeper water facies.

SEQUENCE STRATIGRAPHY OF SILURIAN TO EARLY DEVONIAN SUCCESSIONS IN WESTERN NEW YORK AND SOUTHERN ONTARIO

The Silurian strata of western New York and the adjacent Niagara Peninsula of Ontario have been broadly subdivided into groups that correspond roughly to large-scale (third order of sequence stratigraphers, see Van Wagoner et al., 1988; Vail et al. 1991) depositional sequences (Figs. 3-5); they are divisible into smaller (fourth-order) sequence-like units; we have termed "subsequences" (see Brett et al., 1990, 1995, 1998).

Silurian sequences are bounded by unconformities, three of which, the I-II, II-IV, and V-VI boundaries, are regionally angular (Fig. 3). The magnitudes of these three unconformities (i.e., extent of beveling on the erosion surface) increases westward along the Niagara Escarpment. These surfaces appear to have been accentuated by uplift along the "Algonquin Arch", probably an intermittently active forebulge (Figs. 1-3). The I-II and II-IV boundaries are merged west of St. Catharines, Ontario, forming a compound unconformity (Figs. 3, 4). Conversely, the basal sequence I unconformity (Cherokee unconformity and base of Silurian system) decreases westward (Fig. 3). Varying east to west facies changes within each of the sequences along the Niagara Escarpment reflect differential subsidence and elevation of the Algonquin Arch and adjoining basins, as noted in the following sections. In each, the stratal unit name is followed by series/stage assignment based on biostratigraphy (see Brett et al. 1990, for details).

Sequence I: Medina Group, Lower Llandovery (Rhudannian)

The stratigraphically lowest Silurian interval (S-I) is the predominantly siliciclastic Medina Group (Cataract Group of some Canadian authors). In west central New York the Medina Group contains, in ascending order: the Whirlpool Sandstone (2.5-4.5 m)whitish gray, trough cross bedded quartz arenite, Power Glen Shale (10-15 m) dark gray shale with thin sandstones and dolomitic limestones, Devils Hole Sandstone (2-3 m) whitish gray, phosphatic quartz arenite, Grimsby Formation, (12-15 m) maroon to green shale and reddish and white mottled sandstone, Thorold Sandstone (2-3 m) reddish to whitish gray, bioturbated quartz arenite with greenish gray sandy, bioturbated mudstones, Cambria Shale (0-3 m maroon shales and muddy sandstones, and Kodak Sandstone (0-3 m) whitish gray sandstones and greenish to maroon shales (Figs. 4, 5). The Medina represents a large scale depositional sequence with lowstand (non-marine) to transgressive (foreshore to shoreface) Whirlpool Sandstone (Middleton et al., 1991), overlain by maximally highstand Power Glen Shale (offshore marine muds), and later highstand (progradational shoreface and tidal flat) Devils Hole through Kodak strata. However, the interval is also divisible into smaller subsequences at the bases of the Whirlpool, Devils Hole; Thorold, and Kodak transgressive quartz arenites (Figs. 4, 17).

The Medina Group exhibits relatively minor changes in thickness along the Niagara Escarpment, but all of its component units show westward changes in facies corresponding to increasingly open, fully marine conditions (Figs. 4, 5). Thus, the lower, fluviatile (braided stream) Whirlpool Sandstone (Middleton et al. 1991) apparently pinches out (or changes facies to marine) to the north of Georgetown, Ontario (Rutka et al., 1991). The

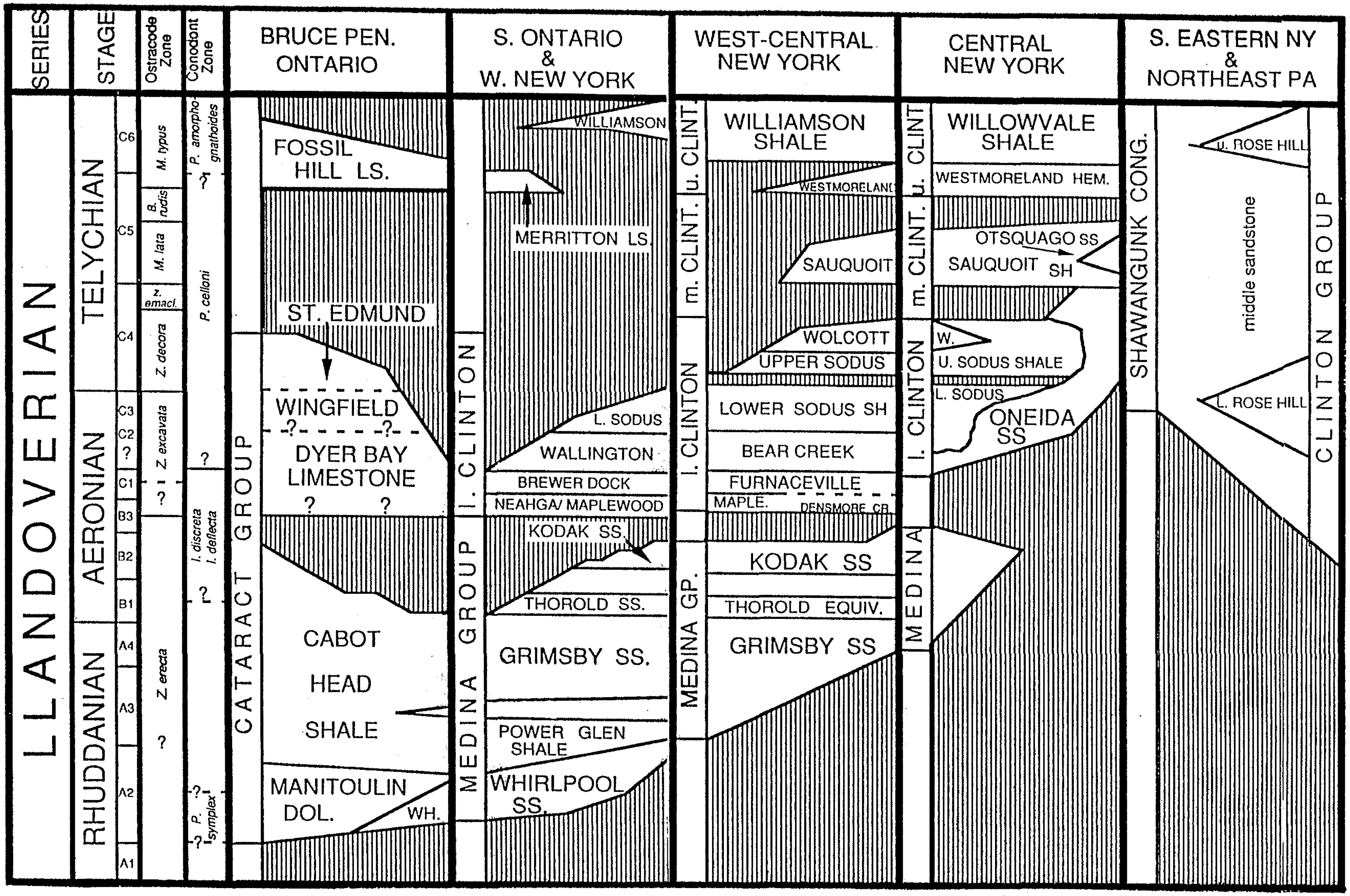

Figure 4. Correlation chart for Lower Silurian (Llandovery) stratigraphic units (Sequences I-IV) in Ontario and New York State. Abbreviations: BC: Bear Creek Shale; DOL.: dolostone; DW; SH: shale; SS: sandstone; WH: Whirlpool Sandstone; WO: Wolcott Limestone.

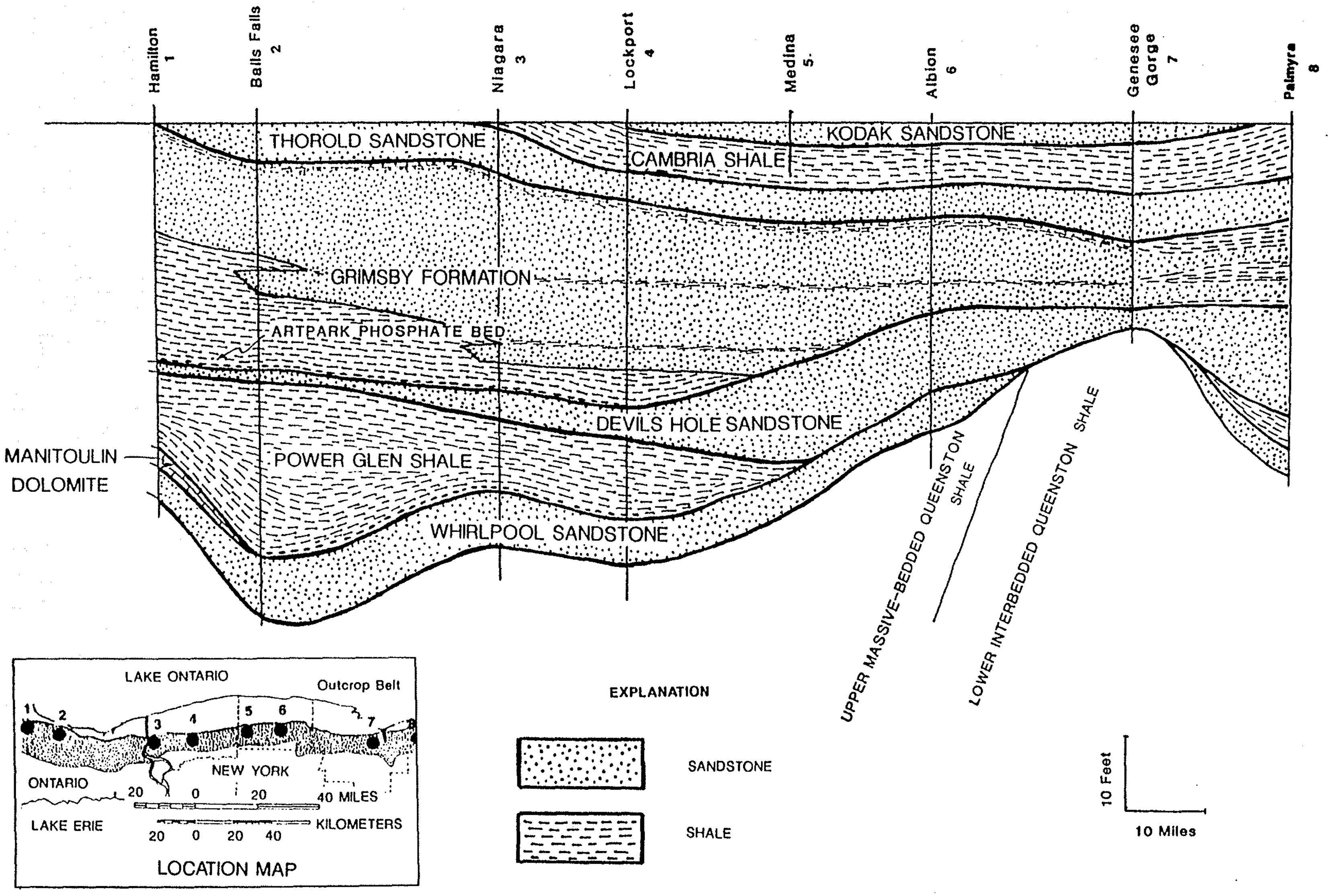

Figure 5. Regional cross-section of Medina Group (sequence I) in western New York and southern Ontario.

upper Whirlpool thickens and displays evidence of shoreface to shallow, sandy shelf deposition near Hamilton, and may be replaced laterally by the Manitoulin Formation open shelf carbonates (Fig. 5). Dark gray, sandy, sparsely fossiliferous Power Glen Shale in the Niagara region, grades westward near Hamilton into greenish gray shales with abundant bryozoan-rich carbonates, indicating open marine conditions. The Grimsby interval changes northwestward from red sandy mudstones and tidally influenced sandstones with a lingulid (BA-1) biofacies at Niagara Gorge (Martini, 1973; Duke and Fawsett, 1987) to red and green mudstone with only thin sandstones and hematitic bryozoan-rich limestones (BA-2-3) in the upper Cabot Head Formation (Duke and Brusse, 1987). Conversely, the Grimsby interval shows a return to marginal marine or non-marine red beds northward along the Bruce Peninsula (Fig. 2A). Thus, the Hamilton area was close to the deepest part of the foreland basin during Medina deposition (Fig. 2A; Ettensohn and Brett, 1998).

Westward erosion of the upper Medina Group below Sequence II beveled an upper fourth order cycle (Cambria-Kodak) between Rochester and Lockport, New York and culminated with removal of the Thorold Sandstone near Hamilton (Fig. 5). This pattern suggests an inversion of topography, with minor broad uplift on the Algonquin Arch region following Medina deposition.

Clinton Group, Middle Llandovery (Aeronian) to Middle Wenlock

The Clinton Group consists of mixed carbonates and shales, representing offshore storm-influenced shelf environments, and was informally subdivided into lower, middle, and upper Clinton by Gillette (1947). This convention is adopted herein because two of the three divisions correspond to depositional sequences (Figs. 3, 4).

Sequence II: Lower Clinton Group, Middle Llandovery (Aeronian)

The lower Clinton (Sequence II) is very incomplete in western New York, consisting only of the Neahga Shale (0-2 m of greenish gray shale marked at the base by a phosphatic dolostone) and Reynales Limestone (0-3 m of calcisiltite, nodular packstone and bryozoan-brachiopod-echinoderm grainstone, and minor shale) (Fig. 4).

So little remains of Sequence II in the Niagara Peninsula that it is difficult to determine facies trends. However, facies changes in the Neahga and Reynales formations in western New York suggest westward deepening patterns (LoDuca and Brett, 1994).

Middle Clinton Unconformity: Upper Llandovery (Telychian)

Middle Clinton Group strata (Sequence III) are absent in the Niagara region, and a major regionally angular unconformity separates the lower Clinton Reynales Formation from the overlying Sequence IV (Figs. 3, 4, 6, 7). A major change in depositional topography of the Appalachian foreland occurred during the mid Llandovery; throughout west-central New York State and Ontario the middle Clinton Group is missing and an erosion surface beneath late Llandovery (Telychian) strata truncates lower Clinton units in a westward

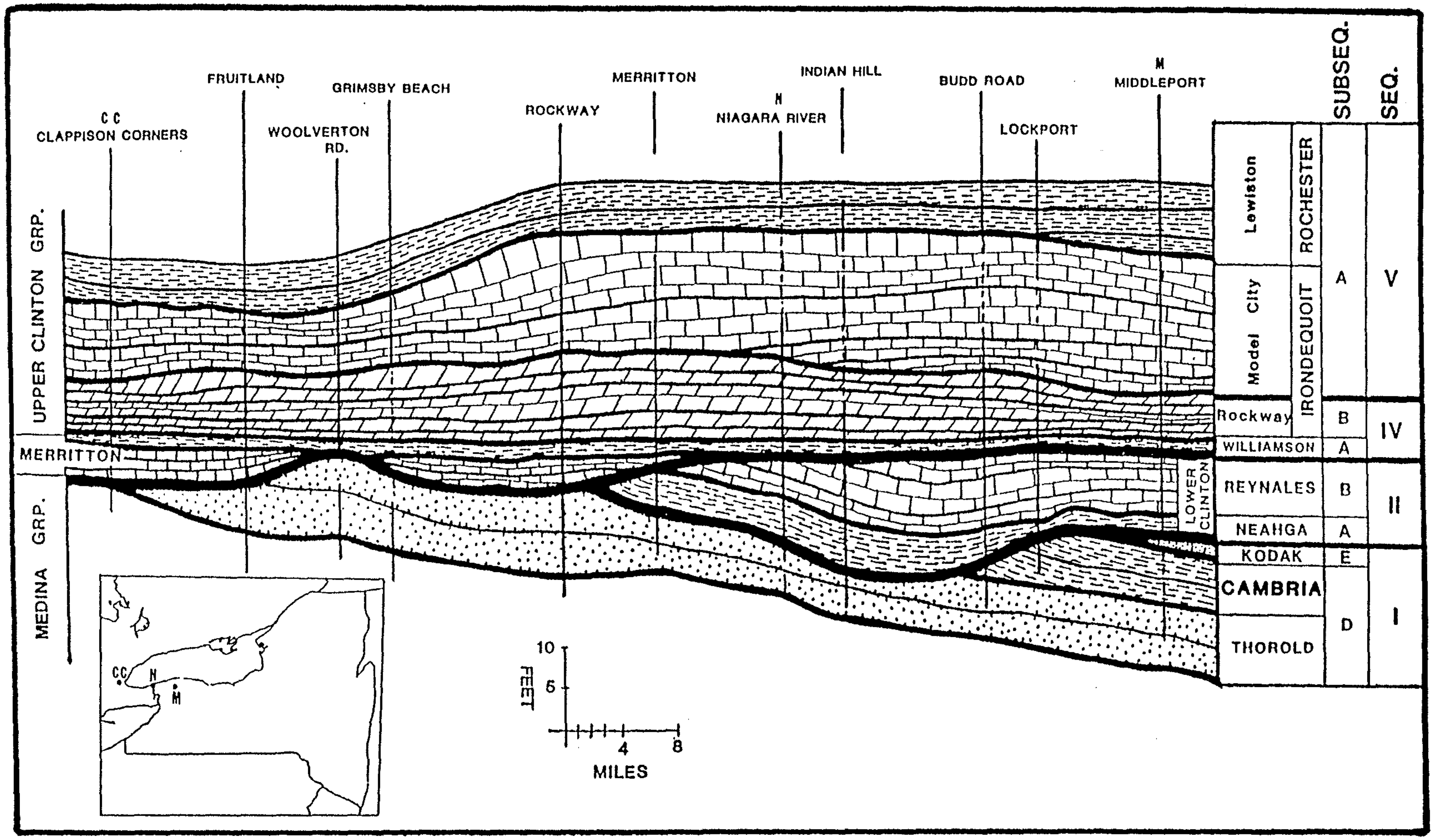

Figure 6. Regional cross-section of upper Medina (Sequence I), lower Clinton (Sequence II) and upper Clinton (sequences IV and V) through western New York and Ontario outcrops (see inset map). Modified from Kilgour (1963).

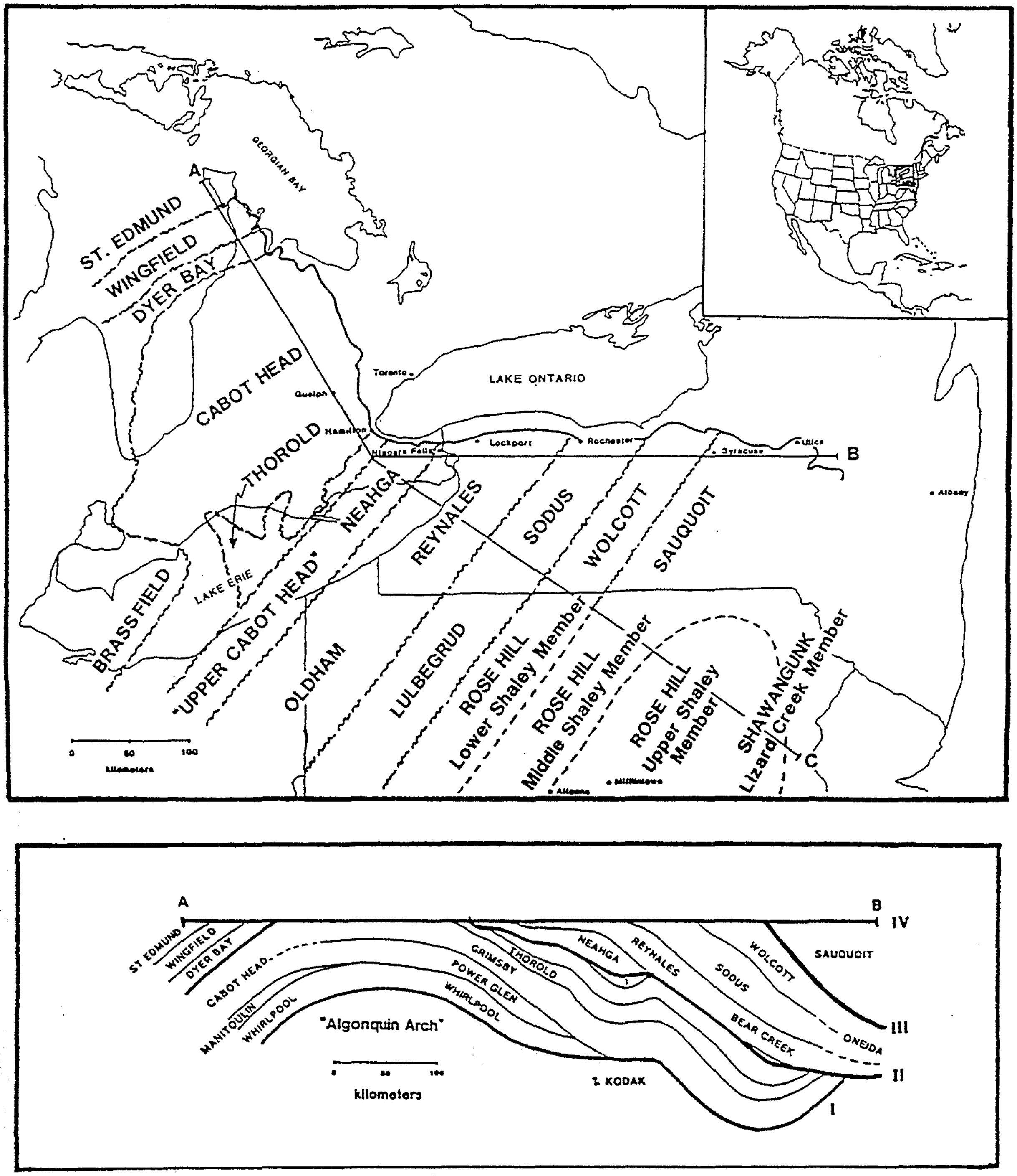

Figure 7. Subcrop map of strata beveled beneath Late Llandovery (S-IV) unconformity. Inset shows general location of map area. From Brett et al. (1998).

direction along the outcrop belt (Fig. 7; Lin and Brett 1988; Ettensohn and Brett, 1998). This substantial regionally angular unconformity suggests another period of broad regional uplift centered on the Algonquin Arch (Fig. 7). Development of the unconformity also coincides with a shift in basin axis migration from eastward (Medina-middle Clinton) to westward (upper Clinton); it may signal renewed tectonic activity in the eastern hinterland (Fig. 14; Ettensohn and Brett, 1998).

Sequence IV: Upper Middle Clinton Group, Upper Llandovery (Telychian)-Lower Wenlock

In western Ontario Sequence IV comprises the Merritton Dolostone and its apparent lateral equivalent, the upper Fossil Hill Formation in the Bruce Peninsula (0.5 to 5 m of dolomitic limestone with many corals and pentamerid brachiopods), a very thin tongue of Williamson Shale (0-20 cm), and the Rockway Dolostone-Lions Head Member (3-4 m) of the upper Clinton Group (Figs. 3, 6, 7).

In Ontario, the thin, condensed Merritton Dolostone overlies the major mid Clinton unconformity (Figs. 6,8); it is unknown in western New York State, although it is roughly equivalent in age (mid Telychian) to the Westmoreland Hematite of central New York (Fig. 8). In general, the Merritton displays a slight westward shallowing trend from glauconite-rich wackestones at St. Catharines to pentamerid- and coral-rich packstone (upper Fossil Hill Formation) northwest of Hamilton. A similar, though very gradual, westward facies change is seen in the overlying Rockway Dolostone, which becomes increasingly carbonate-rich from west central New York to southern Ontario. Biofacies change from *Clorinda*-dominated (BA-5) to *Costistricklandia*-dominated associations (BA-4) also suggest gradual westward shallowing.

Sequence V: Upper Clinton Group, Lower to Middle Wenlock (Sheinwoodian)

The Irondequoit Limestone (crinoidal grainstone; 3-5 m), Rochester Shale (gray, calcareous mudstone with interbedded calcisiltites and bryozoan-brachiopod-pelmatozoan packstone storm beds; 0.5-20 m) , and DeCew Dolostone (argillaceous laminated and typically heavily deformed dolostone; 3-4 m) together, form another genetically related sequence (Sequence V) in the upper Clinton Group (Figs. 3, 4, 8). The lateral equivalents of these units in the Bruce Peninsula are assigned to the Amabel Formation of the Albemarle Group (Fig. 8; Bolton, 1957; Armstrong and Goodman, 1990).

The basal Irondequoit disconformity (Sequence VI-V boundary) is nearly planar with little evidence for regional truncation (Figs. 3, 8). However, this contact becomes increasingly sharp westward from Rochester, New York (probable basin center) and the basal Irondequoit contains clasts of the underlying Rockway dolostones. The Irondequoit, changes from thin bedded skeletal wackestone and packstone in the basin center to massive, amalgamated grainstone to the northwest. The unit represents open shelf to crinoid shoal (BA-3) environments. The upper contact of the Irondequoit is an abrupt, but conformable flooding surface. Locally, in Niagara County, small thrombolitic-bryozoan

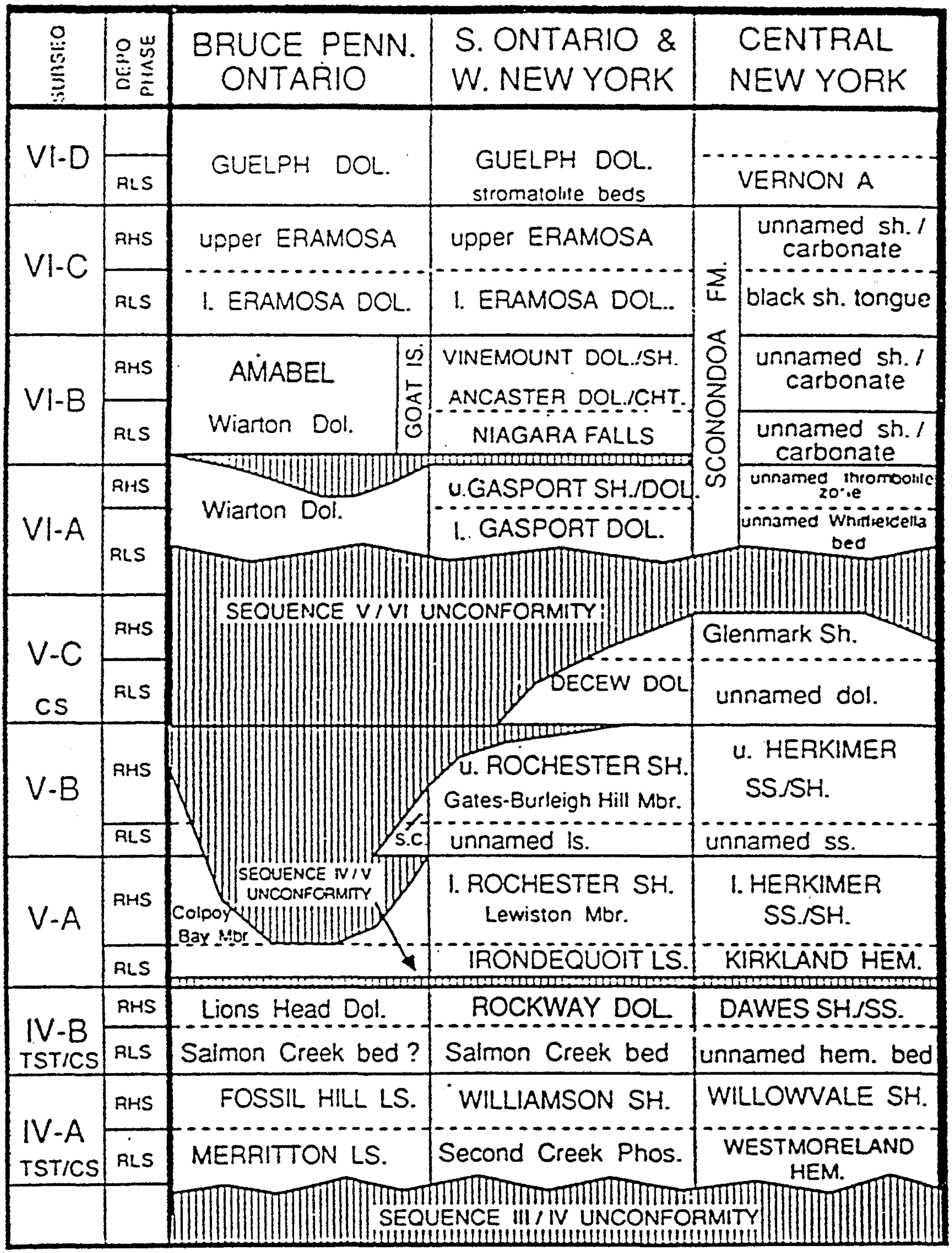

Figure 8. Correlation chart for stratigraphic units in the upper Clinton (Sequences IV, V) and lower Lockport Group (Sequence VI) in Ontario and New York State. Formation names upper case, members lower case. From Brett et al. (1998).

bioherms occur at the Irondequoit-Rochester transition zone; the mounding apparently associated with rapid deepening (Sarle, 1901; Cuffey and Hewitt, 1989).

The Rochester Shale is divided into two members (Brett, 1983a, b). The lower-or Lewiston Member- is highly fossiliferous along most of the Niagara Escarpment, with over 200 species of bryozoans, brachiopods, molluscs, crinoids, blastozoans, trilobites, and graptolites; bryozoan-brachiopod rich limestone beds occur near its base and top (Figs. 8, 9). This facies represents deeper, storm-influenced shelf environments (BA 3-4). However, to the south of the main outcrop, as in southern Niagara Gorge, the Lewiston becomes dark gray shale with sparse brachiopod-trilobite (BA-4 to 5) assemblages, indicating a southward dipping ramp (Brett, 1983a, b). The upper Rochester shows two distinct facies: the Burleigh Hill Member-dark gray, sparsely fossiliferous shale-east of Grimsby, and the Stoney Creek Member -banded dolomitic mudstone and argillaceous dolostone-to the west (Figs. 8, 9; Brett, 1983b). The Rochester Shale becomes increasingly carbonate-rich and thins dramatically to a feather edge from Niagara to Hamilton (Fig. 9). Thinning represents both condensation and erosion below the bases of the Stoney Creek Member, and overlying DeCew and Gasport formations. Rochester-equivalent strata may reappear to the northwest in the lower Amabel Dolostone of the Bruce Peninsula (Bolton, 1957; Armstrong and Goodman, 1994). Together, these observations indicate that during the late Llandovery to late Wenlock interval, the topographic center of the foreland basin lay to the southeast and that Hamilton was situated close to the crest of the Algonquin Arch (Figs. 1, 10).

The DeCew comprises hummocky laminated, dolomitic calcisiltite, probably derived from storm-winnowing of carbonate shoal areas north of the present outcrop limit. As noted above, a zone of extreme soft sediment deformation in the DeCew has been traced laterally along the Niagara Escarpment from east of Rochester, New York, westward to Hamilton, Ontario (Fig. 9) and possibly into southwestern Ohio. Thus, the DeCew deformed zone represents a widespread event, probably a seismite- a horizon of deformed strata associated with a severe seismic shock and consequent slumping on the south-dipping ramp.

Sequence VI: Lower Lockport Group, Upper Wenlock (Homerian) to Lower Ludlow (Gorstian)

The lower part of the Lockport Group (Sequence VI) comprises crinoidal pack- and grainstones, bioherms, and dolomitic wackestones near the base of the sequence (Gasport Formation), and vuggy grainstones, argillaceous, cherty wackestone and minor shales (Goat Island Formation). A clear-cut sequence boundary exists at the erosive base of the Gasport, and a minor, subsequence boundary at the sharp, erosive base of the Goat Island (Figs. 3, 8, 10). Tabulate-stromatoporoid bioherms typically extend upward from lower crinoidal grainstones into the argillaceous Pekin Member; this indicates that the upward growth of these reefs may have been stimulated by rising sea-level (Crowley, 1973; Brett, 1985; Brett et al., 1990). However, cap beds of fragmentary stromatoporoids suggest that the bioherms were extinguished and truncated by sea-level drop (Crowley, 1973).

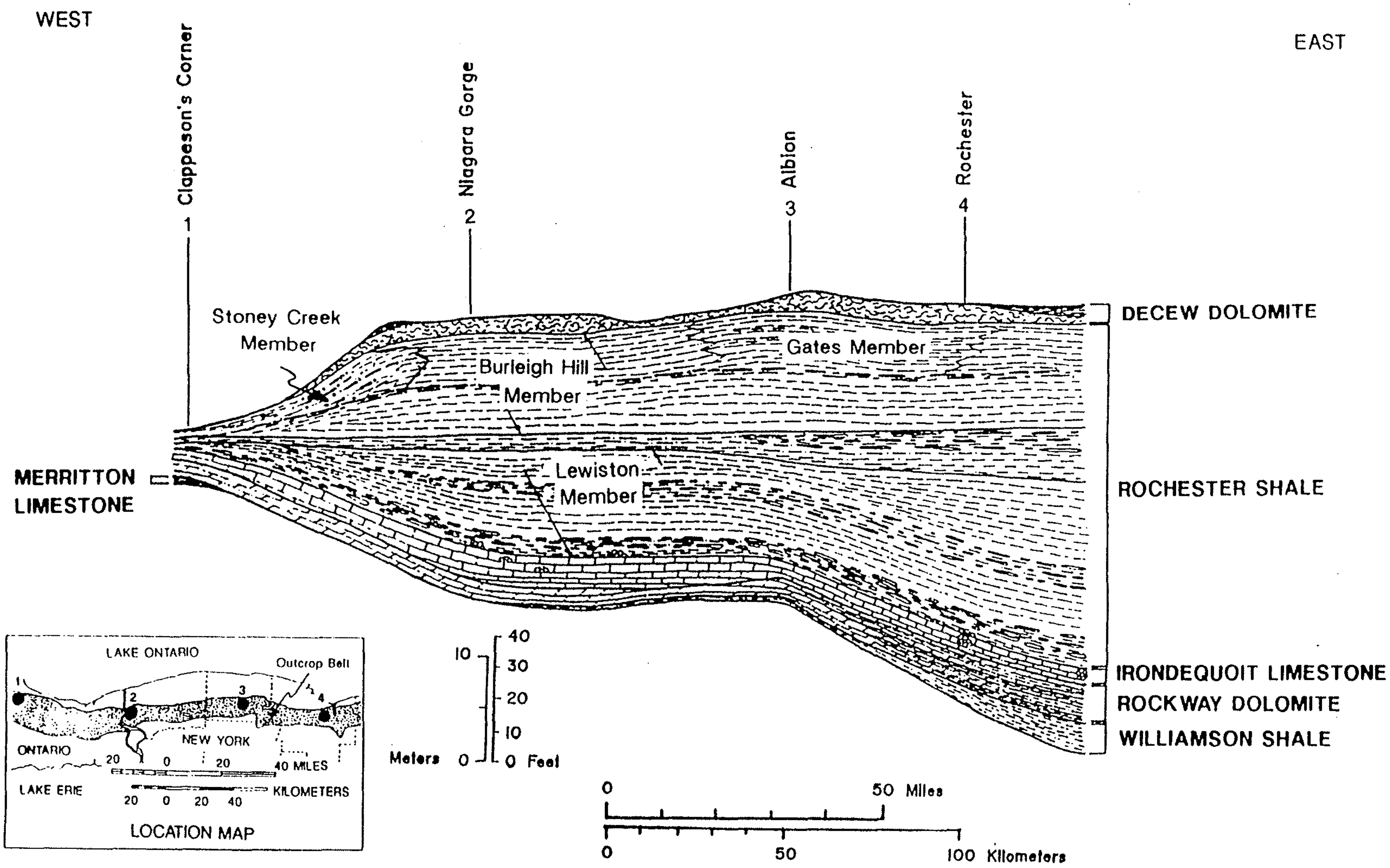

Figure 9. Regional stratigraphic cross section of the upper part of the Clinton Group between Clappisons Corners, Ontario and Rochester, NY. Datum is the contact between the Lewiston and Burliegh Hill members of the Rochester Shale. From Brett et al. (1995).

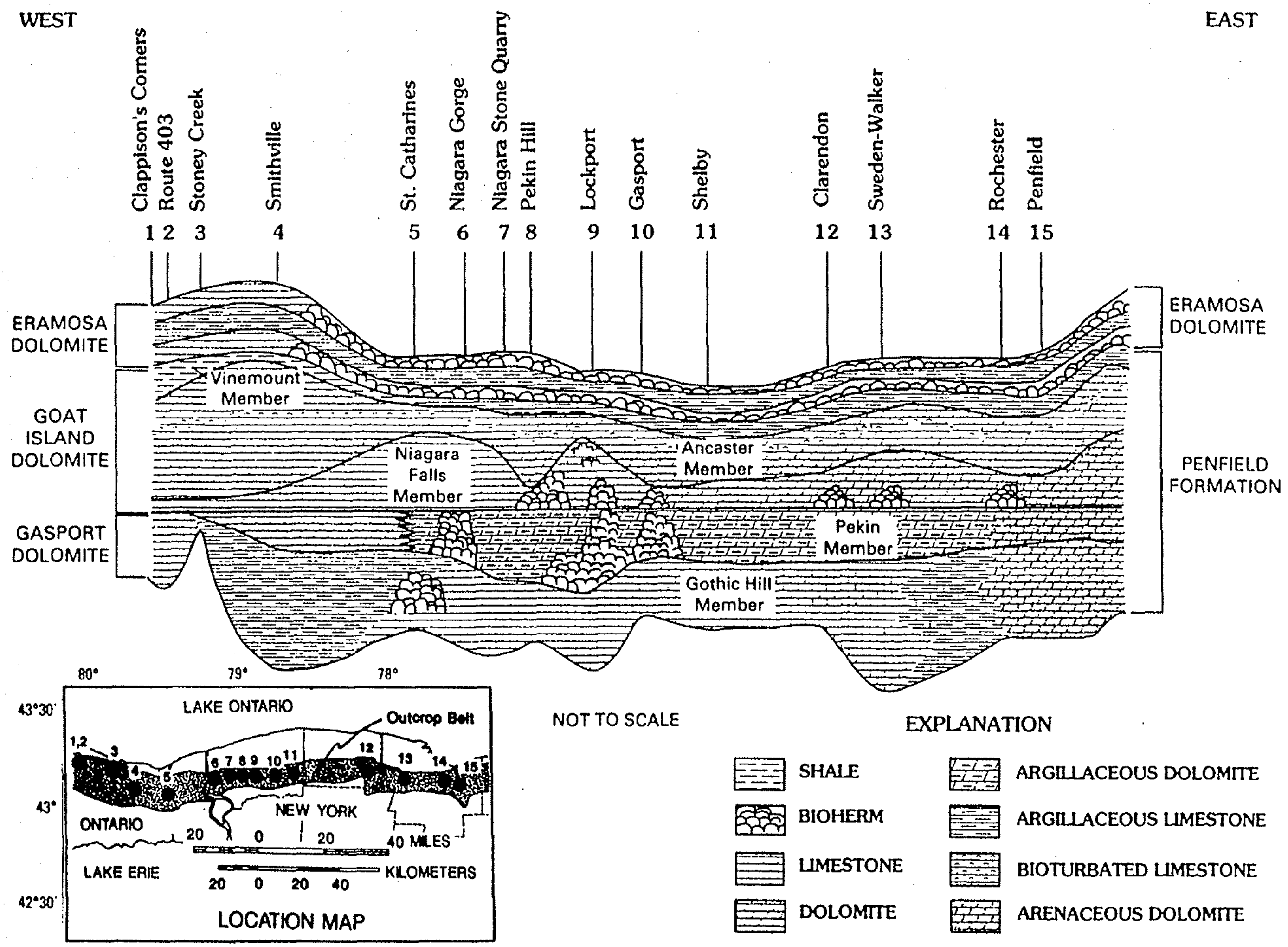

Figure 10. Regional stratigraphic cross section of the Lockport Group between Clappisons Corners, Ontario and Rochester, NY. Datum is contact between the Gasport and Goat Island formations. From Brett et al. (1995).

Westward thinning, coarsening, and loss of argillaceous, biohermal facies in the Gasport Dolostone also suggests shallowing in that unit toward the Algonquin Arch (Fig. 10). The merging of Gasport and Irondequoit grainstones and associated total truncation of the Rochester Shale-near Hamilton also appears to mark a relative topographic high.

Conversely, in, the Goat Island Formation, massive crinoidal grainstone shoal facies (BA-2-3) characteristic of the Niagara Gorge are replaced westward by thin-bedded, cherty wackestone (Ancaster Member; BA-3-4), which thicken to a maximum in the Hamilton area before passing laterally again into massive dolostones (Fig. 10). This westward deepening trend is also evident in the Vinemount Member, which is a slightly cherty dolowackestone to the east but is represented by dark, dolomitic shales near Hamilton, Ontario. These shales only persist northwest to near Dundas where they are replaced or pinched out against upper Amabel dolostones (Fig. 8).

The picture is not entirely straightforward, as small areas of shaly and/or cherty dolostone also occur locally in the Goat Island position in Niagara County, New York. This pattern suggests that minor fault block-controlled basins may have formed during Goat Island deposition. (Sanford et al., 1985) This irregular topography may have been associated with an abrupt westward migration of the main basin center to the Vinemount-Hamilton region (Fig. 10).

Sequence VII: Upper Lockport-Vernon Formation, Middle to Upper Ludlow (Ludfordian)

Biostromal to flaggy argillaceous, dolostones (Eramosa) and massive, buff, biostromal to biohermal dolostone (Guelph Formation) form the upper part of the Lockport (or Albemarle) Group (Fig. 3). The Eramosa, interpreted by Armstrong and Johnson (1990) as an interreefal, dysoxic environment (BA-2-3), has recently yielded assemblages of soft-bodied fossils, including algae, and unusual arthropods (Waddington and Rudkin, 1992; LoDuca, 1995, 1996; Tetreault, 1995, 1996, 1997). A disconformity at the base of the Eramosa Formation in New York is now interpreted as the boundary of a sequence (VII) not previously recognized by Brett et al. (1990). Still further westward migration of the basin axis (and final subsidence of the "Algonquin Arch") appears to have occurred during deposition of the Eramosa and Guelph Formations, in which deepest facies (BA-3) occur northwest of Hamilton, Ontario, while biostromal to stromatolitic facies (BA-2) occur in the Niagara region (Brett et al., 1995).

In drill cores the Guelph can be seen to pass gradationally upward through series of interbedded shaly dolostones and dolomitic shales of the Vernon Formation (upper Ludlow; Salina Group; Fig. 11). The Vernon Formation represents a tongue of siliciclastic sediments from the Bloomsburg-Vernon clastic wedge, that was shed from tectonic regions (Salinic Orogeny) in the mid-Atlantic region. Near its type area. In central New York, the Vernon consists mainly of red mudstones, but in western New York and Ontario the unit consists of over 60 m of greenish gray shales and buff dolostone with interbedded anhydrite.

Sequences VIII, IX: Upper Salina and Bertie Groups, Upper Ludlow-Pridoli

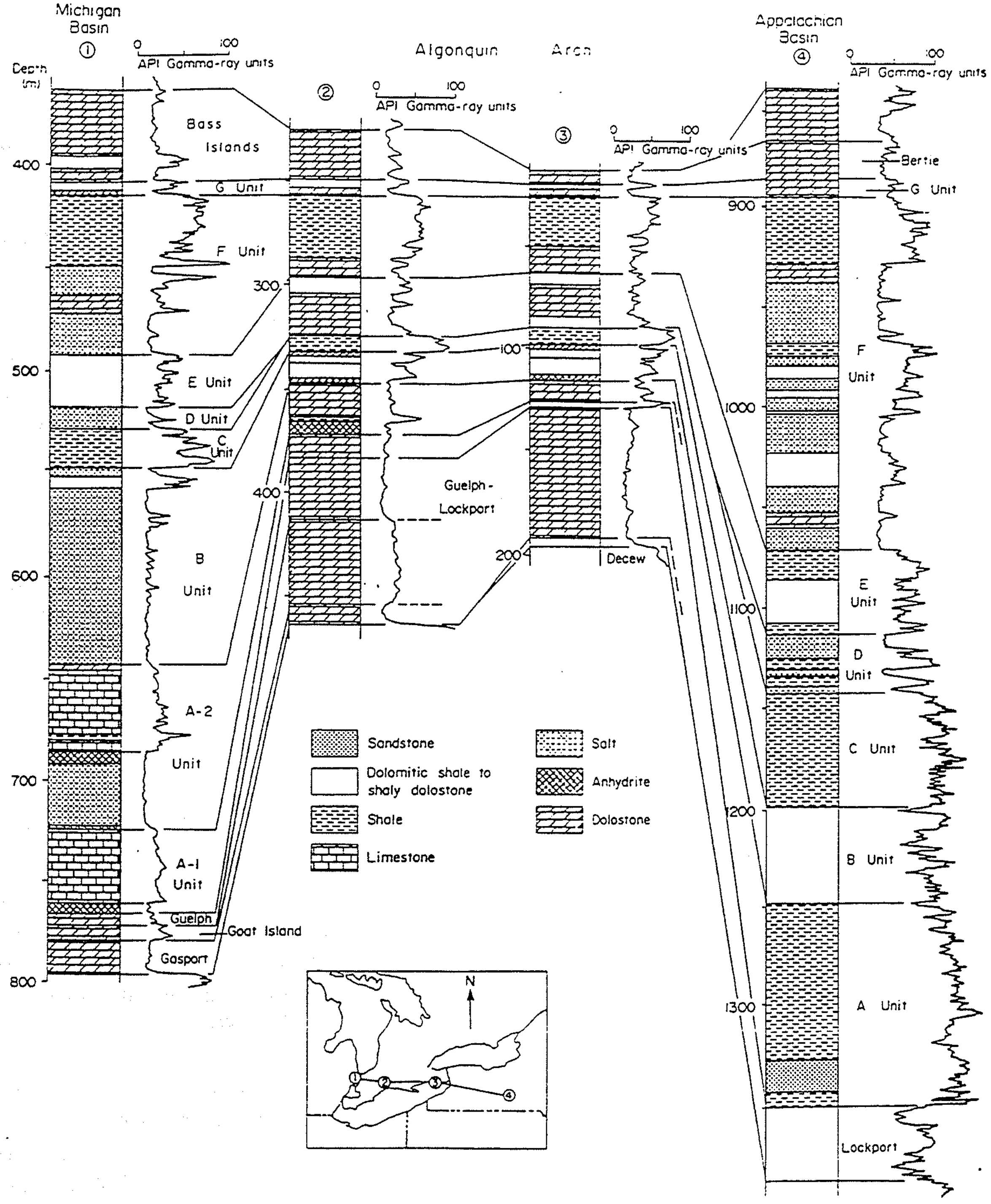

Figure 11. Correlated columns and gamma ray profiles of Upper Silurian Lockport, Salina, Bertie, and Bass Islands groups in southern Ontario to south central New York State. Note persistence of marker evaporite units in the Salina Group and the irregular Wallbridge Unconformity beneath Devonian. From Thurston et al. (1992).

In southern Ontario the upper Salina Group comprises over 60 m of dolostones, shales, and evaporites but it is very poorly exposed. Detailed sequence stratigraphy has not been undertaken. Brett et al. (1990) noted that an erosion zone and regionally angular unconformity exist between the Vernon and overlying Syracuse Formation in central New York and suggested that a sequence boundary exists at this level within the Salina Group (Figs. 3, 11).

The Syracuse and Camillus formations, each about 30 m thick, comprise gray to green-maroon mudstones, buff dolostones and evaporites (Fig. 11). Key salt-gypsum horizons within the Syracuse have been traced in subsurface through Ontario from the Appalachian foreland into the Michigan Basin (Fig. 11; Rickard, 1969; 1975; Milne, 1992). These strata were evidently deposited under arid subtropical climates in interconnected but restricted basins. The widespread nature of the evaporite-dolostone-shale alternations indicates both that topography (e.g. on the Algonquin Arch) was subdued and that the cycles were due to eustatic-climatic effects.

The highest Silurian strata (middle-upper Pridoli) in the western New York-Ontario areas are presently assigned to the Bertie Group (Figs. 3, 11, 12). They comprise a relatively thin (16-18 m) cyclic succession of distinctive, buff gray, slightly argillaceous dolostones ("waterlimes", so-named because of their geochemical properties of natural cement rocks) and dolomitic shales. The basal Oatka Formation is dominantly dolomitic shales and is gradational with the underlying Camillus Shale. The Fiddlers Green (6-8 m) contains both massive brownish waterlimes and some thrombolitic dolomitic limestone that represents the deepest water facies of the Upper Silurian. Scajaquada Formation is a thin unit of dolomitic mudstone, apparently of sabkha origin, while the Williamsville carries a repeat of waterlime facies resembling the Fiddlers Green. Both units are noted for the occurrence of excellently preserved eurypterids, phyllocarids, and others fossils that are suspected to represent a brackish water estuarine biofacies that bordered hypersaline shallow seas. Finally, the Akron Dolostone (2.8 –2.5 m) consists of massive burrow mottled, vuggy dolostone with molds of corals. This unit apparently records a return to somewhat more normal marine lagoonal environments. Locally, a higher (latest Silurian to earliest Devonian) dolostone, the Clanbrassil Formation has been identified above the Akron; it records a return to "waterlime" deposition (Fig. 12; Ciurca, 1973, 1990).

During deposition of the upper Salina and Bertie Groups there was a west to east displacement of depocenters (typically marked by thickest accumulations of halite in the Appalachian Basin) through central to east central New York State (Rickard, 1969). The Lower Devonian Helderberg Group was deposited in a basin the axis of which lay southeast of New York State, while western New York- Ontario were above sea level. The lateral consistency of upper Salina and Bertie Group units along the central New York-southern Ontario outcrop belt suggests also that the facies strike in this region is roughly east-west, parallel to the northern rim of the foreland basin.

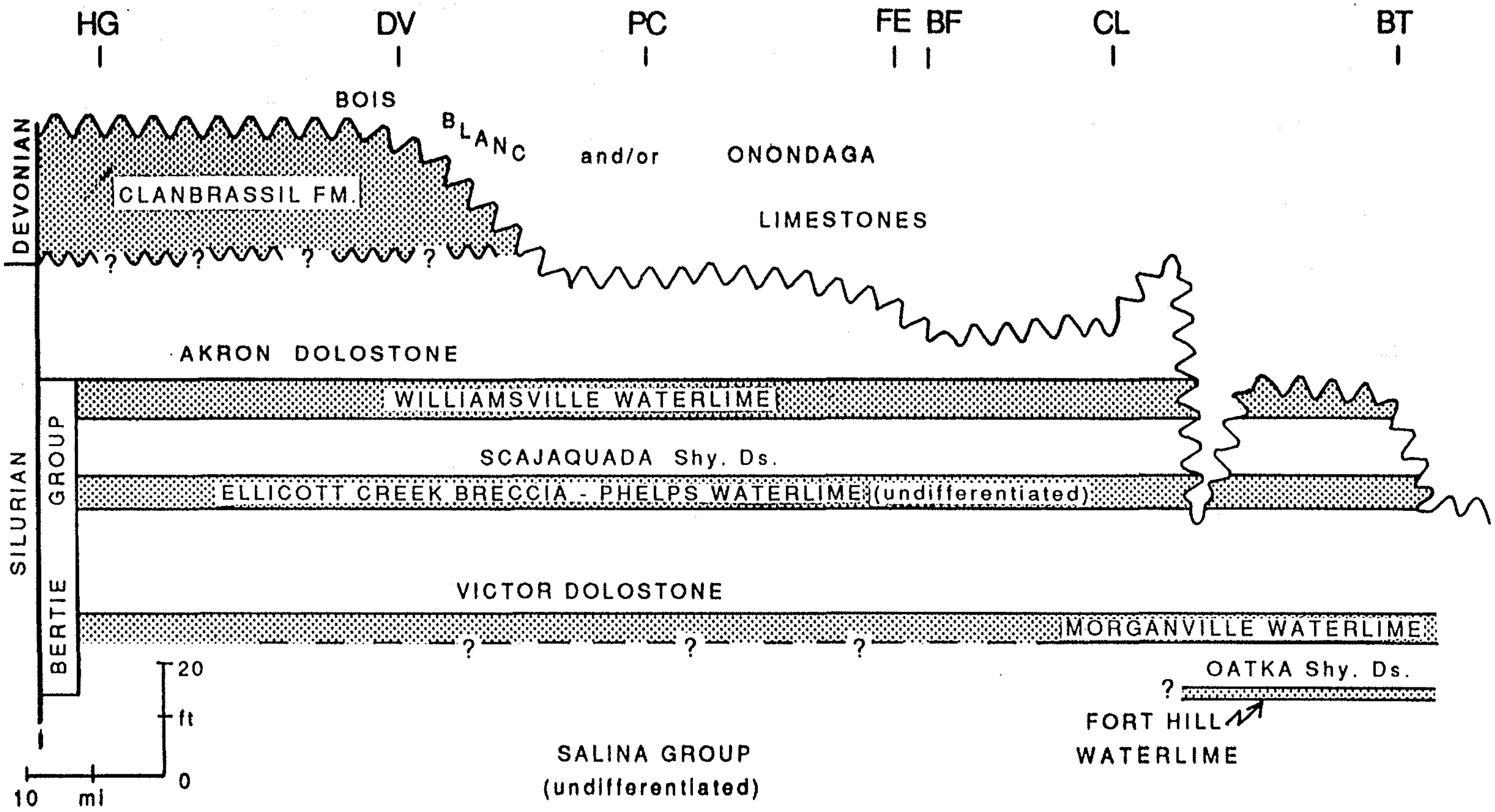

Figure 12. Cross section of Upper Silurian and Lower Devonian strata in western New York and southern Ontario; note the substantial relief on the sub-Devonian Wallbridge Unconformity. Abbreviations for localities along this west-east cross section are as follows: HG: Haggersville, Ont.; DV: Dunnville, Ont.; PC: Port Colbourne, Ont.; FE: Fort Erie, Ont.; BF: Buffalo, NY; CL: Clarence, NY; BT: Batavia, NY. Adapted from Ciurca (1973).

Silurian-Devonian (Wallbridge) Unconformity

In western New York and southern Ontario Upper Silurian strata are unconformably overlain by upper Lower Devonian quartz arenites of the Oriskany Sandstone, and cherty, fossiliferous carbonates of the Bois Blanc and/or the Middle Devonian Onondaga Formation (Figs. 12, 13). This second order "Wallbridge Unconformity" marks the boundary between the Tippecanoe and Kaskaskia supersequences (Sloss, 1963; Dennison and Head, 1975). It displays evidence of karstic development, with irregular relief of up to 3 m. This unconformity apparently records a major late Early Devonian drawdown in sea-level which exposed older Silurian carbonates and evaporites to subaerial weathering and erosion. Sea-level rise in the late Early Devonian (late Pragian to Emsian) resulted in flooding of the irregular erosion surface. Kobluk et al. (1977) described rockground features of the *Trypanites* bored and glauconite-coated upper contact of the Silurian Akron Formation in southern Ontario. To the west, near Hagerstown, Ontario the basal fossiliferous quartz arenites of the Oriskany Formation (Pragian) rest unconformably on the Wallbridge Unconformity, but in the Ft. Erie-Port Colbourne area and in western New York the Oriskany has been removed by subsequent erosion and the basal Devonian unit is the Bois Blanc Limestone.

Early to Early-Middle Devonian (Emsian-Eifelian) Sequences

The Emsian-early Eifelian succession in southern Ontario (Bois Blanc and probably basal Onondaga formations) consists of normal marine mid to shallow shelf carbonate deposits (Fig. 15). The Bois Blanc consists of about 2 m of cherty dolomitic wackestone with thin packstone beds. The basal 0.3 m is sandy and contains spheroidal, phsophatic sandstone concretions. These sediments, sometimes termed Springvale Sandstone represent relict Oriskany sediments reworked into the Emsian Bois Blanc. The Bois Blanc interval is locally argillaceous and may be glauconitic. It contains a distinctive suite of brachiopods (atrypoids and *Leptaena* are most common), corals, and trilobites.

The Bois Blanc is sharply and probably unconformably overlain by the crinoidal grainstones of the basal Edgecliff Member of the Onondaga Formation This surface is locally iron stained. The Edgecliff locally shows small bioherms up to 4 m high, composed largely of favositid tabulates and rugosan corals. These reefs, well exposed at the Ridgemount Quarry in Ft. Erie, all appear to arise at a common level on top of the basal 0.5-0.7 m thick transgressive limestone of the Edgecliff. They are draped by greenish gray calcareous mudstones and cherty crinoiud rich wackestones and packstones. Thus these mounds, like those of the Silurian Lockport Group appear to have grown upward during times of rising sea-level Thet were ultimately drowns and buried by muds. Overlying Onondaga sediments are crinoid and small coral rich cherty packstones reflecting slightly shallowing conditions. The Onoindaga and Bois Blanc show somewhat similar though distinguishable faunas. They were regarded by Brett and Baird (1995) as representing separate ecological-evolutionary subunits.

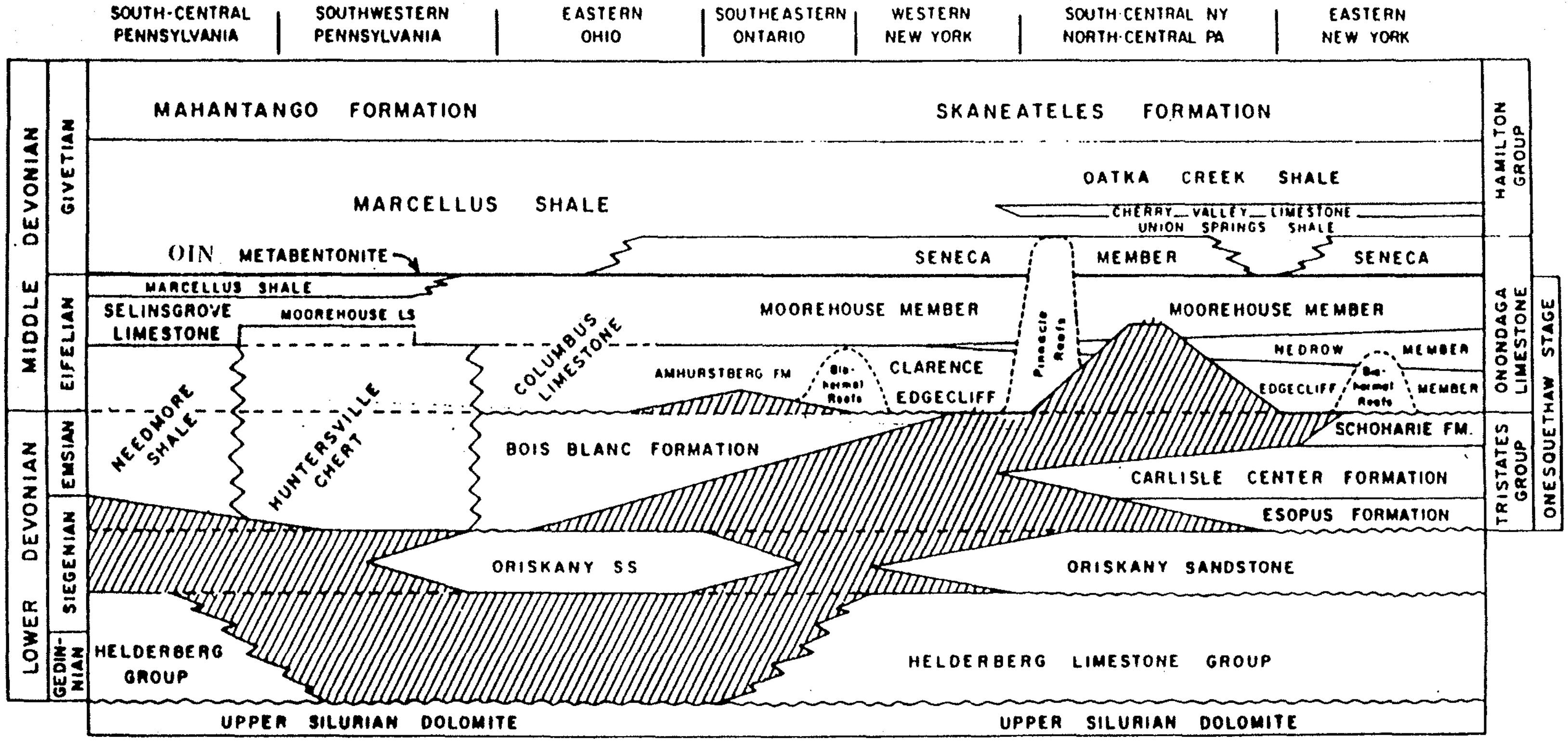

Figure 13. Middle and Lower Devonian stratigraphy of the northern Appalachian basin. (OIN= Onondaga Indian Nations K bentonite). Modified from Casa and Kissling (1982).

SUMMARY

The Silurian-Early Devonian strata of the Niagara Peninsula-western New York are richly fossiliferous, and display recurring depth-related benthic assemblages that aid in interpretation of relative sea-level fluctuation, as well as ecological-evolutionary history. Many fossil assemblages are exceptionally well preserved, reflecting event deposition. These fossils have also permitted relatively refined biostratigraphy. Newer approaches to refining our understanding of stratigraphy and facies relationships in these classic strata. These include identification and tracing of distinctive event beds, such as the DeCew seismite horizon and a hierarchy of disconformity bounded cycles of sequences.

Despite their classic status, these strata have only recently been considered from the standpoint of modern sequence and event stratigraphy (Duke and Fawcett 1987; Brett et al. 1990; Goodman and Brett, 1994; Brett et al., 1998). About nine unconformity-bound stratal sequences have been recognized within the Medina to Bertie groups (Llandovery to Ludlow Series) of the Ontario Peninsula-New York area (see Brett et al., 1990, for details) and two within the Devonian Emsian-Eifelian interval. These sequences and many of their component subsequences can be correlated regionally into Pennsylvania, Maryland, Ohio, Michigan, and the Bruce Peninsula of Ontario (Dennison and Head, 1975; Brett et al., 1990). Furthermore, some of the major events of relative sea-level fall and rise appear to be correlative with those recognized in other basins (see Johnson et al. 1985, for example), suggesting an underlying eustatic mechanism.

The ability to delineate and correlate thin sequence stratigraphic intervals also permits recognition of regional patterns that may be the result of minor tectonic adjustments and shifting depocenters within the Appalachian Foreland Basin (Goodman and Brett, 1994; Ettensohn and Brett, 1998). Within the Silurian as a whole, we recognize a large scale pattern of eastward-westward-eastward migration of the deepest water area and depocenter of the Appalachian Basin during the Early Silurian to Early Devonian time. This tectonically driven effect is superimposed on the more widespread (eustatically controlled) pattern of sea-level fluctuation manifest in the depositional sequences(Fig. 14).

In addition, minor abrupt facies changes within discontinuity-bound sequences, on the scale of a few kilometers, provide evidence for localized flexure of the crust, probably in the form of subsurface fault blocks, as described by Sanford et al. (1985). These local flexures may not be independent from the overall tectonic pattern but may record the local crustal response to migrating "waves" of compression due to episodes of tectonic loading and relaxation (Beaumont et al., 1988).

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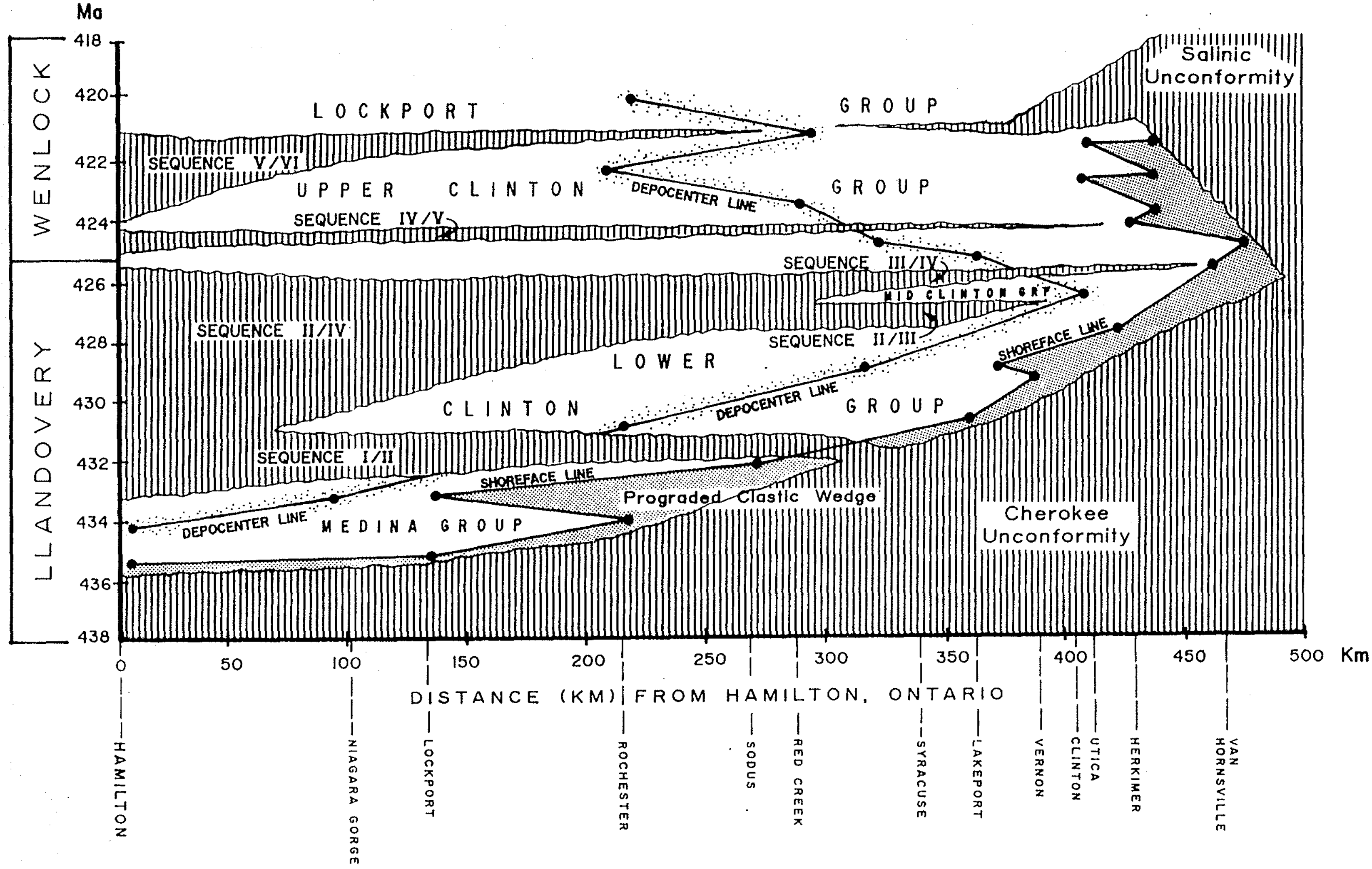

Figure 14. Migration of shoreface and depocenter facies for the Appalachian basin during early to middle Silurian time relative to locations along the east-west outcrop belt from Hamilton, Ontario to Van Hornesville (eastern New York State). Vertical ruling indicates major unconformities. From Goodman and Brett (1994).

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STOP DESCRIPTIONS

This field trip will take place in western New York State and in the Niagara Peninsula of Ontario. Figure 15 shows stop locations for the trip on a simplified geologic base map (Rickard and Fisher, 1970). Abbreviations used in the text and figures for inferred sequence stratigraphic units are as follows: for subsequences (fourth order sequences): RLS = relative lowstands (regressive deposits); RHS = relative highstands; MFS = marine flooding surface; SDS = sea level drop surface; CI, condensed interval, and for sequences: SMT = shelf margin systems tract (lowstand deposit); TST = transgressive systems tract; CS = condensed section; EHS = early highstand; LHS = late highstand; SB = sequence boundary; TS = transgressive surface. The sequences referred to in the previous text are abbreviated as S-I through S-VIII in the following.

ROAD LOG FOR SILURIAN-DEVONIAN SEQUENCES, CYCLES, AND EVENTS

Total Mileage	Incremental Mileage	Description
0.0	0.0	Leave SUNY Fredonia parking lot, turn left on Central Avenue
0.5	0.5	Junction Millard Fillmore Blvd.; turn left
1.6	1.1	Junct. Rts. 5 and 29; continue
1.8	0.2	Entrance to oll booth to NY State Thruway
1.9	0.1	Fork; bear right to I-90 north
2.2	0.3	Merge onto Thruway
14.0-14.2	11.8	Silver Creek Exit; note Portage Escarpment with cuts in gray Hanover Shale overlain by black Dunkirk Shale; Upper Devonian, near Frasnian-Famennian bondary
23.8	9.8	Eden-Angola Exit
33.0	9.2	Hamburg, NY
34.6	1.6	cuts in Rhinestreet Shale; note sulfurous black shale with large concretions; Upper Devonian (Frasnian)
35.6	1.0	Middlesex Shale
35.8	0.2	Ledge of North Evans Limestone on right; this is a highly

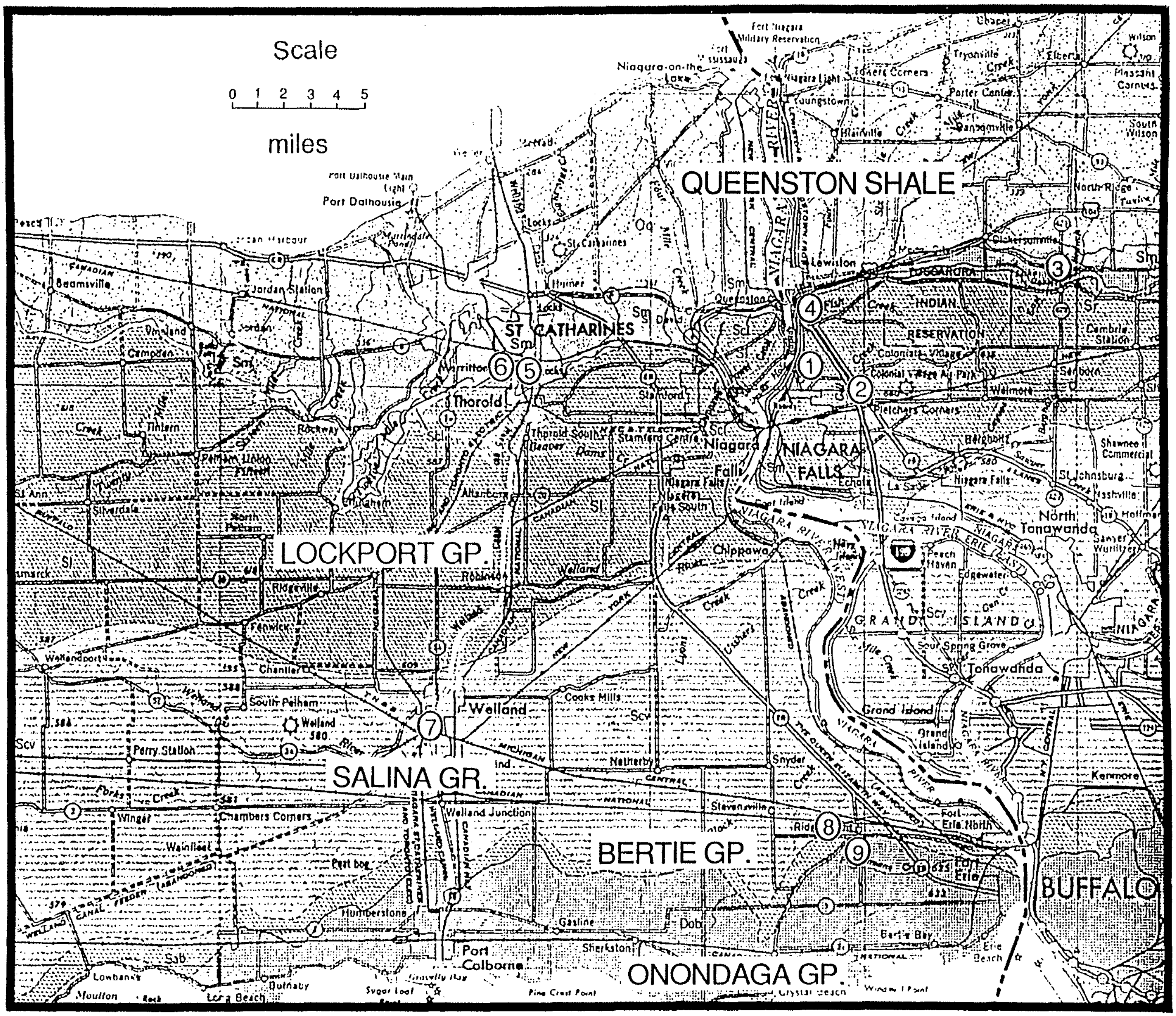

Figure 15. Location map for field trip. Numbers correspond to stop numbers discussed in text. of road log. Geologic base map modified from Rickard and Fisher (1970).

		condensed conodont, bone-rich limestone that straddles the Middle-Upper Devonian boundary
36.5	0.7	Blasdell Exit (52) of NY Truway; exit onto Mile Strip Road
36.8	0.3	Mile Strip Road (Rt. 179); turn right
38.1	1.3	Ford Plant on left; prepare to bear right
38.5	0.4	Rt. 170 ends at NY Rt. 5; bear right onto NY 5 East (north)
39.5	1.0	Lackawanna town line; note large steel mills
41..3	2.0	Father Baker Bridge; views of Buffalo Harbor and City Skyline
43.3	2.0	Skyway; Buffalo Harbor
44.8	0.5	Exit for I-190 North; bear right onto exit and continue around tight ramp to highway (caution; tight right hand exit loop)
44.9	0.1	Merge onto I-190 North
47.0	2.1	Underpass under Peace Bridge; views of Black Rock Channel of Niagara River
48.2	1.2	Scajaquada Expressway (Rt. 198); Squaw Island on left
52.7	4.5	Exit for I-290; continue on I-190 N
53.7	1.0	Toll Booth for South Grand Island bridge; views of east banch Niagara River (pay toll; $.50)
54.5	0.6	Enter Grand Island, NY; one of the largest river surrounded islands in the World; about 9 miles long north to south
59.9	5.4	North Grand Island bridge; views of broad Niagara River about 2 miles above the Falls.
60.0 61.5		I-190 enters Niagara Falls, NY; continue north; views of retaining wall of large toxic waste storage area
65.2	3.7	Exit for NY Rt. 31 (Witmer Road); bear right
65.5	0.3	Junction Rt. 31; turn left; underpass below I-190;
65.8		Pass under major power lines from hydroelectric plant

66.0	0.2	University Road; turn right (just before Rt. 31 makes major curve to left)
66.8	0.8	Junction Hyde Park Blvd. (NY Rt. 62) prepare to go straight across onto South Haul Road; access for Robert Moses Power Plant
66.9	0.1	Pass by fisherman's parking area (cars can be left here; we will continue on South Haul Road to the bottom of the gorge and allow passengers to disembark and return uphill on foot); ahead through underpass beneath Robert Moses Parkway are excellent views of the Niagara Gorge and a complete stratigraphic section from the mid Silurian Lockport Group down to the unconformable contact between the Silurian Whirlpool Sandstone and the underlying Ordovician Queenston Shale
67.5	0.6	Fishermen's access at bottom of Niagara Gorge, just outside gates for Robert Moses Power Plant; passengers will disembark and proceed back up the South Haul Road; vehicles will return back up the road to park

STOP 1: NIAGARA GORGE: SOUTH HAUL ROAD

Location: Large roadcuts in east wall of Niagara Gorge along South Haul access road for Robert Moses Power Plant, and ascending for about 1 km south to a tunnel beneath Robert Moses Parkway (Fig. 16). Parking is available in a fisherman's access parking lot just west of Rt. 62 (Hyde Park Boulevard) immediately south (uphill) from the tunnel. Lewiston, Niagara County, New York (USGS Lewiston 7.5' Quadrangle). Note: Access to the Haul Road exposure is strictly controlled by the Robert Moses Power Project and requires advance permission.

Description: This outstanding outcrop of Lower to mid Silurian strata shows important contrasts with sections of the comparable interval near Hamilton. The section begins near the Power Plant with about 8 m of the Upper Ordovician Queenston Shale (Fig. 17). Its sharp contact with the overlying Whirlpool Sandstone is the Cherokee Unconformity (Silurian Sequence I boundary). The units of the Silurian succession are described in ascending order, as follows:

Medina Group (Fig. 17).

Whirlpool Sandstone: (4.5 m)- White, trough cross bedded, quartz arenite facies which record a non-marine to marine transition. Excellent profiles of channels are visible.

Power Glen Shale: (~ 8 m)- Dark gray, friable shale, with very minor sandstone interbeds

Devils Hole Sandstone: (2 m)- Pale gray, massive, quartz arenite with a distinctive, meter-thick phosphatic, sandy dolostone, Artpark Phosphate Bed near the top (CI).

Grimsby Formation: (15 m)- Greenish gray to maroon shales and mudstones with bundles of thin reddish and white mottled sandstones (Fig. 17).

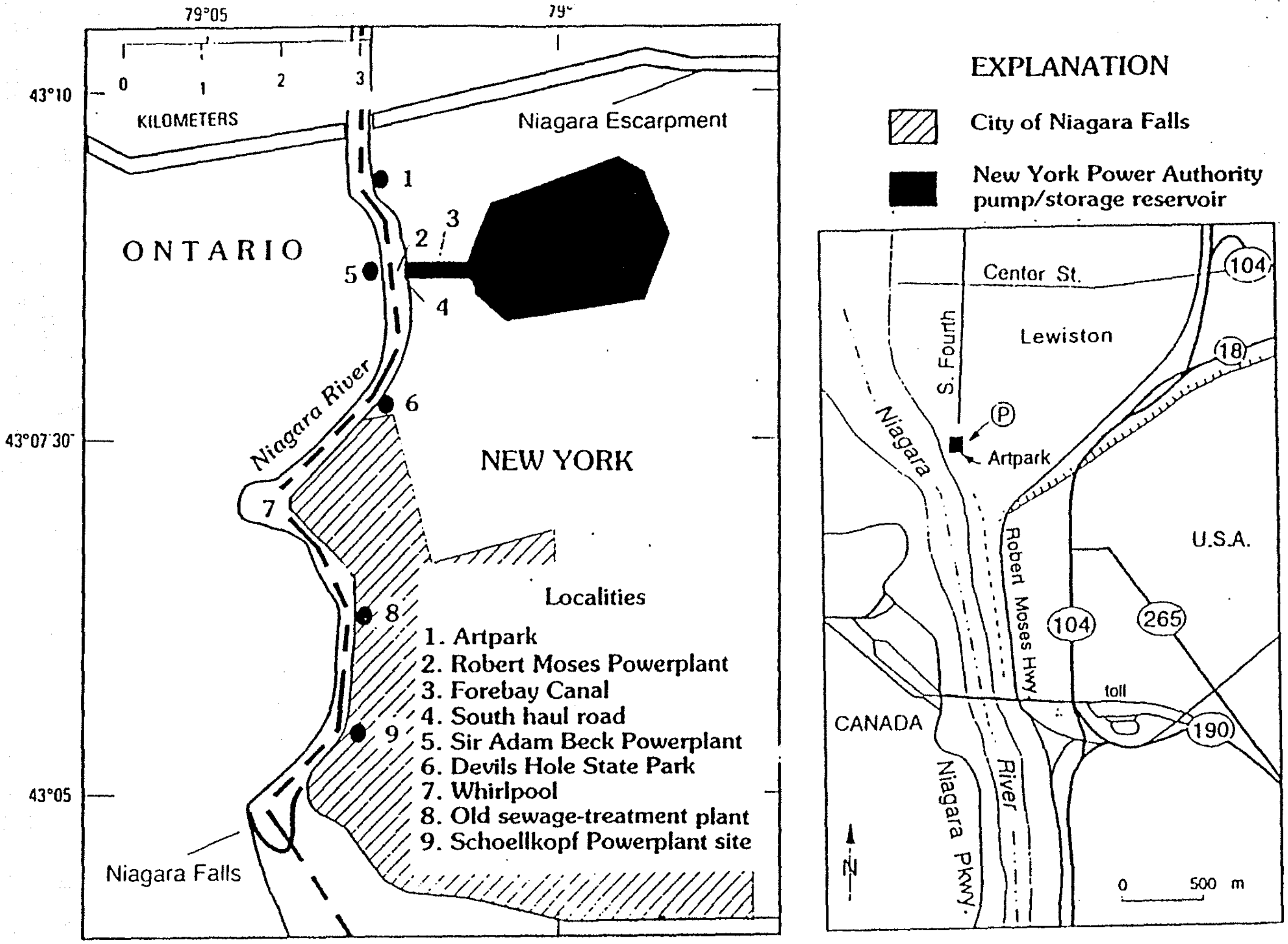

Figure 16. Location of pertinent features in the vicinity of the Niagara River Gorge. Detail of Lewiston area is shown in inset figure. Adapted from Brett et al. (1995).

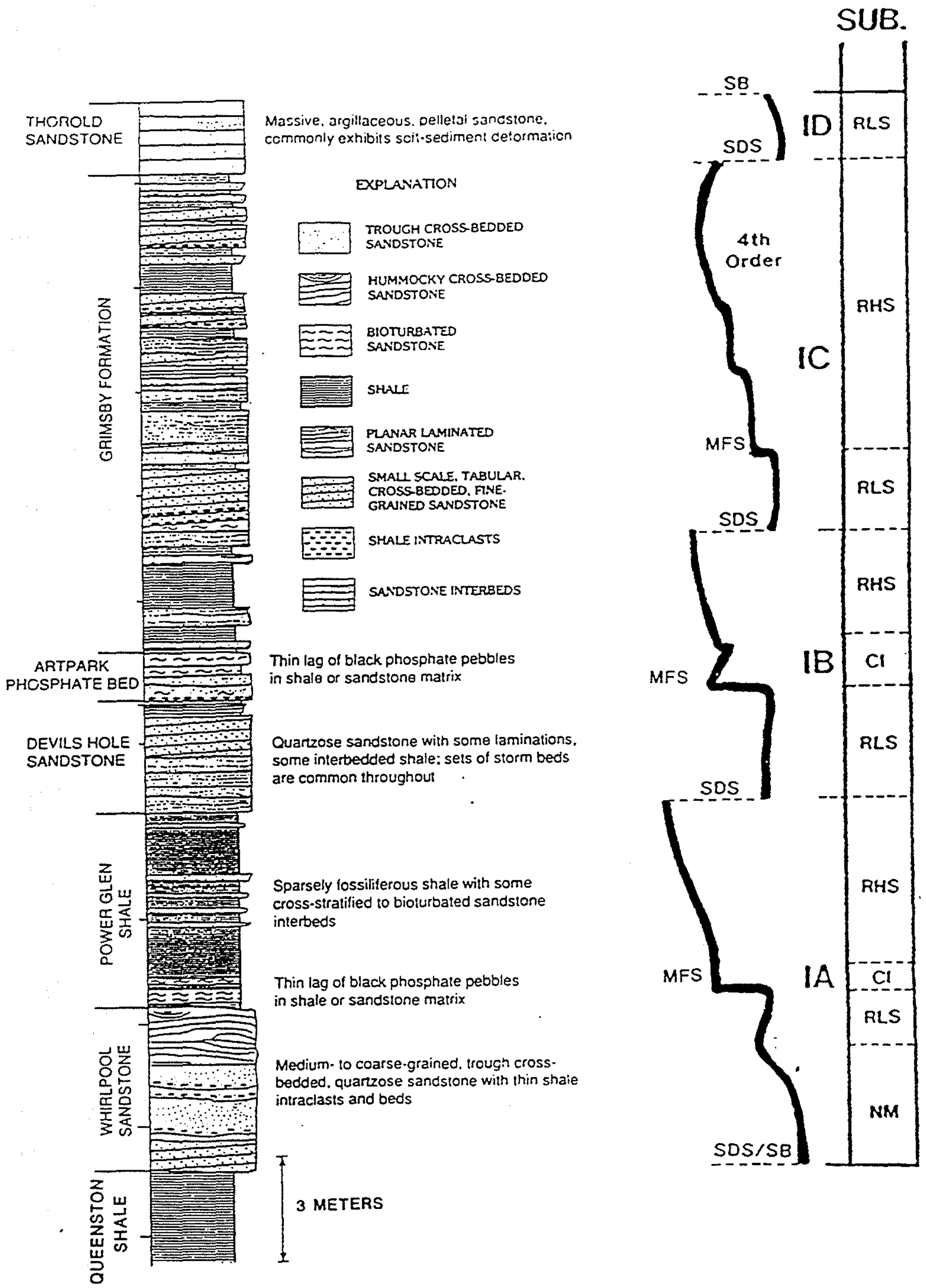

Figure 17. Lithostratigraphy, inferred relative sea level curve, and sequence terminology for Medina Group (Sequence I) at Niagara Gorge, Lewiston, New York. RLS-A = relative sea level curve for lower order cycles. RSL-B = relative sea level curve for large-scale fourth order cycles, generally asymmetrical upward deepening cycles of subgroup scale. Bars on the right side of figure indicate subdivisions of subsequences (SS; left bar) and, for system tracts, the sequence as a whole (SEQ; right bar). For sequence abbreviations see text.

Thorold Sandstone: (2 m)- White, cross-bedded quartz arenite. The Thorold has a sharp, erosive base which marks the base of the next Medina subsequence (IC). A thin (2-10 cm), sandy phosphatic bed, the Densmore Creek Bed (Brett et al. 1995) rests sharply on the Thorold (and on a Cambria Shale remnant north of the Power Plant), marking the base of the Neahga Shale.

Clinton Group (Figs. 6, 18)

Neahga Shale: (2 m)- Dark greenish gray, very friable shale (base sharp (S-II SB).

Reynales Formation (Hickory Corners Member): (~50 cm)- Medium gray, nodular, burrowed, bryozoan-rich wacke- to packstone. Conodonts indicate a mid Llandovery age for the Reynales (see LoDuca and Brett, 1994); this unit represents an erosional remnant of the Reynales.

Rockway Formation: (3 m)- Buff-weathering, argillaceous dolostone with thin dolomitic shales shows prominent rhythmic bands (10-50 cm) of sparsely fossiliferous argillaceous dolostone interbedded with thin gray shales. The Rockway shows a sharp upper contact(S-IV-V SB).

Irondequoit Formation: (2.5 m)- Massive, pinkish-gray, crinoidal pack-and grainstone. Clasts of fine-grained dolostone, derived from the underlying Rockway occur in the basal thin bed of the Irondequoit (Fig. 18). Its sharp upper contact (MFS) is marked by a 30 cm thick shell bed.

Rochester Shale: (18 m)- Medium dark gray mudstone with thin calcisiltites and lenticular fossil rich limestones; 1.5 m of bryozoan-rich limestone beds underlie the sharp top (MFS) of the Lewiston Member . The upper Rochester (Burleigh Hill Member) also displays a sharp contact (SSB) with the enterolithic DeCew Dolostone beds.

DeCew Formation: (3m) -Dark gray, buff weathering, laminated dolostone (calcisiltite). Here and, especially in weathered exposures in the adjacent Devils Hole Park section, the DeCew displays spectacular soft-sediment deformation with isoclinally folded beds (seismite?).

Lockport Group (Fig. 19): The sequence V-VI boundary at the DeCew-Gasport contact is well exposed near the entrance to the "tunnel" beneath the Robert Moses Parkway at the top of the cut; basal Gasport shows rip-up clasts of DeCew Dolostone (Figs. 19).

Gasport Formation: (5 m)-Pinkish gray thin bedded to massive dolostone, divided into a lower pinkish gray dolomitic crinoidal grainstone (Gothic Hill Member) and a 2.5 m upper argillaceous, bioturbated dolostone (Pekin Member) Weathered surfaces of the Gothic Hill grainstones display probable bipolar cross- stratification . The sharp upper contact is a subsequence boundary.

Goat Island Formation : (~10 m)- Buff weathering dolomitic, crinoidal grainstones, buff, thin bedded dolsotone with white chert, and dark brownish gray, argillaceous, banded dolostone; the basal unit (Niagara Falls Member) is massive crinoidal grainstone with scattered *Cladopora* corals and stromatoporoids; abundant vugs appear to be solution cavities in a stromatoporoid-rich zone.

The Ancaster Member is poorly developed here, thin (-2.5 m) and only sparingly cherty. Argillaceous and bituminous gray dolostones of the Vinemount Member form the uppermost unit on the access road. This member is much less shaly than at its type area near Hamilton.

Return to vehicles and proceed

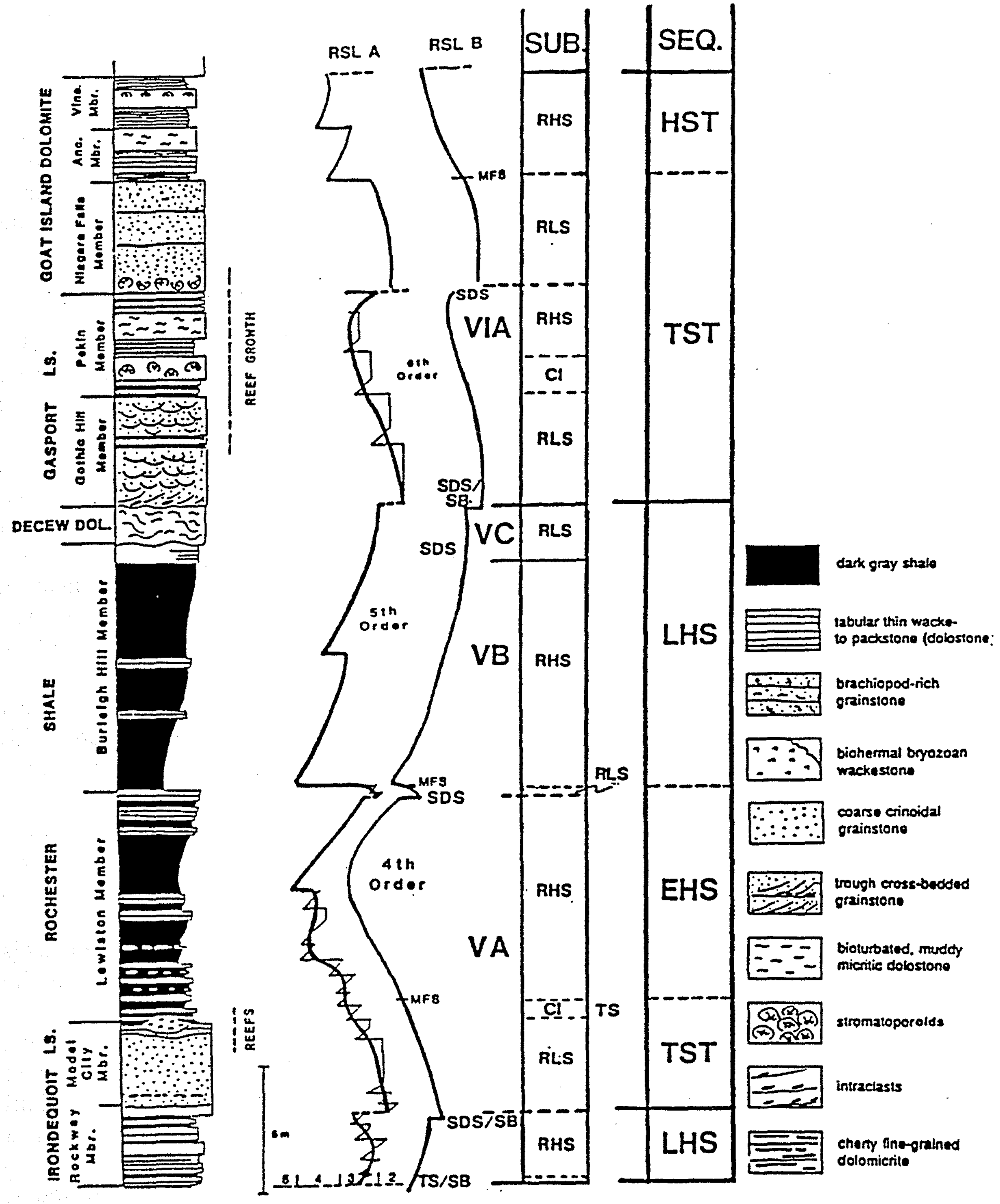

Figure 18. Lithostratigraphy, inferred relative sea level and sequence stratigraphic interpretation for upper Clinton and basal Lockport groups (sequences IV, V and basal VI) at Niagara River Gorge near Lewiston N.Y. Note two zones of reef growth corresponding to early highstand (condensed) phases. Relative sea level curve calibrated to benthic assemblages. For other abbreviations see text.

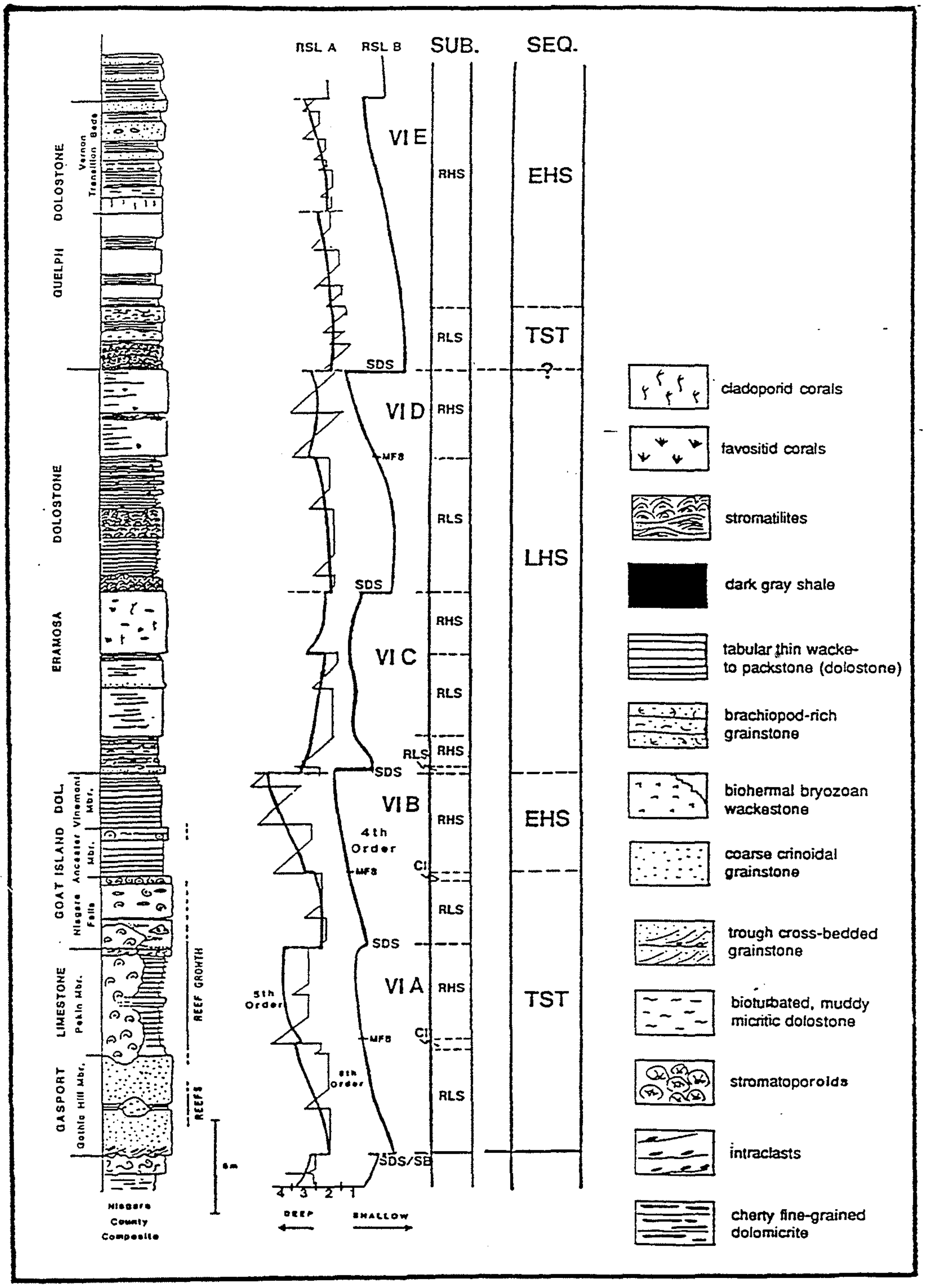

Figure 19. Lithostratigraphy, inferred relative sea level, and sequence stratigraphic interpretation of lower Lockport Group (base of sequence IV) at Niagara Gorge. Niagara Co., NY. Calibration of relative sea level curves based on benthic assemblages.

68.1	0.6	Turn right out of fisherman's parking lot
68.2	0.1	Junction Hyde Park Boulevard; again, proceed straight across onto University Road
68.9	0.7	as road curves to right; turn left onto unamed access road; note jungle of high tension wires ahead
69.3	0.4	T-intersection with Robert Moses Power Vista back entrance road; turn right
69.4	0.1	Pull off and park along road cuts just before underpas beneath I-190

STOP 2: ROBERT MOSES ACCESS ROAD AND FOREBAY

Location: Access road to the Robert Moses Power Plant, and adjacent forebay canal just west of Military Road and 1.2 km north of Route 31, Lewiston, Niagara Co., NY (Lewiston 7.5' Quadrangle).

Description: Higher units of the Lockport Group are visible along the forebay and consist of the upper Eramosa (new usage in New York) and lower Guelph formations (Fig. 19). Large algal bioherms characterize the uppermost units of the Eramosa Formation in the forebay. Exposures in the small road cut at the underpass of the access road beneath the lanes of I-190 show exceptionally large (2 m high) stromatolites, and some non-laminated thrombolites the stromatolitic interval at the base of the Guelph is traceable with subsurface data at least to Hamilton (Fig. 19).

		Pull forward under the I-190 overpass and proceed to Military Road
69.6	0.2	Junction Millitary Road; turn right (north)
70.1	0.5	Crossing east end of Robert Moses forebay area; Pump Generating Power Plant to right; note small thrombolitic mounds in Eramosa Formation exposed i n forebay cuts to left
71.0	0.9	Junction Upper Mountain Road at stoplight

Note For sidetrip to optional Stop 3 (Route 427 cut, Pekin, NY) turn right and follow log below; (approximately 16 miles round trip and about 40 minutes); otherwise proceed straght through the light on Military Road and pick up road log beginning at mile 87.1

71.0	0.9	Junction Upper Mountain Road at stoplight. Turn right onto Upper Mountain Road
73.0	2.0	Enter Tuscarora Indian Natiion

73.5	0.5	Dangerous curve on Upper Mountain Road at junction of Blackman Road; bear right continuing on Upper Mountain Road
78.6	5.1	Pekin, NY; note dolostone church on right at Grove Street; proceed on Upper Mountain Road on ridge over Rt. 429 at the Pekin cut
78.9	0.3	Old Pekin Road (on way) on left; hidden intersection; turn left
79.0	0.1	Junction Rt. 429; turn left (south) and move quickly to ward right shoulder of Rt. 429
79.1	0.1	Pull off on wide area of right shoulder of Rt. 429 and park

OPTIONAL STOP 3. "PEKIN BIOHERM" CUT ON RT. 427

Location: Cuts on both sides of NY 427, just north of underpas bneath Upper Mountain Road, Pekin, Niagara County, NY (Cambria 7.5' Quadrangle).

Description: This classic cut in the brow of Niagara Escarpment has recently been widened, and provides an excellent, but very fresh exposure of the upper Gasport (Pekin Member of Brett et al., 1995) and the lower portion of the overlying Goat Island Formation (Fig, 19). The large, massive mound exposed particularly on the west side of Rt. 427 was originally described as a Gasport bioherm and was considered to show reefal succession (Crowley and Poore, 1974). However, recent excavations have revealed that the mass of stromatoporoid bearing rock is almost entirely within the Goat Island Formation and is separated from older Gasport deposits (including a formerly exposed small bioherm, now detroyed by blasting) by a major erosion surface. The contact between the gray, thin bedded argillaceous dolostones of the Pekin Member of the Gasport and overlying massive, dolomitic crinoidal grainstone of the Goat Island (Niagara Falls Member of Brett et al., 1995), a sequence boundary, appears sharp. but horizontal in the northeastern portion of the cut. However, this contact abruptly descends to near road level just north of the Upper Mountain Road overpass. Here a mass of biohermal lithology overlies the unconformity. On the freshly blasted west side of the cut the irregular contact between the dark gray Pekin and light pinkish biohermal Goat Island is now very clear. The erosion surface separating the units has a relief of over 2 meters. The Goat Island "bioherm" appears to have developed in low areas on the unconformity. It consistrs of a mixture of crinoidal grainstones and light gray dolomicrite, rich in stromatoporoids, many of which are tumbled onto their sides or even inverted, indicating storm disturbance. This biohermal mass built up in "channels" along a sequence boundary during initial transgression.

		Reboard vehicles and proceed south on Rt. 429 through the tunnel beneath Upper Mountain Road; prepare to turn right
79.3	0.2	Junctiion Grove Road; turn right
79.4	0.1	Junction Upper Mountain Road; turn left and retrace route to Millitary Road

END OPTIONAL ROUTE

87.1	7.7	Junction Military Road (NY 265); turn right (north)
87. 8	0.7	Junction NY 104; turn right (north)
88.0	0.2	Brow of Niagara Escarpment; on clear days good views of the mouth of Niagara River and Lake Ontario to the north; cuts to right in Gasport-Goat Island formations
88.4	0.4	Skip Exit for Rt. 18F east, but stay right
88.9	0.5	Exit for Rt.104-18F west; bear right onto exit lane
89.1	0.2	Merge right onto Rt. 18F; Center Street, Lewiston, NY
89.9	0.8	Frontier House McDonald's; pull in for rest stop.
89.95	0.05	Pull out of parking lot and turn left onto Center Street
90.4	0.5	Portage Road; turn right and proceed to entrance for Artpark
90.6	0.2	Entrance to Artpark Road
91.3	0.7	Parking Lot B; bear right and then turn left immediately once in parking lot; proceed up to left on small road labled "Narrow" near Clay Studio
91.5	0.2	Fishermen's parking area; pull in and park; proceed south on foot to entrance of Niagara Gorge

STOP 4. NIAGARA GORGE, LEWISTON (ARTPARK): (LUNCH STOP)

Location: Sections in east wall of Niagara Gorge along old haulage road extending from north end of Niagara Gorge at Niagara Escarpment just south of Artpark (Fig. 16); off Fourth Street, southward to the Lewiston-Queenston bridge, Lewiston, Niagara County, NY (Lewiston 7.5' Quadrangle)

Description: The north-facing cuesta (Niagara Escarpment) stands 76 m above the adjacent Lake Ontario plain. Niagara Falls was initiated here about 12,000 BP.

Exposures of the Upper Ordovician Queenston Shale and its unconformable contact with basal Silurian Whirlpool Sandstone are visible along a short path, adjacent to the river, immediately south of the Artpark theater. Outcrops of the Lower Silurian stratigraphic units above the Whirlpool Sandstone (Fig. 17) are accessible along an old haulage road that leads southward from the Artpark Visitor Center into the gorge. At the entrance to the gorge (edge of Niagara Escarpment) an isolated "butte" of Lower Silurian strata (Power Glen-lower Grimsby; type locality of the Artpark Phosphate bed) between the path and the river, represents a remnant of a promontory in the gorge wall that was breached during excavation for the power plant. A 0.5 m layer of mottled sandstone with prominent ball-and-pillow structures, about 5.5 m above the base of the Grimsby, is well exposed in the cliffs about 200 to 700 m north of the Lewiston-Queenston Bridge. Caution is required in this exposure, as rock falls are common. Abundant fallen debris also provides an excellent look at varied lithologies of the upper Medina, as well as Clinton and Lockport units.

Reboard vehicles and retrace route to parking lot B;

91.7	0.2	Bear right out of parking lot onto exit road and proceed to exit from park.
92.4	0.7	Proceed straight through onto Portage Road
92.8	0.4	Junction Rt. 18F; turn right (east)
93.0	0.2	Junction Rt. 104 West/Robert Moses Parkway; turn right
93.1	0.1	Fork; bear left onto entrance for Rt. 104; DO NOT go onto Robert Moses Parkway
93.9	0.8	Juntion Military Road; proceed straight on Rt. 104
94. 7	0.8	Exit for I-190; bear right onto exit
95.1	0.4	Merge onto I-190 south
95.3	0.2	follow signs for exit to Canada; follow exit ramp around onto I-190 north and entrance to bridge
95.6	0.3	Merge onto -190 north and entrance to bridge
96.0	0.4	Enter Lewiston-Queenston bridge
96.2	0.2	Excellent views of Niagara Gorge from bridge; Canadin border
96.5	0.3	Customs Booths; residents of countries other than US or Canada must show passports
96.8	0.3	Toll booths; cars US $2.50; pay and then proceed straight ahead on to Highway 405
102.4	5.6	Merge onto Queen Elizabeth Way (QEW)

102.5	0.2	Exit for Glendale Road St. Catharines; bear right onto ramp
105.8	0.3	End of ramp; turn left onto Glendale Road
107.5	1.7	Lift bridge over Welland Canal
107.6	0.1	Stoplightbat end of bridge
107.7	0.1	Junction Government Road on left; turn left
108.4	0.4	Welland Lock # 5; parking area adjacent to canal; pull in and park; railroad cuts are to right on opposite side of th road; cautiously cross road and proceed down embankment to railroad cuts

STOP 5: MERRITTON RAILROAD CUT

Location: Cuts along Canadian National Railroad tracks 0.1 km west of Government Road (Canal Street) along west side of the Welland Canal, opposite locks 4 and 5, Village of Merritton, Thorold Township, Ontario. (NTS 30M/3g, St. Catharines Sheet).

Description: This locality is the type section of both the Thorold Sandstone and the Merritton Dolostone (Kilgour, 1963; Fig. 20).

Units exposed along this cut include, in ascending order :

Thorold Formation: (3m)- White and greenish sands and shales with small scale cross stratification, scour and fill stucture, load casts and oscillation ripple marks. The lower 1.5 m of Thorold Sandstone, interbedded pale buff-weathering argillaceous sandstone and thin greenish sandy shales with excellently preserved spreiten of the trace fossil *Daedalus*, while undersurfaces show the annulated trace fossil *Arthrophycus* ; both traces may have been the work of the same organisms. This is a widespread marker interval.

Unnamed limestone: (30 cm) Gray, argillaceous, phosphatic limestone with bryozoans.

Neahga Shale: (24 cm)- Dark gray shale with bored hardground clasts in basal 5 cm.

Merritton Limestone: (50 cm)- Pale gray, glauconitic, phosphatic wacke- to packstone with three major beds as in the Hamilton area . Basal contact sharp, with abundant small phosphatic nodules. The upper contact of the Merritton is also a sharp, shows truncated in situ *Pentameroides* a (Telychian index fossil) and is stained black with phosphatic material.

Williamson Shale: (12 cm)- Greenish gray shale tentatively correlated with the Williamson Shale of New York on the basis of recovered acritarchs (C.E. Brett and M. Miller, unpublished data).

Rockway Dolostone: (~2 m)- Buff to gray, thin bedded argillaceous dolostone with an abundance of the large pentamerid brachiopod *Costistricklandia*..

This cut is crucial in establishing the stratigraphic succession of the lower to mid Clinton rocks in Ontario. The Merritton (often called "Reynales" in Ontario) overlies the major late

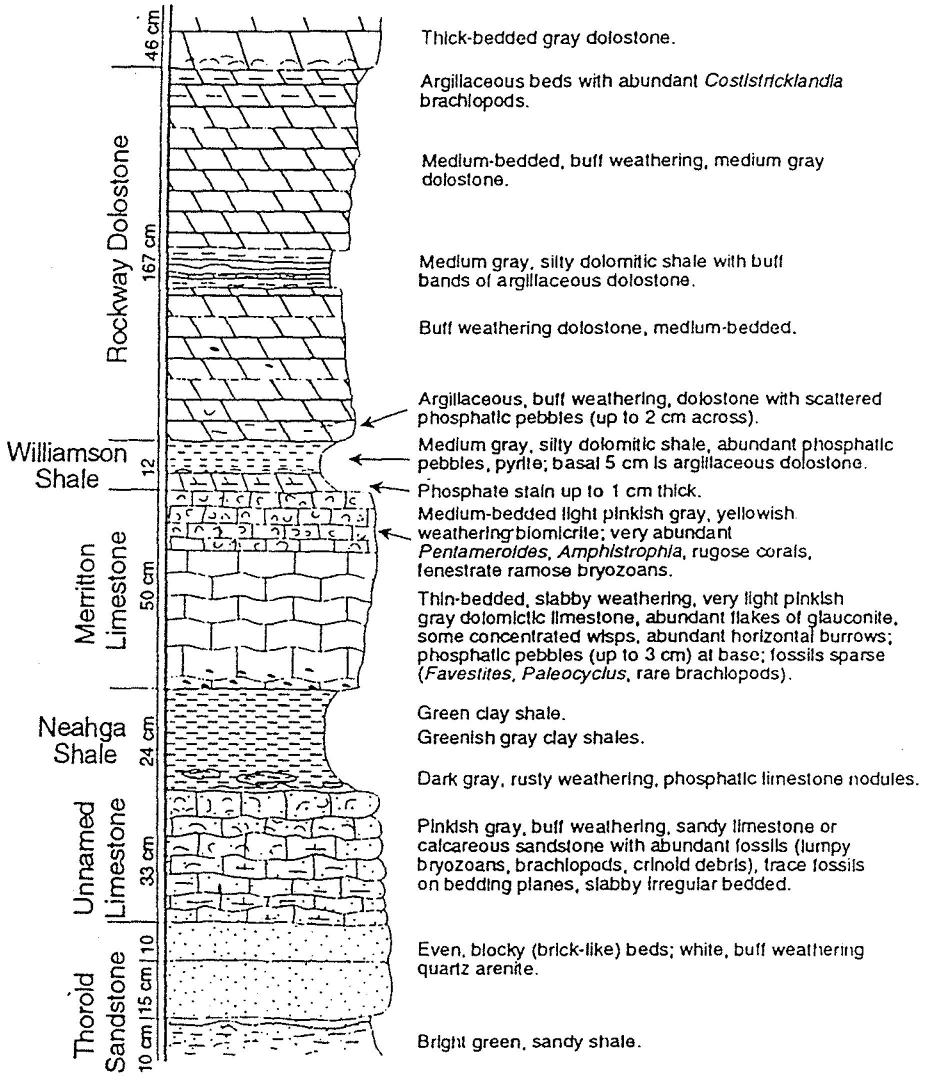

Figure 20. Details of upper Medina and Clinton sequences at Merritton, Ontario.

Llandovery (Sequence IV basal) unconformity, which at this locality has removed the true Reynales Limestone (Figs. 6, 20).

		Pull out of parking area and <u>turn right</u>, retracing route along Government Road to Glendale
108.1	0.7	Junction Glendale Road; <u>turn left</u>
108.6	0.5	Cross railroad tracks
108.8	0.2	T-junction at Merritt Street; <u>turn left</u> (Caution, no light)
108.9	0.1	Junction continuation of Glendale; <u>turn right</u>
109.2	0.3	Junction Burleigh Hil Road; <u>turn left</u>
109.5	0.3	<u>Pull off on shoulder</u> at top of roadcut and walk back to cuts

OPTIONAL STOP 6. BURLEIGH HILL ROAD CUT.

<u>Location</u>: Exposures in long roadcut in brow of Niagara Escarpment along Burleigh Hill Road about 2 km south of Glendale Avenue, Thorold, Ontario (NTS 30M/3g, St. Catharines Sheet).

<u>Description</u>: This long cut exposes the upper portion of the Rochester Shale and its contact with the overlying DeCew Formation (Figs. 9; 18). This is the type locality of the Burleigh Hill Member of the Rochester Shale (Brett, 1983b); which is here about 9 m thick. It is divisible into lower shaly and upper somewhat thicker bedded, dolomitic shale and argillaceous dolostone. Thin calcisilitites display sharp bases and smal scale grading and hummocky cross stratification indicative of deposition as tempestites (storm beds); fossils are generally sparse although rare Stegerhynchus and *Coolinia* brachiopods and the trilobites *Dalmanites* and *Trimerus* can be found. The DeCew Formation is less than a meter thick and displays typical highly convoluted bedding as seen at Niagara Gorge. The contact with a thin 40-50 cm ledge of atypically fine gained Gasport Dolostone is sharp; locally a very thin remnant of a fossilifewrous shale (the St. Catharines shale lentil) are present between the DeCew and Gasport but that unit is largely removed by sub-Gasport erosion.

		Return to vehicles and <u>continue south</u> on Burleigh Hill Road
109.9	0.4	Junction St. Davids Road; <u>turn right</u>
110.9	1.0	Overpass over Highway 406; prepare to turn left
111.0	0.1	Entrance to Hwy 406 South ; <u>turn left onto ramp</u>

111.2	0.2	Merge onto Hwy 406 southbound
114.4	3.4	Junction Rt. 58/ 20 (alternate route to Stop 7); continue on Rt. 406
117.5	3.1	Cross Welland River
119.7	2.2	Highway 406 ends at Main Street, Welland, Ontario; turn left onto Main Street
120.0	0.3	Tunnel beneath Welland Canal
120.2	0.2	Junction Rt. 1440 South (toward Pt. Colbourne); turn right
122.8	2.6	Junction Netherby Road, conector to Rt.. 58A ; turn right
123.3	0.5	Junction Rusholme Road; turn left
123.5	0.2	Junction Town Line Road; turn right
124.0	0.5	Small parking rea on right next to roadcut, slightly before tunnel under Welland Canal; pull in and park to view outcrop

OPTIONAL STOP 7 : TOWN LINE (NETHERBY) ROAD (RT. 58A) CUT NEAR TUNNEL BENEATH WELLAND CANAL

Location: East entrance to the Town Line) Netherby Road and railway tunnel beneath the Welland Canal Bypass, southeast edge of Welland, Ontario (NTS 30L/14g, Welland Junction Sheet)

Description: Strata here are assignable to the Upper Silurian Salina Group (Fig. 21).

Camillus Formation - (5 m exposed) - Interbedded fine-grained blocky to laminated, gray to buff dolostone, shaly dolostone, and gypsum. Much of the dolostone has numerous gypsum crystal molds. Salt hopper impressions are also common. The upper Salina Group (Syracuse and Camillus) is over 60 meters in thickness in drill cores (Fig. 21; Caley 1940); however, because the Salina is such an easily eroded unit, this is represents the only exposure in southern Ontario.

		Pull out off parking area and turn left back onto Town Line Road (58A)
125.7	1.7	Town Line changes name to Netherby Road; continue straight on Netherby
126.1	2.4	Enter Ft. Erie

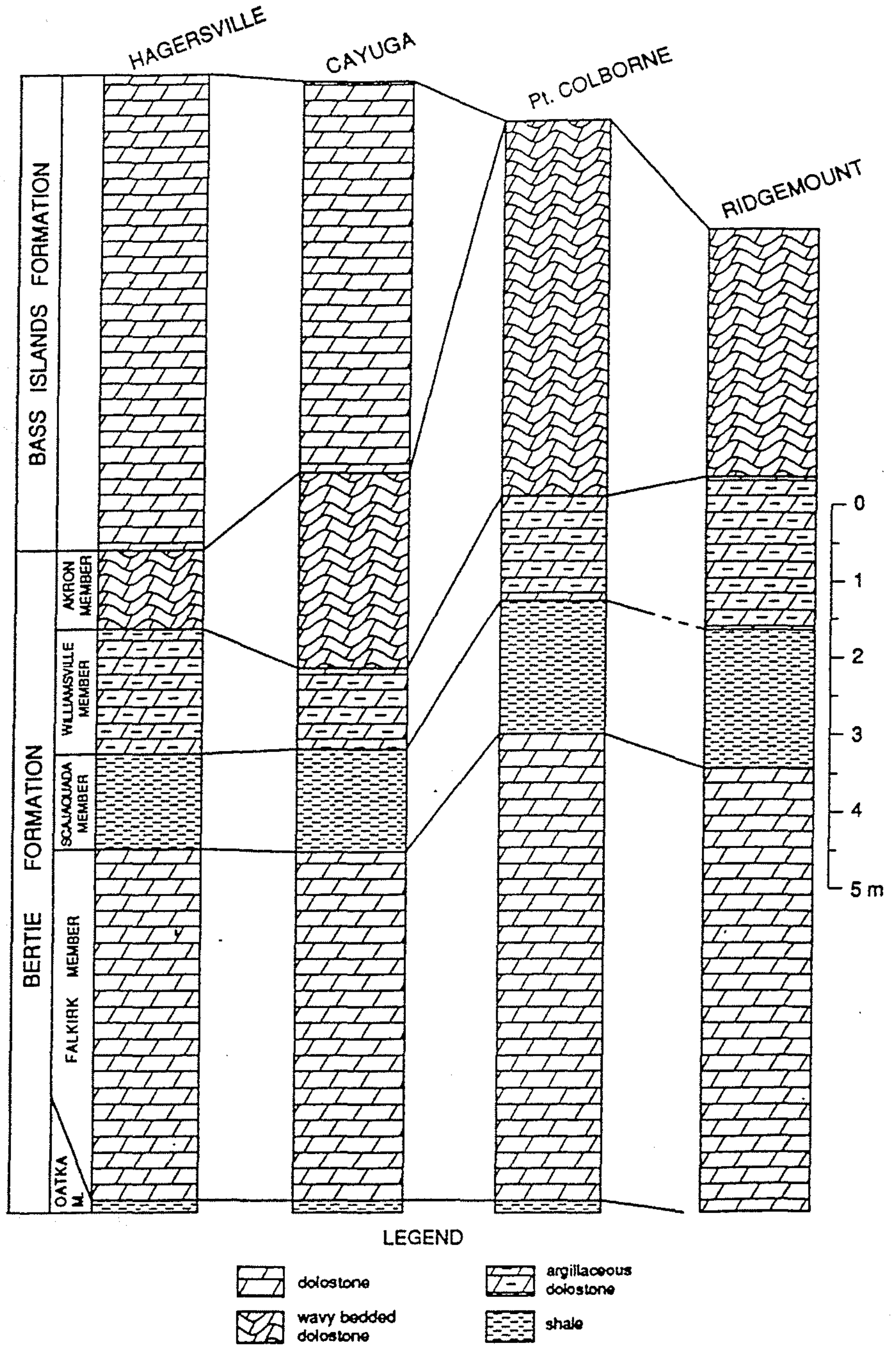

Figure 21. Correlated columns of Bertie Group and Bass Islands Group in southern Ontario, including Campbell Quarry, showing continuity of units. From Milne (ed., 1992).

129.4	3.3	Sodom Road
131. 4	2.0	Ridgemount Road; turn right
133.9	2. 5	Bowen Road
134.1	0.2	Entrance to Campbell Quarry on right; turn into drive and register; then return to vehicleds and drive back to Ridgemount Road; turn right
134.4	0.3	Bridge Street; turn right
134.7	0.3	Pull off and park past vbridge over quarry road connecting north and south parts of Campbell Quarry' walk down dirt road into south quarry

STOP 8. CAMPBELL QUARRY

Location: Large, active quarry just west of Ridgemount Road, south of Bowen Road (Regional Road 21) and north of Garrison Road; the quarry is divided into a northern (old) portion, containing crushers and quarry buildings and an active south portion by a wall that supports Bridge Road; a tunnel under the road connects the two areas. Approximately 4 km northwest of Fort Erie and 1 km south of Ridgemount, Ontario (NTS 30L/14h, Stevensville Sheet).

Description: Campbell Quarry is the northern of two adjacent quarries operated by Ridgemount Quarries Ltd., a division of Walker Industries. This quarry contains one of the most complete sections through the Upper Silurian Bertie-Akron strata (Cooper and Plewman 1983; Figs. 12, 21). A glacially-striated surface is visible at the top of an active area of the quarry. In ascending order, the following units are exposed in the quarry faces:
Bertie Group

Fiddlers Green (Falkirk) Formation (4.5 m)- Dark gray to brown algal-laminated dolostone, weathering yellowish brown and characterized by a coarse conchoidal fracturing; large domal stromatolitic structures 2 to 6 meters in diameter separated horizontally by nonlaminated, fine-grained dolostones containing eurypterids, leperditian ostracodes and small bivalves. The lowest meter contains meter scale thrombolites with *Whitfieldella.* brachiopods.

Scajaquada Formation (1.7 m)- Unfossiliferous dark gray shales and shaly dolostone. The unit is well laminated and some bedding surfaces feature casts of salt and gypsum crystals.

Williamsville Formation (1.25 m) - Planar-laminated fine-grained dolostone, weathering light gray and characterized by a pronounced conchoidal fracture. The lower, massive half-meter bed ("Buffalo Waterlime"), exposed in the quarry floor, contains the famous Bertie eurypterid fauna typified by *Eurypterus lacustris* (see Clarke and Ruedemann, 1912, Copeland and Bolton, 1985).

Akron Formation (3.6 m) - Greenish-grey to light brown, fine grained, thin-,wavy-bedded burrow mottled dolostone with an irregular fracture. The Akron contains a sparse and poorly preserved fauna including corals, brachiopods, and cephalopods (Buehler and Tesmer, 1963).

The contact between the Late Silurian Akron Formation and the Lower Devonian Bois Blanc Formation, well shown near the tunnel, is sharp and shows channels of 1 to 3 meters across and up to 1 meter in depth, with glauconitic sand and gravels at their bottoms. Cracks and fissures reaching as much as 4 meters down into the top of the Akron Formation can sometimes be found and are often infilled with a well-sorted white sandstone, probably representing an erosional remnant of the Lower Devonian Oriskany Sandstone (Caley, 1940). The Devonian Bois Blanc Limestone is exposed high in the quarry wall and can be studied to better advantage in the Ridgemount Quarry to the south (see below). However, fallen blocks of cherty, fossiliferous, and heavily bioturbated Bois Blanc may be seen in the Campbell Quarry.

		Return to vehicles and turn around proceed back on Bridge Street to Rdgemount Road; turn right
135.0	0.3	Junction Ridgemount Road, turn right
135.9	0.9	Entrance gate to now abadoned Ridgemount Quarry on right; pull in and park; proceed on foot into quarry along gravel road

STOP 9. RIDGEMOUNT QUARRY

Location: Large abandoned quarry about 2 km south of Campbell Quarry on west side of Ridgemount Road; and north of Highway 3; a gravel ramp road leads down into quarry from locked gates at a disused weigh station; Ridgemount, Ontario, (NTS 30L/14h, Stevensville Sheet).

Description: Because of the regional 0.5° southward dip, this quarry exposes higher strata than does the Campbell, although the two sections overlap. The Silurian-Devonian (Wallbridge) unconformity (Fig. 12) is spectacularly displayed in the southern part of the quarry and in patches of the quarry floor in the southern area. A *Trypanites*-bored rockground is developed on the upper surface of the Akron Dolostone; borings have been infilled with a bright green glauconitic matrix (see Kobluk et al., 1977).

The overlying Devonian Bois Blanc and Onondaga formations are exposed in the higher walls:

Bois Blanc Formation (2.5 m) - Cherty, dolomitic limestone with shale partings and containing local brachiopod coquinas and coral debris. The lower Bois Blanc contains glauconitic sandy sediments. The Bois Blanc is Early Devonian (Emsian) in age (Uyeno et al, 1982; Telford and Johnson 1984). The Bois Blanc is separated from the overlying Onondaga Limestone by a sharp, limonite-stained unconformity.

Onondaga Formation. Edgecliff Member (5-6 m) - Crinoidal and coral-rich, variably cherty wacke- and packstones and biohermal limestone. Emsian-early Eifelian (Oliver, 1976; Uyeno et al., 1982). The lowest meter consists of interbedded crinoidal grainstone and green, shaly limestone. A second unit is highly variable in thickness along the eastern quarry walls due to the local development of favositid-rugose coral bioherms, particularly well developed in the northeast corner of the quarry (see Wolosz, 1990). The bioherms show abundant colonial rugosans: *Eridophyllum*, *Acinophyllum,* and large hemispherical and ramose favositids (Fig. 22).The bioherms locally rest on a thin greenish shale with fossil debris. They are draped by a cherty wackestone which locally pinches out over the tops of the "reefs"; a thin (5-10 cm) dark gray shale bedcaps the cherty interval and drapes the tops of the bioherms. The higher Edgecliff, above the bioherms, consists of crinoid rich shaly packstone with dark gray cheryt nodules, The highest ubits consist of non-cherty crinoidal grainstones.

135.9		Return to vehicles and turn left (north) out of parking area onto Ridgemount Road
137.2	1.3	Junction Bowen Road; turn right
138.1	0.9	Entrance to Queen Elizabeth Way (QEW) southbound to Peace Bridge
142.3	4.2	Ramp to Peace Bridge to USA
143.4	1.1	Customs booths; have passports ready; no toll this way
143.5	0.1	Ramp to I-190 south; bear right
145.3	1.8	Exit from I-190 to Rt. 5 west; bear right
145.6	0.3	Skyway; view of Buffalo Harbor
148.1	2.5	Tift Street
151.2	3.1	Enter Hamburg
152.2	1.0	Junction Mile Strip Road (Rt. 179) entrance ramp; bear right onto ramp
153.6	0.4	Ford Plant
154.7	1.1	Entrance to NY State Thruway (I-90); turn left
155.0	0.3	Fork for I-90 east and west; bear right onto I-90 west (south) Approximately 34 miles to Fredonia Exit.

END FIELD TRIP

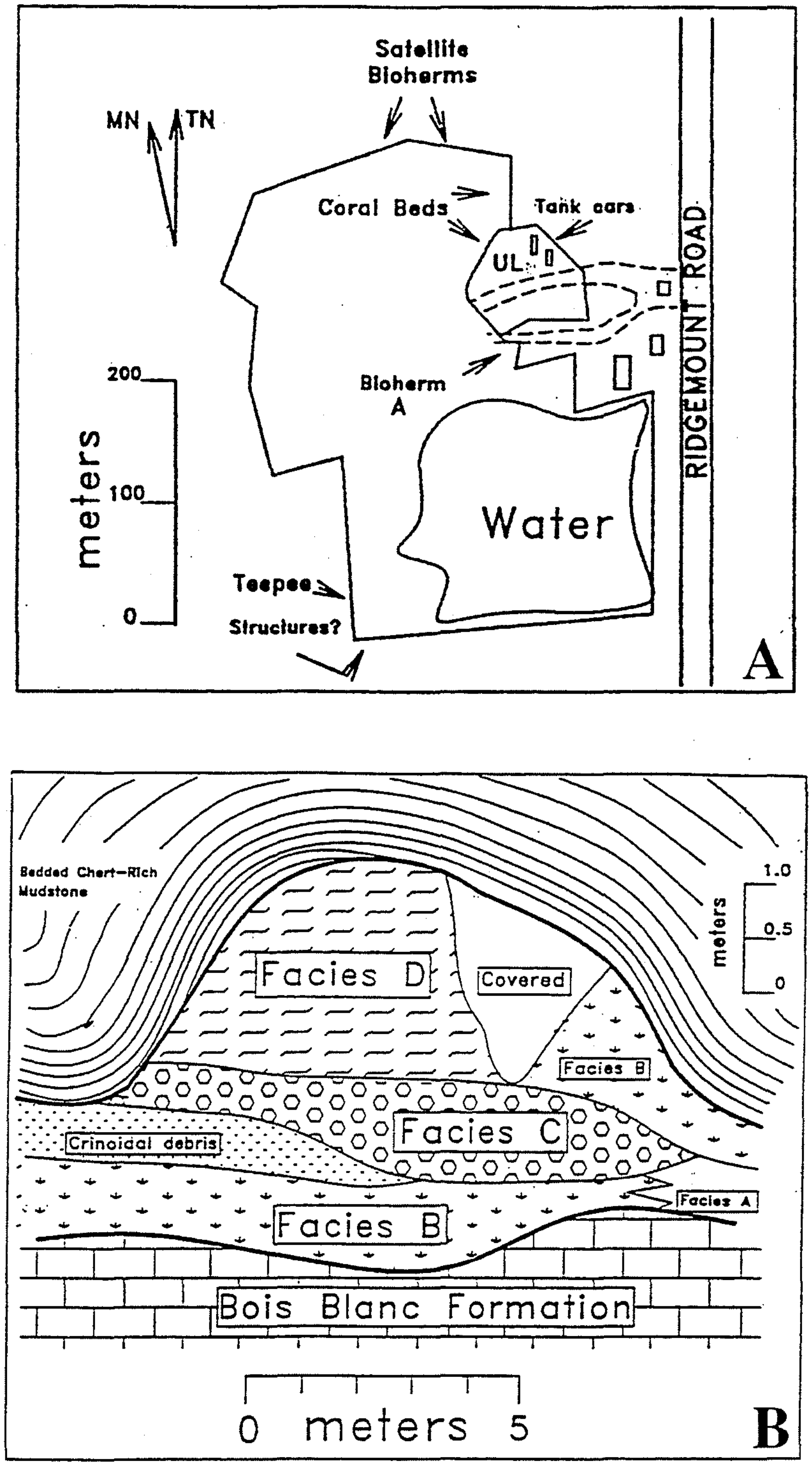

Figure 22. A) Map of Ridgemount Quarry. B) Detail of bioherm A; facies include: A) biostromal packston with intraclasts; B) *Acinophyllum* rich biostrome with small favositids; C) Large phaceloid colonial rugose corals and large solitary rugose corals; D) coral debris, include branching tabulates, *Acinophyllum* and solitary rugose corals; overlying beds are cherty wacke- and packstones with abundant large crinoid columns; these beds drape the bioherms. Adapted from Wolosz (1990).

AN EXAMINATION OF EURYPTERID OCCURRENCES IN THE WILLIAMSVILLE FORMATION (BERTIE GROUP) EXPOSED IN RIDGEMOUNT QUARRY

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INTRODUCTION

Eurypterids were chelicerate arthropods that lived through much of the Paleozoic Era (Early Ordovician to Early Permian), reaching their peak in diversity during the Late Silurian and Early Devonian. Their fossilized remains are found on every continent except Antarctica, with well-known occurrences in places such as Baltic Europe, Scotland, and New York State and adjacent Ontario.

The eurypterid body includes a prosoma followed by an opisthosoma ("abdomen") with twelve movable segments and a posterior telson (Fig. 1). The prosoma bears six pairs of appendages, most of which extend beyond its edge. A typical eurypterid has a pair of chelicerae anterior to the mouth, followed by three pairs of "walking legs," a pair of "balancing legs," and a pair of "swimming legs" that (in most forms) ends in a flattened palette or "paddle." The name "eurypterid" means "broad-winged," referring to the paddles. The basal parts of the legs, or coxae, have teeth on their inner edge that aid in mastication. Posterior to the mouth is the metastoma (postoral plate), a characteristic feature of eurypterids that covers the inner margins of the last pair of coxae and the space between them.

The opisthosoma is divided into a preabdomen and a postabdomen. The preabdomen includes the first six segments, each covered by a dorsal plate or tergite. The ventral side of the first two preabdominal segments is covered by the operculum, a pair of plates meeting at the median line, with a central genital appendage. The remaining four preabdominal segments bear movable ventral plates, or sternites, that cover the respiratory appendages. The six postabdominal segments, or caudal segments, are annular. The telson is styliform (long, pointed) in most eurypterids, but in some (such as the pterygotids) is broad and flattened (spatulate). In the genus *Eurypterus*, an angled ridge, or carina, is developed on the ventral side of the telson.

The eurypterid exoskeleton is thin and chitinous, and thus prone to decomposition. It has an average of 110 parts (Tollerton, 1997) that may separate after death. Eurypterids molted or shed their exoskeletons; most fossil specimens may actually represent cast-off moults (Clarke and Ruedemann, 1912; Tollerton, 1997). It is therefore no surprise that "the finding of well-preserved specimens of eurypterids is fortuitous or the result of diligent search" (Copeland and Bolton, 1985).

Eurypterids have been assigned to at least 59 genera and more than 236 species (Tollerton, 1997). Some controversy exists, however, as to what constitutes a species, especially in the genus *Eurypterus*, the most common in local Silurian rocks. The first eurypterid specimen ever described, from Oneida County, NY in 1818 (and originally misidentified as a fish), was named *Eurypterus remipes*: this species was designated in 1984 as the official "New York State Fossil." The second species described was *Eurypterus lacustris*, found in Buffalo. Other species were assigned to this genus; some (such as *Buffalopterus pustulosus*) had since been placed in other genera. There seems to be a lack of agreement in the number of species of *Eurypterus* found in the Bertie Group. Four (*E. remipes, E. lacustris, E. dekayi, E. laculatus*) were listed by Tollerton (1997) (Fig. 2). Some authors, such as Copeland and Bolton (1985) and Ciurca and Hamell (1994), refer to the first two as subspecies of *E. remipes*, hence *E. remipes remipes* and *E. remipes lacustris*. Others question the distinction of *E. dekayi*. *E. laculatus*, previously misidentified by Copeland and Bolton (1985) as *E. remipes lacustris*, was described by Ciurca (1990) as characteristic of the Fiddlers Green Formation.

Part of the confusion appears to have arisen from the old separation of Bertie Group eurypterids into two geographic localities or "pools" (Clarke and Ruedemann, 1912; and others): the "Buffalo" and the "Herkimer." Forms from each were sufficiently distinct to some workers to merit different species names, while others viewed this as a multiplicity of names based on minor morphological variations. Thus some viewed *E. remipes* and *E. lacustris* as synonymous, and others called them subspecies. Ciurca (1982) demonstrated that *E. remipes* ("Herkimer pool") consistently occurs in rocks (Fiddlers Green Formation) that are older than those (Williamsville Formation) with *E. lacustris* ("Buffalo pool"). The present author believes that consistent differences (such as prosoma shape, expansion of the preabdomen in *E. lacustris*) exist to justify separate species status.

LIFE HABITS AND ECOLOGY

Studies of eurypterid ecology have usually involved comparison with the modern horseshoe crab (*Limulus polyphemus*) of our Atlantic coast, their closest living relative (Fig. 1). Eurypterids and *Limulus* share many morphological features that set them apart from other chelicerates (Clarke and Ruedemann, 1912; Robison, 1987), but it should be noted that eurypterids constitute a diverse group with varied shapes and sizes probably reflecting diverse modes of life.

Limulus is dimorphic, with females typically larger than males. Eurypterids are also dimorphic, with the genital appendage considered to be the key to identification of the sexes. Which type of appendage belongs to which sex, however, is still unclear. Clarke and Ruedemann (1912) considered eurypterids with a longer, more elaborate genital appendage to be females while those with shorter, simpler ones are males. Copeland and Bolton (1985) state the opposite. Tollerton (1997) refers to Type A and Type B without designating sex. Clarke and Ruedemann (1912) noted that in modern *Limulus* the appendage is larger and more elaborate in the female, which also tends to be larger than the male. Personal observation that the larger eurypterid specimens tend to have the longer genital appendage support a female designation consistent with comparison to modern *Limulus*.

Limulus comes ashore during the spring tide to mate, and eggs are laid in the sand. After hatching, individuals (which resemble adults) move to progressively deeper-water settings during ontogeny (Rudloe, 1979; Shuster, 1979), with small adults common at depths to about 30 m and mature adults living on the shelf at depths of less than 50 m (Prothero, 1998). When molting, *Limulus* flips onto its back and uses movements similar to those for burrowing. It exits through a split on the ventral side just behind the anterior edge of the prosoma. *Eurypterus* apparently molted in the same manner. *Limulus* can tolerate a wide range of temperatures and salinities, and can even crawl on land for short distances. It swims on its back by flapping its sternites, but usually crawls right-side up across the bottom. When flipped over, it easily rights itself by flexing its body and digging in the telson.

Limulus spends most of the day buried in the sand (Lockhead, 1950; Eldredge, 1979), and comes out to feed at night. Young animals eat polychaete annelids; adults eat bivalves and polychaetes (Fisher, 1984). They will also scavenge dead fish and mollusks.

Clarke and Ruedemann (1912) suggested that *Eurypterus*, like *Limulus*, fed on worms or dead organisms, and noted that members of the genus were not specialized, being neither wholly adapted to swimming, crawling, or digging. *Dolichopterus,* also found in the Bertie, appears to have been well adapted to swimming, with forward-facing compound eyes, longer and broader swimming legs, and long, spiny walking legs that may have aided in swimming. The much larger and apparently predaceous *Paracarcinosoma* and *Acutiramus* appear to have been more specialized, with the former possibly hiding beneath a thin layer of sediment until prey came close, and the latter adapted for swimming with its streamlined body and spatulate telson.

The habitats of eurypterids have been inferred by examination of associated faunas and the sediment containing their remains. The earliest (Ordovician and Early Silurian) eurypterids are found with typical marine organisms such as graptolites, brachiopods, cephalopods, and trilobites (Clarke and Ruedemann, 1912; Copeland and Bolton, 1985). Later Silurian forms are often associated with phyllocarids and leperditid ostracodes, and probably lived in marginal marine areas such as enclosed lagoons and estuaries. Devonian eurypterids are commonly associated with brackish or freshwater ostracoderms and arthrodire fish. Late Paleozoic forms are found with land plants, freshwater ostracodes, freshwater pelecypods, scorpions, insects, and amphibians, suggesting that eurypterids had by then moved into freshwater habitats and may have even ventured onto land.

The eurypterids of the Late Silurian Bertie Group, the focus of this paper, are found in a chemical dolostone (waterlime) that was precipitated under restricted, near-shore marine conditions off a landmass of low relief under the influence of an arid to semi-arid climate (Copeland and Bolton, 1985). Ciurca and Hamell (1994) interpreted the various environments represented by different parts of the Bertie Group; the Williamsville Formation is believed to represent intertidal conditions.

DISCUSSION

The author has collected fossils from the Williamsville Formation at Ridgemount Quarry beginning in October of 1997. To date more than 180 eurypterid specimens (mostly disarticulated remains) have been collected and recorded, including 28 "complete" (prosoma through telson, with at least some appendages present) individuals plus 10 lacking the telson.

Tollerton (1997) presented a table listing species found in the Bertie Group across New York State and adjacent Canada. Those from the Williamsville Formation in Ontario quarries: eurypterids: *Acutiramus cummingsi* (*Pterygotus* in many papers), *Dolichopterus macrocheirus*, *Eurypterus dekayi*, *E. lacustris*, *Paracarcinosoma scorpionis*; brachiopods: *Eccentricosta jerseyensis*, *Lingula* sp.; gastropods (undifferentiated); cephalopods: orthoconic nautiloids; phyllocarids: *Ceratiocaris* sp. (probably *C. acuminata*); ostracodes (undifferentiated); plants: *Cooksonia*.

Personal collecting experience adds the following to this list of species found in the Williamsville Formation at Ridgemount Quarry: eurypterids: *E. laculatus* (previously reported for Fiddlers Green Formation), *Buffalopterus pustulosus*; nautiloids: *Mitroceras gebhardi*, *Pristeroceras* *timidum*; conularids: *Metaconularia perglabra*; xiphosurans: *Pseudoniscus clarkei*; *Bunaia woodwardi*; Algae: *Medusaegraptis gramminiformis*.

Fossils are most abundant in the upper 20 cm of the lower part of the Williamsville Formation ("Williamsville A Submember" of Ciurca and Hamell, 1994), in a waterlime (chemical dolostone) that in places readily splits into slabs 1 to 4 cm thick but elsewhere may be quite blocky and splits conchoidally. The upper surface of this interval is presently exposed over much of the quarry floor in the southwest corner. Eurypterid remains are often concentrated at two general levels: from the surface to a depth of about 5 cm; and below a depth of about 10 cm.

Eurypterid specimens often consist of a "part," showing either the dorsal or ventral surface, on one slab, and the synjacent slab bearing a corresponding "counterpart" or imprint. Many of the complete and nearly complete specimens were found to include a dorsal counter-part, a ventral counter-part, and a compressed "part" representing the animal itself, which breaks free of the matrix. Most if not all specimens appear to represent cast-off exoskeletons (moults). Several exhibit a distinct separation of the dorsal and ventral surfaces of the prosoma, with a gap of up to 1 cm along the anterior edge where the animal crawled out. The moults, after reaching their final resting places, were apparently filled by precipitated dolomite in the preservation process.

Perhaps the most common of the disarticulated remains to be found are prosomas, which tended to be thicker than the abdominal segments and thus more likely to be preserved (Clarke and Ruedemann, 1912). These are usually still connected to the first tergite, probably reflecting strong articulation between the prosoma and the abdomen. In *Limulus* this aids in burrowing and pushing through the sediment in search of food.

The upper part of the "Williamsville A Submember" tends to be very straticulate, with fine, varve-like bedding visible on the edges of slabs. The interval, however, exhibits rapid lateral facies changes. Areas where the rock splits readily into flat, laminated sheets grade abruptly into areas where it breaks with a more irregular, commonly conchoidal surface. In other areas, the rock splits along very irregular surfaces covered with low domal structures which appear to be similar to certain stromatolitic structures observed in the Fiddlers Green Formation.

The author has noted a lack of specimens in areas with flat, laminated beds, and only few remains have been found in areas with the other extreme. Even where the rock has the "proper texture," eurypterid remains are not evenly distributed. While isolated specimens do occur, a majority of the specimens collected were found to be concentrated in widely-spaced, elongate windrows, attributed by Ciurca (1978) and Ciurca and Hamell (1994) to current activity that accumulated remains in the troughs of large, shallow ripple-like features. The author has collected numerous parts, complete individuals, and representatives of other groups from four recognizable windrows to date. These windrows were found to be parallel to each other, with the long axis oriented at roughly N44W.

It is interesting to note that the shallow, horseshoe-shaped depressions ("boomerangs" of Ciurca and Hamell, 1994) found at the top of the "Williamsville A Submember" in various places on the quarry floor are generally oriented perpendicular to these windrows (trailing edges roughly N45E). If the Williamsville Formation represents the intertidal zone (Ciurca and Hamell, 1994), the windrows may have been shallow depressions oriented parallel to shore in which cast-off moults and the remains of other organisms were accumulated during tidal processes. The "boomerangs" may have been scoured during tidal currents, possibly by local turbulence in front of some curved obstruction.

Of 188 eurypterid specimens collected and catalogued to date, *Eurypterus lacustris* is the dominant species represented (153 specimens), followed by *E. dekayi* (17), *Acutiramus* ("*Pterygotus*") sp. (9), *Paracarcinosoma scorpionis* (3), and two specimens each of *Buffalopterus pustulosus*, *Dolichopterus* sp., and *Eurypterus laculatus*. Because many specimens of *E. lacustris* were not collected (usually due to poor preservation or occurrence as isolated segments), the proportion of that species is probably far greater. It should be noted that because most specimens represent moults and most are separated parts or partial individuals, these numbers do not necessarily reflect a depiction of the actual proportions of living animals, but merely provide an idea of the likelihood of finding specimens of a particular species.

The three species of *Eurypterus* are represented by complete specimens (or specimens lacking the telson). Those of *E. lacustris* were measured to determine the size distribution (approximate telson length was added for those lacking that part). Results are presented in Table I, along with orientation data (dorsal-up or ventral-up) for these specimens. From the size distribution data, most complete specimens are between 4 and 8 inches (10 to 20 cm) in length, with both smaller and larger individuals relatively rare. The paucity of large specimens may reflect a progression toward deeper, offshore habitats during ontogeny like that observed for *Limulus*: the likelihood of moults from large individuals being carried intact into the intertidal zone would be low.

The up/down orientation data indicate that more than two-thirds of the (nearly) complete specimens were upside-down (ventral side up) when they reached their final resting place (10 dorsal-up; 23 ventral-up). In his examination of orientation of six specimens of *E. remipes* from the Litchfield locality, Tollerton (1997) suggested that a ventral-up orientation may result from either a ventral-up molting position or a more stable orientation in the presence of weak currents. No speculation is here made on the reasons for the orientations.

ACKNOWLEDGEMENTS

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TABLE 1. Size distribution and orientations of specimens of *Eurypterus lacustris*. Specimens either complete or lacking only the telson. Orientations: U dorsal-up; D ventral-up.

Size (inches)	Complete	Lacking telson
<1	0	1 (U)
1-2	0	0
2-3	0	2 (D)
3-4	0	0
4-5	4 (2-U,2-D)	1 (U)
5-6	3 (D)	2 (D)
6-7	5 (D)	1 (D)
7-8	7 (2-U,5-D)	0
8-9	2 (U)	0
9-10	1 (U)	2 (1-U,1-D)
>10	2 (D)	0
TOTAL:	24	9

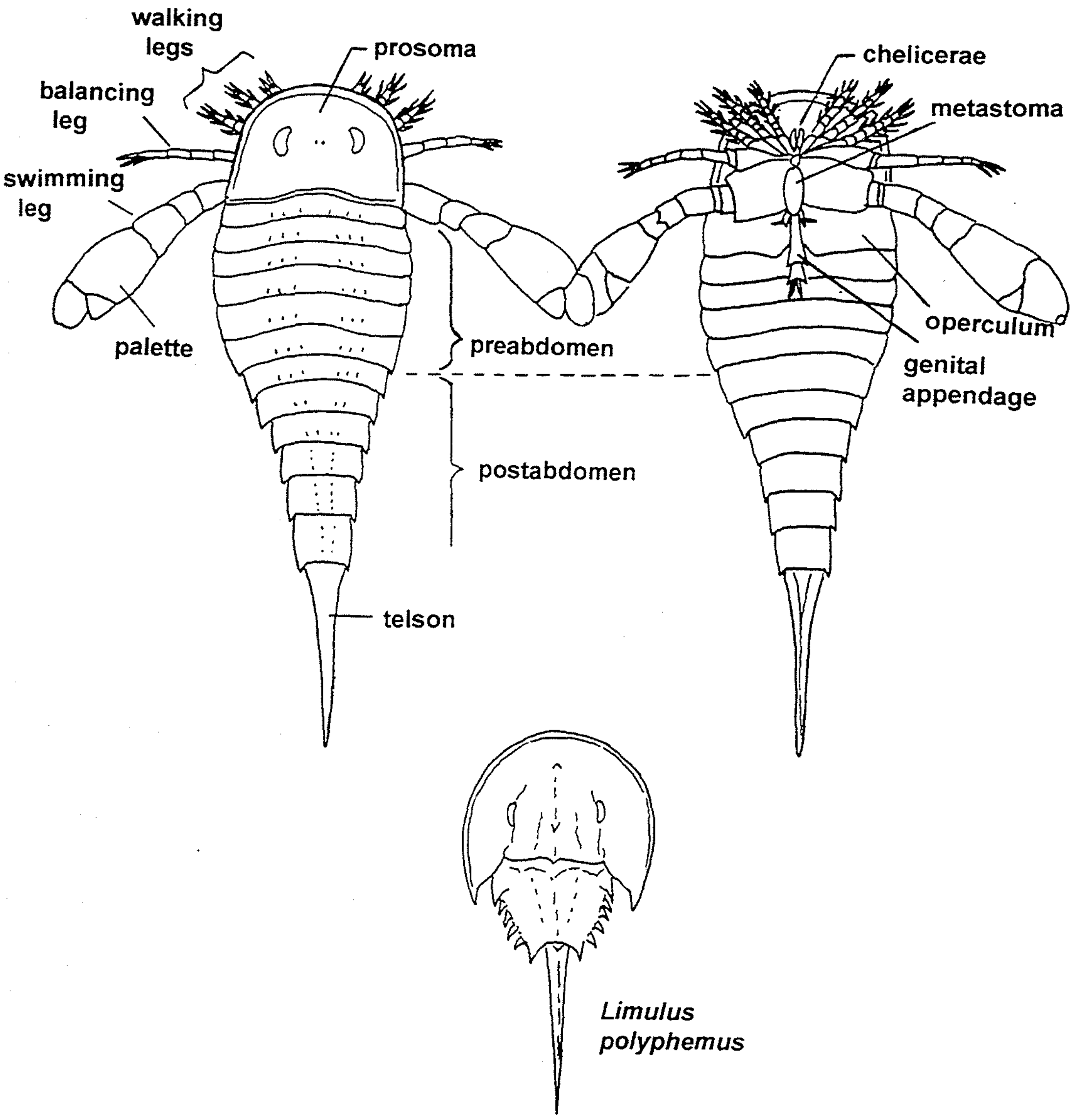

Figure 1. Drawing of *Eurypterus lacustris* with parts labeled. Modern horseshoe crab (*Limulus polyphemus*) shown for comparison.

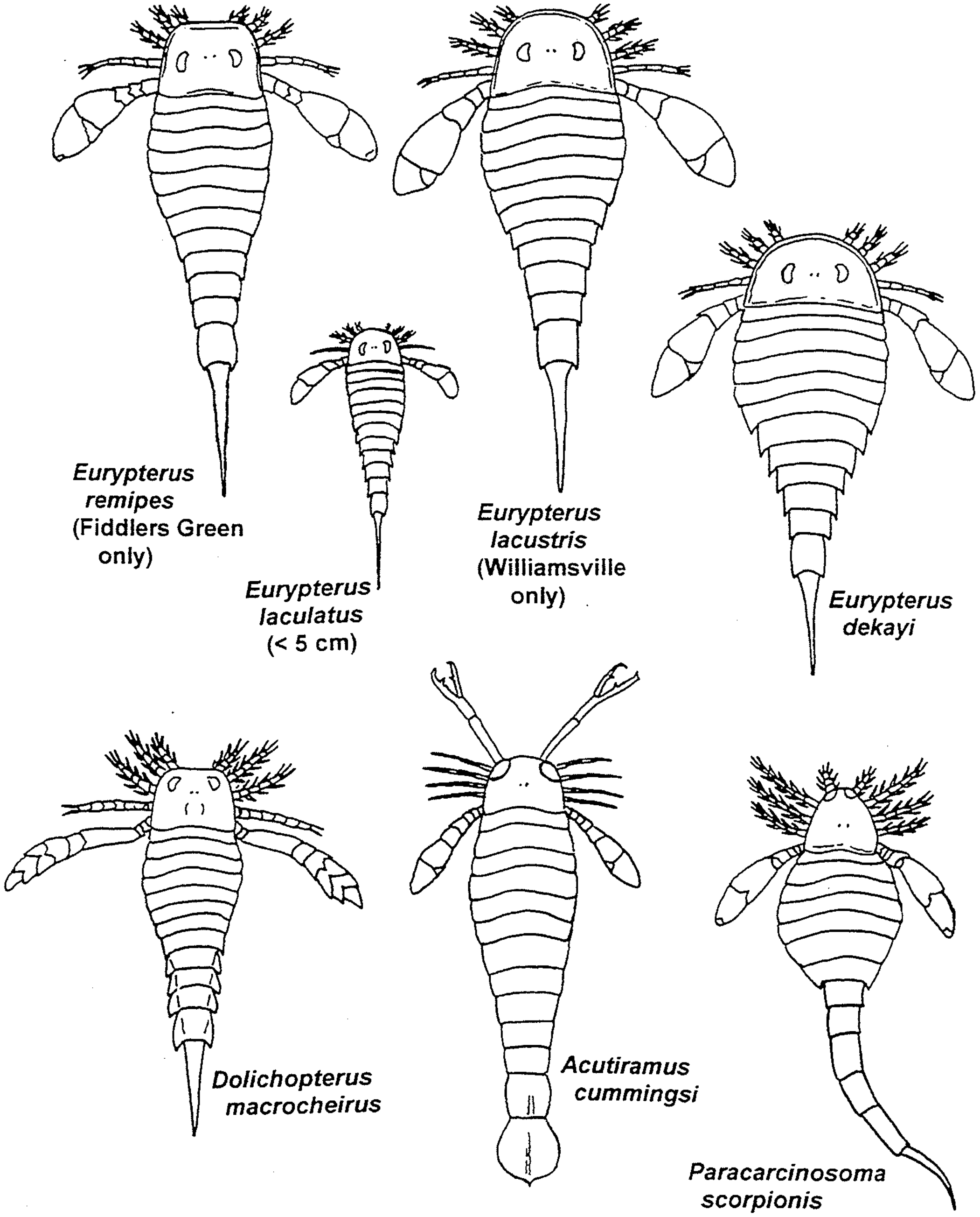

Figure 2. Some of the eurypterid species found at Ridgemount Quarry.

STRUCTURE AND UPPER DEVONIAN STRATIGRAPHY IN THE APPALACHIAN PLATEAU OF ALLEGANY COUNTY, NEW YORK STATE, INCLUDING THE CLARENDON-LINDEN FAULT SYSTEM

by

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INTRODUCTION

The Clarendon-Linden Fault System (CLF) is located in western New York, where it extends south from Lake Ontario into Allegany County (Fig. 1). The CLF has been called the "longest (?) and oldest (?) active fault system in eastern United States (Fakundiny et al., 1978a). Despite these kinds of accolades, and despite over 70 years of geological investigations (albeit sporadic) of the CLF, the CLF proved to be elusive. For example, prior to the most recent research program headed by Jacobi and Fountain (1996), the CLF had never been observed in outcrop.

The primary objective of this field trip (Fig. 2) is to examine one of the sites where the CLF does affect surface bedrock units. Other structural features that will observed on the field trip include 1) a NE-striking brittle thrust related to Alleghanian tectonics, 2) bedding restricted (intra-stratal) pencil cleavage and associated "roll-up's" of assumed Alleghanian age, and 3) fracture intensification domains (Fig. 3). Additionally, we will make several stops that illustrate the detailed Upper Devonian stratigraphy we developed during the course of the investigation (Fig.4). This stratigraphy appears to be controlled in part by motion on the CLF.

ABBREVIATED HISTORY OF INVESTIGATIONS ON THE CLF[1]

The CLF was first recognized by Chadwick (1920), who noticed that the Niagara and Onondaga escarpments exhibited prominent doglegs aligned in a N-S fashion. He suggested that an approximately N-striking fault with about 30 m (100 ft) stratigraphic offset (down-on-the-west) could account for the dogleg pattern. Stratigraphic offsets of Upper Devonian units across a N-striking valley and alignment of springs supported the proposed fault location. However, in 1932 Chadwick (1932) revised his hypothesis, and suggested that the CLF was merely a fold (monocline) in units above the Silurian salt section, although it was indeed a fault in the units below the Silurian salt section. Work by Sutton (1951) and Pepper et al. (1975) supported Chadwick's (1932) revised scenario.

The potential siting of nuclear power plants along the Lake Ontario shore prompted the most in-depth study of the northern portion of the CLF. This study included well log analyses (Van Tyne, 1975), fracture, fault and pop-up measurements (Fakundiny et al., 1978b), and seismic reflection profiles across the fault system (Fakundiny et al., 1978b). At about the same time, Fletcher and Sykes (1977) investigated increased seismicity of the CLF near Dale (NY) that resulted from high pressure injection for hydraulic salt mining.

Van Tyne's (1975) well log analyses showed that below the salt section the CLF consisted of at least 3 main faults with at least one subsidiary fault, the Attica Splay (Fig. 1). More recent well log analyses by Van Tyne (1980a-e), Murphy (1981), Beinkafner (1983), and Harth (1984) supported Van Tyne's (1975) initial work for regions north of Allegany County. Seismic reflection studies (Fakundiny, et al., 1978b) supported the multiple fault hypothesis, but suggested

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[1] - for a more complete guide to the investigations of the CLF, see Jacobi and Fountain (1993)

that each fault identified in well logs was actually two faults. The constant spacing and dip of faults observed on the various seismic lines suggested to Fakundiny (et al., 1978a) that the faults were continuous features from essentially the Lake Ontario shore to the southern line shot near Pike, NY (Fig. 1). The quality of the seismic records was such that little could be discerned above the Onondaga reflector, which appeared to cross most of the proposed faults with little offset. This lack of major offset in the Devonian unit supported Chadwick's (1932) contention. Stratigraphic offset in reflectors below the assumed salt section was observed, and was not constant along strike.

Fakundiny et al. (1978a) measured over 6000 fractures, 87 pop-ups, and several faults in 47 topographic quadrangles that bordered the CLF. They found primarily NW and NE-striking fractures, and did not recognize "an easily understood relationship between joint rose diagrams and the geometry of the [CLF]". However, Gross and Engelder (1991) did find NNE-striking fractures in a quarry at Clarendon, adjacent to the main faults of the CLF.

For the northern part of the CLF in NYS, several researchers recognized the relation among gravity anomalies, magnetic anomalies and the CLF (Revetta et al., 1978, 1979; Fakundiny et al., 1978a,b, 1981; and Culotta et al, 1990). The CLF is located along the western gradient of gravity and magnetic highs, which Culotta et al. (1990) traced southward to seismic lines where intra-Grenvillian faults were imaged. Similarly, gravity and magnetic anomalies associated with the CLF can traced northward across Lake Ontario (Diment et al., 1974; Fakundiny et al., 1978a,b, 1981; Hutchinson et al., 1979; Revetta et al., 1979; and Forsyth et al. 1994) where seismic lines also show east-dipping reflectors in the Precambrian basement that are interpreted to be thrust faults of the intra-Grenvillian suture --the Elzevir-Frontenac Boundary Zone (e.g. Forsyth et al., 1994).

There is little doubt that portions of the northern CLF are seismically active. Nodal plane solutions for seismic events in 1974 and 1975 (Fletcher and Sykes, 1977) and in 1966 and 1967 (Hermann, 1978) are consistent with a NNE-striking CLF fault in the Attica/Dale region. Plots of seismic events in western New York also show a strong spatial correlation between the CLF and increased seismicity (Jacobi et al., 1996; Tuttle et al., 1996), especially where the CLF trend intersects a NW-trending gravity anomaly. This NW-striking gravity anomaly is the locus of increased seismicity NW of Attica (Jacobi and Fountain, 1996). Tuttle et al. (1996) has determined from probable aftershock locations that the 1929 Attica seismic event, with an estimated mb=~5.2 (Street and Turcotte, 1977), occurred on the main faults of the CLF east of Attica. Although this seismic event, the second or third largest in NYS, is generally assumed to be of natural origins, Seeber and Armbruster (1993), raised the possibility that this event was an induced event, similar in origin to those generated by the hydraulic mining of salt at Dale.

Despite all of these studies, much of the CLF character remained unclear in the 1980's. For example, no study had actually identified a CLF-related fault at the surface, and in fact, all researchers believed that the fault system 'died-out' in units above the Silurian salt section (e.g., Van Tyne, 1975; Fakundiny et al., 1978a; Harth, 1984). Similarly, the actual number of CLF faults, the along-strike continuity and the vertical extent of the CLF faults were not known. The southern extent of the CLF faults also was unknown; the CLF was never drawn significantly south of Wyoming County primarily because of a lack of data farther south. Additionally, no NW-striking faults had been mapped in western NYS, and only a few NE-striking, assumed Alleghanian faults were recognized in the same region.

The uncertainties described above were the state of affairs in 1988, when the m=6.5 Saguenay earthquake in Quebec apparently caused fractures of the CLF to open near Pike, NY, allowing gas to seep to the surface. The vigorous gas seep blew mud into the tops of the surrounding trees (Jacobi et al., 1990; Fountain, et al., 1990; Jacobi and Fountain, 1993). At the same time, the NYS Low Level Radioactive Waste Siting Commission (NYSLLRWSC) designated 3 sites in Allegany County as potential disposal sites for low-level radioactive waste. The possibility that the CLF could be reactivated by a distant earthquake, and the possibility that the CLF extended into Allegany County, in a region where the CLF was not previously known to exist, conflicted with the assumed simple geology of the potential disposal sites proposed by NYSLLRWSC. To resolve the geological ambiguities in northern Allegany County, Jacobi and Fountain mounted a comprehensive, integrated research program that involved the following tasks: 1) traditional and innovative fracture and fault analyses, 2) detailed stratigraphic measurements, 3) geochemical analyses of sandstones to aid in correlations, 4) soil gas analyses, 5) VLF analyses, 6) well log analyses, 7) seismic reflection profiles, 8) lineament analyses on remote sensing images including Landsat, SLAR, topographic maps and air photos, 9) gravity and magnetics, 10) seismicity, and 11) neotectonics. Results thus far have been presented in a final report to NYSERDA (Jacobi and Fountain, 1996), as well as several papers and abstracts.

RESULTS OF THE CLF INVESTIGATION

We developed rapid and rigorous structural field and lab methods, including acquisition of digital fracture map patterns and fractal and geostatistical analyses of these digital images (Jacobi and Zhao, 1996a,b). In Allegany County these structural methodologies revealed: 1) several regions where N-striking, small-offset step faults at the surface correspond to stratigraphic offset observed in well logs, surface stratigraphy, seismic reflection profiles, and N-striking lineaments, 2) NE- and NW-striking faults, and 3) fracture patterns that correspond to fault zones at depth. These fracture patterns, termed Fracture Intensification Domains (FIDs, Jacobi and Fountain, 1996; Jacobi and Xu, 1998), can be recognized by a combination of characteristics, including master fractures that parallel the length of the FID, even though that fracture set may not be the regional master set outside the FID, closely-spaced fractures along the trend of the FID, 3) higher fractal dimension and a different semi-variogram spacing and length distribution compared to regions outside the FID, and 4) small step faults along the trend of the FID. Where we have multiple data sets in the region of an FID, the FIDs correspond to a) major lineaments, b) fault offsets inferred from stratigraphy, well log analyses, and seismic, and c) soil gas anomalies for primarily N-striking FIDs. Using FIDs integrated with the other data sets, we were able to construct a map displaying the FIDs in northern Allegany County (Fig. 3). This map shows a number of N-striking FIDs, which correspond to CLF faults. These faults are not continuous; rather, they terminate against NW-striking FIDs and E-striking FIDs. The E-striking FIDs in the region of CLF faults may be NW-striking FIDs that curve into perpendicularity with the CLF trends. NE-striking FIDs correspond to ramping Alleghanian thrusts, and the NW-striking FIDs are essentially cross-strike discontinuities (CSDs) that acted as tear faults (or transfer zones) for the NE-striking faults and as transfer zones for the N-striking faults. We also found numerous bedding restricted (intrastratal) shear zones, or thrusts, marked by pencil cleavage, highly disturbed bedding and exotic clasts. Stacks of these zones, as many as 7, indicate that Appalachian thrusting was accomplished by "flats" in this region in the Upper Devonian shale/sandstone section as well as along the Silurian salt with ramps into the upper sections. The array of FIDs and faults, both observed and inferred from various data sets, is astounding, when one considers that no faults were hypothesized in this area just 10 years ago.

Detailed stratigraphy showed that fault offsets observed at depth in well logs and seismic could be recognized in the surface bedrock units, demonstrating that the fault systems do extend to the surface bedrock, and confirming that faults occur along many of the hypothesized FIDs. The detailed stratigraphy also demonstrated the growth fault geometry of the CLF for several units, including the Hume and Rushford formations (Smith and Jacobi, 1998a, and 1999; Smith et al., 1998). Thus, the surface stratigraphy not only revealed the amount of offset across faults, it allowed us to determine the fault motion history for the time represented by the surface units.

Geochemistry of the sandstones (Bechtel et al., 1996) showed that there is a geochemical stratigraphy in the section that allowed us to confirm some equivocal lithostratigraphic correlations. Soil gas analyses (Fountain et al., 1996) demonstrated that many of the N-striking FIDs, and a few FIDs with other trend, are conduits for deep thermal gas. Thus, soil gas analyses allowed us to trace CLF faults in regions of no outcrop, and to confirm that lineaments did follow fault-related FIDs now buried by glacial and Quaternary sediments.

The small number of available well logs in northern Allegany County at the DEC in Olean did not allow tight resolution of many fault systems hypothesized from surface data. Nevertheless, the wells were spaced in such a fashion that the main central CLF faults in northern Allegany County could be delineated, as well as one of the NE-striking Alleghanian faults (Jacobi and Fountain, 1993). Additional wells demonstrated that a N-striking graben is formed by inward facing faults in the Rushford Lake Region. This graben was also observed in the surface stratigraphic data. Well log analyses also showed that growth fault geometries are common for the CLF throughout much of the Paleozoic for which we have a rock record (Jacobi and Fountain, 1993, 1996).

We shot three seismic lines and purchased one line across the CLF (Fig.2). Each line displays different fault features, although some common characteristics can be recognized in all the lines. The distinct differences emphasize the non-continuity of the CLF faults, at least in the section above the Trenton. On the northern line near Wiscoy (CLF-1), the main central fault of the CLF is clearly displayed as a west-dipping thrust with numerous splays similar to a flower structure. The fault system affects all Paleozoic reflectors and is located below a prominent N-striking valley in which we had soil gas anomalies but no outcrop. The central seismic line (Centerville line, CLF-2) displays deep structure similar to that observed on CLF-1 (in Trenton and deeper reflectors), but the deep structure is displaced westward, compared to CLF-1, assuming a N-strike coincident with fractures and lineaments at the surface. The displacement probably occurs along a NW-striking transfer zone or CSD that is located between the two seismic lines. In both seismic lines east-dipping reflectors in the Precambrian basement are similar to east-dipping reflectors observed on a seismic line in Lake Ontario, where Forsyth et al., (1994) suggested that the reflectors represented thrusts of the intra-Grenvillian Elzevir-Frontenac Boundary Zone. Although Forsyth believed these faults were not active in Paleozoic times, to the south, on our lines, displacement in basal Paleozoic reflectors suggest that the Precambrian thrusts acted as listric normal faults during Iapetan breakup. Furthermore, the CLF faults in the Paleozoic section extend down to the Precambrian thrusts, indicating that reactivations of these basement faults resulted in the CLF faults observed in the Paleozoic section. The third seismic line we shot, the Rawson line (CLF-3) crosses the western main fault of the CLF, which is located beneath the N-trending Rawson Valley. A N-striking FID along the valley (Jacobi and Xu, 1998), minor N-striking faults, N-striking dipping beds, prominent N-striking lineaments, soil gas spikes, and stratigraphic offset of units across the valley (Jacobi and Fountain, 1996; Peters and Jacobi, 1997) all implied a fault zone where the seismic line subsequently was shot. This line shows clear faulting in the Trenton and older units, but faults that extend to the surface apparently are small displacement step faults, as only a monocline is observed in the upper reflectors. The southernmost line, CLF-4 was shot parallel to the NE-thrusts and displays over 500 ft of fault-controlled thickening in the Trenton-Black River section.

Using growth fault geometries, it appears that the CLF, overall, was active through most of the rock record, but detailed comparison demonstrates that individual segments of the fault system, both along-strike segments, and across-strike faults, have different histories of motion. In fact, comparison between the Rawson fault (western main fault) and the central fault imaged on lines CLF-2 and 4 show that much of the time in Silurian and Devonian, the faults moved out-of-phase, i.e. if one was in motion, the other was temporarily quiet. Some common elements can be found along strike, but the amount of offset varies dramatically among along-strike segments.

Lineament analyses integrated with the other tasks demonstrated that major lineaments were related to FIDs along faults, as inferred from all other tasks discussed above. Relatively short lineaments observed on topographic maps and air photos (on the order of 200 ft) commonly are related to fractures, but are not necessarily related to FIDs. Major lineaments are displayed as an integral part of the FIDs in Figure 3.

Gravity from National Geophysical Data Center (NGDC) shows that the CLF lies generally along the western gradient of a gravity high. Near Attica a steep gradient of a gravity high extends NW from the CLF-associated gravity high. Seismic events are located primarily along the western gradient of the CLF and the intersecting NW gravity gradient, especially near the intersection. Jacobi and Fountain (1996) hypothesized that the NW-striking gravity high was related to intrusions along a fault system similar to the Mid-continent Gravity High.

Neotectonic study did not discover clear evidence of liquefaction, either in northern Allegany County or in the Attica area (Tuttle et al., 1996). The lack of liquefaction features such as sand blows may indicate that the CLF has not sustained a m=~6 seismic event in postglacial times (Tuttle et al., 1996). Calkin (pers commun., 1995) has expressed concern over the possible lack of suitable sand units to serve as a source for liquefaction features, but this low magnitude estimate is consistent with the short segments of the faults of the CLF. To estimate the maximum magnitude of a seismic event that the CLF is capable of generating is not easy, because of the lack of large magnitude historical events, the known long recurrence rates of large seismic events on stable craton faults (such as the CLF), and the concerns about the m=6 estimate from the neotectonic studies.) Two studies recently arrived at similar conclusions for stable craton faults (Johnston et al., 1994; Jacobi et al., 1997), including the CLF. These studies suggest that there is a very remote chance that a m=6.5 to 7 could occur on stable craton faults at any time. This upper limit is also consistent with calculations for the maximum magnitude for CLF activity in Upper Devonian time. Using data from Upper Devonian sandstones, considerations of changes of paleoflow direction possibly caused by intermittent fault scarps provide a scale of recurrence rates and maximum magnitude of seismic events. This calculation assumes one seismic event caused a scarp that diverted the paleoflow from its normal west or northwest flow to a northerly flow parallel to the faults of the CLF (Smith and Jacobi, 1998b). Although this calculation, and the premise upon which it is constructed, have wide error bars, the resulting maximum magnitude in the Upper Devonian was about a m=6.9 (Smith and Jacobi, 1998b).

FIELD TRIP DISCUSSION

Mileage			
Total	Distance	Directions	Location
0	0	Start, turn left out of parking lot towards Central Ave.	SUNY Fredonia parking lot, Houghton Hall
0.1	0.1	Right onto Central Ave.	Central Ave.
0.6	0.5	Left onto Temple Rd.	Intersection of Central and Temple
0.8	0.2	Left onto Rt. 20 eastbound	Intersection of Temple and Rt. 20
0.9	0.1	Right onto Eagle Rd.	Intersection of Rt. 20 and Eagle Rd
1.5	0.6	Take right fork, still on Eagle Rd.	Fork between Eagle and Stone Quarry Rd.
2.2	0.7	Right onto Rt. 60 southbound	Intersection of Eagle and Rt. 60
2.5	0.3	Right onto Wilson Rd.	Intersection of Rt. 60, Straight Rd and Wilson Rd.
2.8	0.3	Left at stop sign, head toward village of Laona	Town of Laona
2.9	0.1	Left onto Webster Rd.	Intersection with Webster Rd.
3	0.1	Redlight at Webster Rd., **STOP 1**	Park before light and view the Upper Devonian Laona Sandstone type locality from bridge

Stop 1, the Laona waterfall, has been discussed in previous field trip guides (e.g., Baird and Lash, 1990). The basal sandstone of the Laona is exposed at the top of the waterfall. The importance of the Laona on our field trip is its proposed correlations. One of the proposed correlations is with the Bradford Third Sandstone (Fettke, 1938, Tesmer, 1963), and thus the Laona is a proxy for one of the most well-known, but never exposed, oil sands in the USA. A second correlation is with the Rushford Formation sandstones in northern Allegany County (Chadwick, 1923, 1936). As we shall see in stops 2 and 3, the Rushford Formation is a distinct marker unit in the upper Devonian shales and sandstones of Allegany County. Shallow drilling in northwestern Allegany

County explored the Rushford as a reservoir rock. We suspect that the first oil well drilled in NYS, the McClintock #1 on Agett Rd, was probably drilled into the Rushford Formation. Oil springs in the area of the first well were most likely controlled by migration along fractures of the CLF from the Rushford sandstones, themselves a fractured reservoir in this area.

Mileage			
Total	Distance	Directions	Location
3.2	0.3	Right onto Rt. 60S	Intersection of Webster Rd. and Rt. 60
4.6	1.4		POI (point of interest) - passing Shumla Rd on left, type locality of Upper Devonian Shumla Sandstone.
8.3	3.7		Intersection of Rt. 60 and Rt. 58, village of Cassadaga
15.9	7.6		POI - outside of Sinclairville, wells tap the Bass Island Trend, a set of Alleghanian NE-striking thrusts.
19.7	3.8	Straight onto Rt. 65	Intersection of Rt. 60 and Rt. 65, village of Gerry
25.1	5.4	Right onto old route 17	Intersection of Rt. 65 and old route 17
25.75	0.65	Right onto entrance to Southern Tier Expressway, head east toward Binghamton (Rt. 17E)	Entrance ramp to Rt. 17
43	17.25		POI - entering Allegany Indian Reservation (of the Seneca Indians)
44.6	1.6		POI - crossing Allegheny Reservoir
54.8	10.2		POI - passing the town of Salamanca, named for a Spanish backer of the New York, Lake Erie and Western RR (Erie RR). This railroad was the one that Daniel Webster viewed from a rocking chair tied down to a flat car.
54.8	0		POI - from Salamanca to Rt. 219 S intersection, we will pass scattered outcrops of Conneaut and Conewango Group sediments
60.9	6.1		POI - crossing Allegheny River
61.9	1		POI - crossing Rt. 219, last exposure of scattered outcrops

63.6	1.7		POI - passing Chipmunk Creek on right, location of Chipmunk oil field
66.1	2.5		POI - passing the Olean kame end moraines
67.3	1.2		POI - crossing the Allegheny River for the last time
70.4	3.1		POI - view of Mt. Herman and Rock City (exposures of the Pennsylvanian Olean Conglomerate hold up the top of this mountain)
71.4	1		POI - passing the city of Olean. Olean was a major oil transshipment point on the Erie Railroad, and also the site of refineries. The last refinery to operate was the Socony-Vacuum, which quit in the 1950's
71.4	0		Dresser-Rand (to the right) still constructs compressors and gas turbines for the oil patch. In the 1960's, it accounted for 2/3's of all such equipment built worldwide.
72.4	1		POI - outcrop on left, of something
82.9	10.5		POI - N-trending steep hill on left. The Cuba Indian Oil-Spring Reservation, the first reported occurrence of petroleum in North America, is located in the valley west of the hill. This oil spring is on strike with the Rawson Valley CLF fault.
86.2	3.3		POI - sharp-based packet of storm-generated sandstones outcrop on left, equivalent to the Upper Devonian Cuba Sandstone.
89	2.8		POI - eastern Continental Divide
92.2	3.2	Exit 29 Shortcut to Stop1, take exit, then county Rt. 17 north to Little John Rd.	Exit 29 - Friendship. Oil patch operators to the south built mansions in this town. Now the home of Friendship cottage cheese.
97.8	5.6	Take exit 30	Exit 30 - Belmont, Wellsville, and Letchworth
98.2	0.4	Right onto Rt. 19S	Intersection of Rt.17E exit ramp and Rt. 19

98.5	0.3	Right onto county Rt. 20, and enter TravelPort -Buckhorn-Mobil to regroup and refuel	Intersection of Rt. 19 and c. Rt. 20.
98.5	0	Left onto Rt. 19N	Intersection of Rt. 19 and c. Rt. 20.
101.8	3.25		POI - outcrop of the Rushford Fm on left displaying the contact between sandstone and overlying transgressive lag
101.8	0.02		POI - outcrop of the Rushford Fm on left displaying disrupted bedding, roll ups, folded units and pencil cleavage related to an Alleghanian NE-striking ramping thrust
101.8	0.03	**Optional Stop**, park in clearing before bridge, walk down to the Genesee River via path - outcrop of the Rushford Fm.	Intersection of Rt. 19 and c. Rt. 16 (Angelica Transit Bridge)

Optional Stop, Genesee River, by Transit Bridge. This optional stop displays the Rushford Formation exposed by the river's edge. Shoreface sedimentary structures common to the Rushford Formation and soft sediment deformation can both be observed here. Outcrop of the Rushford at the river level is very similar to the Rushford exposed along Rt. 19 to the South at mile 101.75 of the field trip. The elevation difference is caused either by a NW-striking fault or the thrust zone at mile 101.77 of the field trip.

Mileage			
Total	Distance	Directions	Location
102.7	0.9		POI - gully on left contains outcrop of the Rushford Fm.
104.4	1.7	Left onto c. Rt. 17 (White Creek Rd)	Intersection of Rt. 19 and c. Rt. 17 (White Creek Rd)
104.7	0.3		POI - roadcut on left of the Rushford Fm.
105	0.25		POI - 20 ft beyond the road to the left is old Rushford quarry described by James Hall in 1843
105.3	0.3	Right onto Little John Rd.	Intersection of c. Rt. 17 and Little John Rd.
105.4	0.1	Cross bridge and Park - **Stop 2**	White Creek Outcrop of the Rushford Formation

Stop 2, White Creek. This stop consists of two separate outcrops that illustrate the characteristics of both the CLF faults and the sandstones of the Rushford Formation. We will examine first the downstream outcrop (Stop 2A), where the Lower Rushford sandstone packet outcrops in three stacked lowstand shoreface sequences; each shoreface sequence capped by a transgressive lag deposit (Smith and Jacobi, 1996,1998a, 1999) (Fig. 4). Here the master fractures strike approximately north (Fig. 5A)--an anomaly compared to the usual NW and NE striking fractures found in western NYS (e.g. Engelder and Geiser, 1980). As shown in Figure 5B, the spacing of the N-striking fractures here is quite close, compared to nearby regions that have essentially no N-striking fractures. That the N-striking fractures are relatively closely-spaced, and are masters, suggest that a N-striking FID passes through the outcrop at White Creek.

Site 2A: White Creek Rd, by Little John Rd. bridge. North of the bridge is a large exposure of the three-shoreface sequences that comprise the lower sandstone packet of the Rushford Formation At the northernmost exposure of the outcrop, the 1st shoreface sequence forms the lowest step in the series of small falls that comprise outcrop (Fig. 6B, C) The top bed is a fossiliferous, medium to coarse-grained sandstone that typifies the transgressive lags that occur over the shoreface sequences in lower sandstone packet. Overlying the 1st shoreface is a thick interbedded section that is well exposed on the east cliff exposure. Soft-sediment deformation, primarily ball-and-pillow structures, are well exhibited in the sandstone beds beneath the 2nd shoreface sequence. The 2nd shoreface sequence displays planer laminated beds typical of the shoreface sequence but more noticeably contains a large olistrolith of sandstone surround by a debris flow indicative of a syndepositional mass flow. The top of the 2nd shoreface sequence occurs near the main falls. This sandstone displays small dunes (amplitude - ~0.5m, wavelength ~2.0 m) with symmetrical ripples. The 3rd sandstone sequence forms the upper part of the cascade; the most noticeable feature is the transgressive lag that caps the falls. This lag deposit contains large clasts of white, cloudy quartz as well as numerous brachiopod shell fragments and large red silt clasts. The underlying sandstone contains *Rhizocorallium, Arenicolites and Thalassinoides*, typical of a *Glossifungites* firmground. Overlying the 3rd shoreface sequence is the thick interbedded sequence that separates the lower sandstone packet from the upper sandstone packet (Fig. 6B,C).

Below the waterfall, the vertical and overhanging outcrop on the east side of the creek displays a characteristic of FIDs. Some of the N-striking fractures exhibit small stratigraphic throw (on the order of a few cm). These step faults may be a small scale example of the step faults that are observed on seismic lines as “folds’ or sharp monoclines; i.e., the amount of offset on any one fault is below the resolution of the seismic line. These small scale faults, with a down-on-the-west sense of motion, are consistent with the larger scale fault inferred from the juxtaposition of stops 2A and 2B (Fig. 6B, C).

In the creek bed upstream from the bridge, as well as along the east wall of the creek near the bridge, several bedding-restricted (intra-stratal) zones of pencil cleavage outcrop. Elsewhere in western NYS pencil cleavage has been ascribed to bedding parallel thrusts of Alleghanian age, primarily because the cleavage usually strikes NE, parallel to the Alleghanian fold axes and crinoid strain ellipsoids (Engelder and Geiser, 1979; Jacobi and Zhao, 1996a,b). Here the cleavage has several trends, including NNE, NE and approximately NS, parallel to the CLF fractures. In a few localities it is possible to observe the N30E trend curving into parallelism with the approximately N-S. We suggest that the pencil cleavage does indicate early bedding-parallel shear (bedding thrusts) that has an Alleghanian age; the N-striking cleavages suggest that the CLF was also active at this time also and locally controlled the generation of the pencil cleavage. Throughout the outcrop south of the bridge N-striking master fractures clearly cross the pencil cleavage zones, indicating that at least the last generation of N-striking master fractures post-dated the generation of the pencil cleavage.

Spectacular boudined sandstone blocks (roll-ups) occur in some of the pencil cleavage zones. Some sandstone rollups display dewatering phenomena, such as hairline sandstone dikes. Apparently, the dewatering occurred as the deformation of the block progressed, as the blocks display both brittle (small step faults) and ductile behavior (the primary folding, or roll-up). The question remains whether the roll ups are solely the result of deformation associated with the generation of pencil cleavage, or whether they indicate sediment slides (such as the one below the sandstones) that were then deformed further during generation of the pencil cleavage and bedding-parallel shear. Throughout Allegany County, we have found a strong association between roll-ups and pencil cleavage (Jacobi and Zhao, 1996a,b), and believe that many of the roll up zones did originate during bedding-parallel shear. However, the zone of roll-ups exposed farthest upstream at Stop 2A appears to have a "bumpy" upper contact with local depressions that were filled in by the overlying unit. In this case, the roll-ups may have originated as a sediment slide and then been further deformed during generation of the pencil cleavage.

Near the south end of the outcrop, in the area of pencil cleavage, N-striking master fractures with anastomosing abutting fractures have a raised weathering profile, and indicate either the injection of sand ("neptunian dikes") or fluids that resulted in a more resistant unit.

Stop 2B, about 0.4 km upstream from Stop 2A (0.25 mi south of Little John Bridge - it is easiest to walk along the road, then head down into the creek to the waterfall), appears to exhibit a very similar stratigraphy to that exposed at Stop 2A. The same, major depositional elements are present at both outcrops (Fig. 6B). At both outcrops, a sediment slide without any cleavage development is found below the thick sandstone packet. The sandstone packet at the Stop 2B waterfall itself is similar to the sandstones of the upper part of the 2nd shoreface sequence and all of the 3rd shoreface sequence at Stop 2A. Although the Stop 2B outcrop does not have a thick transgressive lag deposit similar to Stop 2A, a thin coquinite is observed at the top of the 3rd shoreface sequence and on top of the 2nd shoreface sequence, large cloudy quartz pebbles can be observed (Fig. 6B). Finally, both outcrops have zones of pencil cleavage above the sandstones.

The question is: are the two sequences at stops 2A and 2B the same, with a N-striking fault separating the two outcrops, or are the repetitions merely coincidental repetitions of depositional environment, with a stratigraphic succession accounting for Stop 2A below Stop 2B. If the two outcrops do indicate a fault, then the offset between the outcrop at Stop 2A and the repeated section at Stop 2B is approximately 11.6 m (~38 ft), down-on-the-west (Fig. 6B, C). We suggest that the repetition is tectonic for several reasons: 1) elsewhere, the Rushford does not have two sets of similarly repeated units, 2) the N-striking fractures at both sites are anomalous, and provide a warning that N-striking structures may be in the area, 3) the small step faults at the lower wall of Stop 2A are consistent with the sense of motion necessary to account for the repetition of units.

Mileage			
Total	Distance	Directions	Location
105.4	0	Finished with Stop 2, head west along Little John Rd.	Leaving White Creek
106.6	1.2	Right onto Rt. 305	Intersection of Little John Rd and Rt. 305
108	1.4	Left onto Rt. 19N	Intersection of Rt. 305 and Rt. 19, town of Belfast
113	5.05	Left onto Rt. 243	Intersection of Rt. 19 and Rt. 243, town of Caneadea
113.6	0.55	Left onto Hillman Rd.	Intersection of Rt. 243 and Hillman Rd.
113.8	0.2	Right onto Mill Street Rd	T- intersection of Hillman Rd. and Mill St.
114.4	0.6		POI - for road access to Caneadea Gorge, ask permission at house on left
114.8	0.4	Stop past guard rail - **Stop 3**	POI - overlook of Caneadea Gorge, type locality for the Caneadea Fm.

Stop 3 Caneadea Gorge overlook, east of Rushford Lake. The type section for Caneadea Formation as defined by Chadwick (1933) contains exposures of three of the four informal members of the Caneadea Formation (Gorge Dolomitic, Higgins, and the West Lake members). The Rushford Formation outcrops beneath the overlook, 4-5m from the top of the cliff (Fig. 7). There are two ways to gain access to Caneadea Gorge: one is located at the Rushford Dam picnic area where a small, steep path leads from the top of the cliff to the creek. Old quarries to the left of the path expose the thick Rushford sandstones. The 2nd is an access road, near a small farmhouse on this road at the base of the hill east of the overlook. There is a locked gate, but access can be obtained by asking permission at the farmhouse.

Mileage			
Total	Distance	Directions	Location
115	0.2	Turn left then straight at the fork leading into the park	Intersection of Mill Street and Dam roads
115.1	0.1	Keep left and park by pine trees - Stop for lunch -**Stop 4**	Rushford Dam Park - POI - type locality for the Rushford Fm. at lake level.

Stop 4 Lunch stop at the Caneadea dam.
Beyond the fence is the Caneadea Dam and Rushford Lake
Old photographs of the construction of the Rushford Dam show the north wall of the gorge (the side we are on) devoid of trees, and show quarries of the Rushford sandstones. These quarries can still be found along the wall, and provide good illustrations of the thick Rushford sandstones here. By the dam, and around the eastern end of Rushford Lake, is the type exposure of the

Rushford Formation as defined by Luther (1902), although close, hands-on access to these outcrops can be difficult depending on the lake level. The sandstones of the Rushford Formation are much thinner here than at White Creek; the upper and lower sandstone packets and the interbedded section are condensed. Unlike the White Creek outcrop, the lower sandstone packet does not contain transgressive lag deposits, but does contain the three shoreface sequences and contains cloudy quartz clasts in the matrix of the upper shoreface deposits.

When the water level is lowered in the Fall, on the south gorge wall west of the dam can be seen a series of N-striking, east-dipping, closely-spaced step faults, each with minor offset (on the order of a few cm). These small faults are consistent with well logs that indicate a down-on-the-west fault just west of here. Other indicators of the fault include 1) the N-striking valley (lineament) where the wells indicate a fault must be, and 2) surface stratigraphy that suggests about 15.25 m of offset across this fault.

Mileage			
Total	Distance	Directions	Location
115.2	0.1	After lunch/leaving park, turn right then left, staying on paved road	Back onto Dam Rd.
115.4	0.25	Turn left staying on paved road	Intersection of Dam and Lake Rd.
115.9	0.5	Left onto Rt. 243	Intersection of Lake Rd. and Rt. 243
117.6	1.65	**Optional Stop**, park on right shoulder before turn - outcrop of the Rushford Fm.	POI - Rt. 49 (Hillcrest Rd) on left, ~0.3 mi is an outcrop of the Rushford Fm.

Optional Stop, Hillcrest Rd, Rushford Formation roadcut. Turn south on County Rt. 49 (Hillcrest Rd), from Rt. 243. Thick laminated sandstone (~3 meters thick) occurs on either side of the road, where Rt. 49 starts to climb the hill. The road also begins to curve at this location, so care is needed. There is a wide shoulder on the western side of the road. The western side displays the contact between Caneadea and Rushford formations, while the fracture controlled exposure on the eastern side gives an excellent view of the planar laminations and small, white, cloudy quartz clasts incorporated in fine-grained sandstone matrix.

Mileage			
Total	Distance	Directions	Location
119.5	1.9	Right onto W. Centerville Rd.	Intersection of Rt. 243 and W. Centerville Rd.
122.7	3.2	Straight on W. Centerville Rd.	Fork between E. Centerville and W. Centerville Rd.
123.8	1.1		POI - view of NE-trending valley, with inferred Alleghanian thrust fault with 80 ft of offset.

125	1.25	Straight on W. Centerville Rd.	Stop sign at intersection of W. Centerville Rd and Swift Hill Rd.
125.3	0.25	Right on Buffalo Rd (county Rt. 3)	Intersection of W. Centerville Rd and Buffalo Rd (c. Rt. 3)
126.5	1.2	Take right fork onto Higgins Rd	Fork between Buffalo Rd and Higgins Rd (no street sign)
127.8	1.35		POI - passing through the bustling metropolis of Higgins
127.9	0.1	Straight, staying on Higgins Rd. (crossing bridge)	Intersection of Higgins Rd and Stickle Rd.
128	0.05	Cross bridge	POI - outcrop in creek near bridge, typically buried by gravel. pencil cleavage here with sandstone roll-ups and sandstone dikes
128	0.05	Left staying on Higgins Rd. (now Creek Rd.) again crossing bridge.	Intersection of Creek Rd and Ballard Rd.
128.2	0.2	Cross bridge	POI - defined type section of the Higgins Mbr. of the Caneadea Fm.
128.6	0.35		POI - house on left is sheathed with rippled sandstone from Sixtown Creek
128.7	0.15	Park on the right - **Stop 5**	Sixtown Creek, Caneadea Fm. Ask permission for creek access from house on the left or call:

Stop 5 Sixtown Creek by Creek Rd. NE-striking Alleghanian fault zone. This stop is located in a large NE-trending valley, which displays a NE-striking fault and fold system. At the intersection of Creek and Weaver roads is a small bridge that crosses Sixtown Creek; the outcrop starts approximately 200 m upstream (west) of the bridge. Where we shall enter is farther west, towards the middle of the outcrop. The outcrop is comprised entirely of the Caneadea Formation, with the type exposures for the Higgins Member (informal). The lithology is interbedded light to medium gray silty shales, shaly siltstones, and typically thin (1– 5cm) micaceous, fine-grained sandstones. The outcrop displays a coarsening upward sequence, with thick sandstone (20-50cm) near the top of the Higgins Member. The typically linguoid ripples found on exposed sandstone beds as well as numerous furrows (guttercasts) may indicate a storm influence. Soft sediment deformation is present, but becomes abundant towards the upstream end of the outcrop, at the village of Higgins where large ball-and-pillow structures (1-4m in length) are commonly observed in outcrop. These ball and pillows are encased in a strongly pencil cleaved shale that has thin sandstone dikes.

A NE-striking, southeast-directed brittle thrust fault is observed at the sharp bend in the creek on the northern wall of the cliff (Fig. 8). Here the thrust has a fault zone comprised of fault gouge, fault breccia and drag folds. Open folds upstream from the thrust complete the deformation structures at this stop. We suggest that the NE-tending valley in which these structural features occur is related to an Alleghanian thrust that is represented by the structural features seen here.

Mileage			
Total	Distance	Directions	Location
129.2	0.45	Turn right, staying on Creek Rd. (cross bridge)	Intersection of Creek Rd and Weaver Rd.
130.4	1.25	Right on Buffalo Rd (c. Rt. 3)	Intersection of Creek Rd and Buffalo Rd.
131	0.55		POI - Finger Lakes Trail to the right, exposure of the Hume Fm and Caneadea Fm in creek, with pavement displaying NE-striking fractures, consistent with a NE-striking thrust along the valley
131.5	0.5	Right on Rt. 19S	Intersection of Buffalo Rd and Rt. 19
132.2	0.7	Left on Mills-Mills Rd	Intersection of Rt. 19, Mills-Mills Rd, and c. Rt. 23. POI - Hume Falls is below bridge to the right.
132.5	0.35	Take right fork, staying on Mills-Mills Rd.	Fork between Lapp Rd and Mills-Mills Rd.
134.1	1.55	Straight at the fork, staying on Mills-Mills Rd.	Fork between Wiscoy Rd and Mills-Mills Rd.
134.2	0.1	Park on the right, before the bridge - **Stop 6**	Wiscoy Creek, Type localities for the Hume and Mills-Mills Fm. exposure of S. Wales Fm downstream. Fractures here trend NE (64°) and NW (316°)

Stop 6: Wiscoy Creek at Mills-Mills where Mills-Mills Rd. crosses Wiscoy Creek. This is the upstream end of a fairly continuous outcrop that extends down Wiscoy Creek to the RG&E powerhouse that is located on the west side of Wiscoy Creek (Fig. 9). Exposures of the type section of the Hume Formation as defined by Pepper and deWitt (1951) are along the banks of the stream near the dam and along the roads near the dam. The base of the Hume Formation is obscured by the dam at Mills-Mills, but the roadcuts on either side display the black silty shale, with large (50-120 cm) carbonate concretions. The Hume displays a regional thickening that is coincident with the CLF (Fig. 10), suggesting that CLF fault activity controlled the shape of the depositional basin in which the Hume was deposited.

Below the bridge is our defined type section of the Mills-Mills Formation (informal) that is correlative to the Canaseraga Formation. Near the downstream (northeast) end of the outcrop at the top of the waterfall near the powerhouse the contact between the Mills-Mills Formation and the underlying South Wales Formation is displayed (Fig. 9). At the waterfall thick (20-40cm), fine-grained sandstone beds of the Mills-Mills Formation form the caprock. The exposure of the

Mills-Mills continues upstream with the sandstones forming small cascades to the dam at Mills-Mills. The sandstones forming the Mills-Mills are turbiditic. The shales and siltstones grade from dark gray to black at the top of the formation.

The underlying South Wales is comprised of interbedded light-dark gray silty shales and shaly siltstones, interbedded with thin, fine-grained sandstones. The lowest exposure of the South Wales Formation is a thick (~1m) amalgamated packet of calcareous, fine-grained sandstones.

Fractures at Mills-Mills trend NE (64°) and NW (316°); the NE-striking fractures both abut and intersect the NW-striking fractures. In some areas the NE-striking fractures are relatively closely-spaced, consistent with a NE-striking FID in the general region.

Mileage			
Total	Distance	Directions	Location
134.3	0.15	Cross bridge and turn around and turn left onto Wiscoy Rd.	Leaving Mills-Mills
135.6	1.3		POI - View of the Genesee River valley
136.3	0.65	Left onto Mill Rd, enter village of Wiscoy	Intersection of Wiscoy Rd and Mill Rd.
136.5	0.2	Left onto Tenefly Rd, cross bridge	Intersection of Mill Rd and Tenefly Rd.
136.6	0.1	Cross over, park on left side of Tenefly Rd so that vehicle is facing north - **Stop 7**	Type locality for the Wiscoy Fm.

Site 7: Wiscoy Falls on Wiscoy Creek at the village of Wiscoy. From the bridge crossing Wiscoy Creek, 2 of the 3 major falls comprising Wiscoy Falls can be seen. Below the bridge, beds (10-15cm thick) of dolomitic sandstones form large shelves, while the calcareous shaly siltstones and calcareous silty shales form small cascades. This is the type exposure of the Wiscoy Formation as defined by Clarke (1898). Upstream, by the dam, is the contact between the Wiscoy Formation and the Dunkirk Formation, which is also the transition between the West Falls and Canadaway groups, as well as the Famennian-Frasnian boundary (Fig. 9). Trace fossils are abundant on the surfaces of the sandstones, with large *Teichichnus* commonly observed; *Skolithos* and *Arenicolites* can be seen in cross-section.

Fractures on the pavement above the first major waterfall trend NW and NE, with NW fractures consistently the master. There is no anomalous spacing of fractures in the outcrop, and so no FID has been proposed for this region. Note that, as is typical for much of the county, no NS-striking fractures are present. Stepping, NW-striking fractures suggest a counterclockwise stress rotation during the Alleghanian generation of the NW-striking fractures (Zhao and Jacobi, 1997). The patterns of fracturing on this pavement were shown in Figure 4 of Zhao and Jacobi (1997).

Mileage

Total	Distance	Directions	Location
136.6	0	Continue north on Tenefly Rd.	Heading back to Fredonia
139.1	2.55	Left onto East Koy Rd	Intersection of Tenefly Rd and East Koy Rd.
139.9	0.75		pass intersection with Lamont Rd
142.7	2.8	Left onto Rt. 19	Intersection of East Koy Rd and Rt. 19 (Dewitt Rd)
142.8	0.1	Right onto Water St.	Rt. 19 and Water St.
143.6	0.8	Left onto Rt. 39	Intersection of Water St. and Rt. 39
144.7	1.15		POI - passing intersection with Hardy Rd., to the right is Ward Berry's farm and location of gas blows resulting from the Saguenay earthquake in 1989
148.7	3.95		POI - passing through Bliss, kind of Zen, huh?

Now continue West on NY Rt. 39 through Arcade, Springville, Gowanda and Perrysburg to US Rt. 20 near Fredonia

Turn left on US Rt. 20 at intersection with Rt. 39

Turn Right on Temple in Fredonia

Turn Right on Central (in Fredonia)

Turn Left into SUNY Fredonia at light

Turn Left into road approach to Fenton parking lot

BRIEF OVERVIEW OF THE LITHO-STRATIGRAPHIC SECTION OF NORTHERN ALLEGANY COUNTY SEEN ON THIS FIELD TRIP (after Smith et al, 1998).

Pipe Creek Formation (Chadwick, 1933)

Type Locality: Pipe Creek Glen, near West Falls, NY
Thickness: 5.2+ m (~17.1 ft)
Lithology: The Pipe Creek Formation is comprised of interbedded black siltstones and shales with sporadic thin limestones and calcareous siltstones. Small carbonate concretions are observed in most beds. The basal contact with the Nunda Formation is not observed in the field area. The upper contact with the Hanover Formation is sharp.
Depositional Environment: The combinations of black shales and carbonate deposits are interpreted to represent a restricted, anoxic environment, probably deeper basinal deposits.

Hanover Formation (Chadwick, 1923)

Type Locality: Silver Creek, NY, near Hanover
Thickness: 13.1 m (~48 ft)
Lithology: The Hanover Formation is characterized by a series of interbedded gray shales, siltstones and sporadic fine-grained sandstones. Organic grains and wood-fragments are commonly found in the siltstones and sandstones. Furrows (guttercasts) are common in the thin sandstones.
Depositional Environment: The shaly interbedded lithology is interpreted to represent shallower basinal deposits that experienced episodic influx of sands. The presence of wood-fragments, furrows and escape burrows are interpreted as an area of rapid deposition of organic-rich material probably through storms or storm-derived turbidites.

Wiscoy Formation (Clarke, 1898):

Type Locality: Wiscoy Falls, Wiscoy, NY
Thickness: 29.4 m (~96.4 ft.)
Lithology: The Wiscoy Formation is characterized by an interbedded assemblage of calcareous/dolomitic siltstones, calcareous fine-grained sandstones and gray shales with thin limestones. Outcrops are comprised predominantly of calcareous siltstones that weather massively. The appearance of the formation is a distinctive grayish-purple color that weathers a buff to brown-gray color. The top 7.5 meters of the formation consists of interbedded gray shales and calcareous siltstones and a persistent, thick (10 to 30 cm) black shale bed. The black shale is a possible precursor to the Dunkirk Formation or may indicate a shallower, organic-rich lagoon environment (Beynon and Pemberton, 1992). Basal and upper contacts are both sharp.
Depositional Environment: The calcareous siltstones and sandstones are interpreted to be deposited near or above fair weather wave base in the lower shoreface environment or possible lagoon/ bay environment. These depositional environments were inferred from the predominance of *Skolithos* ichnofacies found within the sandstones, as well as from the abundance of wood and coalified plant fragments found between bedding planes and the lack of preserved hummocky cross stratification (HCS). The *Arenicolites-Teichichnus* assemblage may indicate lagoon or bay facies for some of the interbedded shales, siltstones and thin sandstones (Pemberton, van

Wagoner, and Wach, 1992). The uppermost-interbedded section may represent a deepening of sealevel, and/or restriction of oxygen and currents.

Dunkirk Formation (Clarke, 1903):
Type Locality: Point Gratiot, Dunkirk, NY
Thickness: 24.1 m (~79.05 ft)
Lithology: The Dunkirk Formation is characterized by black shales and interbedded siltstones grading upsection into interbeds of gray shales, siltstones, and thin sandstones. Units of the Dunkirk Formation are planer-bedded, with the thin, fine-grained sandstones becoming rippled near the top of the unit. The rippled sandstones display climbing ripples. Upsection, there is an increase in the occurrence of small, 3-D ripples and HCS in the thin sandstones. The basal 2.5 meters are thick black silty shale, forming a sharp contact with the Wiscoy Formation calcareous siltstones. The upper contact is gradational, with the formation changing at the first appearance of the thicker sandstones of the South Wales Formation.
Depositional Environment: The black interbedded shales and siltstones with storm deposits increasing upsection are interpreted to represent shallowing basinal deposits. The abrupt change from the shallow deposits of the Wiscoy Formation to the black shales and siltstones of the Dunkirk Formation is reflected in the sharp deepening in the relative sea level curve. However, the presence of thin sandstones and siltstones with HCS in the middle and upper Dunkirk Formation indicate that during the deposition of the sandstones and siltstones the depositional environment of the Dunkirk seafloor lay within the depth of maximum storm-wave base. The planer bedded siltstones and climbing ripples in the thin sandstones near the top of the formation suggest turbidite deposition.

South Wales Formation (Pepper and deWitt, 1951):
Type Locality: Cazenovia Creek, 3 mi. south of South Wales, NY
Thickness: 16.4 m (~53.8 ft)
Lithology: The South Wales Formation is characterized by interbedded gray shales, siltstones and thin sandstones with uncommon thin, black shales and siltstones; calcareous concretions occur sporadically. The lower contact with the Dunkirk Formation is gradational. The working definition of the contact to the west was the base of the lowest thick sandstone (Jacobi et al., 1994) In the present study area major element geochemistry (Bechtel et al., 1996) shows a break at the lowest, thick (60+ cm), fine-grained sandstone with load casts. The upper contact with the Mills-Mills Formation is sharp, with thick cross-bedded sandstones of the Mills-Mills Formation overlying very thin, planar-bedded silty-shales and thin sandstones of the South Wales Formation. The South Wales Formation sandstones are micaeous and become slightly calcareous toward the top of the section. The sandstones are typically rippled with 3-D linguoid ripples and HCS common. The South Wales Formation becomes sandier towards the top, although the thickest sandstone bed is the basal contact sandstone.
Depositional Environment: The interbedded gray shales and thin sandstones are interpreted to represent deposits in the lower to upper offshore environment. The South Wales Formation represents a shallowing from the Dunkirk Formation as evidenced by the abundance of HCS, and the change in lithology from black shales to gray shales. The South Wales Formation contains few fossils or trace fossils; however, the contact between the Dunkirk Formation and the South Wales Formation is marked by a thick (approximately 60 centimeters), fine-grained sandstone that

has load casts and vertical worm burrows. These vertical worm burrows are likely to represent escape burrows of fauna carried in the turbidity flow.

Mills-Mills Formation (informal):

Type Locality: Wiscoy Creek, Mills-Mills, NY, (Slader Creek, south of Canaseraga, NY)
Thickness: 14.9 m (~48.9 ft)
Lithology: The Mills-Mills Formation is characterized by outcrops of thick, amalgamated sandstones. The sandstones are fine to medium- grained and are micaceous. The Mills-Mills Formation can be separated into upper and lower sandstones. The lower sand packet is a 3 m thick, upward fining sequence of sandstones interbedded with thin gray shales and siltstones. The lower sandstone packet has tabular cross-stratification and displays prominent climbing ripples. The upper sandstone packet ranges from 1 to 2 m thick and consists of thick beds (40 to 60 cm) of medium sandstone. Between the two sandstone packets is an interbedded section of gray sandstones, siltstones and shales that change upsection from gray to black. The basal contact of the Mills-Mills Formation is sharp; the upper contact with the Hume Formation is also sharp. The base of the sandstones shows rill-like features at the type section at Mills-Mills along Wiscoy Creek.
Depositional Environment: The thick turbidite sandstones are interpreted to represent offshore to basinal deposits. The Mills-Mills Formation represents turbidite deposits thicker than those observed in the underlying formations that are possibly associated with lowstand, representing a prograding deep sea fan channel-levee complex. The $T_{A/B\text{-}C}$ starting turbidites are interpreted to be as possible channel-levee deposits or, similar to those identified elsewhere in the Catskill Delta Complex, suprafan channel turbidites (Lundegard et al., 1985). The black shales and siltstones are similar to the overlying lithology of the Hume Formation except that the calcareous concretions within the Mills-Mills Formation are small (approximately 20 cm in diameter). The interbedded shales and siltstones may represent inter-channel deposition.

Hume Formation (Pepper and deWitt, 1951):

Type Locality: Mills-Mills (Hume Township), NY
Thickness: 36.6 m (~120 ft)
Lithology: The Hume Formation is characterized by interbedded black siltstones and shales with thin sandstones occurring near the top of the formation. Large (diameter or long axis > 1 meters), calcareous concretions with septaria are common in the Hume Formation. Deformed bedding around the concretions and formation of septaria, similar to carbonate concretions studied by Raiswell (1971, 1976), indicate that the concretions formed early in the deposition of the Hume Formation: before compaction of the shales. Unlike the Dunkirk Formation, the Hume Formation units are predominantly cross-laminated. The basal contact is sharp with black shales and siltstones overlying the gray shales and thick sandstones of the Mills-Mills Formation. The upper contact is gradational with gray shales, siltstones and thin sandstones interbedded with black shales and siltstones. The field contact is placed at the first appearance of a thick (~30 cm) sandstone which has straight crested ripples. Thin bentonite beds occur in the unit. Thin, fine-grained sandstones near the top of the formation contain HCS.
Depositional Environment: The black shales and siltstones with increasing abundance of thin sandstones interbeds toward the top are interpreted to represent basinal to offshore deposits. The Hume Formation represents a deepening in the depositional environment from the lowstand fan

observed in the underlying Mills-Mills Formation. The Hume Formation is interpreted by us to represent a deepening of the basin accompanied by restriction of both sediment-supply and oxygen levels. To the west, the Hume Formation may become incorporated in the lower part of the Gowanda Formation, as the Mills-Mills Formations pinches out.

Caneadea Formation (Chadwick, 1933):

Type Locality: Caneadea Creek, Caneadea Gorge, NY; *Members*: East Sixtown Member – 0.6 km. west of Rt. 19 and Cold Creek, Gorge Dolomitic Member – Caneadea Creek by bridge at Mill Rd., Higgins Member – at Higgins NY, West Lake Member – west shore of Rushford Lake, along Hillcrest Rd.

Thickness: Total: 114.8 m (~376.5 ft); East Sixtown Member – 21.2 m (~69.5 ft); Gorge Dolomitic Member – 39.7 m (~130.2 ft); Higgins Member – 31.2 m (~102.3 ft); West Lake Member –22.7 m (~74.5 ft)

Lithology: The Caneadea Formation is characterized by interbedded gray shales, siltstones and thin sandstones. The interbedded shales and siltstones typically display alternating light and dark gray, thinly laminated beds. Sandstone beds are fine-grained; micaceous, light gray in color, and are commonly 2 - 8 cm thick. The thin sandstone beds contain paleoflow features such as furrows, striations, grooves, flute casts, and asymmetrical ripples that are usually 3D ripples, commonly linguoid ripples or HCS.

Starting from the basal contact order of Members is as follows: East Sixtown Member, Gorge Dolomitic Member, the Higgins Member and the West Lake Member. Sandstones found in the basal member, the East Sixtown Member, display thin mud drapes and have flaser bedding to lenticular bedding. Sporadic, thicker sandstones in the East Sixtown Member (~25 cm) contain festoon ripples and/or large (~ 40-50 cm wavelength) straight-crested 2D ripples.

The Gorge Dolomitic Member consists of calcareous to dolomitic sandstones that are amalgamated in packets up to 1 meter in thickness. The interbedded shales and siltstones of the Gorge Dolomitic Member consist of thin alternating laminae of dark and light gray shales, the siltstones weather a distinct red-salmon color. Within the sandstone and calcareous- dolomitic sandstone packets, HCS are common; small tempestite coquinites of brachiopod shells occur in small lenses; thin, red weathering siltstones and fine-grained sandstones occur within the interbeds, symmetrical ripples are found. Ripples are primarily small 3D ripples (HCS and linguoid ripples) with sporadic straight-crested and symmetrical ripples. The Gorge Dolomitic Member also marks the lowest appearance in the section of micaceous sandstones in which the bedding surfaces are typically coated with muscovite. These micaeous sandstones become more prevalent upsection.

In the Higgins Member, the sandstone beds can be as thick as 60 cm and form a thick packet comprised mostly of sandstones with thin interbeds of silty shale. The Higgins Member contains furrow (guttercasts) dominated beds.

The West Lake Member is predominantly interbedded shales and siltstones with thin sandstones occurring more common toward the top. The upper contact with the Rushford Formation is sharp identified by the first appearance of thick (>1 m) well-cemented sandstone beds.

Depositional Environment: The entire Caneadea Formation is interpreted to represent upper offshore to lower shoreface deposits. In the East Sixtown Member, turbidite deposition followed by storm reworking may account for the sandstone packets. The sandstones are sharp-based;

contain flute casts, rip-up clasts and load casts, but some sandstone beds have been reworked slightly by storms as evidenced by sporadic HCS. Flaser bedding within some of the fine-grained sandstones suggests a possible tidal component as well. The depositional environment for the Gorge Dolomitic Member is above maximum storm-wave base, based on *Cruziana* ichnofacies and abundant HCS in the sandstones. The *Cruziana* ichnofacies is replaced by the *Arenicolites* and *Zoophycos* assemblage. The trace fossil suite and the deposition of carbonates suggest restricted circulation and oxygen that could indicate a deep-water depositional environment, however, the HCS, tempestites and symmetrical ripples strongly indicate that the depositional environment must have been above storm-wave base. These dolomitic packets are interpreted by us to represent periods of shallowing in the Caneadea Formation; the depositional environment fluctuating near fair weather wave base possibly a lagoon/bay facies. The Higgins Member reflects a high depositional energy; abundant rip-up clasts, loaded beds, and swaly cross-bedded is interpreted to be a storm dominated, nearshore environment. The West Lake Member is predominantly interbedded shales and siltstones that show signs of increasing paleocurrent energy toward the top of the section. Based on occurrence of solemarks (primarily furrows (guttercasts), grooves and striations) and 3D ripples and HCS in the thin (~2-10 cm) sandstone beds, suggest a storm dominated, offshore environment.

Rushford Formation (Luther, 1902):
Type Locality: Caneadea Gorge, Caneadea, NY
Thickness: 30.4 m (~99.7 ft)
Lithology: The Rushford Formation is characterized by two sandstone packets separated by interbedded gray shales and thin sandstones. Each of the sandstone packets ranges in thickness from 2 to 6 meters. The lower sand-packet can be divided into three shallowing cycles. The thick sandstones are massive to thickly bedded with amalgamation surfaces that are planer to slightly undulating. The Rushford Formation is primarily fine-grained sandstone; however, the lower sand-packet contains coarse-grained sandstone/conglomerate that occur as tabular beds which overlie each shallowing upward cycle and are separate from the fine-grained sandstone beds by a disconformity. Between the sandstone packets is a thick (2.3 – 16.3m) section of interbedded gray shales, siltstones and thin sandstones.

The shallowing cycles of the lower sand-packet are characterized by transitional bedding changes from tabular cross-sets at the base to trough cross-sets upsection to massive or planer and westerly (seaward) dipping subplaner beds at the top of the cycle. Conglomerate deposits contain steeply dipping cross-beds and trough cross-sets. In the interbedded section, thin sandstones contain HCS and 3D ripples (linguoids), and shell beds occur sporadically with a very limited lateral extent. The upper sand-packet contains trough cross-sets, tabular cross-sets as well as hummocky cross-sets and swaly cross-sets (SCS) (Walker and Plint, 1992). Mud-drapes in the upper sand-packet are common.

The basal contact is defined as the base of the lowest thick sandstone of the Rushford Formation. The upper contact is rarely observed in the field, but is placed at the top of the upper sand-packet of the formation.
Depositional Environment: The lower sandstone packet of the Rushford Formation has been interpreted by Smith and Jacobi (1998a &1999) to represent three-stacked shoreface cycles that grade from upper offshore to foreshore environment. The conglomerates separated from the

underlying shallowing upward cycles by a basal disconformity have been interpreted as transgressive lag deposits (Smith and Jacobi, 1996, 1998a &1999). The abundance of *Teichichnus* in the interbedded section overlying the lower sand-packet may indicate a deepening, such that the assemblage is equivalent to the *Cruziana* ichnofacies or the assemblage may indicate that the interbedded shales, siltstones and thin sandstones represent either lower shoreface to upper offshore environment or possibly brackish, low energy lagoon bay or deposits (Beynon and Pemberton, 1992; Pemberton, van Wagoner, and Wach, 1992; Pemberton and MacEachern, 1995; MacEachern et al., 1998). The upper sandstone packet represents a storm- and/or tide dominated lower shoreface deposits, possibly a barrier bar based on the predominance of trough-cross-sets, HCS, SCS and reversals in paleoflow directions.

Machias Formation (Chadwick, 1923):

Type Locality: Pierce Quarry, Machias, NY

Thickness: 94.2+ m (~308.9+ ft)

Lithology: The Machias Formation is characterized by interbedded gray shales, siltstones and thin sandstones. Thick sandstone packets occur (episodically) above 10 meters from the base. The sandstone packets display HCS with prominent swaly cross-bedding and trough cross-sets with thin (~10 - 20 cm) fossiliferous layers. Paleoflow orientations of trough cross-sets and ripples indicate bi-directional flow, to both the east and west. The interior surfaces of the troughs and swales contain interference ripples. In Allegany County, the Machias Formation contains five thick sand packets that can be traced across the field area; although thickness variations and the ubiquitous presence of thrust faults makes these correlations tenuous. The sandstone packets in the Machias Formation are easily distinguished from the sandstone packets in the Rushford Formation by prevalence of HCS and SCS throughout the Machias sandstone, and the presence of thin, lenticular conglomerates that are part of the tempestite packets in the Machias Formation. Another distinguishing characteristic is that the sandstones of the Rushford Formation are slightly coarser and better cemented than the sandstone is the Machias Formation.

The basal contact is sharp placed at the top of the Rushford Formation uppermost sandstone. The upper contact is placed at the basal sandstone of the overlying Cuba Formation. However, discriminating between the Cuba Formation and the thick sandstones in the Machias Formation is equivocal in some regions.

Depositional Environment: The storm beds common to the interbedded, thin-sandstones suggest that the interbedded sections were deposited above storm wave base, most likely upper offshore. Numerous tempestite beds indicate deposition in an intermediate-to-high energy, storm dominated environment (MacEachern and Pemberton, 1992). The alternating paleoflow orientations in the trough cross-sets and ripples suggest either a tidal component or a shoreface environment. The amount of coarse material and high organic material indicate that the trough cross-set dominated sand packets also represent a storm-dominated, middle to upper shoreface environment.

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FIGURE CAPTIONS

Figure 1: General location of the field trip area. Enlarged map of western New York shows the location of the field area relative to the Clarendon-Linden Fault System (CLF).

Figure 2: Map of the field trip area displaying roads, towns and major streams. The location of stops 2 – 7 are shown, as well as the optional stops.

Figure 3: Map of field trip area displaying Fracture Intensification Domains (FIDs) (Jacobi and Fountain, 1996; Peters, 1998; Zack, 1998). Locations of Stops 2 –7 are shown for reference.

Figure 4: Stratigraphic column for the field trip area in northern Allegany County, New York State. The column is constructed from over 1,000 sites measured in northern Allegany County (from Smith et al., 1998).

Figure 5: A) Fracture data from White Creek. Rose diagrams show both the number of fractures (upper, dark gray half) as well as relative length of fractures (lower, white half). Fracture networks have been digitized from photographs, and are oriented with respect to north (modified from Jacobi and Fountain, 1996)
B) Fracture frequency curve showing the increase of N-S fractures in the area of White Creek (from Jacobi and Xu, 1998).

Figure 6: A) Legend for stratigraphic columns used in this paper.
B) Annotated stratigraphic columns for stops 2A and 2B, showing the similar sequence of lithologies at Stops 2A and 2B, including sandstones, sediment slides and deformed zones with pencil cleavage. Columns are "hung" at proper elevations (ft above sealevel).
C) Cross section of White Creek showing the southerly dip of the units and the offset between Stop 2A and 2B.

Figure 7: Annotated stratigraphic column for Caneadea Gorge, (see Fig. 6a for legend).

Figure 8: Cross section of Sixtown Creek section at Higgins. Heavy lines show correlated beds with faulting, and the dashed lines show the correlation without faulting.

Figure 9: Cross section of Wiscoy Creek including the stratigraphic columns for Stop 6 and Stop 7.

Figure 10: Regional cross-section comparing the upper West Falls Group (Pipe Creek, Hanover and Wiscoy formations) and lower Canadaway Group (Dunkirk to Rushford formations). The stratigraphic columns are from Pepper and deWitt (1950, 1951), except for the Genesee column, which is the data from Allegany County (from Smith and Jacobi, submitted).

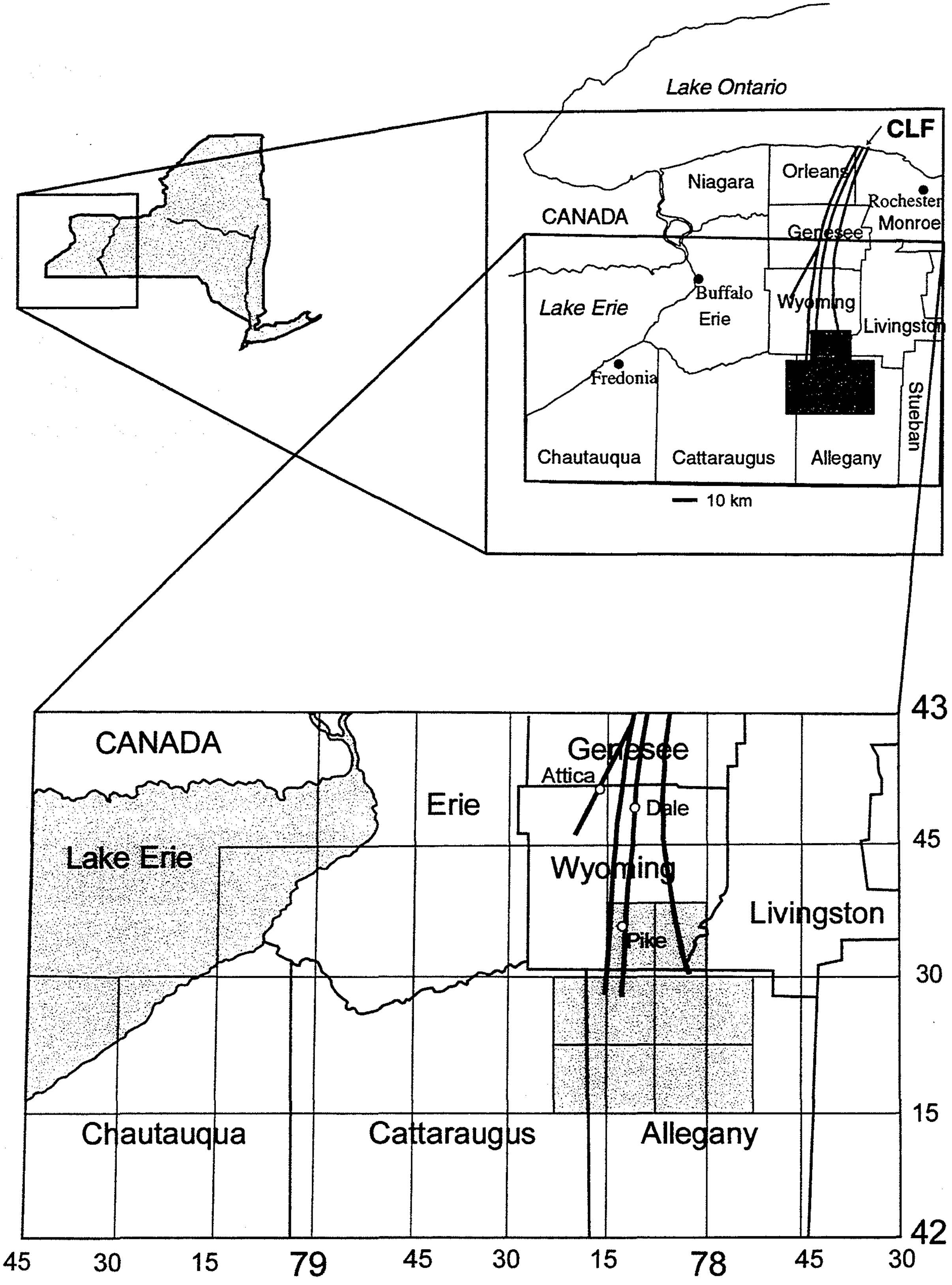

Lake Ontario
CLF
Orleans
Niagara
Rochester
Monroe
CANADA
Genesee
Lake Erie
Buffalo
Erie
Wyoming
Livingston
Fredonia
Stueban
Chautauqua
Cattaraugus
Allegany
10 km
CANADA
Genesee
Attica
Dale
Erie
Lake Erie
Wyoming
Livingston
Pike
Chautauqua
Cattaraugus
Allegany
43
45
30
15
42
45
30
15
79
45
30
15
78
45
30

Figure 1

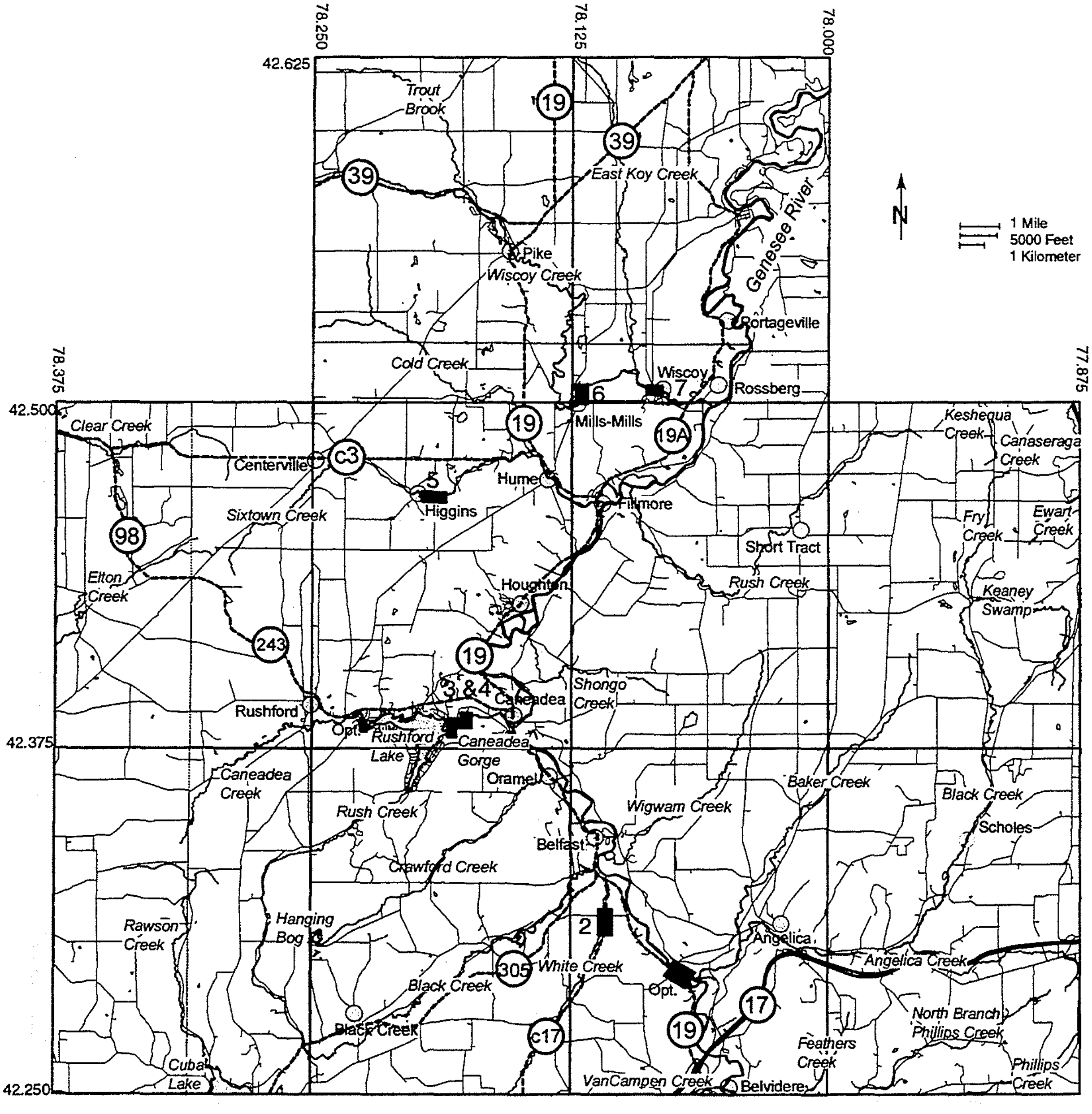

78.250
78.125
78.000
42.625
78.375
77.875
42.500
42.375
42.250
Trout Brook
19
39
East Koy Creek
Pike
Wiscoy Creek
Genesee River
Portageville
Cold Creek
Wiscoy
6
7
Rossberg
Mills-Mills
19A
Clear Creek
Centerville
c3
5
Higgins
Hume
Fillmore
Sixtown Creek
98
Short Tract
Keshequa Creek
Canaseraga Creek
Fry Creek
Ewart Creek
Elton Creek
Houghton
Rush Creek
Keaney Swamp
243
3 & 4
Caneadea
Shongo Creek
Rushford
Opt.
Rushford Lake
Caneadea Gorge
Oramel
Caneadea Creek
Rush Creek
Baker Creek
Wigwam Creek
Black Creek
Scholes
Belfast
Crawford Creek
2
Rawson Creek
Hanging Bog
Angelica
Angelica Creek
305
White Creek
Opt.
Black Creek
Black Creek
17
North Branch Phillips Creek
c17
Feathers Creek
Phillips Creek
Cuba Lake
VanCampen Creek
Belvidere
N
1 Mile
5000 Feet
1 Kilometer

Figure 2

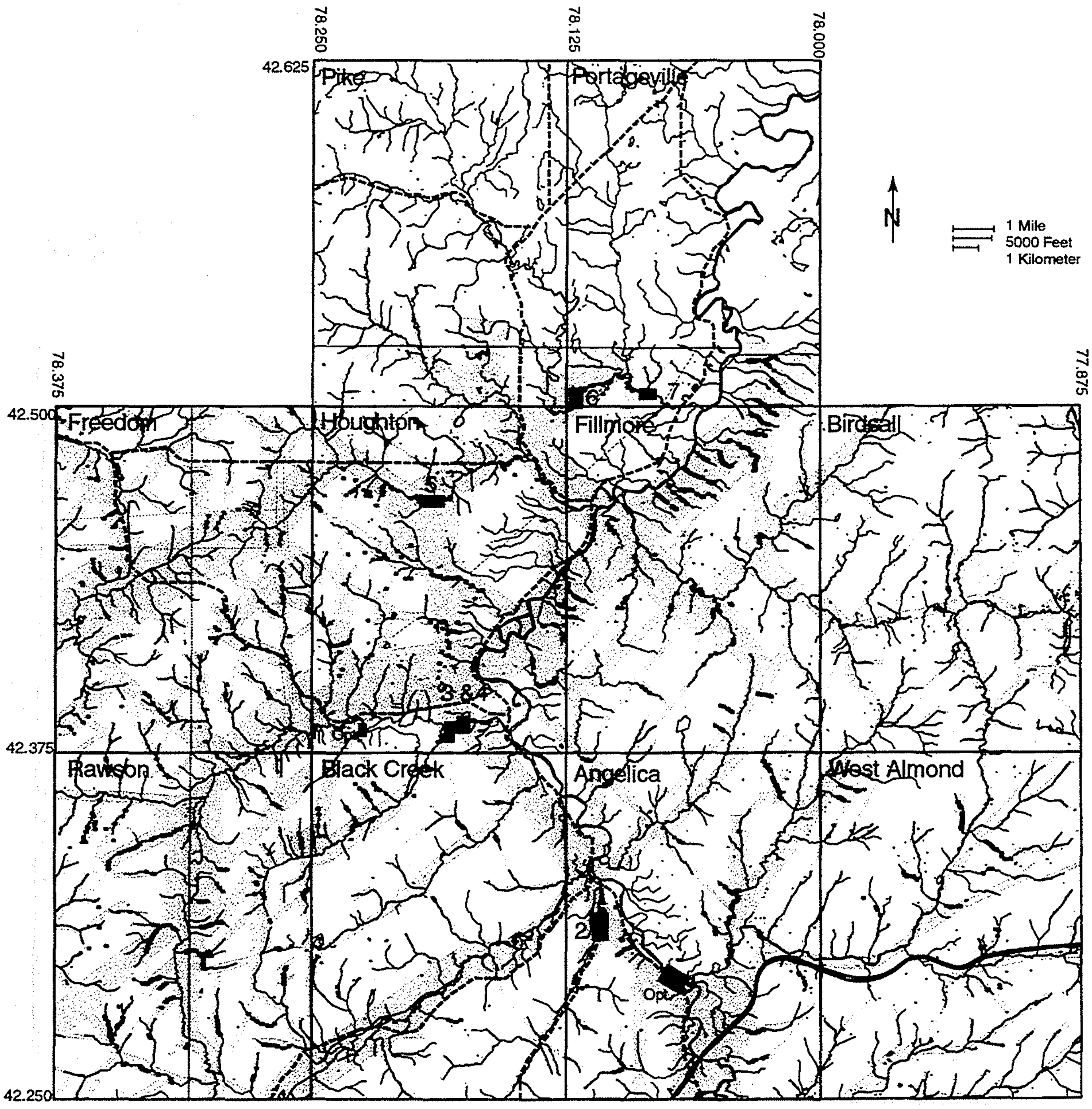

78.250
78.125
78.000
78.375
77.875
42.625
42.500
42.375
42.250
Pike
Portageville
Freedom
Houghton
Fillmore
Birdsall
Rawson
Black Creek
Angelica
West Almond
6
7
3 & 4
2
Gd
Opt
N
1 Mile
5000 Feet
1 Kilometer

Figure 3

Stratigraphic section for northern Allegany County, New York, modified from Smith et al., 1998

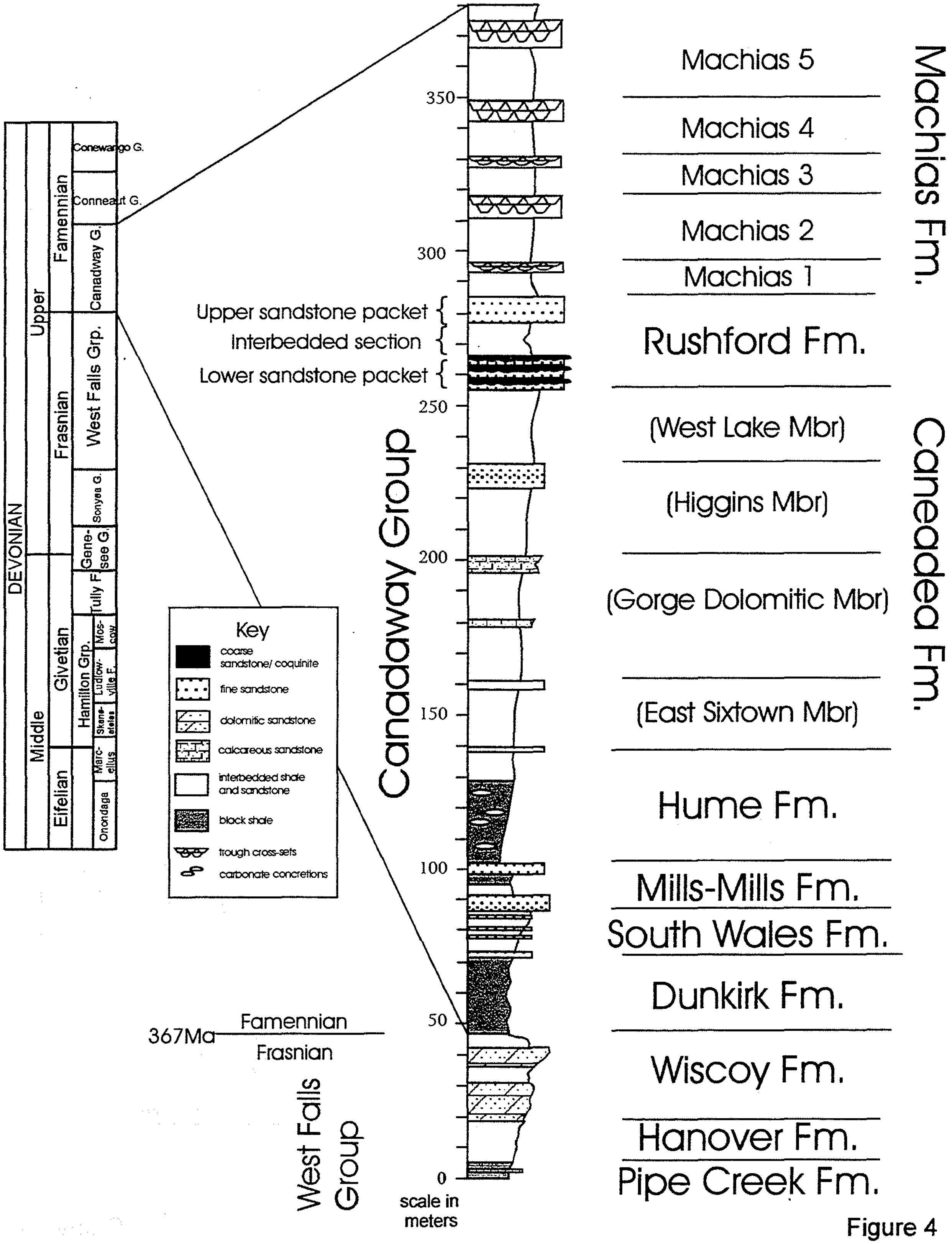


Figure 4

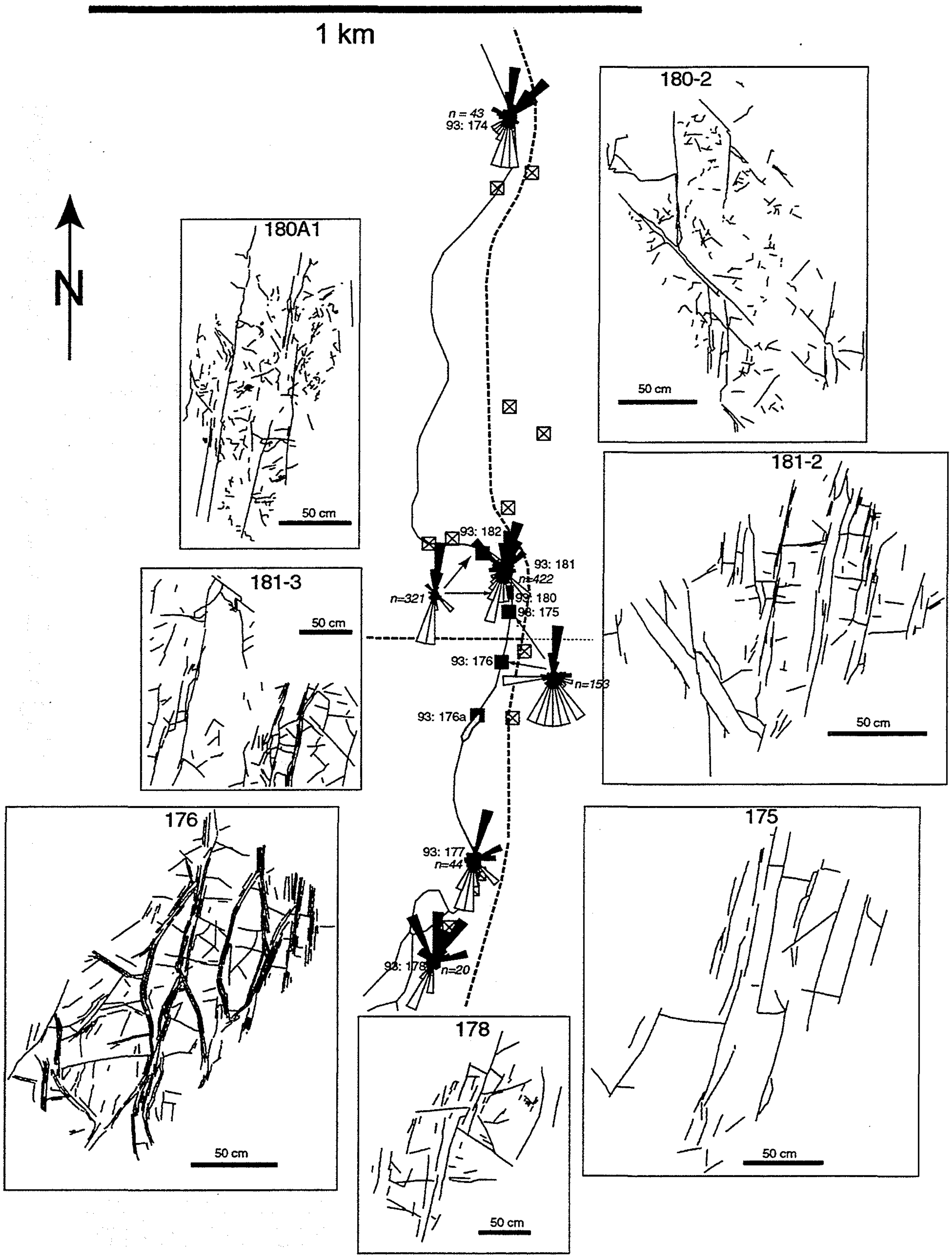

1 km
N
180-2
50 cm
180A1
50 cm
n = 43
93: 174
93: 182
93: 181
n=422
n=321
93: 180
93: 175
93: 176
93: 176a
n=153
181-2
50 cm
181-3
50 cm
93: 177
n=44
93: 178
n=20
176
50 cm
175
50 cm
178
50 cm

Figure 5A

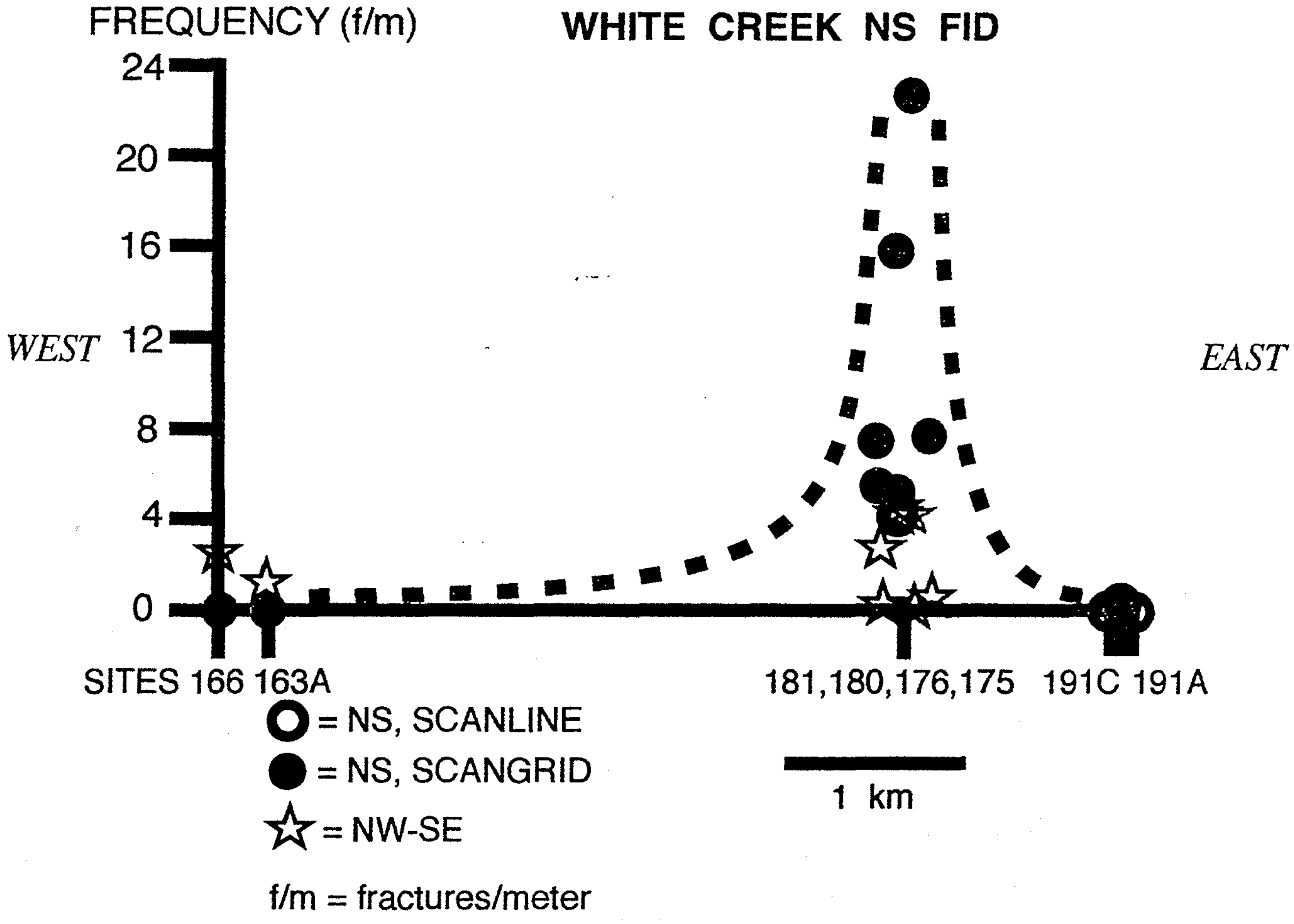
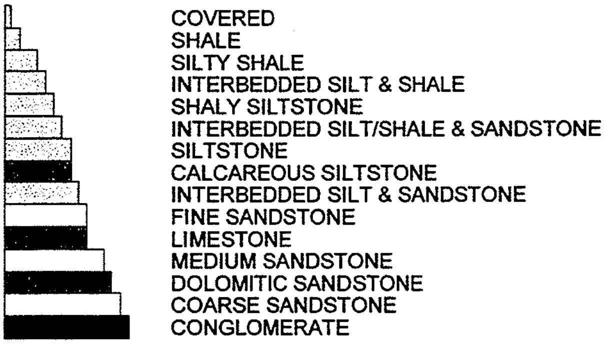

FREQUENCY (f/m)
WHITE CREEK NS FID
24
20
16
12
8
4
0
WEST
EAST
SITES 166 163A
181,180,176,175
191C 191A
○ = NS, SCANLINE
● = NS, SCANGRID
☆ = NW-SE
f/m = fractures/meter
1 km

Figure 5B .

Key for stratigraphic columns

Erosional Profile used in stratigraphic columns



Color Key for stratigraphic columns

- ■ black shales and siltstones
- ■ black & dark gray shales and siltstones
- ▨ gray shales and siltstones
- □ sandstones
- ■ calcareous and dolomitic

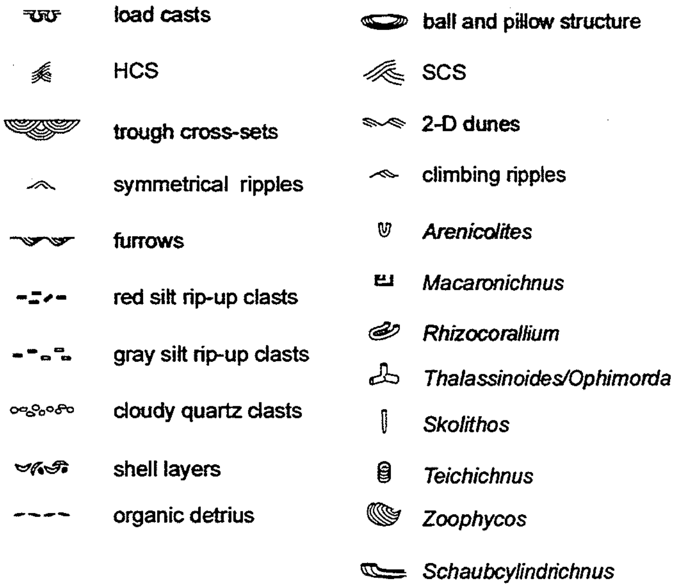


Figure 6A

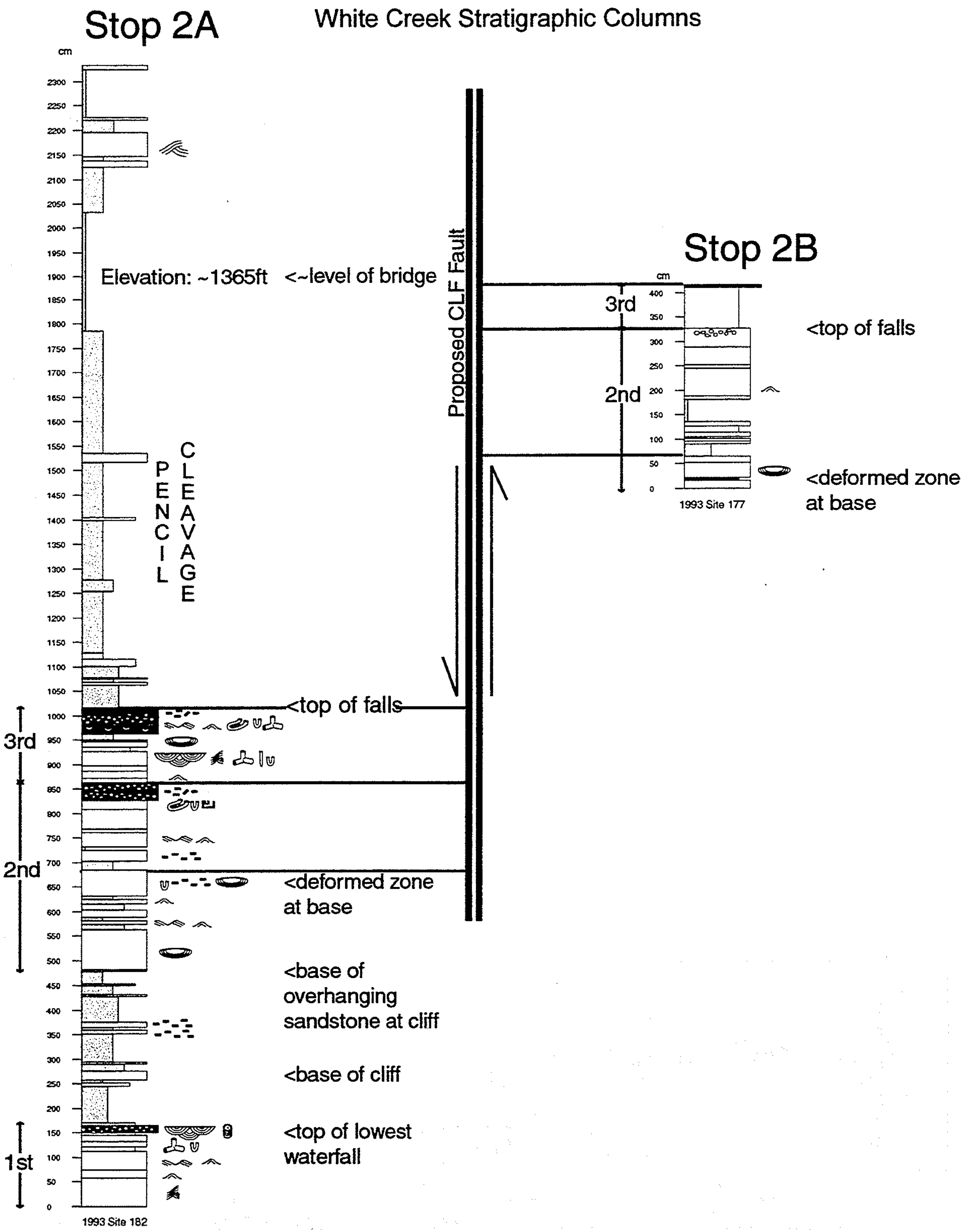

Stop 2A
White Creek Stratigraphic Columns
cm
2300
2250
2200
2150
2100
2050
2000
1950
1900
1850
1800
1750
1700
1650
1600
1550
1500
1450
1400
1350
1300
1250
1200
1150
1100
1050
1000
950
900
850
800
750
700
650
600
550
500
450
400
350
300
250
200
150
100
50
0
Elevation: ~1365ft
<~level of bridge
PENCIL
CLEAVAGE
<top of falls
3rd
2nd
<deformed zone at base
<base of overhanging sandstone at cliff
<base of cliff
<top of lowest waterfall
1st
1993 Site 182
Proposed CLF Fault
Stop 2B
cm
400
350
300
250
200
150
100
50
0
3rd
2nd
<top of falls
<deformed zone at base
1993 Site 177

Figure 6B

Stop 2: White Creek
Angelica Quadrangle

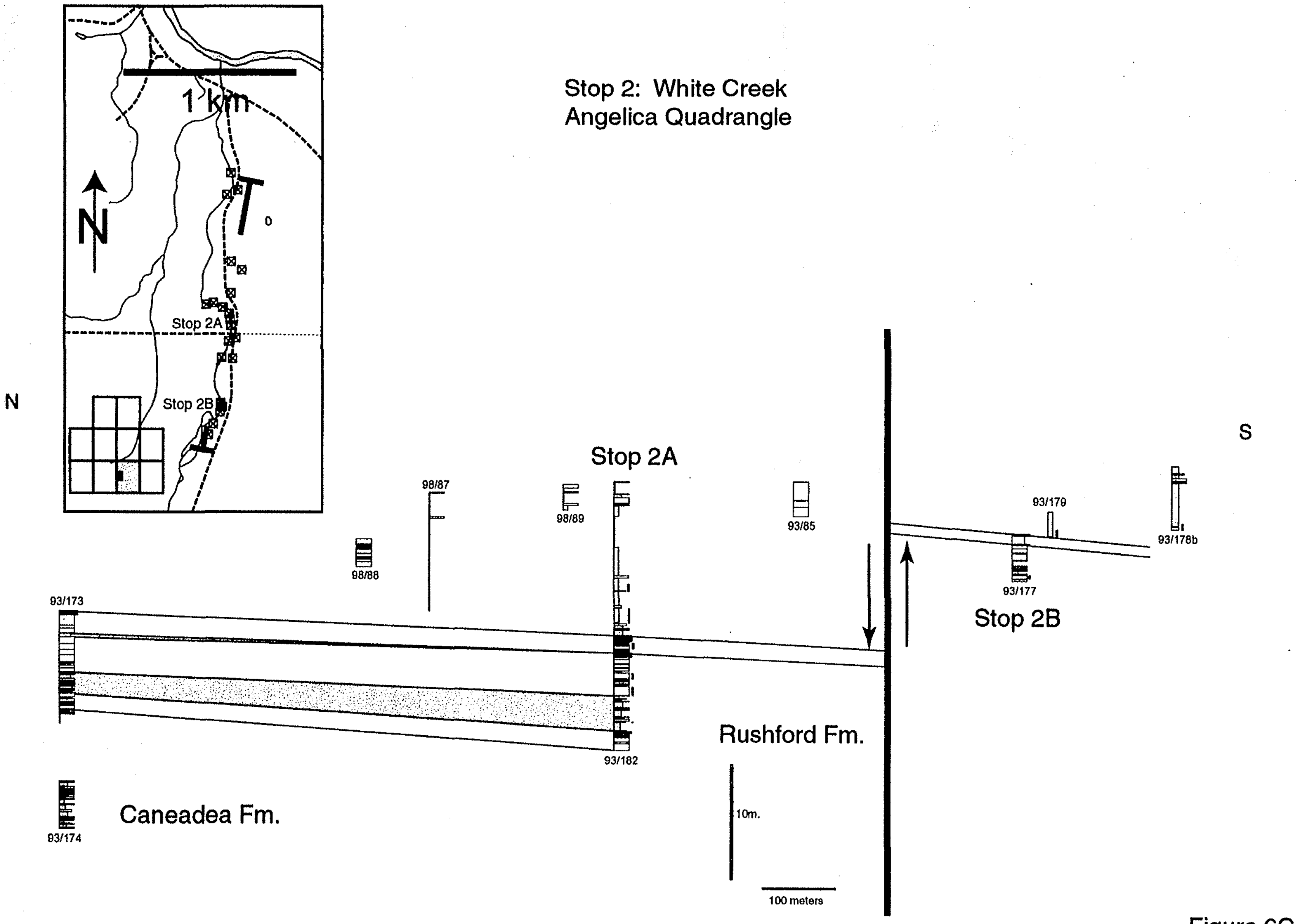


Figure 6C

Stop 3: Caneadea Gorge Stratigraphic Column

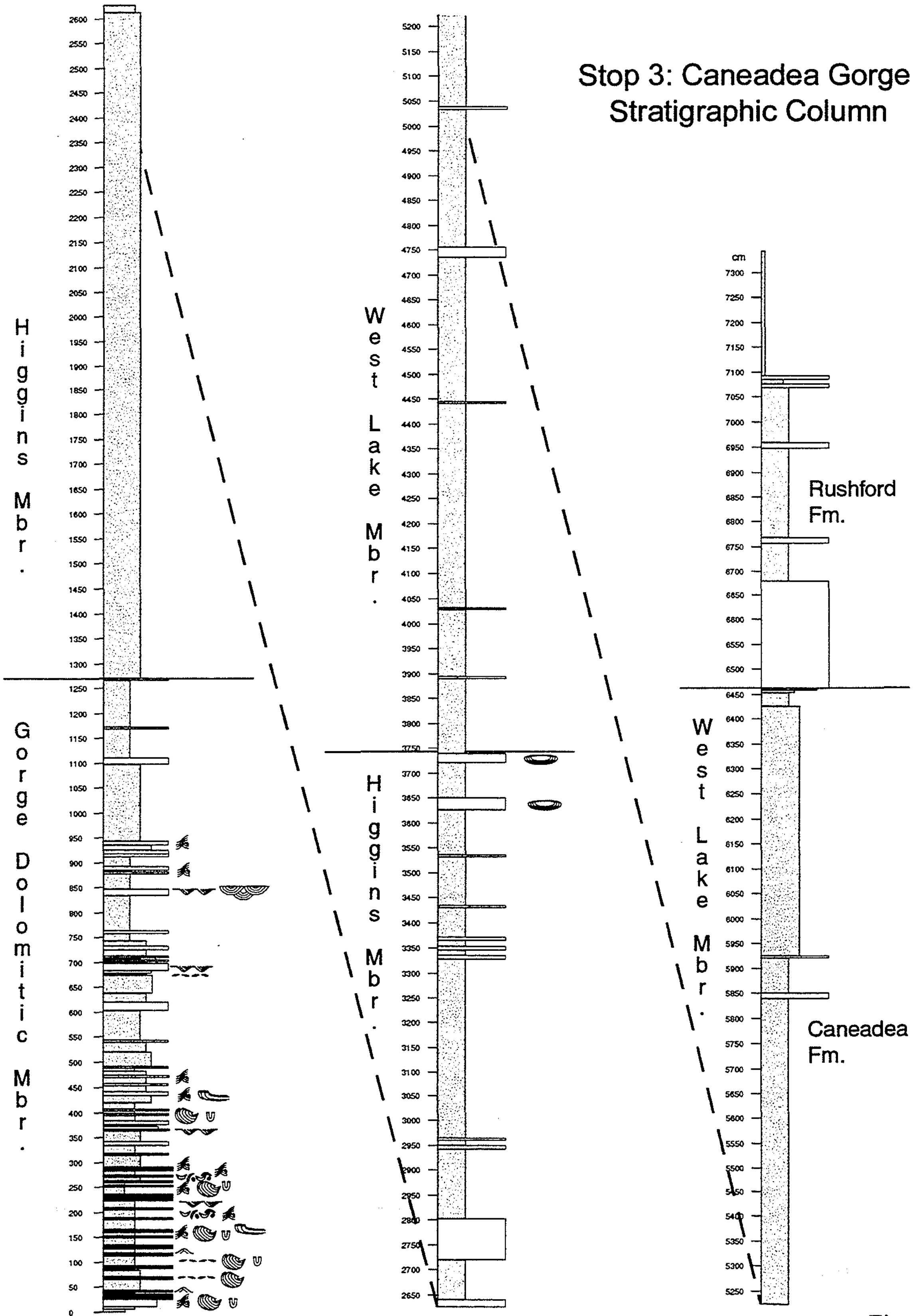


Figure 7

Stop 5: Sixtown Creek
Houghton Quadrangle

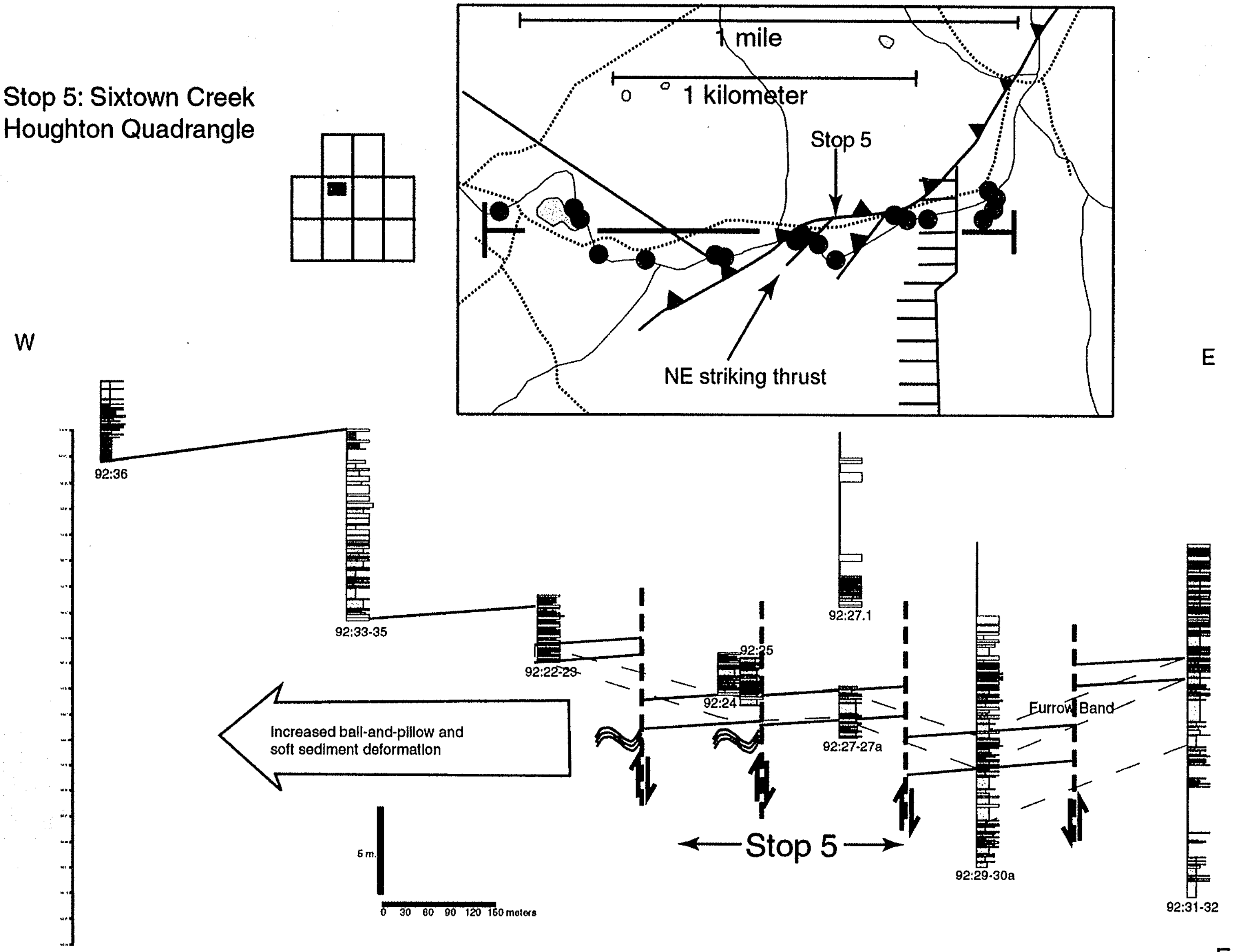


Figure 8

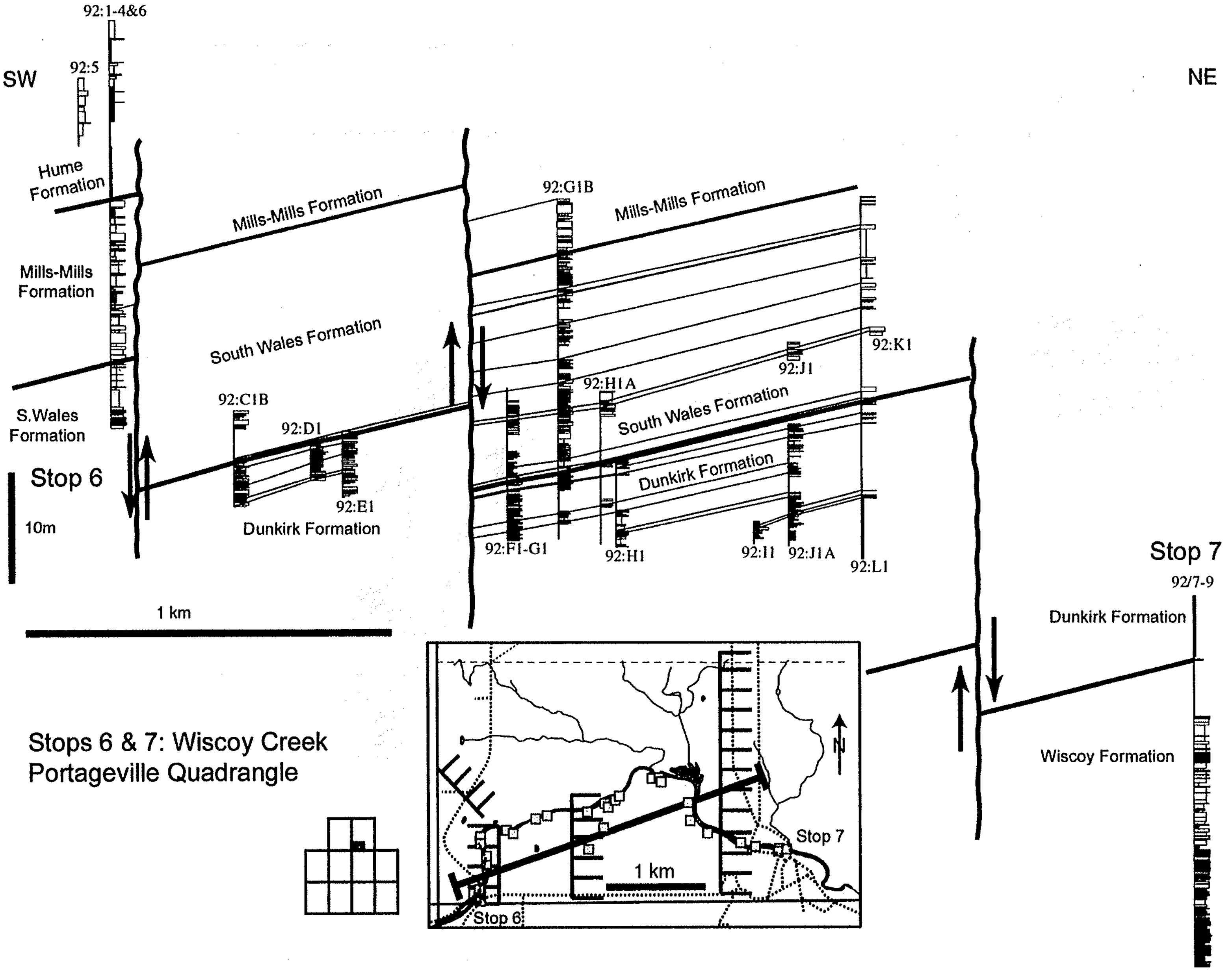

SW
NE
92:1-4&6
92:5
Hume Formation
Mills-Mills Formation
S.Wales Formation
Stop 6
10m
1 km
Mills-Mills Formation
South Wales Formation
92:C1B
92:D1
92:E1
Dunkirk Formation
92:G1B
Mills-Mills Formation
92:H1A
92:J1
92:K1
South Wales Formation
Dunkirk Formation
92:F1-G1
92:H1
92:I1
92:J1A
92:L1
Stop 7
92/7-9
Dunkirk Formation
Wiscoy Formation
Stops 6 & 7: Wiscoy Creek
Portageville Quadrangle
N
Stop 7
1 km
Stop 6

Figure 9

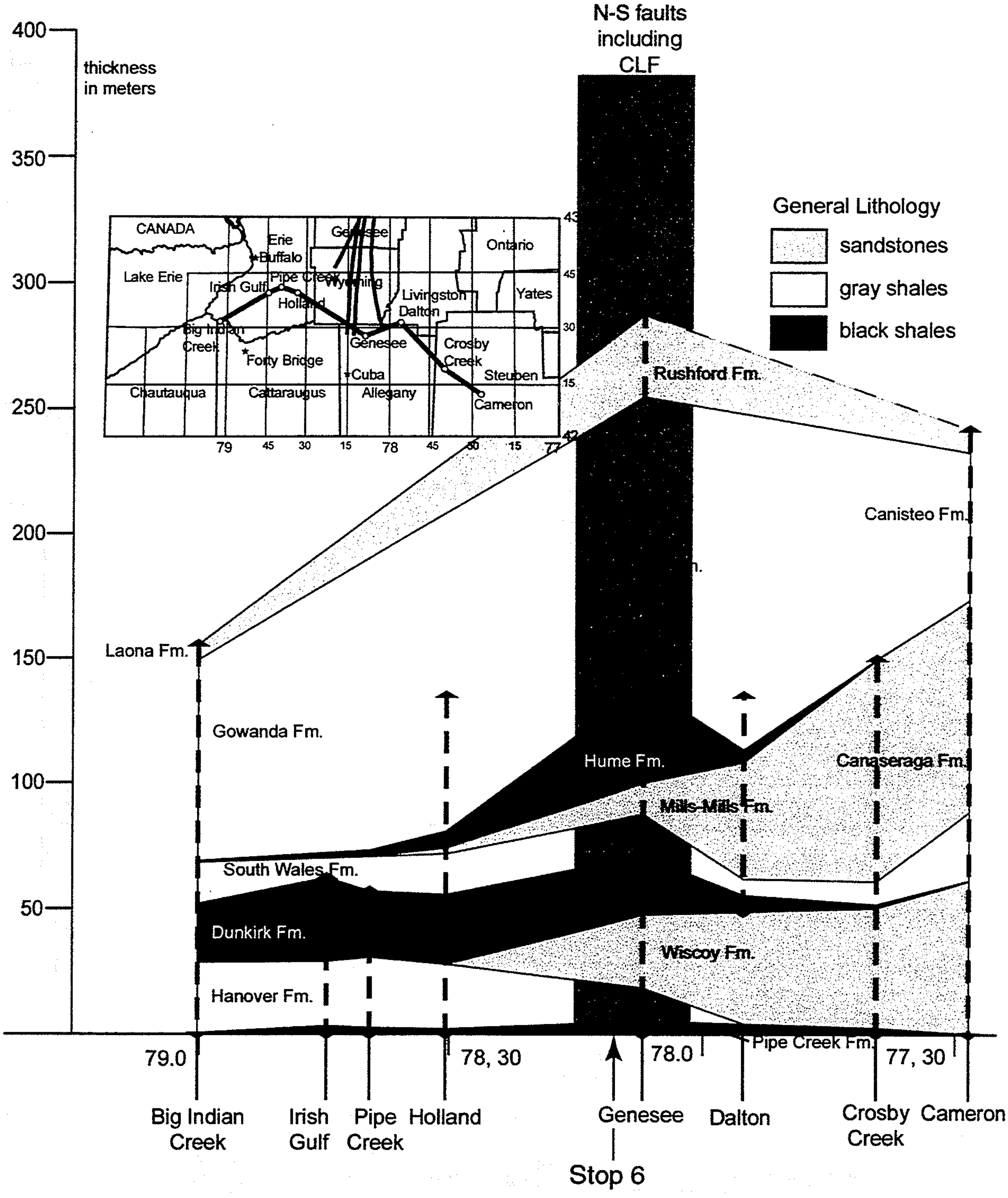

N-S faults including CLF
400
350
300
250
200
150
100
50
thickness in meters
General Lithology
sandstones
gray shales
black shales
CANADA
Erie
Buffalo
Genesee
Ontario
Lake Erie
Irish Gulf
Pipe Creek
Wyoming
Holland
Livingston
Dalton
Yates
Big Indian Creek
Forty Bridge
Genesee
Crosby Creek
Cuba
Steuben
Chautauqua
Cattaraugus
Allegany
Cameron
43
45
30
15
42
79
45
30
15
78
45
30
15
77
Rushford Fm.
Canisteo Fm.
Laona Fm.
Gowanda Fm.
Hume Fm.
Canaseraga Fm.
Mills Mills Fm.
South Wales Fm.
Dunkirk Fm.
Wiscoy Fm.
Hanover Fm.
Pipe Creek Fm.
79.0
78, 30
78.0
77, 30
Big Indian Creek
Irish Gulf
Pipe Creek
Holland
Genesee
Dalton
Crosby Creek
Cameron
Stop 6

Figure 10

ENCOUNTERS OF NATURAL, FISCAL AND LEGAL KINDS ON THE COAST OF THE GREAT LAKE ERIE:

DEALING WITH HARBOR CONTROVERSY AT NORTH EAST AND HARBORCREEK – SHADES BEACH, PA AND REVISITING THE COST – EFFECTIVENESS OF THE $23 MILLION DOLLAR PRESQUE ISLE EROSION CONTROL PROJECT AT ERIE, PA

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INTRODUCTION

Coastal erosion and deposition effects caused by human generated structures is a key theme of this trip. Although we might assume that the impact of coastal processes on the general public of the United States is restricted to oceanic shorelines we will see that construction on Great Lakes shorelines is fraught with the same difficulties as those faced on the Atlantic and Pacific Oceans. Thus inland colleges with access to Great Lakes shorelines have established Coastal Geology programs that offer hands-on training to their students and advice to local, State, and Federal Government agencies responsible for coastal zone management.

Both erosion and deposition patterns altered by hard structures built on the coast are problematic to those of us who live, work and play there. Proceeding from east to west along the shoreline we will first visit the harbor at North East, PA that is in the latter stages of litigation against those responsible for its construction and management. Our next stop will be at the site of the proposed harbor and detached breakwater at Shades Beach in Harborcreek PA where a federal and state Coastal Zone Management study is underway to avoid such legal complications. And, finally we will revisit the 55 offshore breakwaters of the Presque Isle Erosion Control Project at the peninsula enclosing the harbor at Erie, PA. US Army Corps of Engineers efforts to stabilize the sand spit and thereby to protect the harbor by construction of on-shore hard structures such as groins stretches back to 1828. In spite of these efforts, an average of well over $1 million worth of sand has had to be added to the beaches each year since 1956 (annual nourishment). Completed in 1992, the cost-effectiveness of the latest $23.8 million US Army Corps of Engineers' project will be judged, at least in part, on achieving a major reduction in this annual sand nourishment expenditure. Less sand from off–site has been required subsequent to construction partially due to the newly developed possibility of recycling sand deposited behind some of the breakwaters. However, to date a goal of a 75% reduction in replenishment costs has been elusive. With Lake Erie at its lowest level in decades this year, a new problem has emerged. "Excessive" deposits at the end of the spit threatened to close off a very popular beach (Beach 11) from the open lake rendering it useless due to stagnation, excessive weed growth, and potential pollution. Dredging of 10's of thousands of cubic yards of sand has been required to preserve the recreational resource. The good news is that the sand is being used as a lower cost source of nourishment updrift (to the west) on the peninsula.

The first of our three stops on Presque Isle will give us the opportunity to see how variable the effect of the offshore breakwaters has been on beach erosion and deposition. Near the lighthouse erosion has continued to be severe despite the presence of breakwaters offshore. Immediately downdrift (to the east), "excessive" deposition results in the annual connection of the beach to a breakwater forming a tombolo. The proximity of the two areas will highlight an unexpected benefit of the project; harvesting of the unwanted sand deposits from the tombolo serves as a low cost source of sand which is recycled as nourishment for the nearby area of erosion. We will ascend the lighthouse in small groups to obtain an aerial view of the situation. Our second stop will be at Beach 10 and Gull Point where the nourishment sand from the Beach 11 spit dredging and recycling operation is being placed. The easternmost of the 55 offshore breakwater sequence and three additional earlier constructed prototype breakwaters will also be visible. Not surprisingly, it is the area immediately downdrift from the last of these erosion control structures that was designated as most in need for receiving the dredged sand. The fate of the nourishment sand over the next several months will be monitored by students as part of a undergraduate coastal studies GIS project. The data and project report will be provided to Presque Isle State Park management and to the US Army Corps of Engineers. The final stop of the trip will be at the Beach 11 site of the sand spit which was dredged. The dredging and nourishment project is due for completion in mid-September 1999 so all activity should be over by the time of our visit.

DESCRIPTION AND COMMENTARY ON INDIVIDUAL STOPS

STOP 1. NORTH EAST MARINA , NORTH EAST, PENNSYLVANIA

North East Marina (formerly Safe Harbor Marina) was constructed on the southeast shore of Lake Erie at North East, Pennsylvania in 1989-1990 to provide access to the recreational use of the lake and shelter for boaters. In fact, for boaters caught in a storm, it is the only shelter between Barcelona, New York and Erie, Pennsylvania. Prior to construction, Buyce and Kent Taylor applied for a grant from Coastal Zone Management of NOAA to provide a base line study of the littoral drift system for use in formulating requirements for construction and management of the facility. The study was not funded.

A private corporation, under lease from the Pennsylvania Fish and Boat Commission, obtained the necessary permits from the US Army Corps of Engineers and the Pennsylvania Department of Environmental Resources and constructed the marina. The regulating agencies clearly anticipated that harbor construction would interrupt the normal littoral drift pattern because ongoing nourishment was required by the permits to prevent starvation of the downdrift beaches. The facility managers made only token attempts at nourishment and, because the preconstruction littoral drift volume was unknown due to the lack of a baseline study, it was difficult to specify what would be an adequate annual volume of nourishment. Meanwhile homeowners downdrift (on the east side) instituted lawsuits against everyone involved with the marina as they saw sand accumulating on the west side of the harbor and felt that their beaches were narrowing and bluff erosion potential was being exacerbated in front of their homes.

Caving in to the dual pressures of agencies threatening to revoke permits and to lawsuits the corporation went bankrupt in 1993 and the facility and its problems reverted to the Pennsylvania Fish and Boat Commission who immediately instituted a substantial nourishment program for downdrift beaches. Realizing that, in a litigious environment, an adequate amount of annual nourishment would be difficult to establish to the satisfaction of all concerned, the Fish and Boat Commission wanted objective scientific data. They finally funded a study of the littoral drift system (Taylor and Buyce, 1994 and Buyce and Taylor, 1998).

A major objective of the study was to determine exactly how much and what size sediment would have reached the downdrift beaches each year if the harbor were not constructed. After establishing that no significant volume of sediment was being lost offshore or continuing to reach the downdrift beaches (bypassing the marina) the task was to measure the annual volume of sediment accumulating updrift from the west wall of the harbor and determine its textural characteristics. As beach width is assumed to be inversely related to potential for bluff erosion potential, there was also a need to determine if construction of the marina had, in fact, resulted in the narrowing of downdrift beaches. The examination of historic photographs from 1986 was used to compare to modern beach widths.

The extensive nature of the study is evident below in extracts from Buyce and Taylor, 1998. Selected Results and Discussion are also included:

METHODOLOGY

A variety of data collection techniques were employed to help provide rational coastal management guidance. Repeated detailed topographic mapping of the study area was conducted to provide estimates of annual littoral drift volume, the prerequisite for devising a suitable nourishment protocol. Delineation of littoral-drift-related features on the maps also permitted a better understanding of the processes acting along this stretch of coastline. Repeated precision mapping of the shoreline was also conducted to determine post-construction changes in beach widths of the updrift and downdrift beaches for use in comparison with historic (pre-construction) aerial photographs. Beach width is considered to be inversely related to bluff-erosion potential. Aerial observations were made to identify sediment accumulation features and subaqueous bedrock exposures that may control sediment transport (especially bypassing), recording fathometer surveys were conducted to profile the subaqueous bedrock exposures, and dives were performed to confirm the significance of mapped and remotely observed features for textural analysis. Textural analysis of sediments in the beach and nearshore were employed: (1) to determine whether sediment size can provide clues concerning transport dynamics and bypass potential and (2) to match nourishment material to the natural sediment. Finally, littoral environmental observation (LEO) data were collected to link sediment dynamic parameters such as waves and currents. These methods are described in detail below.

Precision Topographic Mapping and Volume Change Calculation

Maps of the exposed beaches and the nearshore bathymetry adjacent to the harbor were genrated using standard rod-surveying techniques (Figure 1, this guidebook). Topographic contour maps and profiles were generated from Leitz Set-2BII total station survey data using proprietary Sokkia map, Contour, and Profile software packages. The computerized method used for the volumetric analyses involved the following steps: (1) generation of computer-drafted topographic maps using survey data collected from the designated mapping area, (2) projection of each data point to the second topographic surface and creation of an isopach map showing differences in accretion or erosion, and (3)determination of the net vulumetric change for the designated area.

Profiles were mapped in transects extending from the back of the beach, parallel to the roughly north-trending harbor walls, out onto the nearshore zone to a maximum depth of 2.5 m (8.2 ft). Along shore a total of 16 profile transects were mapped at 20m (65.6 ft) intervals; 11 transects were mapped updrift, extending 230m (754.6 ft) west of the western wall of the harbor; and 5 were mapped downdrift, extending 90 m (295.3 ft) east of the eastern wall of the harbor. Transects were also established at 30 m (98.4 ft) intervals along the entire northern perimeter of the harbor.

Two volumetric assessments were completed for the beach and nearshore zone west of the harbor. These analyses were completed in order to determine the annual rate of sediment accumulation on the updrift side of the harbor. Assuming that no natural bypassing is occurring, this entire volume is being withheld from the downdrift beaches and thereby indicates a realistic estimate of beach nourishment requirements. Data suggesting the lack of significant sediment bypassing are presented …

Beach Width and Potential for Bluff Erosion

The study was also concerned with narrowing of beach width, as such narrowing is considered to coincide with increased potential bluff erosion. Recent beach width and variability was investigated during the study via precise mapping of a 1.8 km (1.1 mi) stretch of coastline extending from a headland ca. 650m (2132.7 ft) west of the harbor to the mouth of Twenty Mile Creek, located 900m (2952.9 ft) east of the harbor. This phase of work was conducted on three separate occasions: 16 October 1993, 16 December in 1993, and 10 June 1994. The resultant maps also provide an accurate modern basis for comparison with pre-construction beach widths. Analysis of historic aerial photographs dated 10 july 1986, provided by the US Army Corps of Engineers permitted the mapping of beach widths for the same stretch of coastline prior to construction of the harbor for comparison with the 16 October 1993 shoreline map. Beach widths were measured at 20m (65.6 ft) intervals up and down the coast and compared between the two maps to determine whether and where net accretion or net erosion had occurred since 1986.

Erosion control structures visible on the photographs were noted and the areas where they occurred were determined to be subject to high potential bluff erosion even before the harbor was constructed. Lake level data for the two map dates, obtained from National Oceanic and Atmospheric Administration (NOAA) and modified with the proper datum corrections, had to be considered in the interpretation of these data. ...

RESULTS

Littoral Drift Volumes

For each volumetric analysis, monthly and yearly accretion rates were calculated using data obtained from the computer-generated total volumetric estimate. The accretion rate for the 16 October 1993 to 10 June 1994 mapping interval was 678 m^3/month (886.8 yd^3/month) or 8136 m^3/year (10,641.9 yd^3/year). The accretion rate for the 4 December 1991 to 10 June 1994 mapping interval was 613 m^3/month (801.8 yd^3/month) or 7361 m^3/year (9628.2 yd^3/year).

Changes in Beach Width

Recent

Mapped widths of the exposed updrift beaches did not change appreciably over the time elapsed in this study. To the east of the harbor, only the October 1993 map represents the system prior to the start of the nourishment which overlapped this study. The nourishment seems to have measurably increased the width of the beaches in the area.

Preconstruction Conditions

Observations drawn from 1986 aerial photographs show relatively consistent narrow beach widths both updrift and downdrift of the harbor site prior to its construction. The lake level at Erie, Pennsylvania, was 175.03m (574.27 ft) on 10 July 1986.

Post-Construction Conditions

Close comparison of beach widths on the July 1986 and October 1993 maps documents an obvious substantial increase in the width of the updrift (west) beaches, building to a maximum width eastward toward the west breakwall of harbor. Also confirmed is the impression that the 1986 and 1993 east or downdrift beaches are very similar except for the slight recent accretion close to the east harbor breakwall. Nowhere did the measurements show a reduction in beach width. Lake level at Erie, Pennsylvania, was 174.29 m (571.85 ft) on 16 October 1993, 0.73 m (2.43 ft) lower than on 16 July 1986.

Portions of coastal areas subject to bluff erosion prior to harbor construction were also identified by the presence of erosion control structures observable in the 1986 photographs. Bluff-erosion control structures were present along the entire stretch of coastline in 1986, both in the updrift and downdrift areas. Bluff-erosion protection structures are still observable vestigially behind the present wide beaches to the west attesting to previous vulnerability there.

DISCUSSION

Littoral Drift Volumes

...Based on detailed topographic mapping and computer-generated volumetric calculations, the annual volume of sediment trapped on the updrift side of the harbor breakwaters is 6504-8136 m^3/year (8507.2-10,641.9 yd^3/year). The estimated accretion rate for the 4 December 1991 to 10 June 1994 analysis is 7361 m^3/year (9628.2 yd^3/year).

In all probability, the volumetric estimate of littoral drift presented above are the best that have yet been determined for the Lake Erie shoreline in Pennsylvania because they have been generated using an extremely accurate calculation of actual sediment accumulation in a controlled setting. ...

Changes in Beach Width

If the data obtained from single days in July 1986 and October 1993 truly represent those years and the intervening seven years, the eastern beaches have not changed appreciably in width since the harbor was constructed. It is reasonable to conclude that the bluffs behind those beaches are no more subject to erosion than they were prior to harbor construction. Moreover, the presence in 1986 of bluff-erosion control structures along the entire stretch of coastline, indicates that both segments of the shoreline were at risk prior to harbor construction.

Even prior to the completion of the study the nourishment program instituted by the Pennsylvania Fish and Game Commission exceeded the annual littoral drift estimates determined. Records for each year following similarly exceed the recommended volumes that the downdrift beaches would have received if the harbor had not been constructed. Because the sediment which accumulated on the updrift side of the harbor was used for the replenishment the texture of the material provided downdrift was also the same as the sediment that would have arrived naturally.

The homeowners immediately downdrift apparently were favorably impressed with the efforts of the new managers of the harbor and dropped out of the lawsuit. Improbably the homeowners over 350 m (over1200 ft) downdrift continued to press the lawsuit. The erosion situation along the entire shore line of Lake Erie was severe in the Spring of 1997 due to extremely high lake levels, early spring loss of protective ice dunes, and the incidence of violent and long duration storms striking after the ice dune protection was lost. Lake levels in April, 1997 were within 5 inches of the 1985 all time high (573.62 ft, 174.84 m). At the request of the defense attorneys I mapped the same beaches at Presque Isle which I had mapped in 1995 and provided documentation of severe erosion there which could not have been due to Safe Harbor Marina which was 26 km (16 mi) downdrift (east) along the coast. A portion of the letter report (Buyce, 1997) provided to the attorneys and the court is presented below.

This letter report concerns shore erosion at Presque Isle during the fall of 1996 and the Spring of 1997 as a basis for comparison with the situation adjacent to the marina at North East, PA. I wrote the report " Presque Isle Sediment Transport Study" which documented the 1995 study by Kent Taylor and I in fulfillment of a grant from the PA Department of Natural Resources and the U.S. Coastal Zone Management Agency of the National Oceanic and Atmospheric Administration (NOAA). My studies of the situation at Presque Isle have been ongoing since 1995 as evidenced by the report on tombolo growth onto an offshore breakwater as a symptom of the variable effect along shore of the breakwaters for erosion control on Presque Isle by Wilson, Van Tassel, Buyce, et al. delivered at the NE regional meeting of the Geological Society of America in March 1997. Maps of shorelines attached to this letter were surveyed in May of 1997 and compared to the 1995 shorelines of the same areas (Figures 2 and 3 this guidebook).

The map of the Beach 6 area of Presque Isle shows that the shoreline in May of this year is essentially at the retaining wall for almost the entire west end of the study area, the beach having been almost completely eroded away there (Figure 2). The May 1997 shoreline of the eastern portion of the area is also behind the shorelines of 1995 despite at least 3.6 meters (12 feet) of growth of the beach out from the maximum extent of the erosion during earlier storms (marked by a prominent escarpment behind the present shoreline). The Beach 10 area shows drastic erosion along the eastern end of the study area.. The beach used to extend lakeward to the three easternmost prototype breakwalls but is now eroded back over 75 meters (246 ft.) shoreward from the easternmost breakwall leaving a precipitous escarpment cutting the dune behind the beach. Three control stakes used as survey markers for this part of the beach in the 1995 study were lost to wave erosion of the beach and dune behind it and had to be replaced to make the most recent map (Figure 3).The maps provide documented proof that beach erosion has been unusually severe along this portion of the shore of Lake Erie in the spring of 1997. Unlike the situation near the harbor at Northeast where littoral drift is being interrupted the breakwalls at Presque Isle were put in place to widen and protect the beaches. Recent newspaper reports indicate that Park officials found the project was so effective during the past few years that the annual nourishment was able to be reduced by 75 percent (Erie Daily Times, April 26, 1997... The same article reports that unusually severe erosion this spring have changed the situation so drastically that this year's replenishment is projected to be back to the one million dollar level. Factors other than the interruption of littoral drift must be responsible.

The factors responsible for the exacerbation of erosion along the shores of Lake Erie during the Spring of 1997 include :
a) Lake levels are higher than normal,
b) Beaches were left unprotected by ice dunes much earlier in the spring than normal, and
c) Storms of considerable strength and duration struck the beaches after ice dune protection was lost earlier in the spring than normally occurs.

Figure 4 is an Archived Nowcast Image of Lake Erie water level elevations for the 5 days prior to November 3 including the November 1 storm and shows the water being blown to the east end of the Lake (Buffalo) and away from Toledo on the west end. At Erie PA the so called storm "setup" is less than the 1 meter (3.3 feet) shown for Buffalo but can still be significant. Taken in conjunction with higher than normal lake levels a set up of nearly 0.6 meter (2 feet) rise in the lake level at Erie associated with storm winds blowing the water to the east end of the lake magnifies erosive effects. The set up during spring storms on top of the high lake levels enabled the energy of the storm waves to reach further back on the beaches than in recent years and even to be brought to bear on the bluffs and/or dunes behind the beaches with obvious exacerbation of the erosional effects.

This past fall, a major storm ravaged the shoreline on October 30 to November 1 prior to ice dune formation. Lake levels were down near the end of the seasonal decline of water levels and the breakwaters lessened the potential devastating effects. In the spring, however, the ice dunes melted away earlier than usual and were not there when major storms hit in March and April. The Corps reports that the level of Lake Erie has risen steadily from the November 1996 seasonal low and is projected to peak in June 1997. Lake levels for April 1997 reported by the U.S. Corps of Engineers, "Great Lakes Update" was 573.62 feet (174.84 m) which is only 5.5 inches below the 1985 all time high. Beaches and even dunes behind the beaches were more severely eroded than at any time since the installation of the breakwaters. Another storm on May 2 resulted in overwashing the beaches again and redistributed much of the early nourishment sand emplaced in the most severely eroded portions of the beaches at Beach 6, Stone Jetty Beach and beyond the tombolo at Breakwater # 49 east of Lighthouse Beach.

Thus factors such as
a) Unusually high water levels of the Lake,
b) Early melting away of the normally protective ice dunes and
c) Especially strong and long duration spring storms
have caused particularly severe erosion on the Presque Isle portion of the Lake Erie shore even in the absence of a newly constructed harbor or groin updrift.

Armed with an astute lawyer, the objective scientific data based on exhaustive research and the author as an expert witness the Pennsylvania Fish and Game Commission went to court July 28-30, 1997. And lost.

Studies are underway by the US Army Corps of Engineers to determine possible further engineering steps that might be instituted and actual assessment of "damages" to be paid, if any, by the Pennsylvania Fish and Boat Commission are on hold until results of the study are in. Negotiations were held that resulted in a specified amount of nourishment being placed in front of the homes of the winners until final resolution of the issue could be arrived at.

Participants will observe the physical situation on-site and discuss the possible reasons for the legal outcome.

STOP 2. SHADES BEACH, HARBORCREEK, PENNSYLVANIA

This is the proposed site for construction of both a harbor and a detached breakwater up drift (to the west). The harbor will be similar to the one at North East and the detached breakwater will be similar to those we will see at Presque Isle (Figure 5). To avoid legal complications such as those at North East Marina a federal and state Coastal Zone Management study has been funded and is underway to provide pre-construction baseline data. The coastal marine contractors selected for the study will need to determine the natural, pre-construction, conditions during the course of an ice-free year. Pre-construction conditions include both the shape of the exposed and submerged beach and the dynamics of the littoral drift processes. They will document the configuration of the exposed beach and the nearshore bathymetry and its natural seasonal variability. That, along with the interpretation of the dynamics of waves, currents and sediment transport in the area could be used to predict the effects of the off-shore construction improvements planned as part of the overall Shades Beach Park Development Project. The data and interpretations will be used to predict adverse coastal effects including impacts to downdrift (eastern) bluff areas which may occur in the short and long terms and considering the effects of fluctuating lake levels.

It would be obvious to draw heavily on the lessons learned nearby on the Lake Erie shore at North East (for the harbor) and at Presque Isle (for the offshore breakwater). Significant differences between the Shades Beach site and the others would have to be taken into account. Obviously site-specific differences will have to be considered. Examples of the differences include (1) At Presque Isle there is far more sediment in the system to accrete wide beaches behind offshore breakwaters, (2) Bedrock of the Northeast Shale which outcrops below lake level at North East and is only seen offshore is present a meter or more above lake level at Shades Beach providing the bluff protection from wave erosion here, and (3) At Shades Beach Eightmile Creek brings sediment into the littoral zone immediately downdrift from the proposed harbor whereas, at North East, the nearest input downdrift is from Twentymile Creek 900 m (2953 ft) downdrift.

The geomorphic development of the site is interesting and relevant. Discussed by Schooler (1974) and expanded upon by Delano (in Thomas et al., 1987), the following except is from Delano (p 74-75):

> This township park takes advantage of a rare low flat valley with lake access. The reason for the existence of the flat area which the park occupies is evident from the topographic map of the area (Figure 44) and Figure 45 (Figures 6 and 7 respectively herein) Eightmile Creek, which now enters the lake just east of the access from the park to the lake shore, formerly occupied this valley. Lake erosion and bluff recession caused the shore line to retreat until it intersected a northward meander loop in the entrenched stream valley. The lake effectively captured the stream, leaving the lower valley occupied by a severely underfit stream (and the parking lot -author). Eightmile Creek falls approximately 12 m (40 ft) from the abandoned channel channel upstream of the mouth. This example of piracy is evidence that erosion and bluff recession along the Lake Erie shore are not recent developments. ...

Delano goes on to consider why bluffs are relatively stable here (p75-77):

> ...Two possible explanations for this are (1) the bedrock ledge protects the bluffs from toe erosion, and (2) the isolation of the bluff section by the abandoned stream channel limits the source area for groundwater, and the resulting small amout of seepage out of the slope face is a factor in the apparent increased stability of the bluff. Both factors are probably important, but the relative importance of each is unknown.

Several features to notice from the beach and from the bluff overlook accessible from a trail beginning in the parking lot are : (1) The beach is very coarse grained with abundant gravel and it extends only a short distance out from the shore line before it gives way to extensive exposed bedrock ledges of Northeast shale (actually an interbedded shale and siltstone facies), (2) The protective ledge extend well above lake level and is overlain by unconsolidated glacial diamict (very poorly sorted boulders, sand, silt and clay) which extends to the top of the bluff, and (3) the poor condition of the concrete remnants of shore line structures provides evidence of the power of Lake Erie to destroy inadequately engineered coastal structures, especially in time of high lake levels.

STOP 3. PRESQUE ISLE: LIGHTHOUSE BEACH AREA

The first of our three stops on Presque Isle will give us the opportunity to see the how variable the effect of the offshore breakwaters has been on beach erosion and deposition. Near the lighthouse erosion has continued to be severe despite the presence of breakwaters offshore and immediately downdrift (to the east) "excessive" deposition results in the annual connection of the beach to a breakwater forming a tombolo. The proximity of the two areas will highlight an unexpected benefit of the project: harvesting of the unwanted sand deposits from the tombolo serves as a low cost source of sand which is recycled as nourishment for the nearby area of erosion. We will ascend the lighthouse in small groups to obtain an aerial view of the situation. A study of one cycle of tombolo growth was completed by undergraduates and reported to the northeastern Section of the GSA (Wilson et al., 1997). The abstract is presented below:

The Presque Isle Shoreline Erosion Control Project's 55 segmented offshore breakwaters constructed at a cost of 23.8 million dollars has had variable effectiveness along the shoreline; stretches of continued erosion alternate with those of salient-widened beaches some of which culminate in tombolo formation. Part of an extensive Coastal Zone Management funded study during 1995 documented erosion and deposition in the Lighthouse beach area, breakwaters (BWs) 43 through 47. The area updrift of the lighthouse jetty opposite BWs 43 and 44 were salient-widened accretionary beaches, but downdrift the littoral-drift sand moves to an extensive offshore bar complex outside of BWs 45,46,47 where the beaches continued to be erosional despite breakwater construction. June, 1995 aerial photographs show the offshore sandbar complex along the erosional beach and downdrift, where it wraps back into the shore at the salient widened beaches behind BWs 48 and 49, the location of the current study.

During June 1996 a tombolo that had attached to BW 49 was harvested to nourish the erosional beach immediately updrift. From June through November the tombolo's regrowth was documented by oblique aerial photographs from the nearby lighthouse, 10 plane-table maps of the shoreline, six sets of Emery profiles along four transects from BWs 47 to 49, and augmented by a current direction study using drogues. The beach was depositional throughout the study period but with significant changes in growth rate. The tombolo grew at a rate of 9 m/mo during July-Sept.,17 m/mo in late Sept.-Oct.,and 46 m/mo in late Oct.-Nov. The earlier study showed a similar, major increase in deposition in late Fall for the Lighthouse beach and nearshore area. The source of the sediment for the growth is at least in part from the nourished erosional beaches updrift as shown by their obvious loss of sediment as beach scarps retreated landward providing sediment to the longshore current documented by the drogue study. The role of the offshore bar complex is not known, but may serve two functions supporting beach growth in the study area: 1) possible addition of bypassed sediment by landfall of bar complex 2)reduction of wave energy arriving at the BWs and beach by stimulation of repeated breaker zones offshore. Future studies are proposed to investigate these possibilities using tracer sand, offshore current studies and mapping, detailed bottom morphology and sediment distribution.

Figure 8 shows the shorelines mapped as the tombolo grew, Figure 9 indicates the remarkable growth rate documented and Figure 10 shows longshore currents documented using a floating device called a current drogue. The aerial photographs referred to were taken from the top of the lighthouse which you will also visit. The internal structure of the beach developed during accretion of a tombolo will be revealed in the trench that you will help excavate at this location.

About one third of all the sand used for nourishment in the last six years was recycled on-site from build-ups such as this one. While not free, the cost of such replenishment of eroded beaches is substantially reduced over that for obtaining and placing sand from elsewhere. Table 1 entitled, Sand Nourishment History for Presque Isle State Park, compiled and provided by Eugene Comoss (Bureau of Facilities Design and Construction Pennsylvania Department of Conservation and Natural Resources) helps us to consider such factors in our attempt to determine the cost effectiveness of the $23.8 million dollar offshore breakwaters. The numbers can be looked at in several ways, of course, but such quantification is crucial to the process. It is important to realize that each ton listed is equal to 0.8 cubic yards, or alternatively each cubic yard is equal to 1.25 tons. You are free to crunch the numbers yourselves but I will give you the benefit some of my own efforts which involve some interpretation as well as selective use of the data. Be warned!

Ignoring 1956, the annual nourishment from 1975 to 1991 was about 228,000 tons/year. Also ignoring the 330,000 tons added as part of construction, the annual nourishment from 1993 to 1998 was about 86,000 tons, which is about 38 % of the earlier total or about a 62% reduction. If the recycled sand volumes are also ignored the annual off-site nourishment is about 57,600 tons annually or 25% of the earlier amount; a 75% reduction. Success? Lets look at the money. For the seventeen years prior to 1992 (again ignoring 1956) the annual cost of nourishment was about $1,312,000. For the last six years (1993 to 1998) the annual cost comes in at about $780,000, 59% of the previous expenditure, or a reduction of 41%. Failure?

A basic assumption inherent in the analysis above is that the annual nourishment provided to the system was enough to maintain healthy beaches over the long term pre-construction studies. Nummedal et al. (1984) found that annual erosion volumes at the neck of the peninsula were matched by accretion volumes at Beach 10 and Gull Point. Our post-construction study (Buyce, 1995) suggested that accretion volumes were substantially less at Beach 10 (and by implication Gull Point) than the erosion volumes at the neck (Figure 11). Apparently the nourishment was not enough to maintain the system at pre-construction levels. Without such volumetric studies to assess the nourishment program it was decided to use the annual growth rate of Gull Point as an indicator. If the surface area of Gull Point continued to grow at least 0.4 acres annually the system was adequately nourished. Data in the US Army Corps of Engineers report, (1999) show that the growth has been below this value since 1996. The same report notes data gathered by new volumetric techniques (SHOALS aerial mapping) indicates substantial subaqueous growth is occurring. The Beach 10 area adjacent to Gull Point has been targeted for major nourishment this year and will receive all the sand derived from the removal of the excessive spit growth that threatened Beach 11.

STOP 4. PRESQUE ISLE: BEACH NO. 10 AND GULL POINT

. Our second stop on Presque Isle will be in the area where the nourishment sand from the spit dredging and recycling operation is being placed. The easternmost of the 55 offshore breakwater sequence and three additional earlier constructed prototype breakwaters are visible updrift (to the west). To the east is the environmentally sensitive area called Gull Point which is a bird sanctuary and has restricted access. Not surprisingly, it is this area immediately down-drift from the last of these erosion control structures that was designated as most in need for receiving the dredged sand. The fate of the nourishment sand over the next several months will be monitored by students as part of a undergraduate coastal studies GIS project. The data and project report will be provided to Presque Isle State Park management and to the US Army Corps of Engineers.

STOP 5. PRESQUE ISLE: BEACH NO.11 AND THOMPSON BAY

The final stop on Presque Isle and of the trip will be at Beach 11, the site of the sand spit which was dredged. Beach 11 is on the southwest shore of Thompson Bay which is bordered on the northeast by Gull Point and opens onto Lake Erie to the southeast. The sand spit developed on the end of Gull Point and began enclosing Thompson Bay from the north. These "excessive" deposits were coincident with very low lake levels. Ultimately the spit detached from Gull point and attached to the eastern end of Beach 11 nearly enclosing the bay (see Figures 12 and 13 from the US Army Corps of Engineers report, (1999).The effects of nearly separating Beach 11 from the open waters of Lake Erie were stagnation, abundant weed growth and threat of frequent beach closing due to pollution. The necessary studies were done to obtain permits and dredging began in the summer of 1999. The dredging and nourishment project is due for completion in mid-September 1999 so all activity should be over by the time of our visit. We will have little to see here, having arrived after the fact but can at least visualize the situation facing the park management. The debate was heated concerning the option of allowing the "natural" processes to proceed. The fact that the Presque Isle has been a heavily managed and, at least partially, an "unnatural" system since at least 1828 apparently won out.

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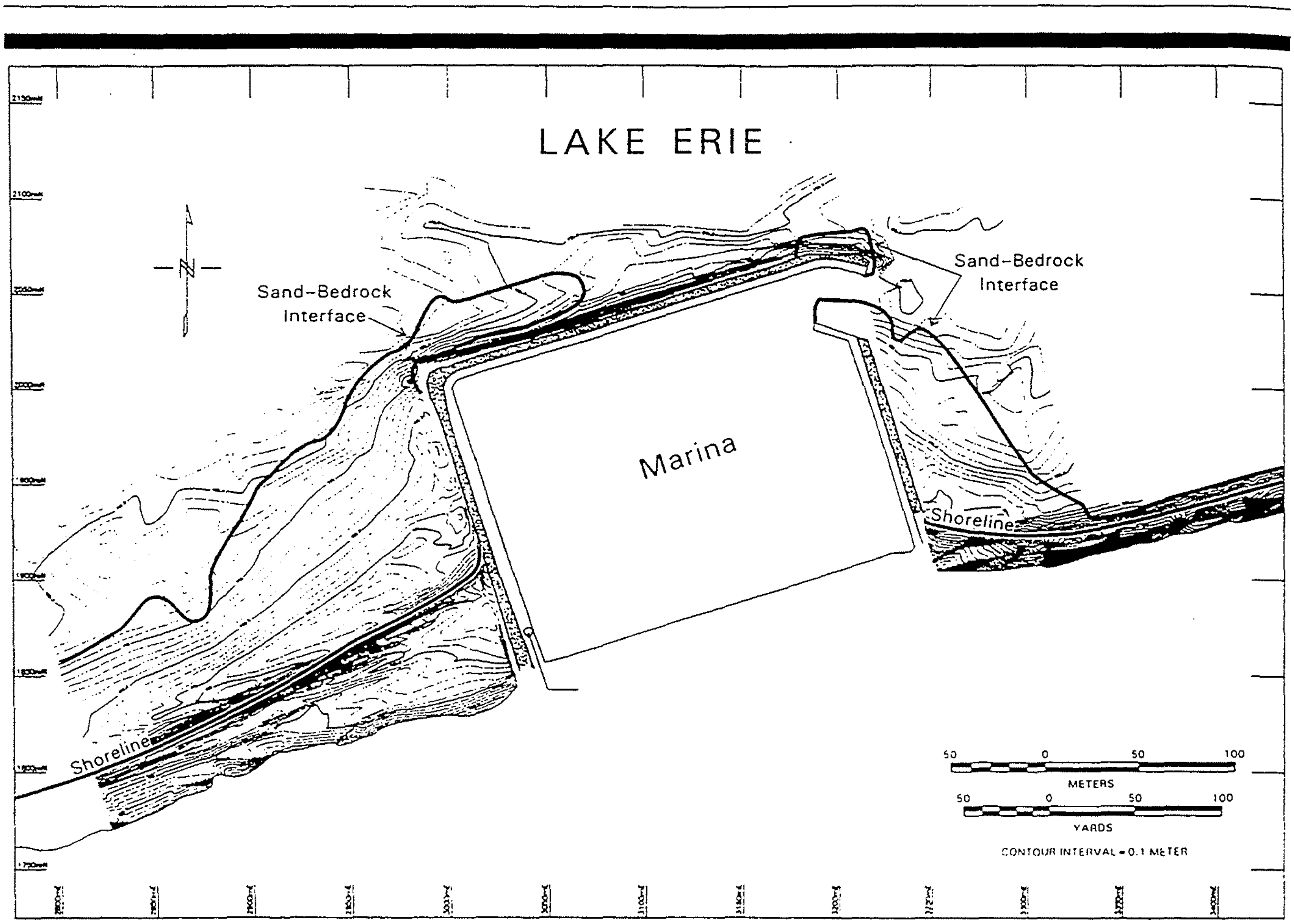


Figure 1. Detailed 10 June topographic map of the beach and nearshore zones for the perimeter of the harbor at North East, Pennsylvania. Sand/bedrock interface indicates sediment accumulation against the updrift (west) wall and extending a short distance around the northwest corner of the harbor. Along the eastern harbor the sand/bedrock interface indicates a narrow accumulation zone extending into the harbor entrance and grading into a cobble/bedrock interface to the east.(from Buyce and Taylor, 1998)

Figure 2. Presque Isle Beach 6 Shorelines. Compared to 1995 shorelines the May 1997 shoreline is eroded back due to higher lake levels and severe spring storms impinging on beaches unprotected by ice dunes. On the west the beach has been removed back to the retaining wall.

Sat. D14

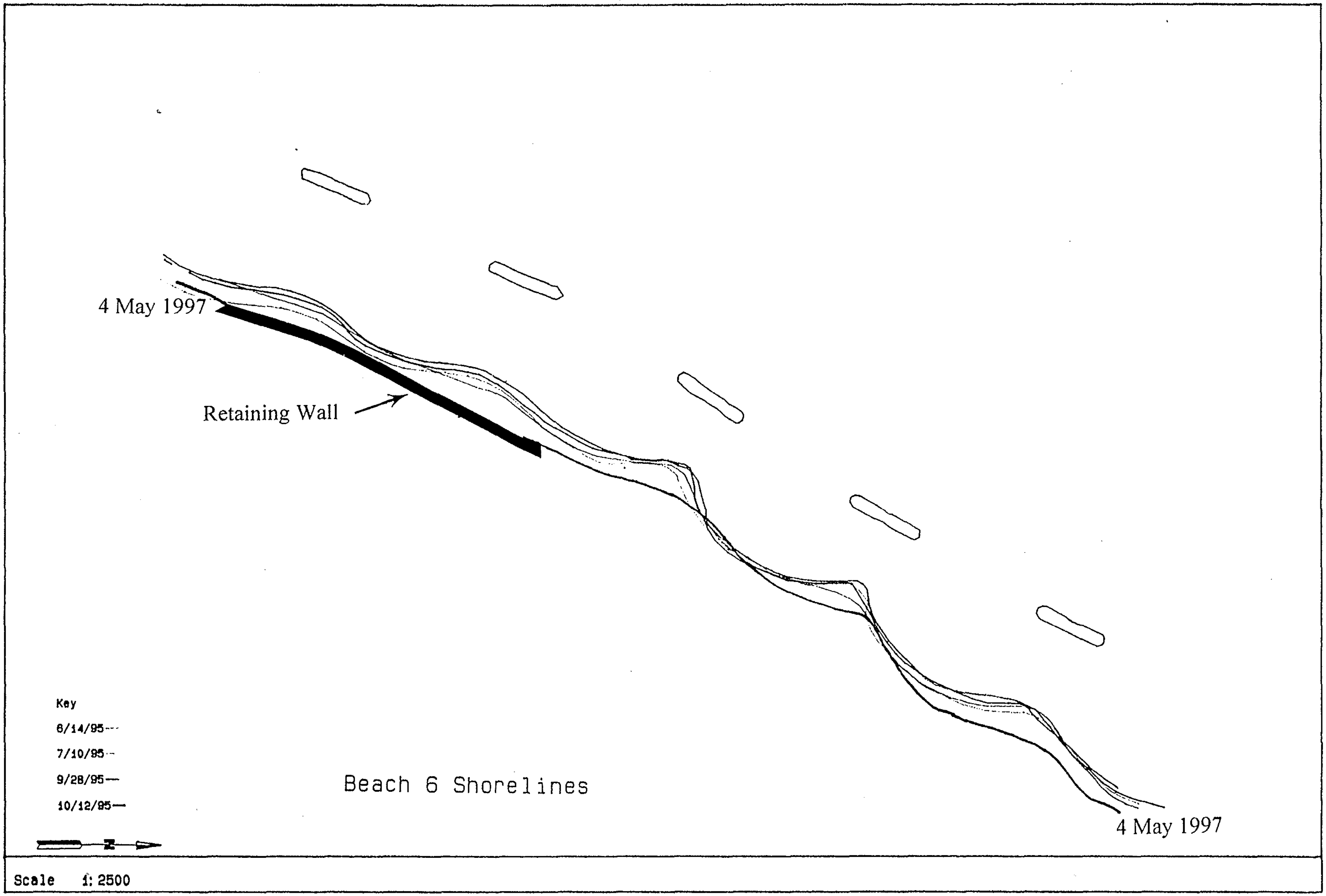

4 May 1997
Retaining Wall
Key
6/14/95
7/10/95
9/28/95
10/12/95
Beach 6 Shorelines
4 May 1997
Scale 1:2500

Figure 3. Presque Isle Beach 10 Shorelines. . Compared to 1995 shorelines the May 1997 shoreline is eroded back due to higher lake levels and severe spring storms impinging on beaches unprotected by ice dunes. The beach was largely removed from behind the three prototype breakwaters and the scarp was into dunes behind the beach.

Sat. D16

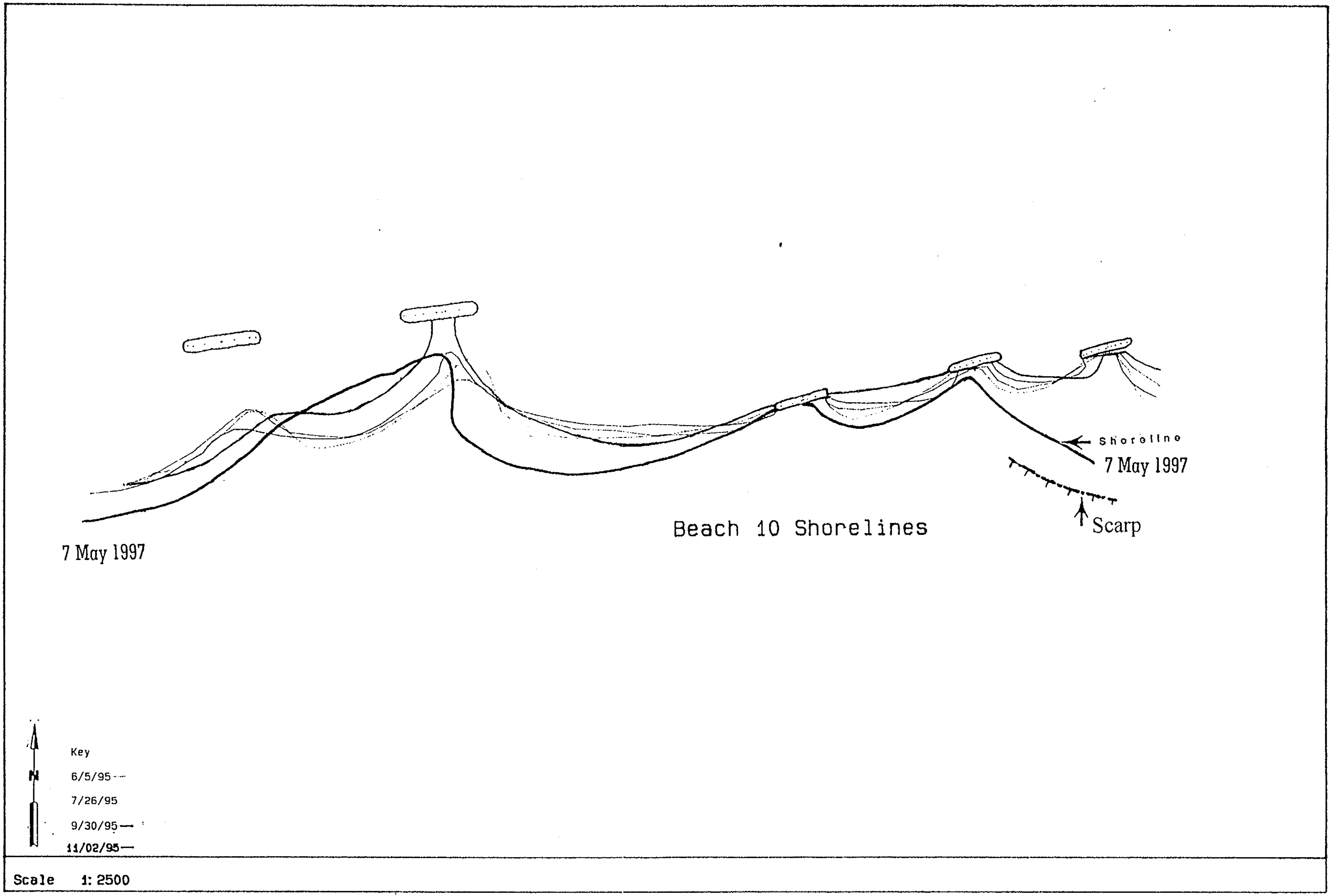

Beach 10 Shorelines

Figure 4. Archived Nowcast Image of Lake Erie water level elevations for the five days prior to 3 November 1996 including the 1 November storm date. A storm "setup" is shown with water being blown to the east end of the lake (toward Buffalo) and away from Toledo on the west end. This short-term lake level rise magnifies the erosive effects of storm waves.

Archived Nowcast Images

Time Series Water Elevation (File : stn9630800.gif)

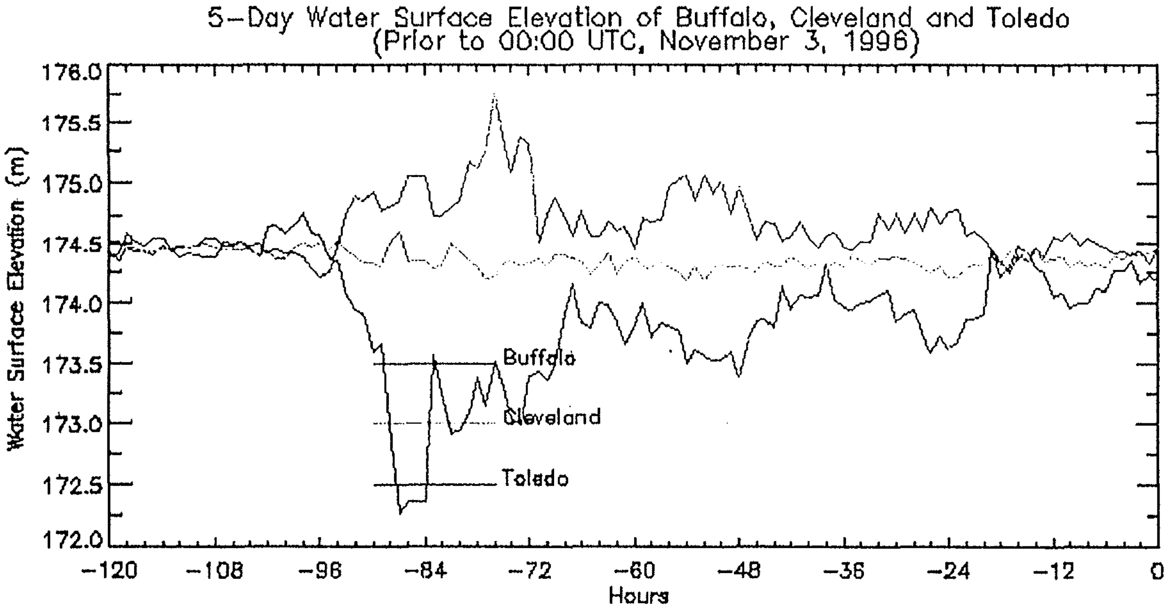
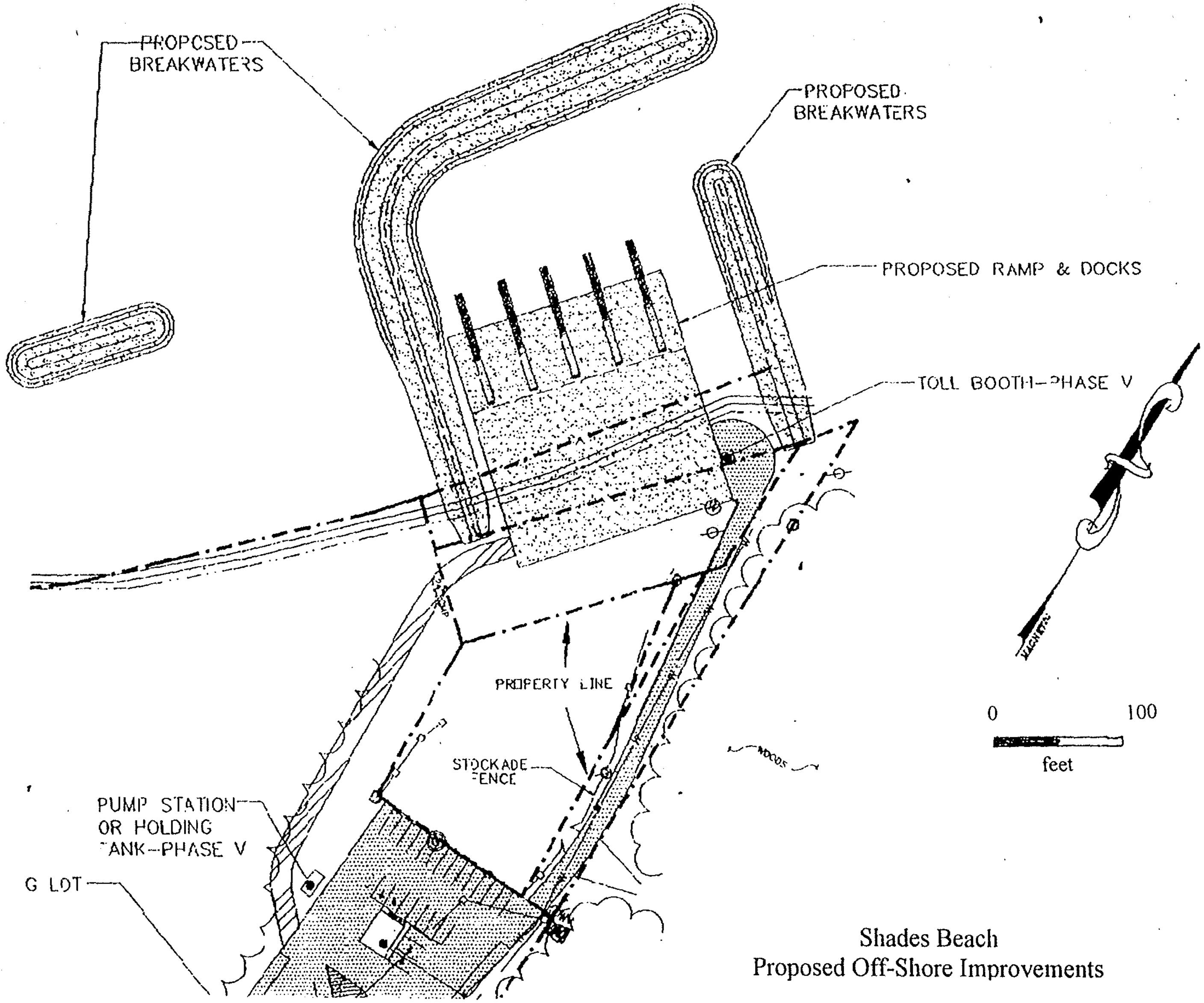


Figure 5. Shades Beach Proposed Off-Shore Improvements. Notice that the plan includes a harbor similar to North East Marina and an offshore breakwater similar to those at Presque Isle. The sketch was provided to bidders on the pre-construction littoral drift study funded by the Coastal Zone Management Division of NOAA.

Sat. D20



Shades Beach
Proposed Off-Shore Improvements

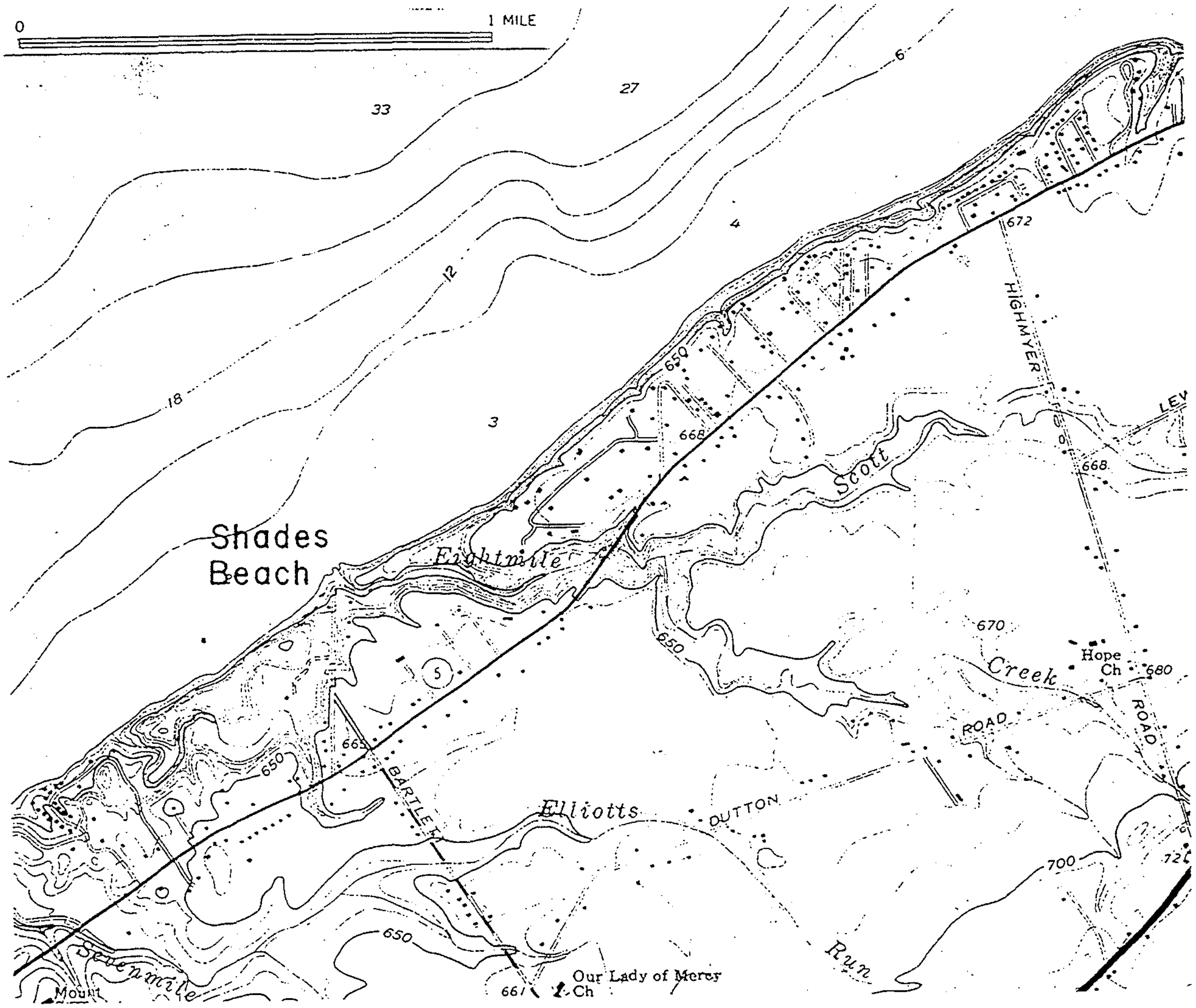


Figure 6. Location map for Stop 2 (from Harborcreek, PA 7.5 minute topographic map)

Figure 7. Schematic diagram showing hypothesized origin of the topography at Shades Beach Park. A similar but less detailed diagram is shown by Schooler (1974, Fig. 5, p. 18)

A. Reconstruction of drainage pattern at a time before extensive bluff erosion.
B. Shoreline erosion led to bluff recession and "stream capture" by the lake.
C. Present drainage pattern and the abandoned channel of "7 &1/2 mile Creek."

(from Delano <u>in</u> Thomas et al. 1987, p.76)

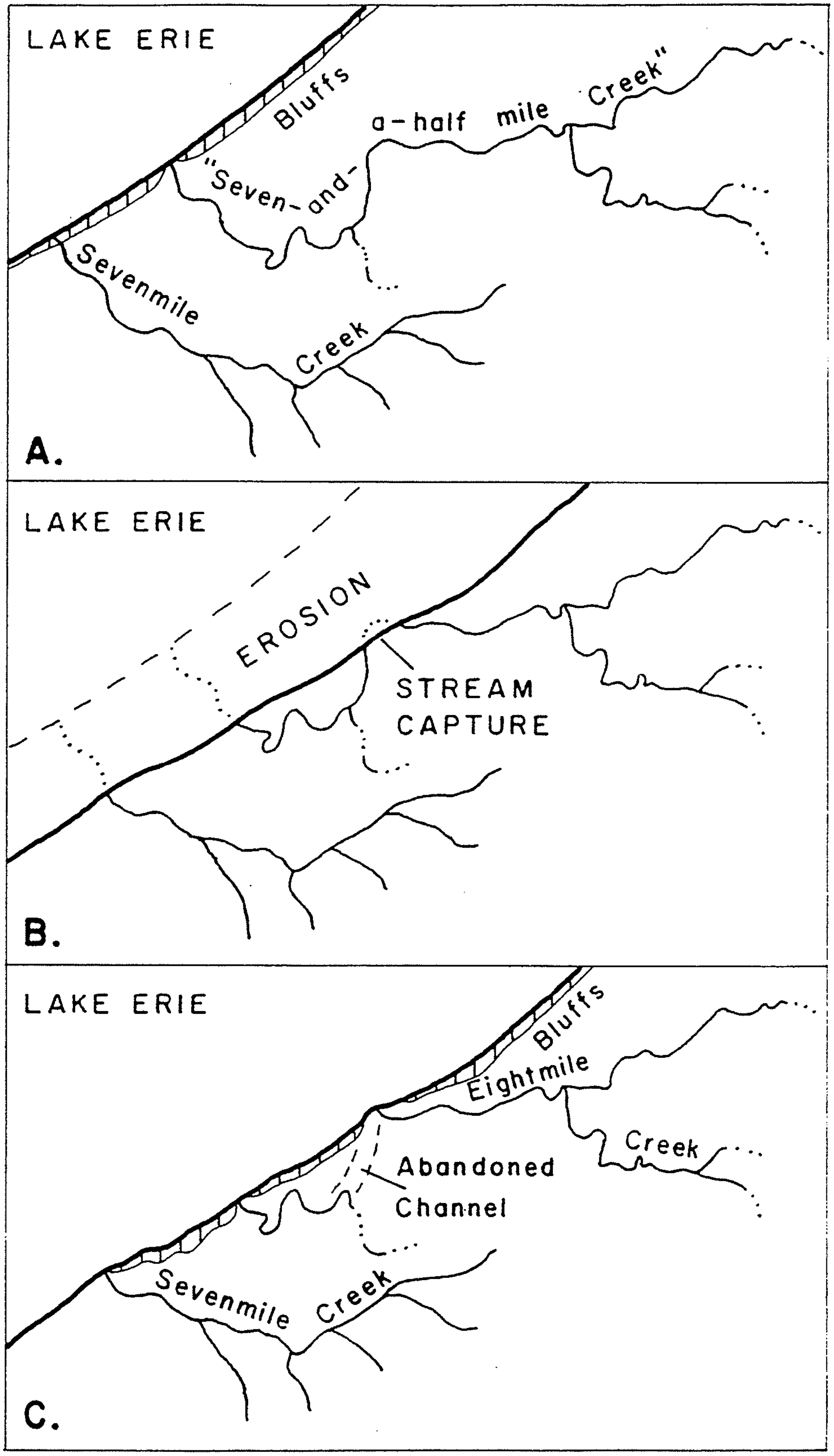
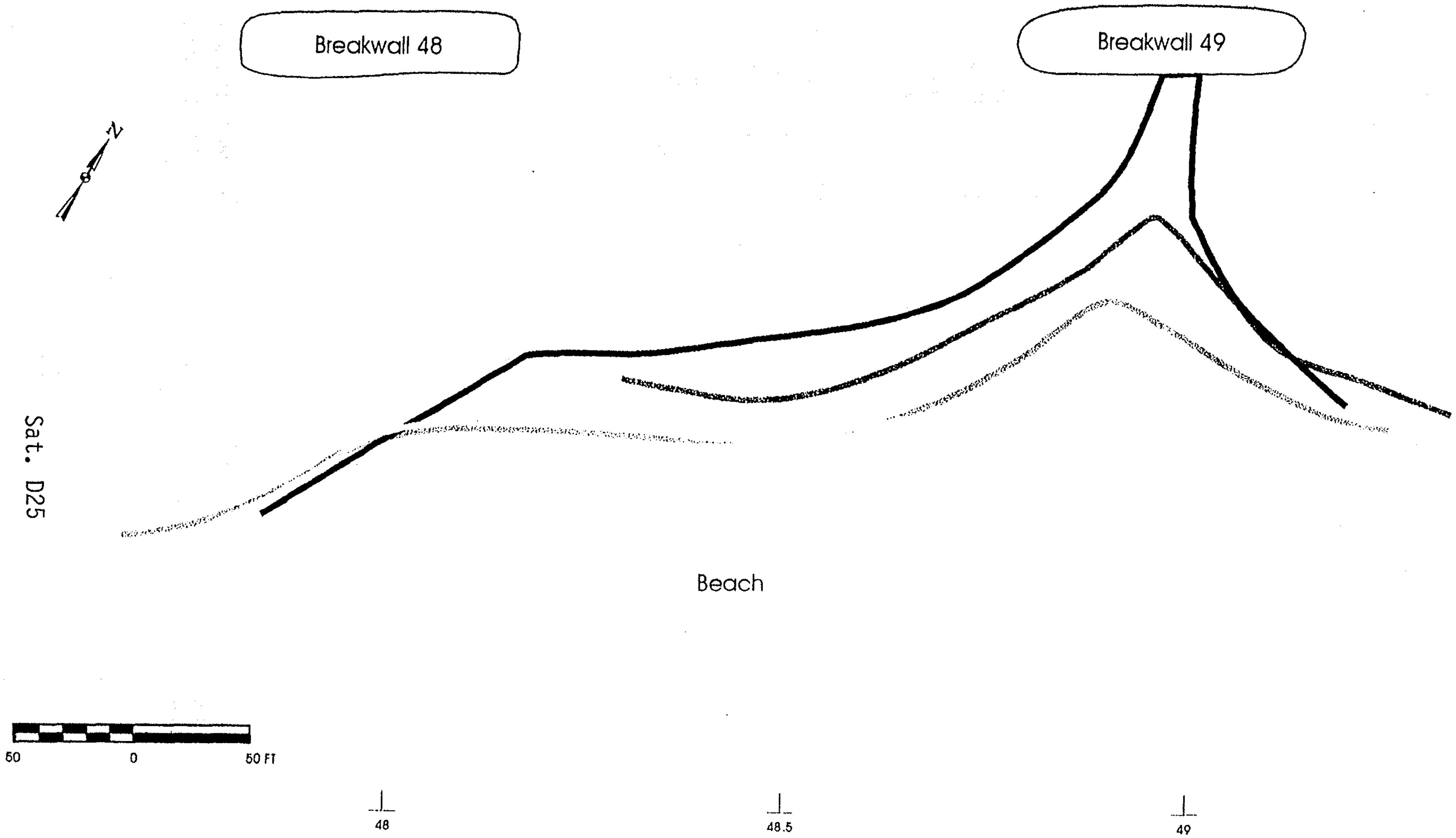

LAKE ERIE
Bluffs
"Seven-and-a-half mile Creek"
Sevenmile Creek
A.
LAKE ERIE
EROSION
STREAM CAPTURE
B.
LAKE ERIE
Bluffs
Eightmile Creek
Abandoned Channel
Sevenmile Creek
C.

Figure 8. Presque Isle lighthouse beach shorelines as the tombolo grew in the fall of 1996. The shorelines shown were mapped on 22 July, 6 September, 17 October , and 5 November 1996.



Sat. D25

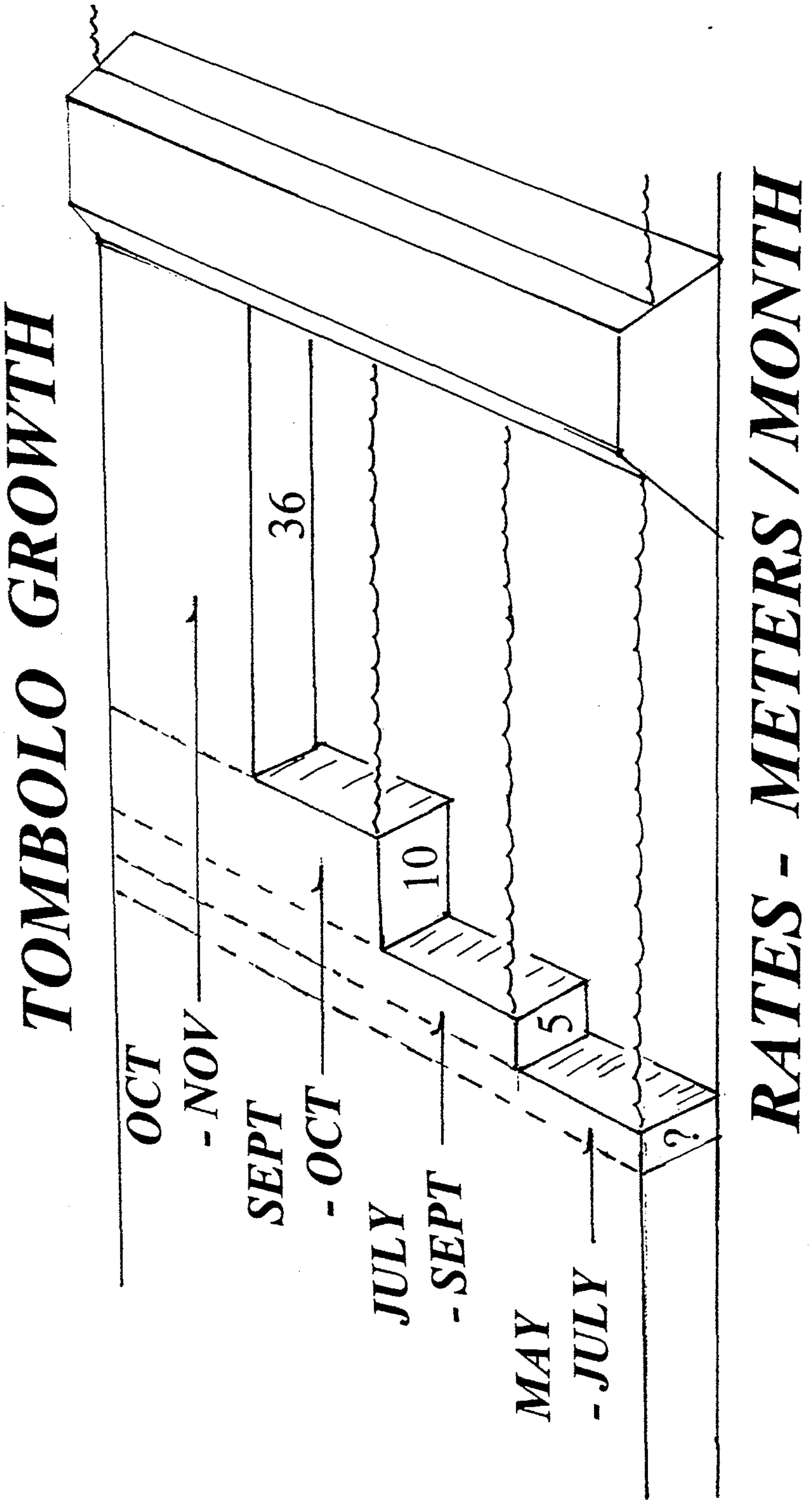
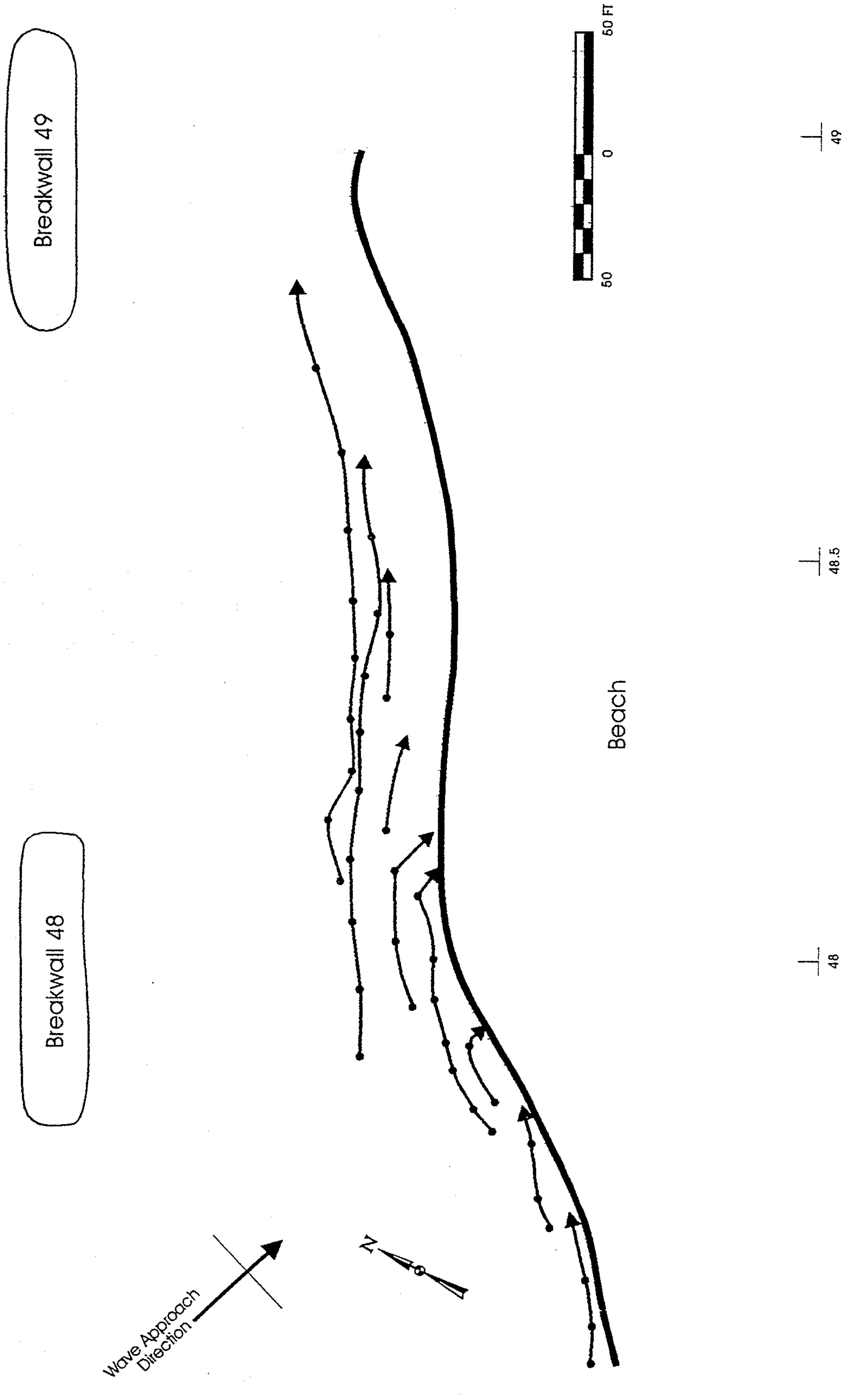


Figure 9. Tombolo Growth. The fall 1996 growth rates of the light house beach tombolo which formed behind breakwater 49 on Presque Isle. After very little accretion in summer the growth rate accelerated significantly through the fall until connection was achieved.

Figure 10. Presque Isle light house beach longshore current directions in early summer 1996. Sediment moved to the beach behind breakwater 49 where a tombolo ultimately formed can be inferred to have come from beaches to the west via the currents mapped by tracking a floating current drogue.


Breakwall 49
Breakwall 48
Beach
Wave Approach Direction
N
50 FT
0
50
49
48.5
48

Sat. D28

Figure 11. Presque Isle sediment transport volumes in 1995. The accretion volume at Beach 10 (and by implication at Gull Point) is substantially less than the erosion volume at the neck of the Peninsula (Beach 6). Prior to construction accretion volumes roughly balanced erosion volumes (Nummedal, 1984). Evidently the volume of artificial nourishment (much reduced in anticipation of benefits from the presence of the breakwaters) was inadequate to maintain pre-construction conditions.

Transport Volumes
1995

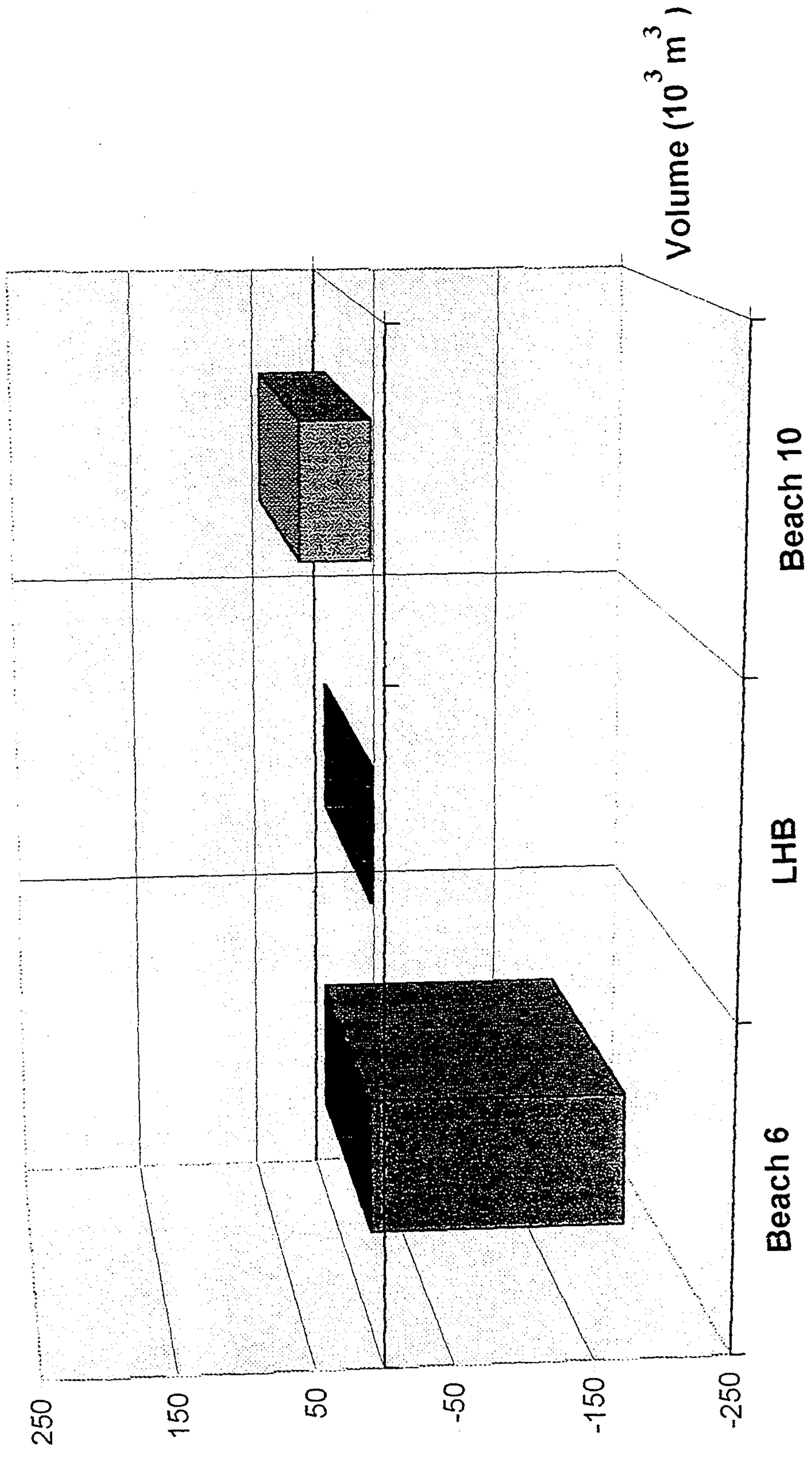
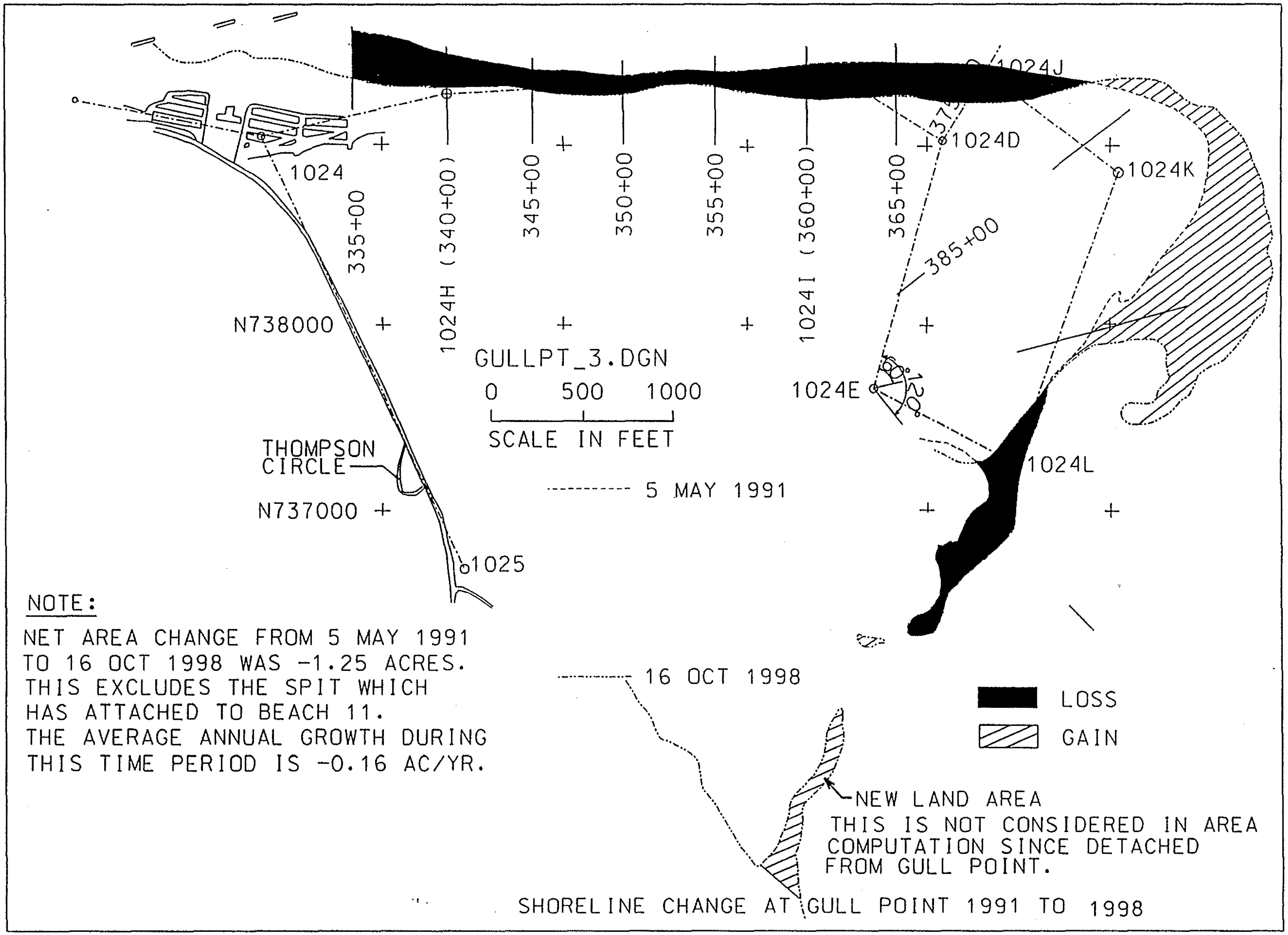


Figure 12. Aerial Photograph of Gull Point, June 1998. The grid pattern on the lower left is the Beach 11 parking area. The "excessive" deposition represented by the spit is evident at the bottom of Beach 11. It threatens to enclose the waters of Thompson Bay between Beach 11 and Gull Point. See Figure 13. Source: US Army Corps of Engineers, 1999.

AERIAL PHOTOGRAPH OF GULL POINT

Figure 13. Shoreline change at Gull Point 1991 to 1998. The spit which threatened to enclose Thompson Bay and Beach 11 is labeled, “new land area”. See Figure 12. Source: US Army Corps of Engineers, 1999.



THIS IS NOT CONSIDERED IN AREA COMPUTATION SINCE DETACHED FROM GULL POINT.

NOTE:

NET AREA CHANGE FROM 5 MAY 1991 TO 16 OCT 1998 WAS -1.25 ACRES. THIS EXCLUDES THE SPIT WHICH HAS ATTACHED TO BEACH 11. THE AVERAGE ANNUAL GROWTH DURING THIS TIME PERIOD IS -0.16 AC/YR.

SHORELINE CHANGE AT GULL POINT 1991 TO 1998

Table 1. Sand nourishment history for Presque Isle State Park. Compiled by Eugene Comoss, Bureau of Facilities and Construction, Department of Conservation and Natural Resources.

Sand Nourishment History for Presque Isle State Park

Tuesday, June 22, 1999

Year	Primary Sand Amount in Tons	Primary Sand Source	Secondary Sand Source	Funds Expended
1956	4,150,000 cy	pumped from bayside	none	$2,451,270.00
1975	186,700	offshore borrow area	none	$1,097,000.00
1976	183,000	offshore borrow area	none	$1,109,500.00
1977	287,000	upland sand source	none	$1,077,000.00
1978	173,000 (3 prototype breakwaters constructed at Beach 10)	upland sand source	none	$1,073,400.00
1979	216,000	upland sand source	none	$1,060,500.00
1980	216,000	upland sand source	none	$1,082,100.00
1981	236,000	upland sand source	none	$1,213,400.00
1982	284,000	upland sand source	none	$1,424,400.00
1983	194,000	upland sand source	none	$1,049,000.00
1984 & 1985	505,000	upland sand source	29,500 tons of gravel on test Beach 5.	$3,007,000.00
1986	258,000	upland sand source	none	$1,631,400.00

TABLE 1

Year	*Primary Sand Amount in Tons*	*Primary Sand Source*	*Secondary Sand Source*	*Funds Expended*
1987	173,000	upland sand source	45,000 tons coarse sand and 10,000 tons of fine sand from offshore borrow area	$1,671,500.00
1988	211,000	upland sand source	27,000 tons fine sand from offshore borrow area	$1,529,200.00
1989	234,066	upland sand source	35,500 tons offshore borrow area	$1,400,000.00
1990	99,403	upland sand source	13,000 tons offshore borrow area	$600,000.00
1991	55,824	upland sand source	23,000 tons offshore borrow area; 230,000 from offshore borrow area as part of breakwater project	$2,273,600.00
1992	330,000	offshore sand sources	none	$2,580,600.00
1993	47,870	offshore sand source	29,825 cy recycled tombolo sand	$675,000.00
1994	53,069	offshore sand source	19,000 cy recycled tombolo sand	$650,000.00
1995	50,936	offshore sand source	29,500 cy recycled tombolo sand	$700,000.00
1996	51,108	offshore sand source)	49,000 cy recycled tombolo sand	$730,000.00
1997	90,500	offshore sand source	40,500 cy recycled tombolo sand	$1,110,000.00
1998	52,342	offshore sand source	44,000 cy recycled tombolo sand	$810,000.00
			Total Funds Expended	$32,005,870.00

Sat. D37

TABLE 1

ROAD LOG

Mileage
(INC.= INCREMENTAL
CUM=CUMULATIVE)

INC	CUM	Route Description
0.0	0.0	START: I-90, Exit 11 PROCEED NORTH on Route 89
1.4	1.4	Blinking light – East Wellington St.
0.2	1.6	Jct. Rt. 426 South
0.5	2.1	Jct. Rt. 20, Downtown North East
0.3	2.4	Mercyhurst College – North East Campus
0.2	2.6	Sunset Drive – North East Schools
0.9	3.5	End Rt. 89. TURN RIGHT (east) on Rt. 5
2.5	6.0	North East Marina, TURN LEFT

STOP 1. NORTH EAST MARINA. Stop at office. Proceed to bottom of hill and park opposite marina. Proceed downdrift (east) along shore. Notice nourished beach width, bluff, and any erosion control structures. Return to harbor continuing to updrift (west) side noticing partially- harvested beach width, bluff, and any erosion control structures.

0.1	6.1	Leave North East Marina. TURN RIGHT (west) on Rt. 5
2.5	8.6	Jct. 89 South
1.6	10.2	Penn Shore Winery
1.4	11.6	Catholic Cemetery Rd.
1.7	13.3	Shoreward Rd., Harborcreek
2.8	16.1	Bartlett Rd., TURN RIGHT, Shades Beach Sign
0.3	16.4	Shades Beach, Parking lot.

STOP 2. SHADES BEACH. Park in lot at foot of first hill. Walk to shore. Observe site of new harbor and offshore breakwater. Notice bedrock of the Northeast Shale (and siltstone) extending well above the lake level protecting the bluff from wave erosion. Glacial till (unconsolidated boulders, sand, silt and clay) extends to the top of the bluff.

Return to parking lot and follow trail to bluff top. Aerial view from bluff edge may show the limited amount of sediment in littoral drift system tucked up against the shoreline with extensive exposed bedrock on the lake floor beyond.

0.3	16.7	Route 5, TURN RIGHT (west)
0.9	17.6	Mount Saint Benedict Monastary
1.4	19.0	Bonnie Brae Rd.
1.6	20.6	Jct. 955 East. Continue on Rt. 5. GE Plant on left.
0.9	21.5	Rt. 5 split to Rt. 5 & Alt Rt. 5. STRAIGHT AHEAD on Alt. Rt. 5
1.5	23.0	East Ave. Continue Alt. Rt. 5. Follow signs to Bayfront Parkway
0.2	23.2	Bayfront Parkway. TURN RIGHT.
0.5	23.7	Left arrows. Continue on Bayfront Parkway.

0.8	24.5	Holland St. Erie Co. (Blasco) Library
0.2	24.7	State St., Erie. Dobbins Landing Continue on Bayfront Parkway. Presque Isle Bay (Erie Harbor) enclosed by Presque Isle sand spit, locally called "ThePeninsula"
2.0	26.7	8th St. traffic light. TURN RIGHT
0.4	27.1	Lincoln St. light. TURN RIGHT
0.1	27.2	West 6th St. TURN LEFT
1.1	28.3	Tracey School
0.4	28.7	Peninsula Drive. TURN RIGHT.
0.6	29.3	Sara Coyne Plaza
0.2	29.5	Presque Isle State Park. "The Peninsula", Bear right.
0.9	30.4	Stull Interpretive Center, on left. Presque Isle Bay (Erie Harbor) and City of Erie, on right.
1.3	31.7	Park office, Beach 6 entrance
0.6	32.3	Cookhouse, Waterworks (previous water supply for City of Erie)
0.9	33.2	To Lighthouse. TURN LEFT
0.0	33.2	Stop Sign. TURN RIGHT
0.6	33.8	Lighthouse
0.1	33.9	Lighthouse Beaches

STOP 3. Assemble on Beach by Lighthouse groin. Small groups (12 or less) will ascend lighthouse for aerial view of lighthouse beaches and tombolo area. The beaches immediately downdrift (east) of the lighthouse groin behind breakwaters 45, 46, and 47 remain erosional in spite of the new structures. Excessive deposition begins further downdrift culminating in the annual formation of a connection of the beach to breakwater 49 each fall (a tombolo)

Walk beaches from lighthouse groin east past breakwater 45 to beach opposite breakwater 49 (site of tombolo growth)

LUNCH

Participate in digging beach trench to expose stratigraphy developed during growth of tombolo.

0.0	33.9	Continue east on Peninsula Drive
0.4	34.3	Bear right. Stop sign.
1.0	35.3	Beach 10, Budny Beach

STOP 4. Enter parking lot beyond BathHouse. From beach observe to the west, the east end of the sequence of 55 offshore breakwaters with the three prototype breakwaters extending beyond to this location. Nourishment sand widens the beach here and evidence of previous erosion is evident behind the beach downdrift (to the east).

0.2	35.5	Leave Beach 10. TURN LEFT and continue east on Peninsula Drive.
0.5	36.0	West entrance to Beach 11. TURN LEFT.

0.3	36.3	Parking lot by Beach 11 Bath House.

STOP 5. Observe Gull Point and Thompson Bay. Note site of spit deposition that had to be removed to prevent the closing off of Beach 11 from the open waters of the Lake Erie.

0.0	36.3	Proceed through the parking lot to exit Beach 11 via east entrance road.
0.2	36.5	Peninsula Drive and east entrance to Beach 11. TURN LEFT.
1.2	37.7	Perry Monument and ferry dock.
		Presque Isle Bay (Erie Harbor) on left. Lagoons and dune ridges, right.
1.8	39.5	All traffic right signage. TURN RIGHT.
0.0	39.5	Stop sign. TURN LEFT. Return to park entrance.
1.4	40.9	Beach 6 entrance and Park Office.
1.4	42.3	Stull Interpretative Center
0.9	43.2	Park Entrance
0.8	44.0	6th Street
0.1	44.1	8th Street
0.3	44.4	12th St., Rt. 5. TURN LEFT.
0.8	45.2	Pittsburgh Ave.
0.3	45.5	I-79 South. TURN RIGHT
3.0	48.5	Millcreek Mall
2.9	51.4	I-90 East, Buffalo. TURN RIGHT.

-- END ROAD LOG --

QUATERNARY GEOLOGY AND WATER SUPPLY ISSUES

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INTRODUCTION

Scope

While specialists in water resources have always been aware of the connection between recent geologic sediments and water supply issues, concerns have heightened during the past 15 years. Across the nation, Source Water Assessment Programs (SWAP),Wellhead Protection Programs (WHPP), new turbidity standards for drinking water, etc., are responses to outbreaks of giardiasis, cryptosporiodosis, and other concerns such as viruses as hitch-hikers on colloidal particles and the inability of traditional chlorination to treat these parasites. SWAP and WHPP also counter concerns for landfills, outfalls, agricultural runoff, and other point or non-point source contamination.

During stops 1, 2, and 3 (Figure 1) on this trip, we will pay particular attention to SWAP and WHPP issues at the recently renovated Village of Forestville Hall Springs and the long occupied Village of Sinclairville wellfield. This guidebook article particularly zeros-in on aquifer characterization and relationships to source areas, natural filtration of microparticulates and associated phenomena such as dilution.

Stops 1 through 5 (Figure 1) aid in understanding water well drilling successes and failures. Public and private water wells north of the St. Lawrence-Mississippi drainage divide in Chautauqua County have had low productivity. While gravel deposits and sometimes the fractured top of bedrock have moderate to high hydraulic conductivities, these zones north of the drainage divide are typically poorly recharged due to extensive confinement. Confinement relates not only to shifts in ice marginal environments but also to melt-out of underlying ice which yielded structural failure of the sediment masses and consequent abrupt changes in sediment hydraulic conductivities. The sediments exposed in cross-section in gully walls and landslide blocks, and indicated by cores, help to visualize the situation (Stop 5). Also, for those interested, the Sunday trip (this guidebook) visits a buried valley exposure with abrupt changes in hydraulic conductivities.

Turbidity sources, effects and human responses regarding drinking water from reservoirs and stream diversions are especially covered in Stops 5 to 7 (Figure 1). One of the nastier problems locally is the loss of reservoir capacity, in addition to upgrading filter plants. Which reservoir receives high sediment loads depends partly on reservoir design and partly on subtle glacial features such as end moraine control of watershed boundaries or stratigraphic control of erosive seepage or landslides.

Setting

Figure 2 is an index map for Chautauqua County municipal water supplies. Chautauqua Institute uses a surface water source, Chautauqua Lake. Otherwise, supplies north of the St. Lawrence-Mississippi drainage divide are surface waters and sources to the south are goundwaters. While the Forestville spring collectors (Stop 1) are north of the Mississippi River divide, the spring source waters (Stop 2) are south, as are Forestville's wells. With the exception of Cherry Creek's springs (fractured top of bedrock), all the groundwater sources are sandy

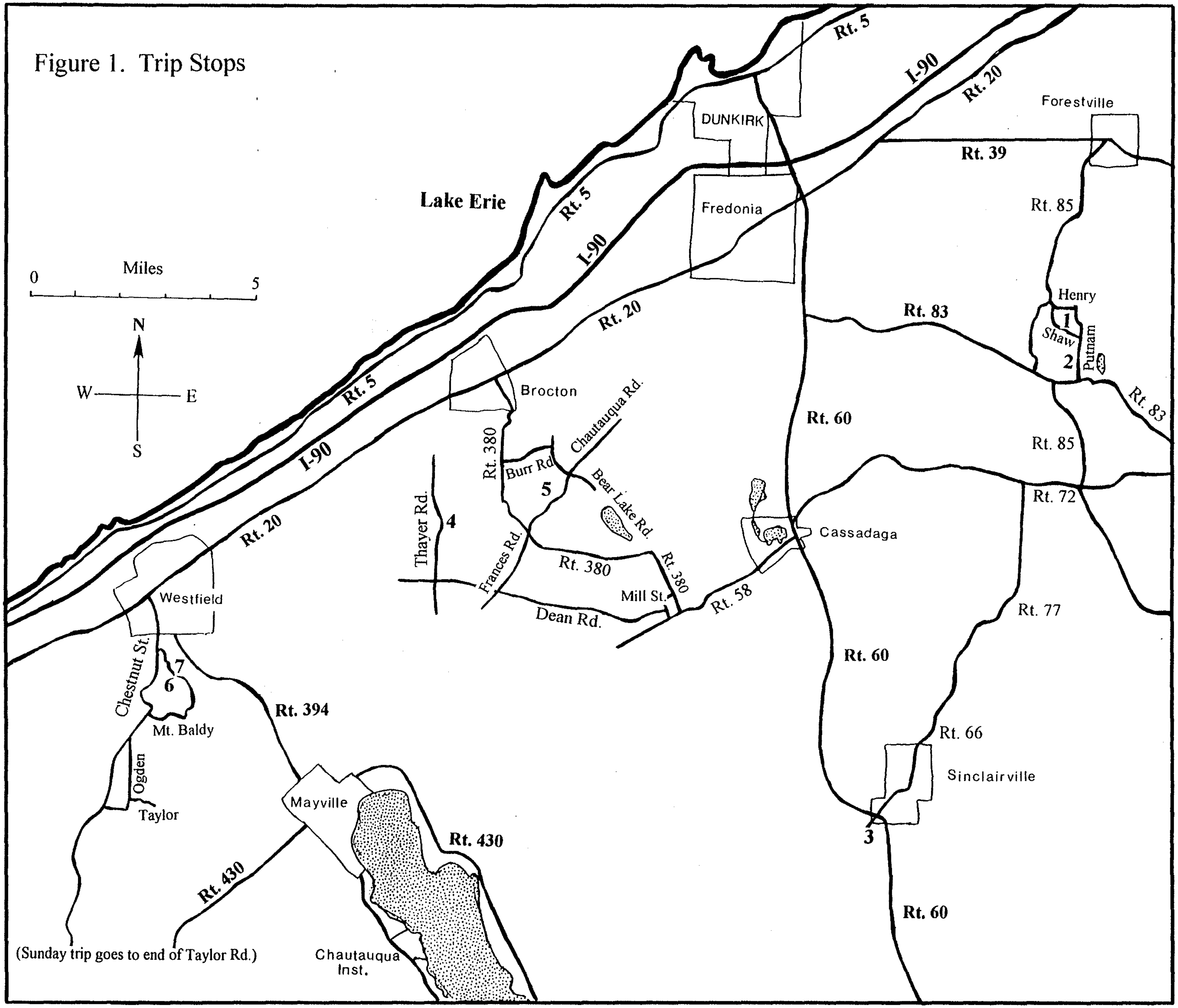


Figure 1. Trip Stops

gravels. Surface sources (north of the divide) are small reservoirs, with Westfield's Minton Reservoir supplemented by partial diversion of Chautauqua Creek. The City of Dunkirk draws from Lake Erie, and beginning in the 1990s, the Village of Silver Creek abandoned its reservoirs and connected to the Erie County, New York, Water Authority (Lake Erie). Most of the reservoirs have been plagued with high turbidities and excessive sedimentation.

WHP areas for municipal supplies are shown in Figure 2. The extensive primary protection areas that lie between Sinclairville (Stop 3) and Jamestown are the fan-delta deposits on the margins of Cassadaga Creek valley. These alluvial fan and delta gravels and sands interfinger with a continuous 20-foot thick gravel under an extensive 100 foot thick silt. This confined gravel aquifer is known as the Jamestown Aquifer (Crain 1966). Streams flowing off the uplands lose water into their beds as they cross the fan-delta gravel deposits which then recharge the aquifer. The City of Jamestown is supplied by this aquifer and the Village of Sinclairville wellfield (Stop 3) lies in one of the fan-delta deposits.

Other municipal well supplies occur in valley-bottom settings generally similar to Sinclairville or Jamestown. Most of these large valleys have bottoms that are a mile or two wide and underlain by sediments several hundred feet thick. Composition of sediments at depths greater than about one-hundred feet are poorly understood. The Appalachian or Alleghany Plateau that occupies about three-fourths of the county is roughly segmented by about a half dozen of these large valleys oriented in mostly northwest-southeast directions. The uplands between the valleys commonly create 500 feet of relief. The upland surfaces form a gently rolling plateau covered with drumlins oriented northwest (Muller, 1963). The underlying bedrock is composed of 1,000 or more feet of Devonian-age shale with 10% siltstone and sandstone in the north and much larger amounts of sandstone to the south (Tesmer, 1963). The bedrock dips 20 to 40 feet per mile southward and contains very modest structures such as 10 foot amplitude, 100 foot wavelength folds at quarter or half mile intervals.

The northern portion of Chautauqua County borders Lake Erie and contains the Lake Erie Plain. The lake plain has very low relief and is about 2 miles wide to the southwest and 5 miles wide to the northeast, typically extending a mile south of Rt. 20 (Figure 1). The lake plain and plateau are separated by the Portage Escarpment (also called the Allegheny Escarpment). The name Portage comes from attempts by the French army in the 1750s to establish a portage over the escarpment in order to link a canoe route between the eastern Great Lakes and their fortifications at Pittsburgh. Today, reservoir watersheds occupy the steep escarpment ravines (Stops 5 to 7). The drainage divide between the escarpment ravine headwaters and the southerly draining Mississippi headwaters is known as the Lake Escarpment Moraines (Muller, 1963). These glacial end moraines are thought equivalent to the Valley Heads Moraines to the east (Muller, 1963; Muller and Calkin, 1993). The Forestville Springs form by water percolating through outwash south of the Lake Escarpment Moraines and draining northward back under the moraines and out the escarpment face.

Figure 2.

SW New York Water Utilities

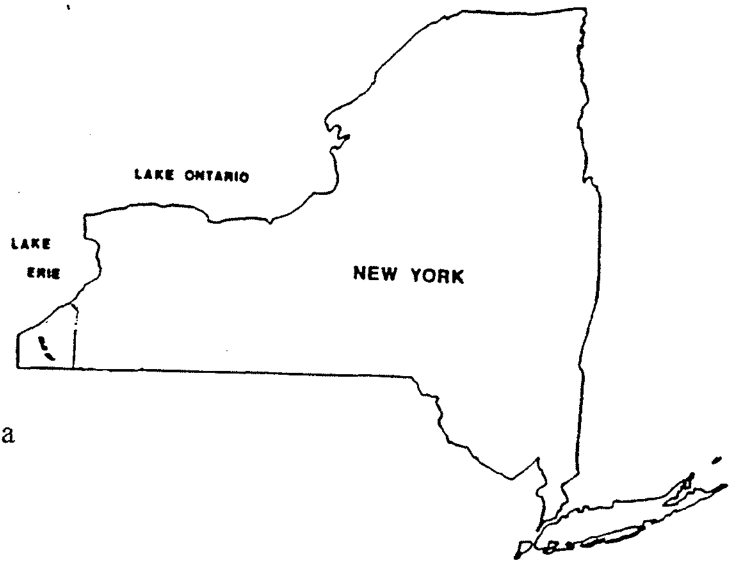
Lake Erie: Dunkirk, Silver Creek

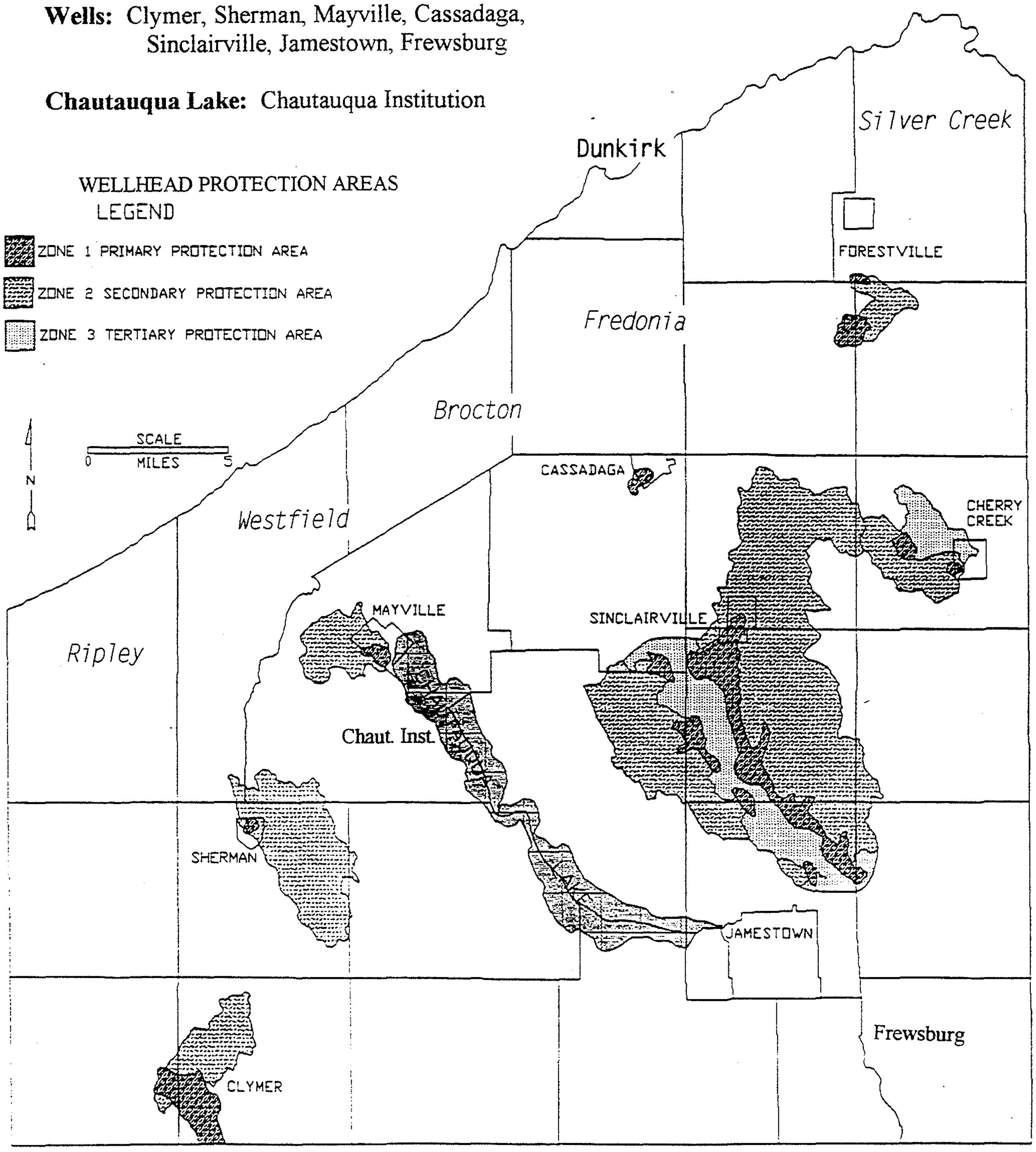
Reservoirs: Ripley, Westfield, Brocton, Fredonia

Springs (and wells)**:** Forestville, Cherry Creek

Wells: Clymer, Sherman, Mayville, Cassadaga,
Sinclairville, Jamestown, Frewsburg

Chautauqua Lake: Chautauqua Institution





FORESTVILLE HALL SPRING SYSTEM AND PRODUCTION WELLS 6 and 7

Hydrogeologic Setting

The Village of Forestville utilizes three spring systems and two drilled wells to meet their potable water demands. These ground-water collection devices are located 1.5 to 3.5 miles south of the village. Figure 3 shows locations for the two principal springs, two production wells, and one non-producing well (#5). This guidebook reviews Hall Spring and the wells (Henry Spring is similar and the third spring has inconsequential production).

Unconsolidated surficial deposits across northern Chautauqua County consist of glacial till (matrix of silt with clay and sand; clasts dominated by Canadian granitics, Medina sandstones, Lockport dolostone, Onondaga limestone, and local shale and sandstone) and sand and gravel outwash. Near-surface bedrock at this site consists of Upper Devonian, Northeast Shale (Tesmer, 1963). Various other shales (with about 10% sandstone) extend a thousand feet below the site.

The study site contains several unique physiographic features. The Lake Erie-Allegheny River divide transects the area bordering the drainage basins for Hall spring and Henry spring (Figure 4). A buried bedrock valley was described by Wilson and others (1983; using well logs, geophysics and surface mapping) as obliquely undercutting the divide. This through valley was filled by glacial drift and lies below the spring areas. This buried valley occurs (Figure 5) beneath the West Branch of Conewango Creek south of the study area and beneath Walnut Creek and its tributaries to the north. Near the study area, the buried valley is confirmed to be at least 334 feet deep by drilling records, and estimated to be 450 feet deep using geophysical methods (Wilson and others, 1983).

Water Use

The Village's public water supply serves about 725 people and several businesses. Water yields from the springs decreased into the early 1990s and although new wells were drilled, they provide minimal quantities of water. These wells (6 and 7) were drilled in response to declining spring production. Because of poor well production, and our evaluation of aquifer geometry and evidence that the spring source waters were **not** likely to be classified as "ground water under the direct influence of surface water," the spring collectors were rebuilt in 1995 and 1996.

In 1991 the average daily water use in Forestville was 156,700 gpd, and in 1992 was 143,400 gpd. The Village was able to reduce daily use at the end of 1992 by performing repairs to water mains and services. However, when ground-water production was near the minimum (100,800 gpd) the Village could not meet its average daily water demand in late 1992 (126,600 gpd) even though the system was operating conservatively (i.e. no major water leaks). Consequently, Henry and Hall springs were reconstructed in 1995 and 1996, respectively.

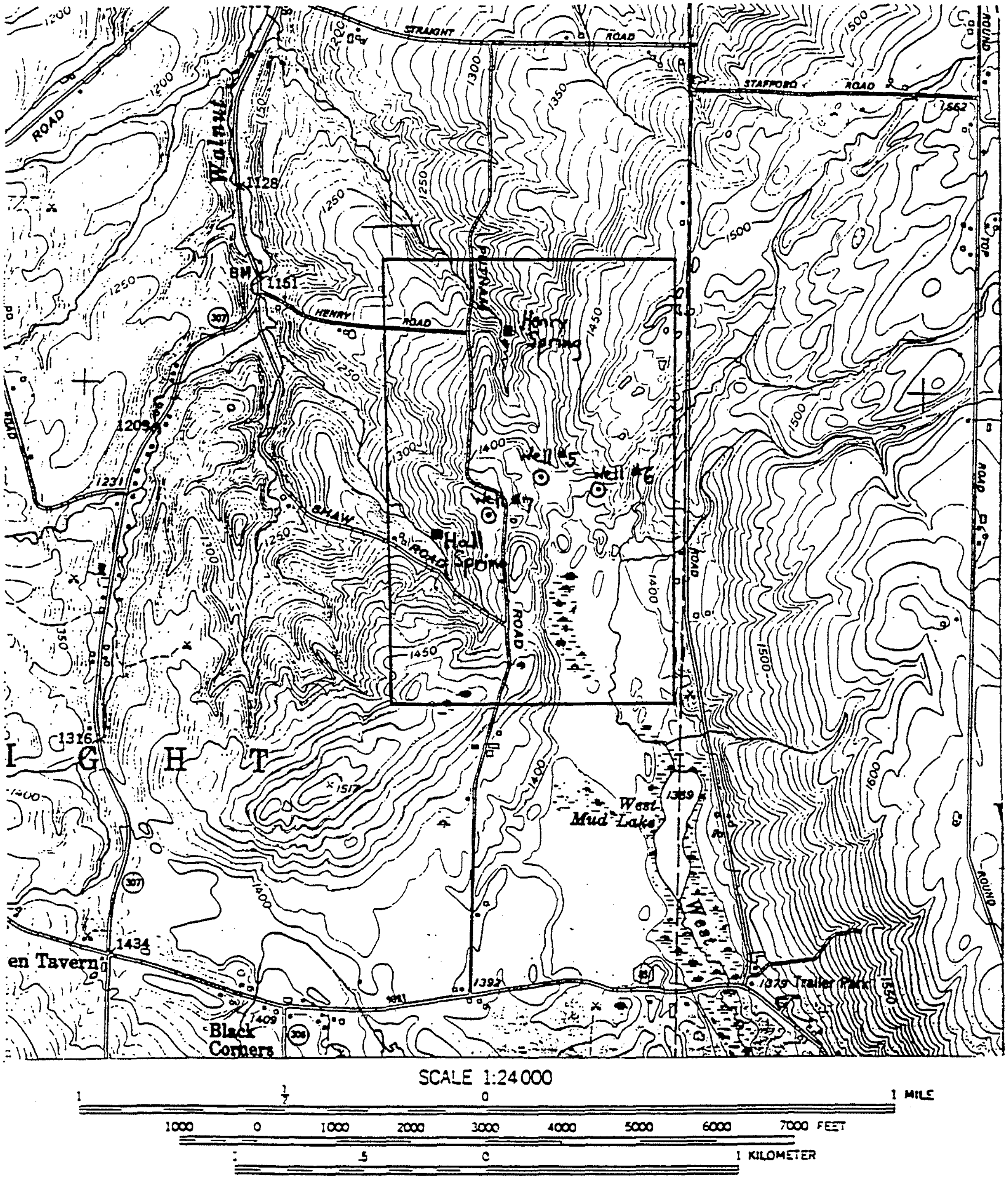


Figure 3. Location of Forestville's springs and wells in the Town of Arkwright, NY (Source: USGS 7.5' topographic map - Forestville quad, scale: 1"=2,000 ft). Note: Bradigan Spring (not shown) is located approximately 1.5 miles north-northeast of Henry Spring.

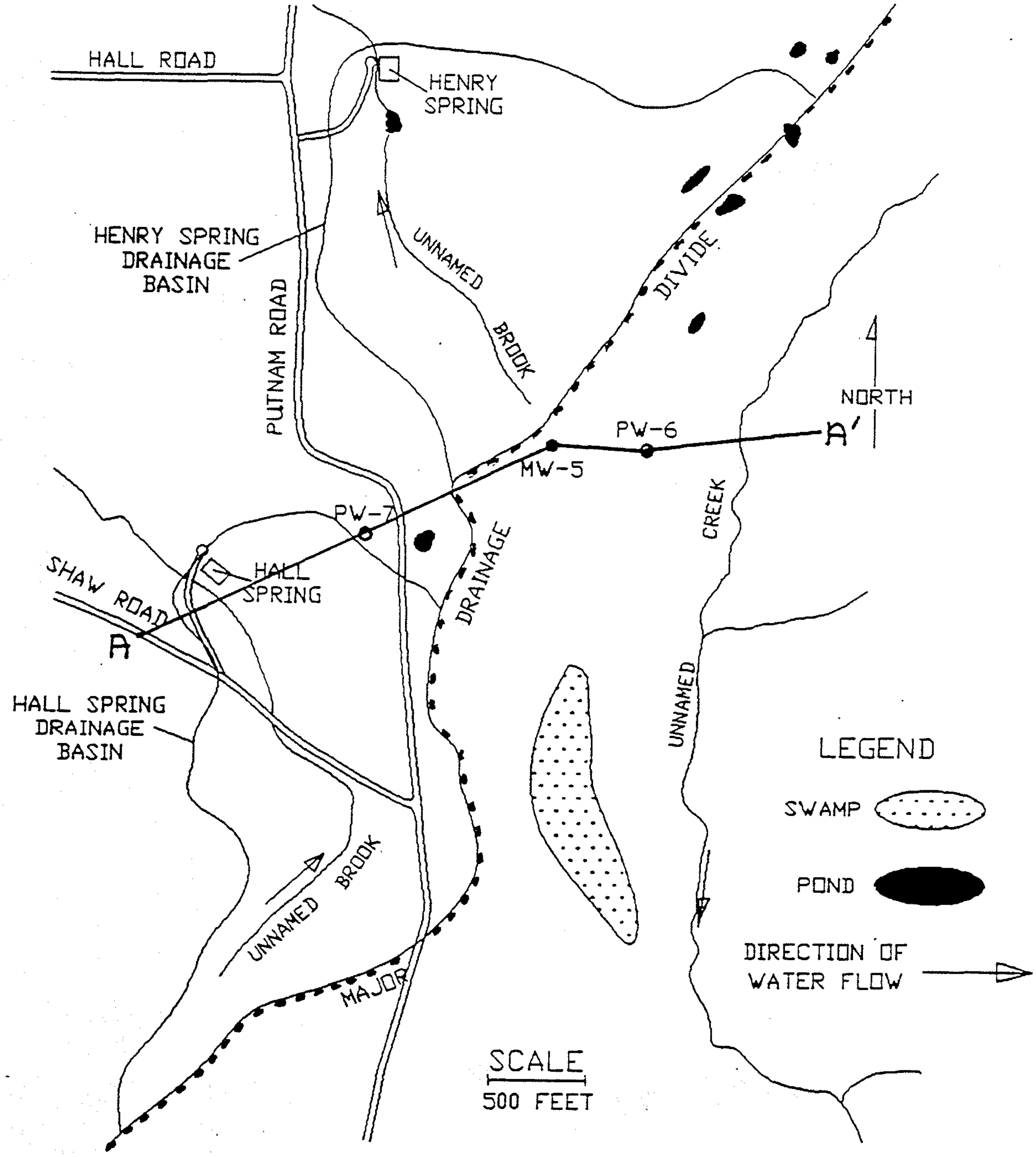


Figure 4. Drainage basins in the vicinity of Hall and Henry springs, the major drainage divide separates the Lake Erie and Alleghany River drainage systems. The locations of the two production wells (6 and 7) and observation well 5 are also shown along with the location of cross section A-A' provided in Figure 7.

The longitudinal section in figure 5 lies about one-half mile west of AA' and perpendicular to AA', encompassing several times the NS dimension of either figure 3 or 4.

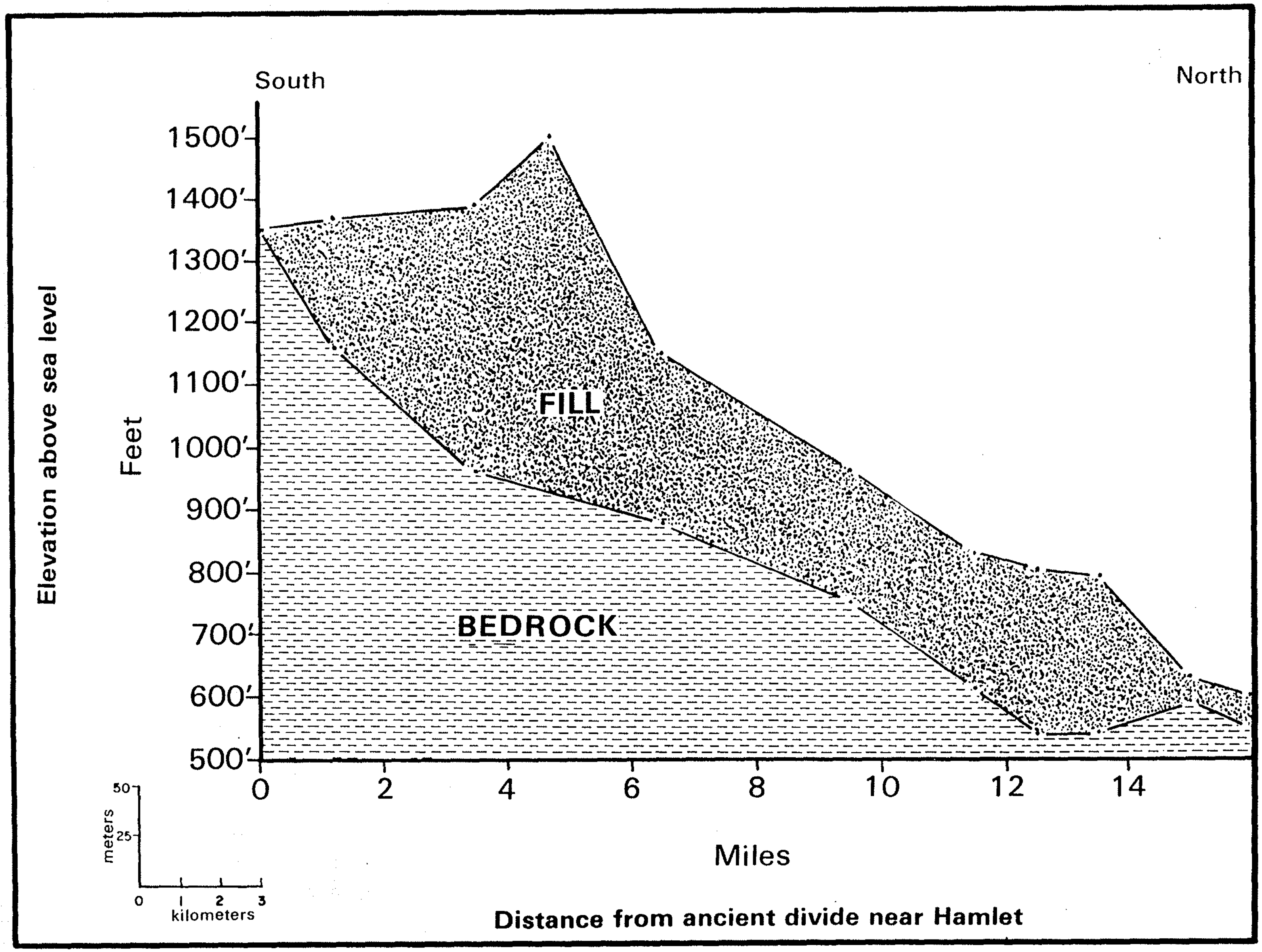


Figure 5. Buried Valley Longitudinal Section. Oriented approximately NS; from Lake Erie, through Forestville, then parallel to Walnut Creek (Fig. 3), and continuing southeast of Black Corners (Fig. 3).

Hall Spring Prior to 1996

Hall spring, contained three separate lateral systems, laterals 1, 2, and 3 (Figure 6). Lateral 1 was constructed in 1985 and disconnected in 1993 (for reasons discussed later in this article). Lateral 2 was originally constructed in 1898 and reconstructed in the 1940s. Laterals 1 and 2 consisted of perforated or open-joint 4 in. tiles laid in pebble gravel 2.5 to 4.5 feet below ground surface and back-filled with native materials. These extended radially from a series of manhole collectors, which were connected together by solid pipe. Lateral 1 had one collector and lateral 2 had eight. The ground water entered the system through the pebble gravel and open joint pipe, then flowed by gravity to a manhole collector and then down a transmission line to the spring house. Lateral 3 was recently constructed (1976) and consisted of two round, 8 ft long precast concrete manholes with open bottoms buried 6 to 7 ft deep. These were 4 ft in diameter and were set on a bed of pebble gravel. Ground water infiltrated through the bottom of the manhole where it was sustained at a constant head by a 4 in. overflow pipe, which transmitted the water to the spring house.

The Hall spring house is a 30 x 39 ft covered concrete reservoir, similar in design to a pole barn with steel sides and roof. The water level in the spring house is held constant, at about a 3 ft depth, by means of a spillway, which overflows into the adjacent brook. The water in the spring house ultimately seeps through a pebble filter approximately 1 ft thick, then through a 4 in. water main to the village.

Since 1990 the Hall spring water supply has been supplemented by ground water from well #7 (Figure 3 and 4). Ground water from the well is pumped into the Hall spring house pool via a 1.5 in. flexible plastic pipe buried a few feet below ground. In 1989, well 6 was added to the system. This was connected to the system with 4 in. cast iron pipe running from the well to the 4 in. main, which carries water from the Henry spring house to the village.

Principal Aquifers

Bedrock in this area consists of about 1000 ft of Upper Devonian shales with interbedded siltstone (Tesmer 1963). An escarpment-face (i.e., north flowing) valley cut into the bedrock by pre-glacial or interglacial drainage, was altered (scoured and filled with glacial, lacustrine and fluvial sediments). This buried valley runs through the area trending in a northerly direction. Wilson and others (1983) suggested that two components of ground-water flow exist in the buried valley fill, one flowing toward the center of the valley, the other flowing northward along the valley axis. All the spring systems are located between or very close to multiple glacial end moraines (Muller, 1963). These end moraines include those formed during both the most recent Lake Escarpment (approx. 14,000 BP; Muller and Calkin, 1993) and the somewhat older Lavery (approx. 16,000 BP) glaciations. Muller (1963) also found evidence of glacial meltwater channels near Henry and Hall springs and demonstrated that multiple episodes of glacier overriding took place in Wisconsinan and earlier times.

Wilson and others (1983) postulated that a portion of precipitation south of the divide (Figure 5) infiltrates and flows in the valley fill, under the divide, and into the Lake Erie basin. Figure 7 is a cross-section oriented roughly east-west (Figure 4), or obliquely transverse to the Figure 5 section. The major watershed divide (the Lake Escarpment moraine) trends northeast-

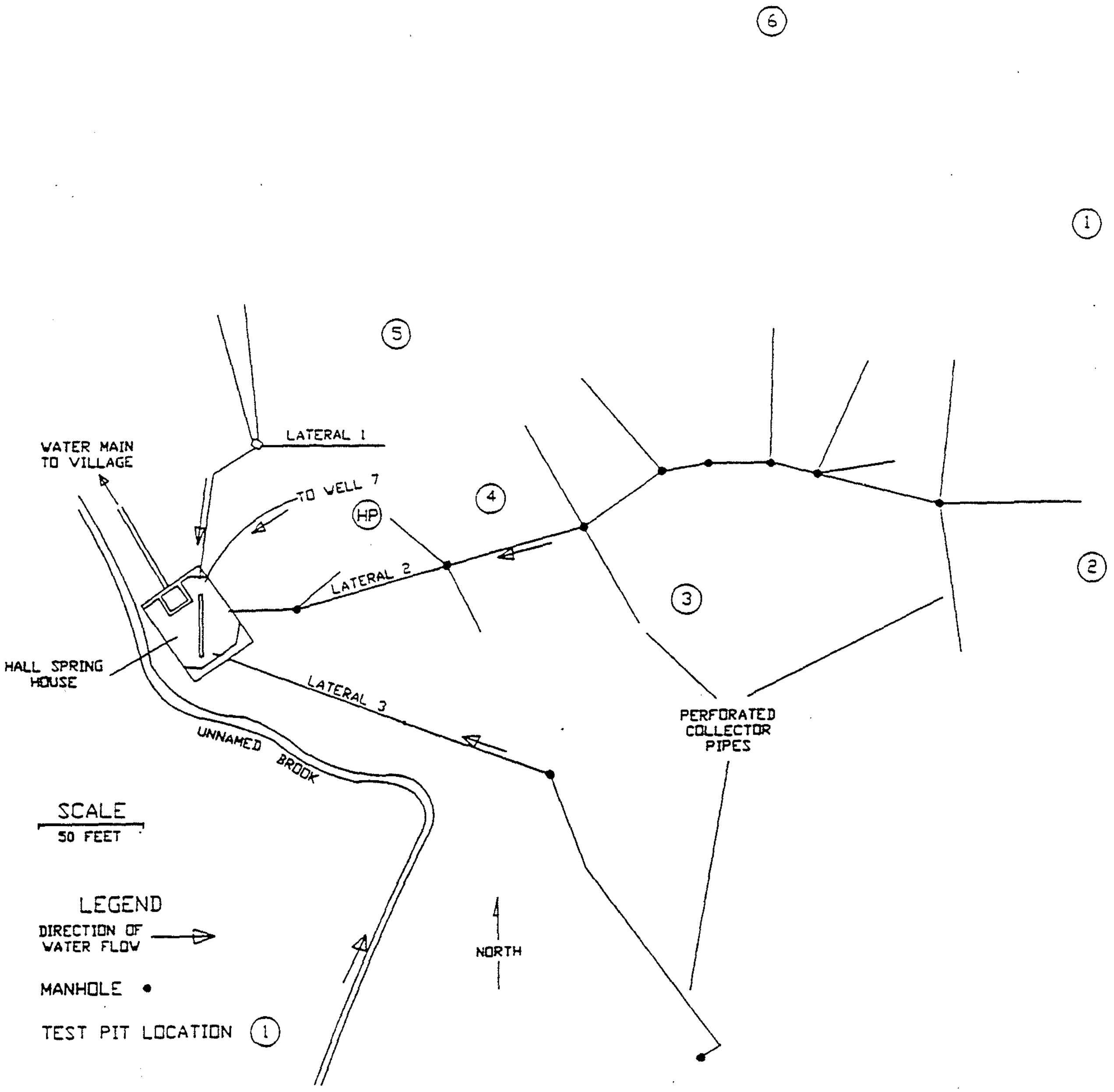


Figure 6. Schematic drawing of the Hall spring lateral system (Before 1996).

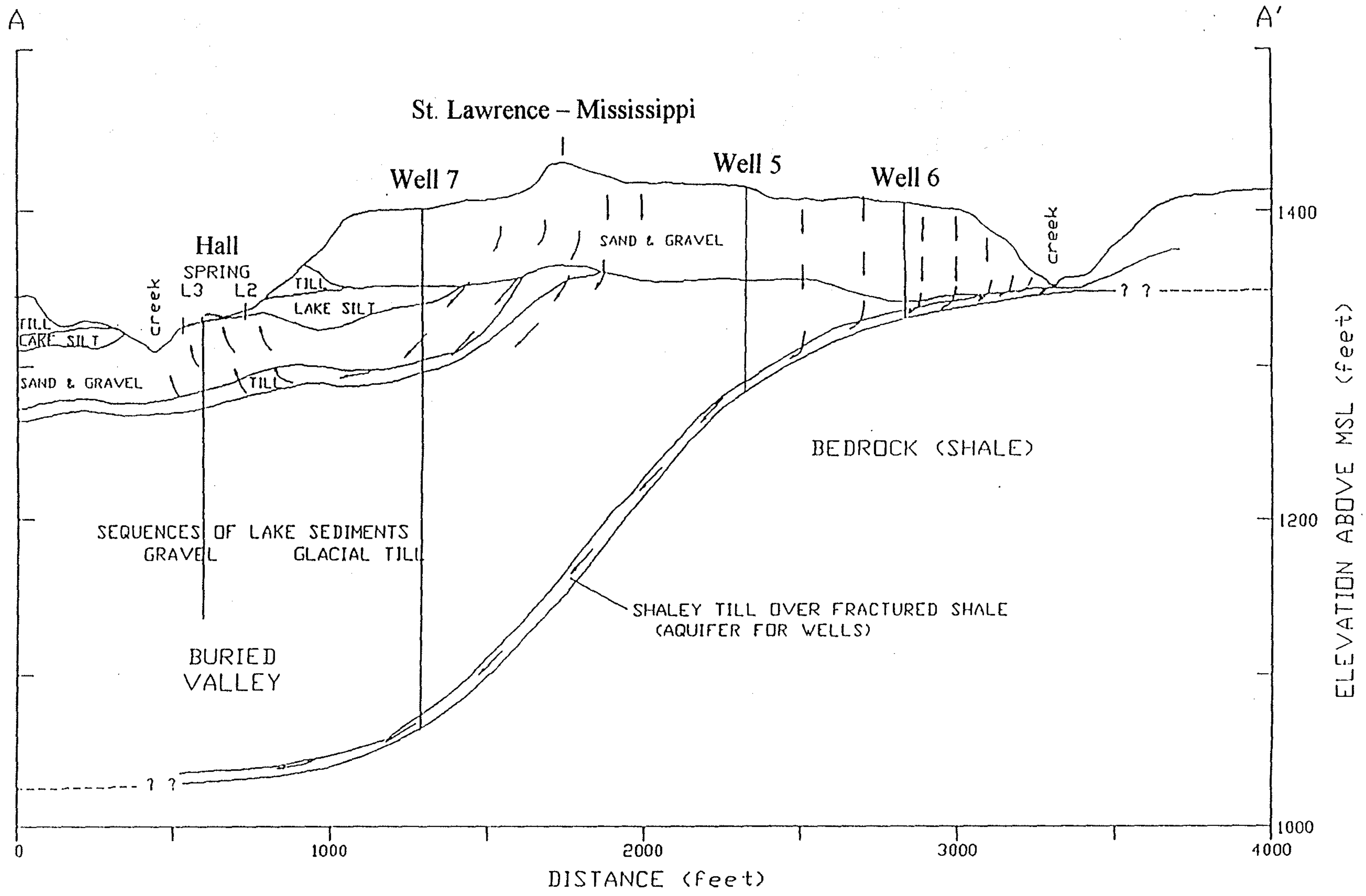


Figure 7. Cross-section A-A'

southwest obliquely across the two sections. Thus, there is a natural interbasin transfer of water. The **springs** flow from porous media, in this case a gravelly sand, partially confined by lake silts and glacial till. The **wells** are screened across fractured rock (firm, Devonian-age shale and fine sandstone) and overlying shaley glacial till with some interbedded sands and gravels.

An extensive near-surface investigation was conducted at Hall spring in the area around lateral 2. Toward the lower end of the lateral, a shallow monitoring well was installed . The aquifer was encountered from about 5 ft to 22 ft at which point drilling was terminated. This aquifer is likely deeper than 22 ft. An 8 ft deep, 2 in. PVC piezometer was installed having a gravel pack at the bottom and a well annulus sealed with bentonite clay. The static water level in the piezometer was several feet above ground surface. A second piezometer was installed at the far end of lateral 2. This piezometer is 7 ft deep and back-filled with native material; the water level was at land surface. Seven, 8 to 10 ft deep test pits were dug around lateral 2 to determine the areal extent of the aquifer at shallow depths. As indicted by the pit logs and particle size analysis, the shallow aquifer consists of medium to coarse sand with fine gravel. This is overlain by a confining layer of fine sandy silt, 3 to 5 ft thick, and 1 ft of organic topsoil. The confining unit is leaky in some spots; this is what originally created ground-water seeps at the surface. The aquifer in the vicinity of lateral 2 appears topographically to be bounded between local highs, but in the subsurface must be more laterally extensive (Figure 7). This can be substantiated by performing some simple calculations. The drainage basin for the small valley that confines lateral 2 is 600,000 ft^2. Maximum precipitation available as recharge falling on this area averages 7.1 million gallons per year (precipitation-evapotranspiration) while average yearly production of lateral 2 was approximately 13 million gallons. This indicated that recharge to the shallow aquifer was captured from more than just the immediate area. Recharge in the form of precipitation falling near and south of the divide contributes water to a regional ground-water flow system. Ground-water flow not tapped by collectors follows the long axis of the buried valley toward Lake Erie, or recharges Walnut Creek.

The buried bedrock valley which transects the study area plays an important role in ground water available to production wells 6 and 7. It is apparent from water level observations made in wells 5, 6, and 7 along with two abandoned deep wells (one near the Hall spring house, and the other near the Henry spring house), that pumping of the production wells affects water levels in other wells. These wells must therefore be hydraulically connected (Figures 3, 4, and 7).

Well 6 was drilled to a depth of 73 ft. The well penetrates 10 ft of "overburden" (glacial till?) and 56 ft of numerous gravel layers, becoming clayey at the base. Under static conditions, the water level in well 6 is above the land surface. Under pumping conditions, the water level is stable at 50 to 55 ft below ground surface. Well 6 is near the margin of the buried bedrock valley; well 5 is 500 ft west of well 6. Well 5 was drilled 128 ft to bedrock. Well 6 produces about 12 gpm and is pumped as needed; well 5 is not used.

Well 7 was drilled to a depth of 334 ft into the buried valley. The well penetrates 10 ft of "overburden" (glacial till?), 324 ft of various gravels with some sand and clay layers, and bottoms in bedrock (Figures 3, 4, and 7). This well produces about 20 gpm and is pumped when needed.

The static water level in the well is 41 ft below land surface. The pumping water level in well 7 has gradually decreased from 90 ft to about 160 ft since first drilled.

Logs for wells 5, 6, and 7 demonstrate that multiple glacial advances yielded complex sediments, possibly containing several sequences of fine-grained, low permeability lake sediments, gravel, and glacial till. The direction of ground-water flow in the deep aquifer is controlled by the orientation of the bedrock surface in the area. Recharge to this aquifer occurs east and southeast of wells 5, 6, and 7. Previous work by Muller (1963) shows extensive outwash deposits of sand and gravel where primary recharge most likely occurs. Additional work by the U.S. Dept. of Agriculture Soil Conservation Service (1994) confirms Muller's work in greater detail. Stream loss on shallow gravel deposits over the bedrock likely occurs along a tributary to the West Branch of Conewango Creek 500 ft east of well 6, providing recharge to the aquifer (Figures 3 and 4). Additional recharge to the aquifer is from precipitation and other surface water infiltration across these coarse grained deposits. Because well 6 is closer to the recharge area, its pumping water levels are more stable than well 7's. Well 7 appears to be drawing water from storage faster than it is replenished, hence there is a decreasing water level trend in the well. Bedrock in this area has a general downward slope towards the buried valley. We conclude that water from the recharge area, southeast of the major watershed divide, enters the system and migrates into and along the buried valley.

Time of Travel

Because of concerns for water borne diseases.such as giardiasis or cryptosporiodosis, knowing the time of travel between surface source waters and ground-water collection devices is helpful. When time of travel (TOT) is months or longer, parasites loose infectivity and ultimately die in the subsurface, regardless of other issues such as natural filtration.

Daily temperature data for well 6 (Figure 8), collected in 1991 at the wellhead, exhibits a range of 3.2^{0}C while a plot of conductivity data is extremely stable, almost a straight line. These data suggest that ground-water velocities from the recharge areas to well 6 are relatively slow with fairly long (months to years) times-of-travel within the aquifer. Temperature data for well 7 show seasonal summer warming and winter cooling trends (Figure 9). This is due to the exposure of the water line to near surface temperatures between the wellhead and sampling point at the Hall spring house 1,000 ft away. A plot of conductivity data for well 7 is similar to that for well 6, a straight line (Figures 8 and 9). Times-of-travel from the area of recharge to well 7 are probably years to decades, considering aquifer geometry.

Using the seepage velocity equation, (i.e., velocity equals gradient times hydraulic conductivity divided by porosity), times-of-travel from recharge areas to the wells were estimated. Static water levels in the wells decline toward the buried valley axis defining a hydraulic gradient of 0.025 ft. The water levels and gradients are in keeping with a regional recharge zone physically above and to the south of the wells, with flow northward toward the Lake Erie Plain. Hydraulic conductivity of the interval across the top of fractured rock and base of glacial sediment is between 0.023 and 5.7 ft/day with a porosity of 20%, estimated from extensive tests at

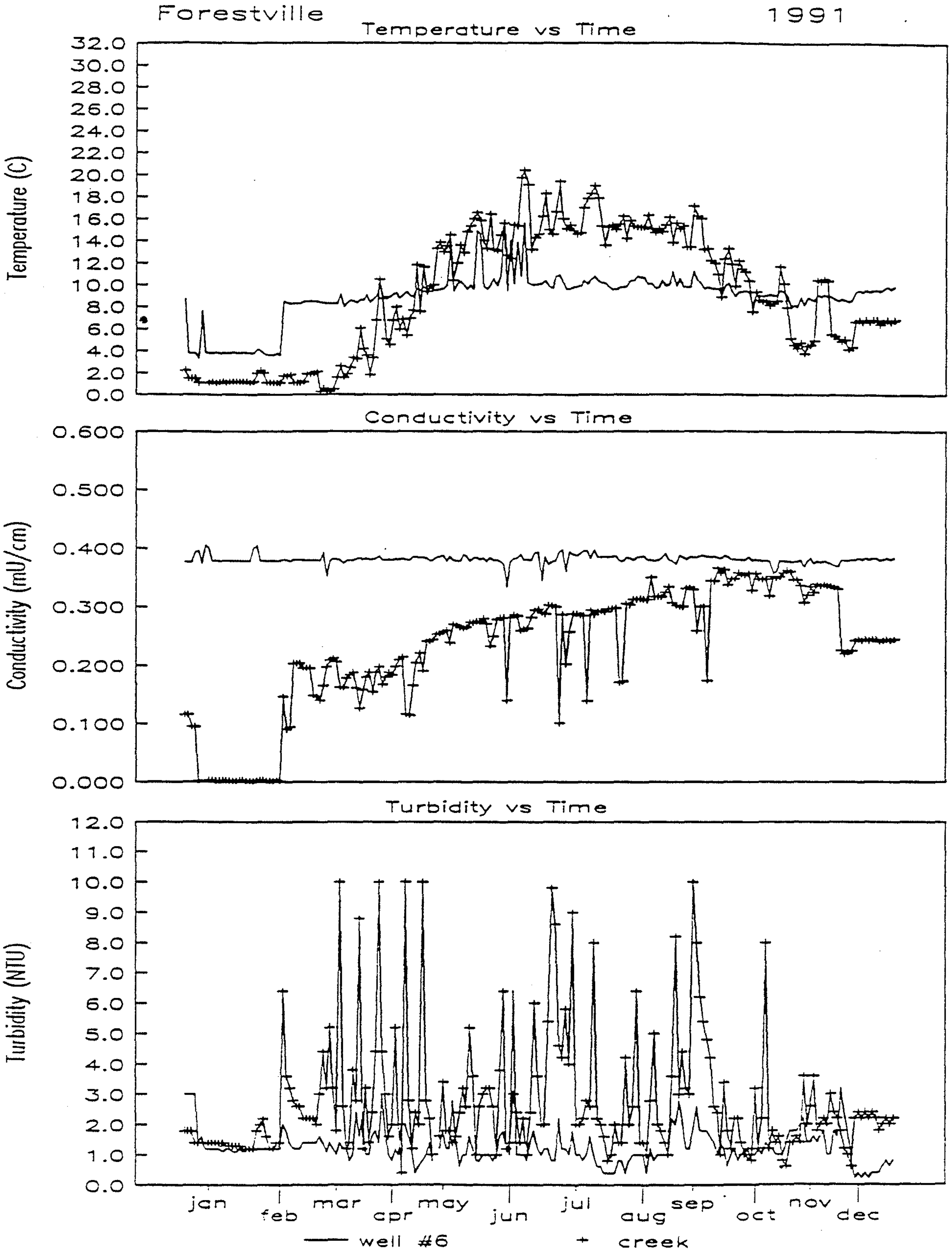


Figure 8. Water quality graphs for well 6 and the creek near Henry spring.

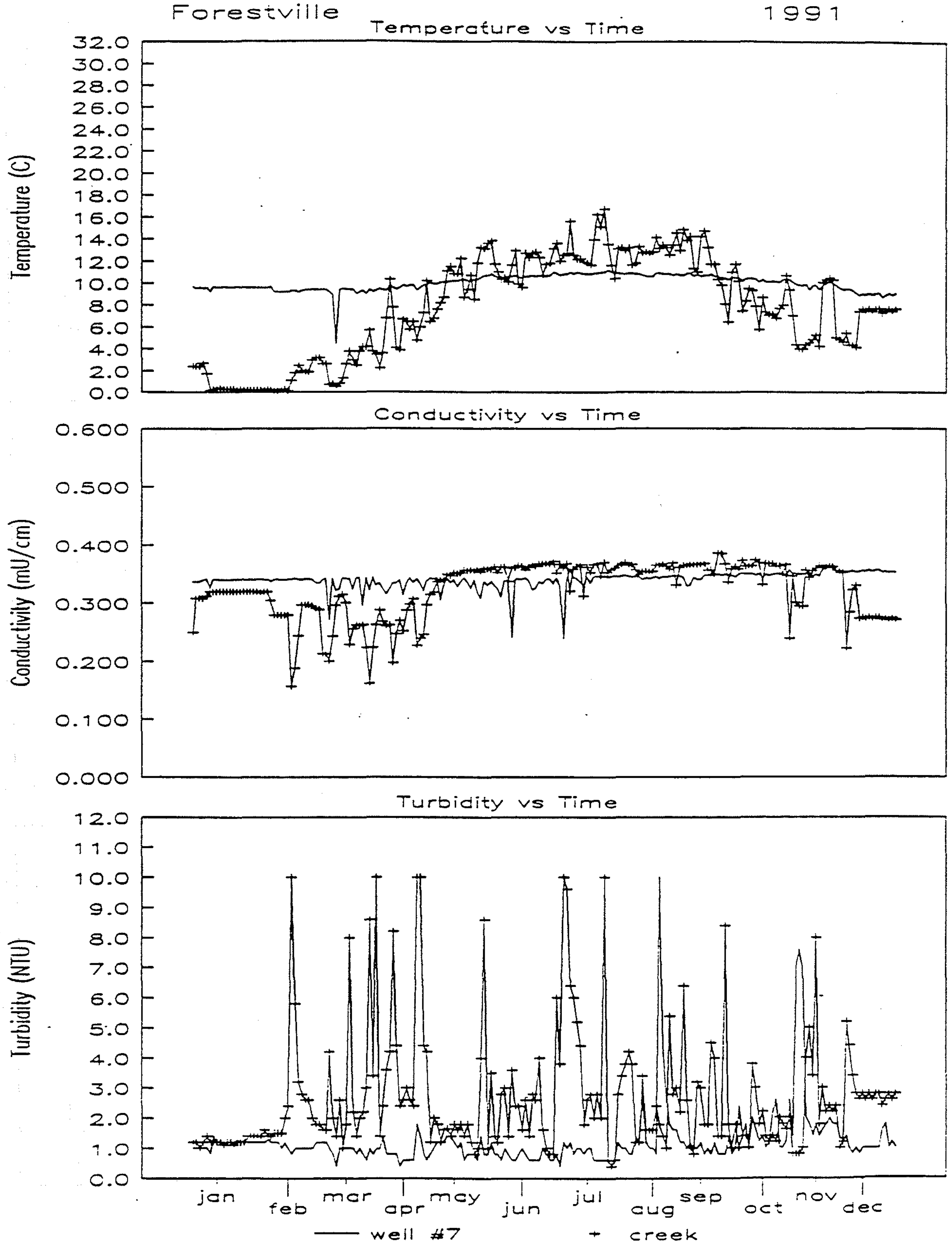


Figure 9. Water quality graphs for well 7 and the creek near Henry spring.

Chautauqua County landfills (Wilson and others, 1993). Solving the equation gives a time-of-travel of greater than 2 years for well 6 and greater than 8 years for well 7.

After using seepage velocity estimates and conductivity and temperature graphs as three indicators of TOTs of years for the wells, we can obtain additional information by comparing among the three spring laterals. Comparing temperature graphs for the Hall spring laterals is very revealing, each plot is different (Figures 10, 11 and 12). The temperature for lateral 1 varies 7.5^0, from 5.2^0 to 12.7^0C, and generally tracks surface water temperature trends. The ground-water temperature from lateral 2 varies 5^0 from 6.0^0 to 11.0^0C and also exhibits a correlation to surface water temperature trends but not as pronounced as lateral 1. Lateral 3 temperature varies 2.6^0 from 7.0^0 to 9.6^0C and shows very little correlation to surface water temperatures other than a general warming trend occurring during summer months. Because the laterals are so shallow, the ground-water temperature would be expected to track the air temperature, but why is the temperature plot of each lateral different? At the Hall spring, the differences in lateral construction may be responsible. Lateral 1 intercepts ground water closest to the surface (approximately 1 to 2 ft deep), lateral 2 intercepts ground water 3 to 4 ft below the surface, and lateral 3 receives ground water from about 6 ft below the surface. Because ground water closer to the surface will reflect surface temperatures to a greater extent than deeper ground water, these temperature plots do partly make sense. However, the profiles were excessively flattened with depth if the sole cause was thermal dampening from the insulating effects of overlying sediment. Significant portions of lateral 3 water must be from a distant source.

Scrutinizing daily conductivity and turbidity data (Figures 10, 11 and 12) and comparing them to the temperature data may provide further insight as to the cause of the variations between the temperature plots. Conductivity data for lateral 1 at Hall spring closely tracks that of the surface water between January and May, then levels off as a straight line on the graph. Conductivity data for lateral 2 shows a very minor correlation to the surface water during the same period and then also levels off. Lateral 3 conductivities show no significant correlation to surface water conductivities. It should be pointed out that due to the lack of precipitation from May to October 1991, the conductivities measured in the streams were elevated. This is because the streams were primarily receiving base flow (ground water) derived at least partly from mineral-rich bedrock-contact ground-water.

These data suggest that the temperature trends for lateral 1 at the Hall spring are due to surface runoff entering the lateral system. Additional data cited in following sections supported this conclusion. Review of the data in 1992, along with presentation of findings to municipal officials, led to disconnection of lateral 1 in 1993. These temperature and conductivity data are also interpreted to suggest that a small amount of early season surface water (such as snowmelt) entered lateral 2 and almost none entered lateral 3. In addition to depth of burial of laterals, the poor external manhole seals (annular space), and sometimes low tops, were thought to be sources of surface water entry to the system.

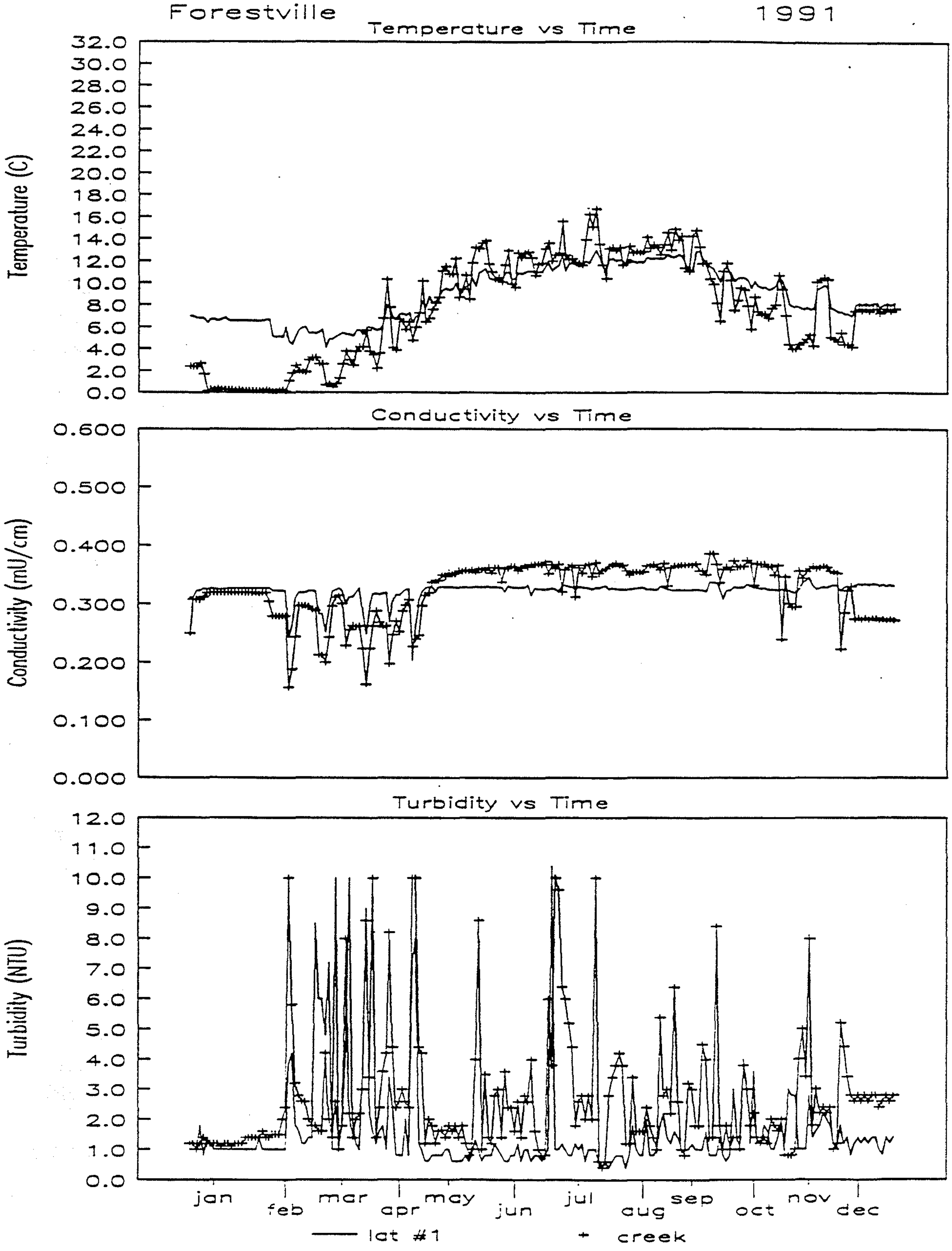


Figure 10. Water quality graphs for Hall spring lateral 1 and the nearby creek.

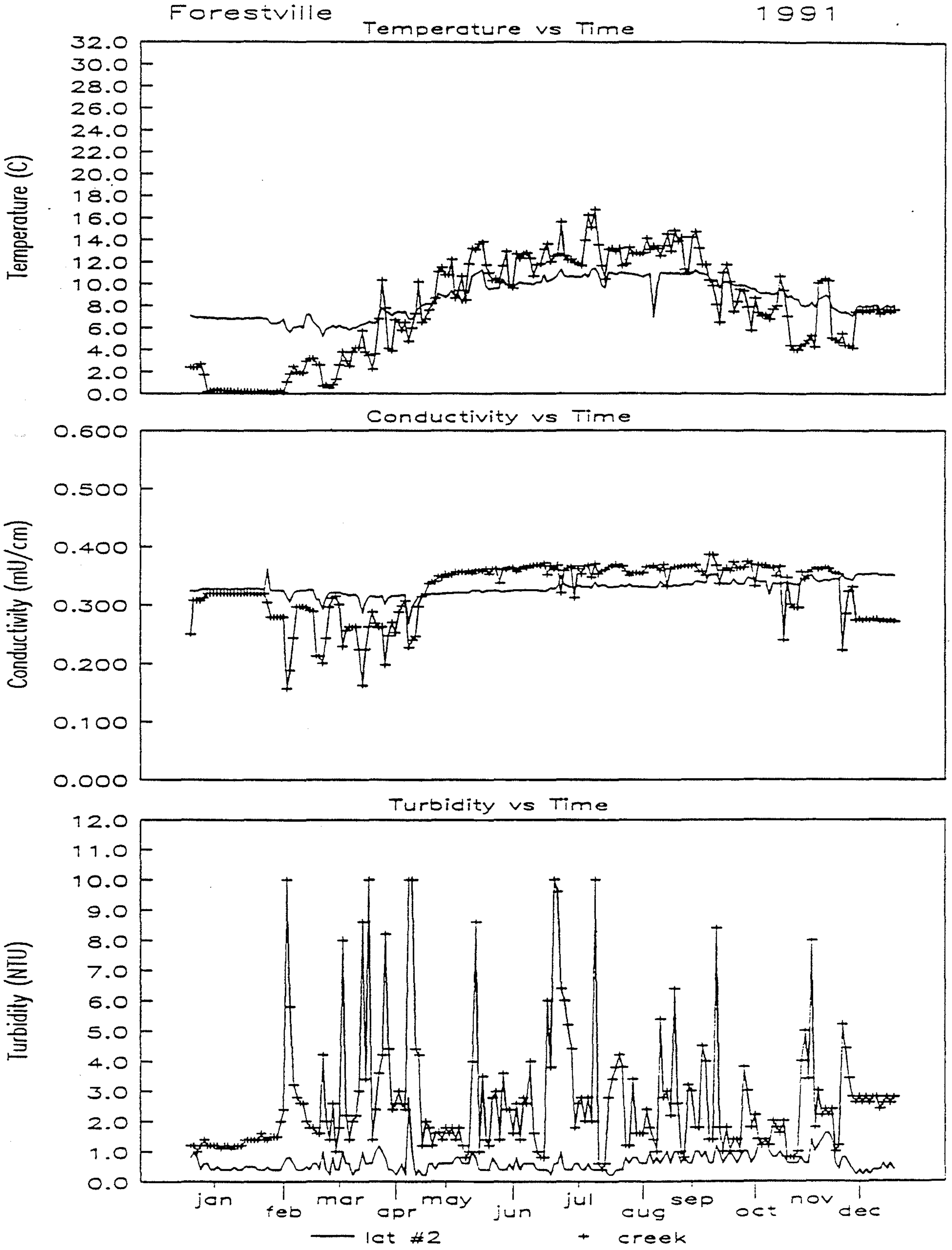


Figure 11. Water quality graphs for Hall spring lateral 2 and the nearby creek.

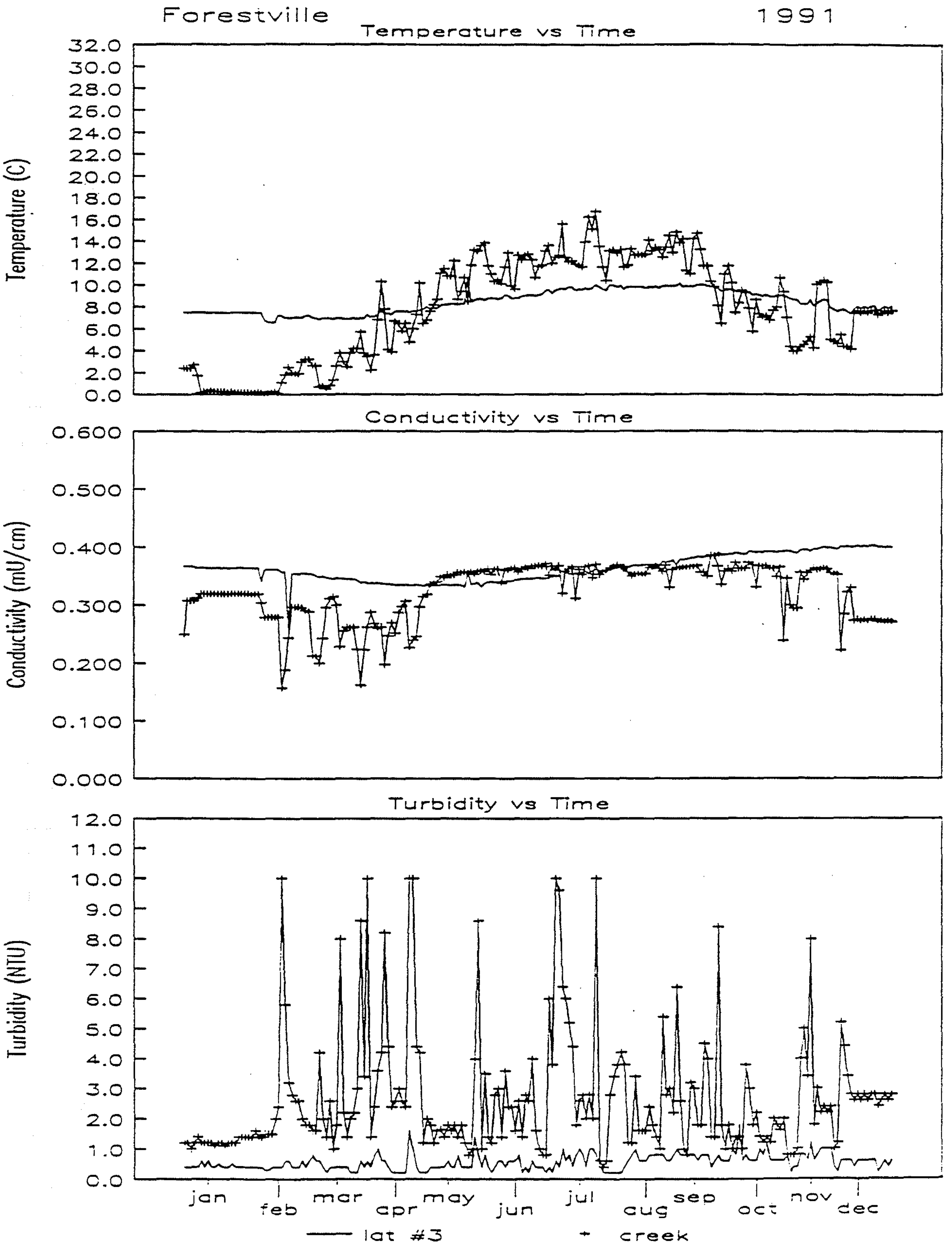


Figure 12. Water quality graphs for Hall spring lateral 3 and the nearby creek.

Microscopic Particulate Recharge

Historically, the water quality in Forestville has been acceptable. There have been instances, during water shortages, where the village has had to divert unfiltered surface water from either the creek near Hall spring or the old reservoir near Henry spring into the water supply to meet their demand. During these emergencies, a "boil water order" was enacted.

Turbidity data (Figures 8-12) were collected daily (5 days per week) for one year from the laterals in both Hall and Henry springs, wells 6 and 7, and nearby surface waters. Turbidity for Hall spring lateral 1 tracks closely with surface water turbidities and averaged 1.6 NTU for 1991. Turbidities for laterals 2 and 3 averaged 0.6 NTU, supporting the contention that lateral 1 was under the direct influence of surface water. Bacteria levels (sampled weekly) varied according to lateral with coliform present in 38% (lateral 1), 32% (lateral 2) and 20% (lateral 3), of the samples. Heterotrophic bacteria levels were 500 CFU/ml or greater in: 17% (lateral 1), 8% (lateral 2) and 0% (lateral 3), of the samples.

Water quality data for wells 6 and 7 also vary. Turbidity graphs (Figures 8 and 9) exhibit a random fluctuation for both wells ranging from 0.5 to about 3 NTU. Average daily turbidity during 1991 was 1.3 NTU for well 6 and 1.2 NTU for well 7. There is no correlation between ground-water and surface water turbidity trends or ground-water turbidities and precipitation. The turbidity is probably due to the presence of fine sediment (clay and silt) within the aquifer. When wells 6 and 7 were being developed after drilling, they were pumped for several weeks before the water cleared of sediment (prior to this the well water was visually turbid). Conductivity graphs show plots typical of deep ground waters, fairly high and stable curves. Bacteria levels in well 7 were low, with coliform present in 4% of the samples and heterotrophic bacteria levels 500 CFU/ml or higher in 16% of the samples. Bacterial levels in well 6 were higher with coliform present in 43% of the samples, and heterotrophic bacteria levels 500 CFU/ml or higher in 77% of the samples.

The bacteriological data for well 6 is puzzling. It is unlikely that the bacteria was traveling through the aquifer from its point of recharge. The wellhead was below grade and sample collection was difficult; some samples may have been compromised. A recent follow-up bacteria sample from well 6 was negative for coliform (<1/100 ml) and contained very low heterotrophic bacteria (2 CFU/ml).

MPA (microscopic particulate analysis) samples were taken in 1991 at well 7 and Hall spring laterals 1, 2 and 3 (Table 1). An MPA sample taken from well 7 in July showed no biological material whatsoever. We do not know if surface recharge to well 7 is steady state and therefore it is difficult to draw a conclusion from this one MPA sample. However, the low Consensus Method (Vasconcelos and Harris, 1992) relative risk value is what was expected.

MPA samples were collected at Hall spring (Table 1) in March and July 1991 from laterals 1 and 2, and in July from lateral 3. The results indicate that increased biological activity occurred in the summer as compared to winter. The March samples for lateral 1 contained primarily plant debris; lateral 2 contained only one nematode and one crustacean per 100 gallons of water

Table 1. Forestville - MPA DATA

Device	Source Type	Filter ID#	Date	Giardia	Coccidia	Diatoms	Other Algae	Insects/ larvae	Rotifers	Plant Debris
*	Surface Water	1434	07/02/91	0	0	30,000	0	0	0	0
L 1	Spring	1320	03/18/91	0	0	1	1	0	0	320,000
L 1	Spring	1433	07/03/91	0	0	2,000	0	0	800	0
L 2	Spring	1307	03/12-13/91	0	0	0	0	0	0	0
L 2	Spring	1436	07/03/91	0	0	0	0	0	16	0
L 3	Spring	1437	07/03/91	0	0	0	0	1	0	0
W 7	Drilled Well	1435	07/03/91	0	0	0	0	0	0	0

- MPA DATA (cont'd.)

Device	Source Type	Nematodes	Crustaceans	Amoeba	Non-Photo. flagellates & ciliates	Photo-synthetic flagellates	Other: iron bacteria	EPA TOTAL RISK	EPA RELATIVE RISK
*	Surface Water	9,000	0	0	0	0	0	16	Moderate
L 1	Spring	1	0	0	0	0	100	13	Moderate
L 1	Spring	0	0	0	0	0	500	20	High
L 2	Spring	1	1	0	0	0	0	0	Low
L 2	Spring	80	0	0	0	0	1	1	Low
L 3	Spring	100	0	0	0	0	0	3	Low
W 7	Drilled Well	0	0	0	0	0	0	0	Low

Sat. E22

sampled. Results from the July sampling showed that lateral 1 contained 2,000 diatoms and 800 rotifers per 100 gallons sampled, lateral 2 had 16 rotifers and 80 nematodes present per 100 gallons, and lateral 3 had 100 nematodes per 100 gallons of water sampled. These results show that the biological quality of the spring water (excluding bacteria levels) is good.

Conclusion: spring water quality was good but was degraded by surface water infiltration to the laterals. Lateral 1 was unacceptable. Laterals 2 and 3 were much better than lateral 1. Considering MPA evidence along with TOT findings and aquifer geometry led us to advise reconstruction of the springs to increase the quantity of a water source with good quality. Consultants and regulators should be cautious not to be over-influenced by construction deficiencies, which would lead to premature abandonment of spring aquifers in addition to spring collection devices. Apparently, collection devices at this location were faulty, not the ground-water.

Renovation of Springs

In April of 1995 the Village of Forestville, New York was awarded a grant from the New York State (NYS) Department of Environmental Conservation to partially fund a non-point source (NPS) pollution abatement project. The purpose of the project was to improve the Village's public water supply by reducing NPS pollution impacts to their source water, i.e. reconstruction of Hall and Henry Springs.

Over the years, both water quality and production declined, spurring the village to search for a suitable well source to replace the springs. However, the discontinuous and confined nature of the aquifers near Forestville led to poor well performance due to poor ground-water recharge. While the Village was able to obtain an additional 32 gpm from the two wells drilled in 1989 and 1990 (wells 6 and 7) it required almost 100 gpm to meet daily water demands.

In an effort to address source water problems, the Village formed partnerships with the Chautauqua County Health Department (CCDOH) and SUNY College at Fredonia (SUNY-Fredonia), both members of the Chautauqua County Water Quality Task Force (Task Force). In the 1991 County Water Quality Strategy, the Task Force had identified the Village of Forestville water supply as an important aquifer lacking sufficient water quality data. Therefore, once exploration for more wells was considered unlikely, CCDOH and SUNY-Fredonia performed a source water and water quality evaluation in 1991 and 1992 (Wilson and others, 1996), the results of which were presented above. The investigators determined (as previously discussed) that the ground water itself was of high quality but that surface water carrying NPS pollutants such as parasites, bacteria, sediment and organic matter could seep into the lateral collectors of the Hall and Henry Springs. In addition, tree roots had clogged the lateral pipes, reducing the yield of the spring systems and providing another avenue for NPS pollutants to enter the spring collectors. Reconstruction of the existing spring systems was identified as the best, most cost effective solution to the village's water quality problems.

At this point, it seemed natural to involve the Task Force to obtain funding and engineering services to proceed with restoring and protecting the springs. Task Force members helped village personnel write a successful proposal seeking NPS funds to renovate Hall and Henry springs.

The primary goal of the project was to eliminate NPS pollution impacts to the village public water supply. Secondary goals were to improve system efficiency and increase water production. The project was divided into three major parts. Part one was to reconstruct the two ground-water collection systems by replacing most of the lateral systems and developing deeper zones that are sealed from surface runoff. Part two was to conduct a project evaluation by measuring and comparing pre-construction to post construction conditions. Finally, part three was to implement a watershed maintenance plan in order to preserve the integrity of the new systems and protect them from contamination.

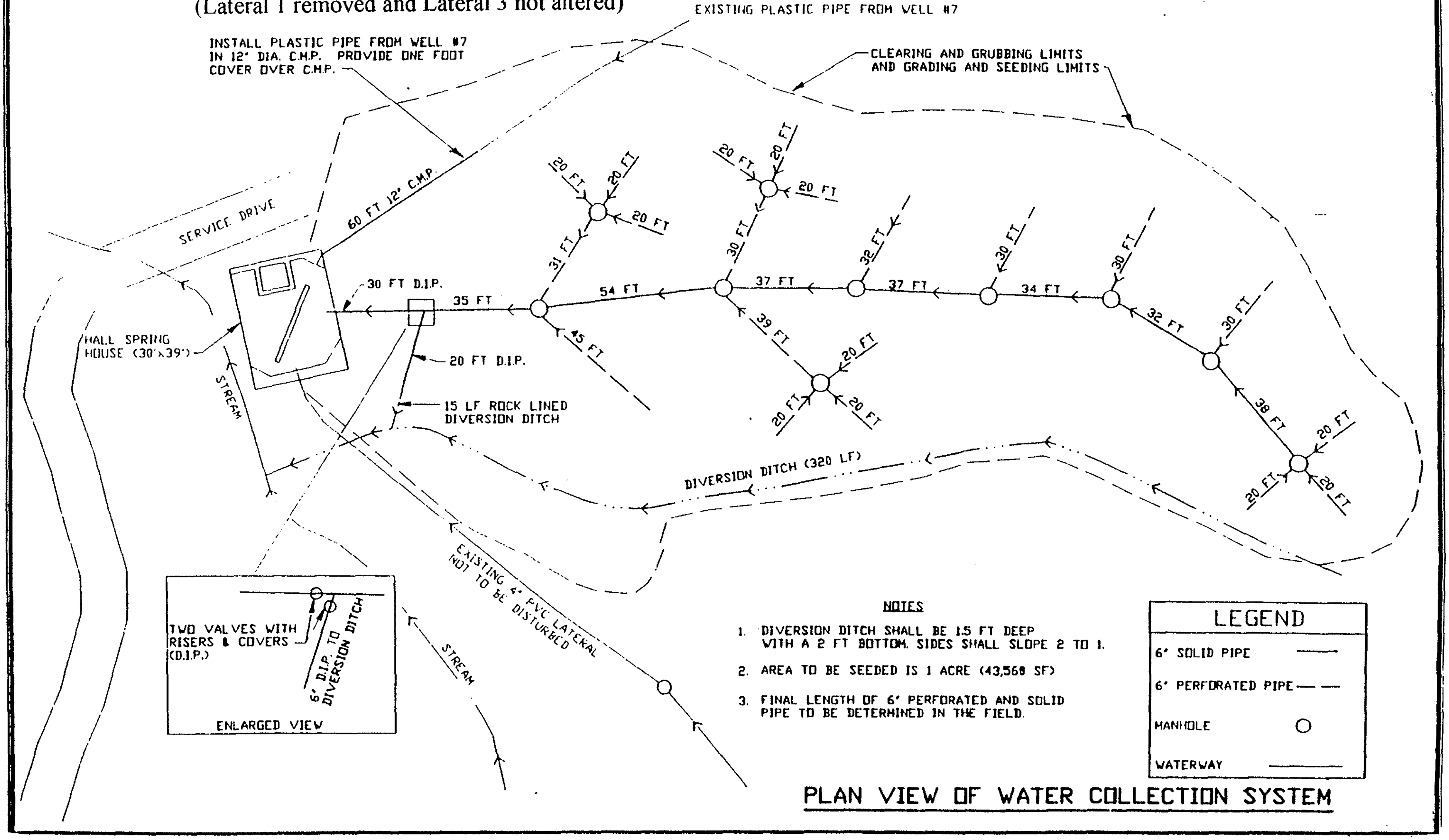
A collaborative approach went far to contain costs and guarantee success. In order to reduce engineering costs, Task Force members contributed technical suggestions to the design of a spring water collection system that would be adequately sealed from surface contamination (Figures 13 and 14). The current and previous village water operators, the Mayor, the Chairman of the Village Water Supply Committee and the Village's engineer contributed other design suggestions. With water supplies limited during spring renovations, volunteer water conservation measures and mandated use restrictions were implemented. To minimize project costs, the village did as much site preparation as possible with help from NYS correctional facility prisoners.

Once topsoil was stripped and stockpiled, the old manholes and related laterals were removed to assure that surface water could not migrate into the new collection system through the old pipes. Ten manholes with related piping were installed at Hall Spring to replace lateral 2 (Figures 13 and 14). Lateral 3 was not altered. New lateral-2 pipes were buried at least 5 ft below ground. Other features to inhibit surface water infiltration to the collection systems included several rock lined and grassed diversion ditches to intercept overland flow prior to the lateral areas and divert it to a nearby stream. Disturbed areas were then fine graded, seeded, and mulched.

In order to assess the effectiveness of this NPS implementation project, the Village water operator and the CCDOH monitored water quality (Figures 15-18) and spring flow rates before and after construction. Temperature (Figure 15), conductivity (Figure 16), and turbidity (Figure 17), were measured daily, five times a week, and bacteria samples (Figure 18) and flow measurements were collected once a week. The water quality tests in 1995 through 1997 used the same equipment and methods as during 1991. In addition, spring water was examined several times during the project for the presence of Giardia, Crytosporidium and other biological particulate matter using MPA as during 1991.

Both the pre-construction temperature and conductivity data showed greater short-term variability than post-construction measurements. Once construction was complete, these fluctuations diminished, indicating that surface water seepage into the collectors was greatly reduced or eliminated altogether. Immediately following construction turbidities increased, then gradually declined to about 1 NTU and remained stable. Bacteria levels (Figure 18) before construction varied sporadically in response to runoff events. Immediately after construction was

Figure 13. Design construction, Hall Spring Lateral 2.
(Lateral 1 removed and Lateral 3 not altered)



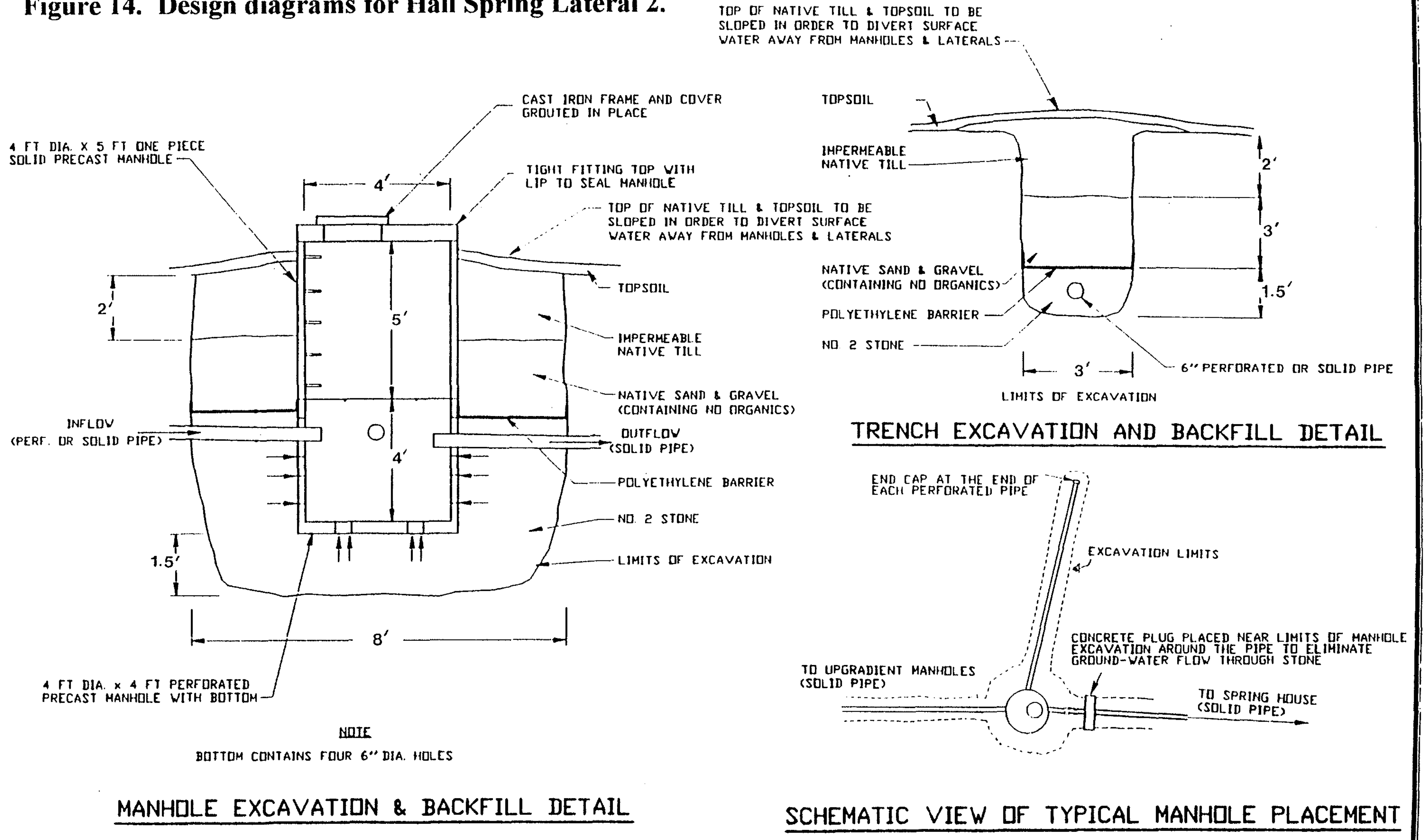


Figure 14. Design diagrams for Hall Spring Lateral 2.

Figure 15. Ground Water and Surface Water Temperature

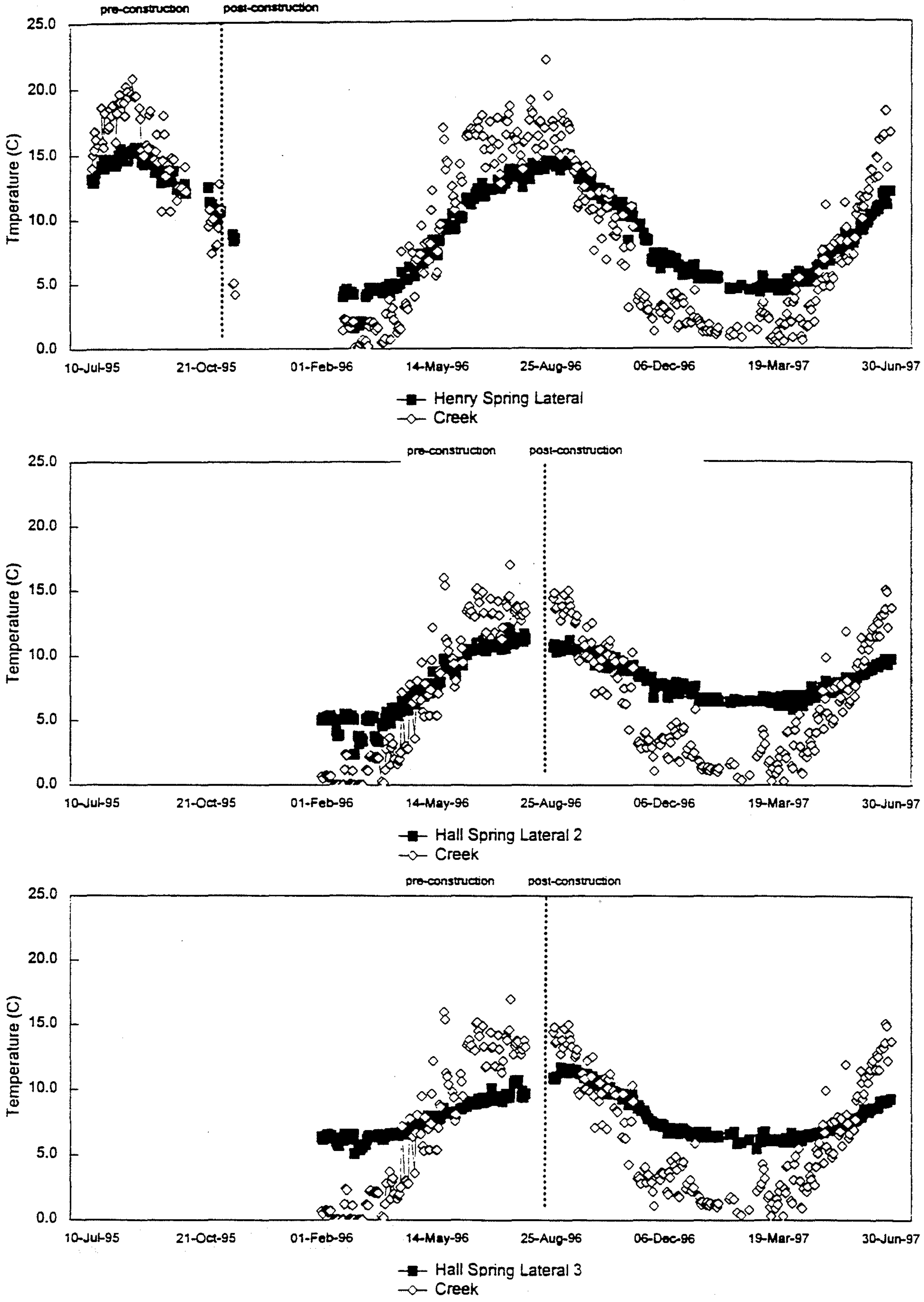


Figure 16. Ground Water and Surface Water Conductivity

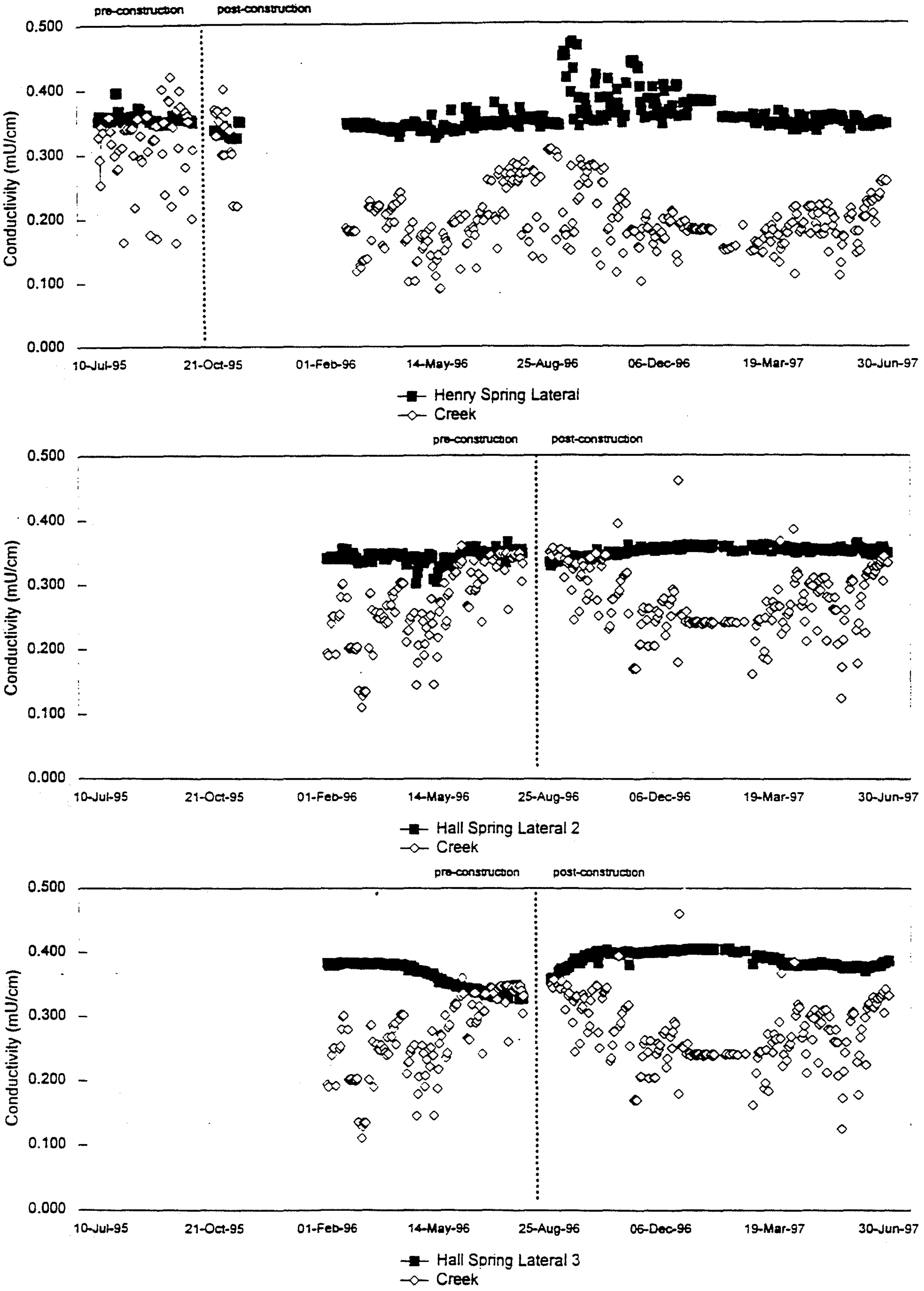
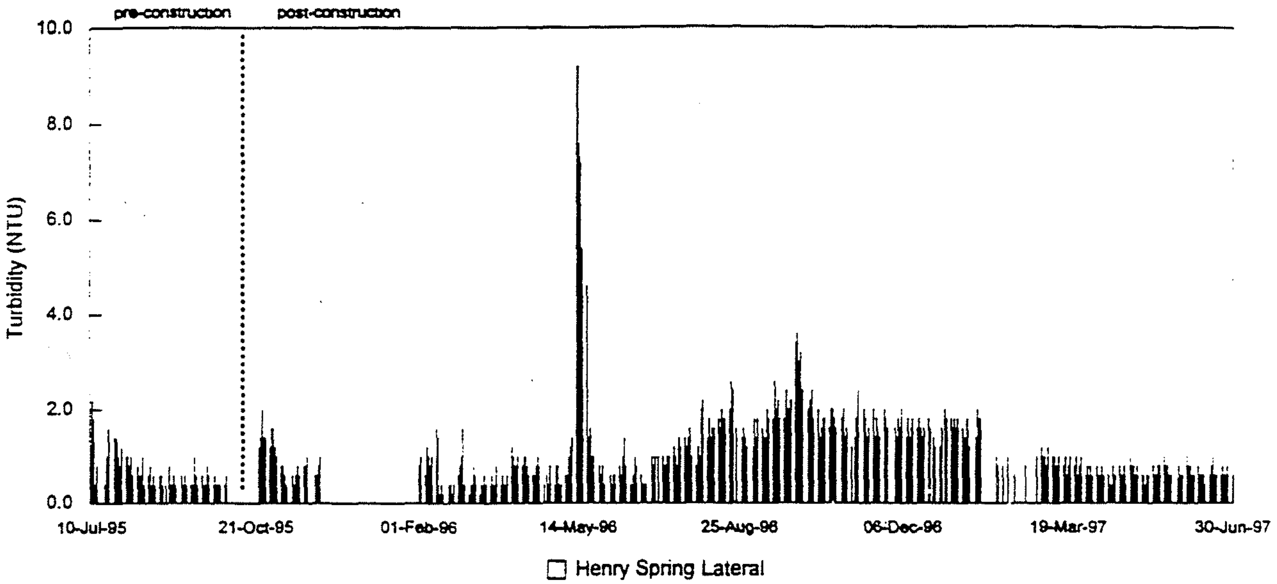
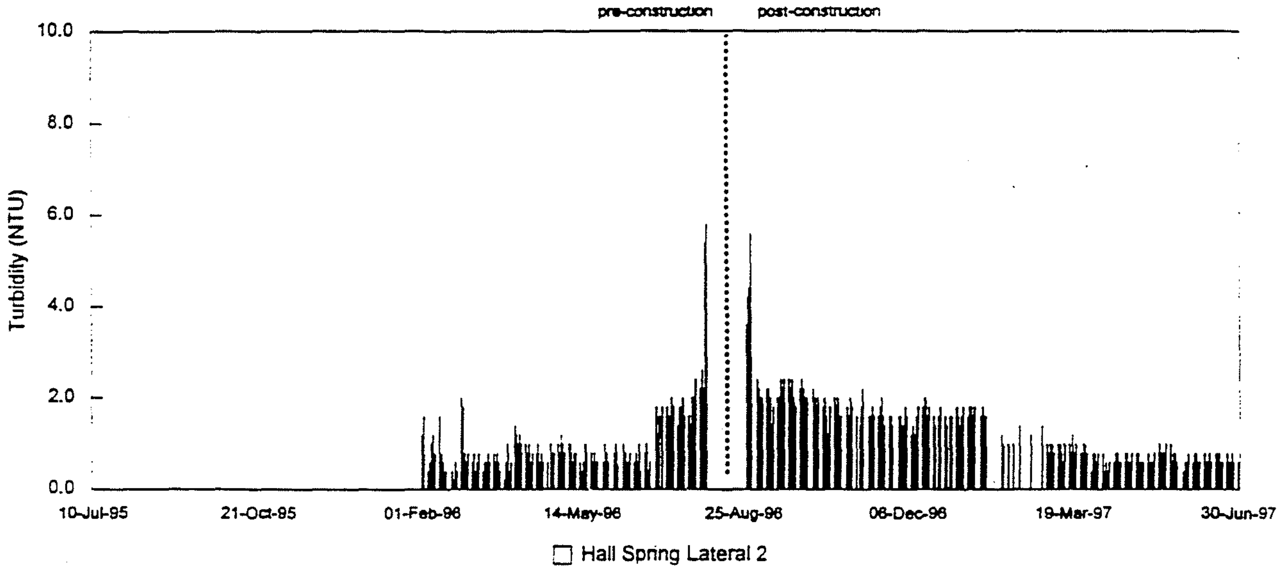


Figure 17. Ground Water Turbidity





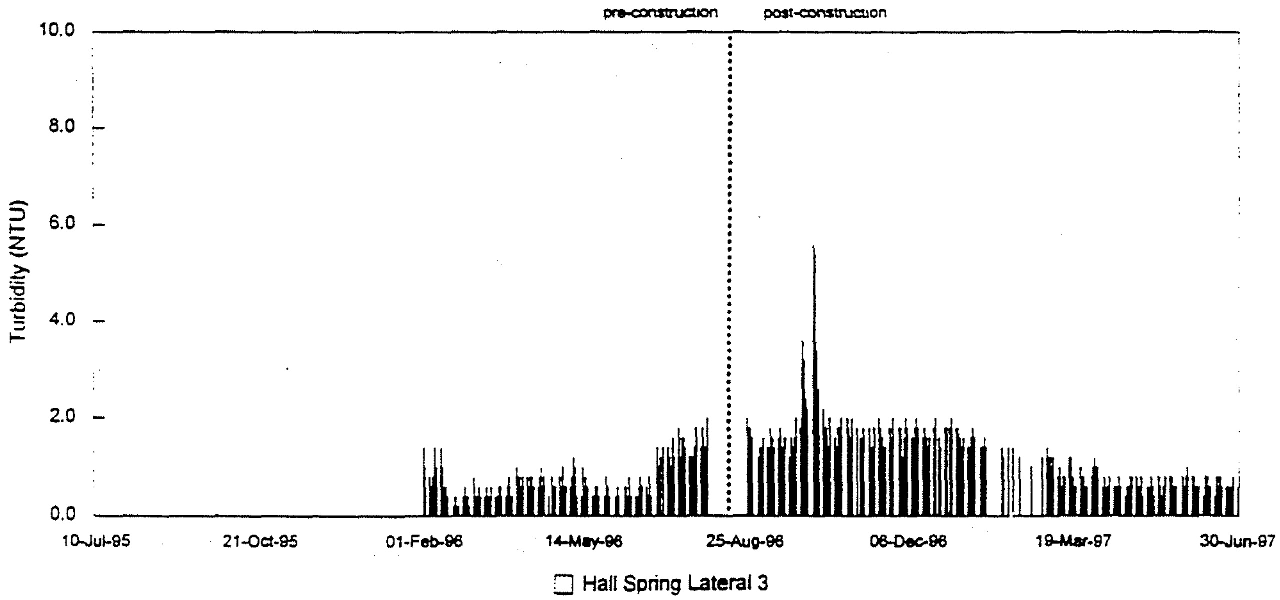
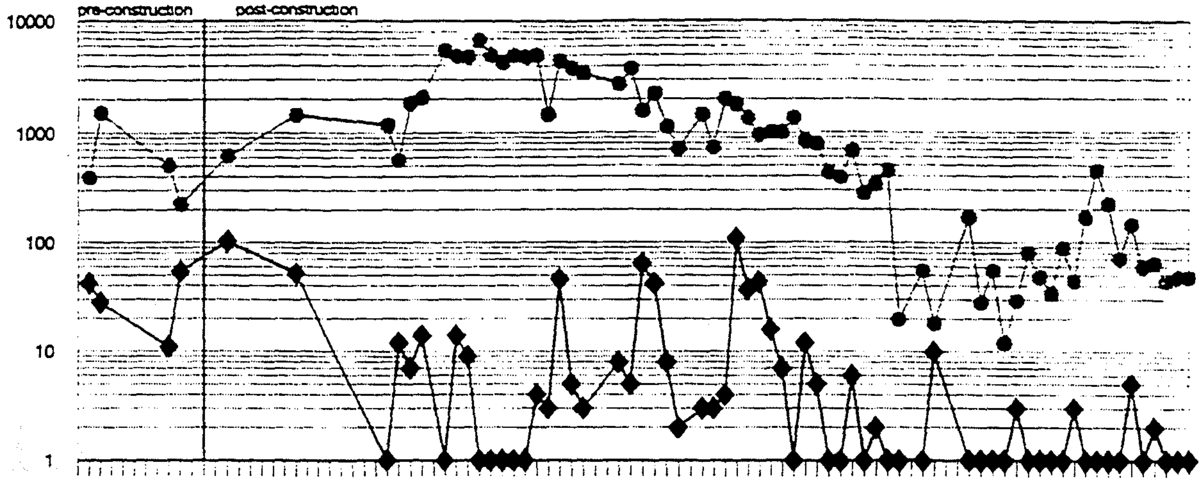
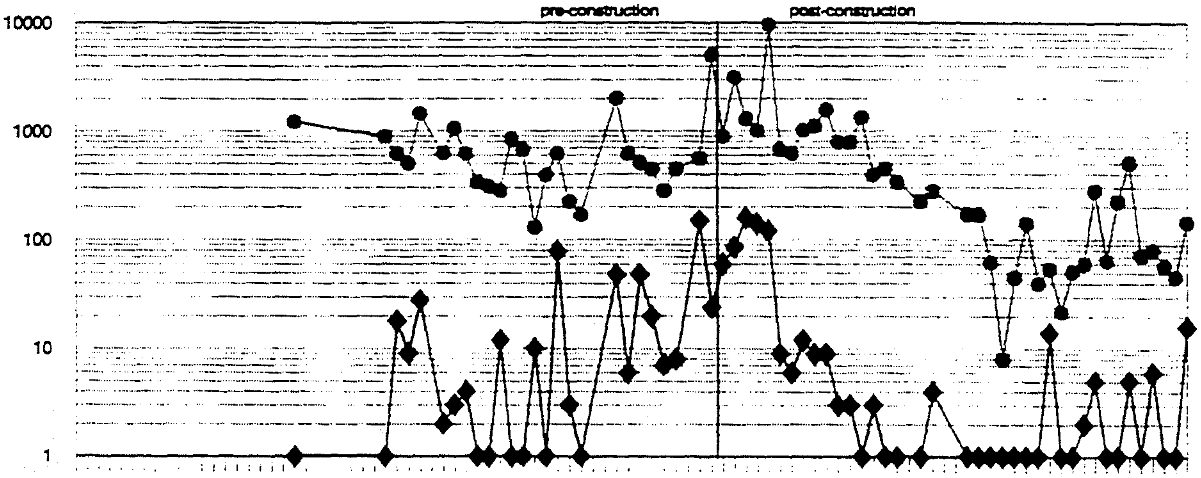


Figure 18. Ground Water Bacteria Levels 1995 - 1997

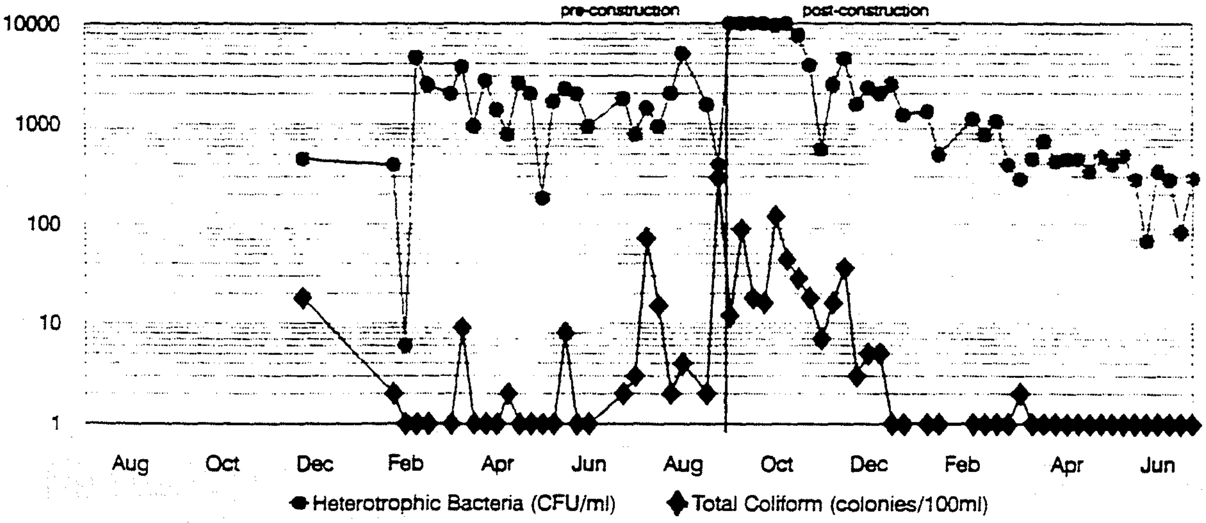
Henry Spring Lateral



Hall Spring Lateral 2



Hall Spring Lateral 3



complete, bacteria levels rose, indicating abundant bacteria from topsoil was introduced into the aquifer during spring renovations. Following construction, bacteria gradually died in the aquifer. Post-construction MPA samples indicated good biological quality at both springs with diatoms at zero. Average production increased from 13 gpm before construction to 24 gpm after construction at Henry Spring and from 24 gpm to 60 gpm at Hall Spring.

In order to preserve both ground-water quality and spring system integrity, a watershed maintenance program was developed. Village officials met with CCDOH and SUNY-Fredonia representatives (Boria and Wilson) to review existing groundwater protection programs, develop a routine watershed inspection and spring maintenance plan, and identify other mechanisms that would protect the village water supply.

Thanks to the cooperation between local, county, state and federal agencies, the Village was able to procure the funding needed to upgrade its spring systems. A total of $124,405 in cash was spent to perform the construction improvements, $53,600 of which came directly from NPS grant monies. As well as dramatically improving water quality and production, the Village has also realized some long-term financial benefits by decreasing chlorine use by half to attain the same level of disinfection as before reconstruction. Finally, increased spring production has allowed the Village to rest their two low yielding wells, saving on electricity. Probably the most noteworthy measure of improvements is the experience of Village water customers, who no longer have annual water restrictions or roily water coming from their drinking water taps during heavy rain storms.

Delineated Wellhead Protection Areas

Due to the complex nature of the aquifer systems that supply water to both the springs and the wells, traditional ZOC delineation methods could not be used. Instead, wellhead protection areas (Figure 19) are based on geologic mapping and drainage basin limits. From what is known of ground-water flow in the Henry and Hall spring areas, recharge to both the springs and wells occurs south of the Mississippi – Great Lakes divide in areas containing highly permeable soils from outwash.

The primary protection zones for the springs are based on the extent of the small drainage basin of each spring system. The basins were delineated using topographic maps beginning at a point immediately down-gradient from each spring house.

The primary protection zones for the wells extended to the area east of Hall and Henry springs where permeable soils are present. This area was chosen by reviewing geologic maps (Muller 1966) and soils information (Puglia 1994). It also encompasses the land area around each well.

The small drainage basins for Hall and Henry springs form the western boundary of the primary protection zone for the two springs and wells. The eastern boundary extends to the permeable deposits along the West Branch of Conewango Creek. Since all of these areas border one another, they were combined to form one primary protection zone. A 500 ft buffer was then

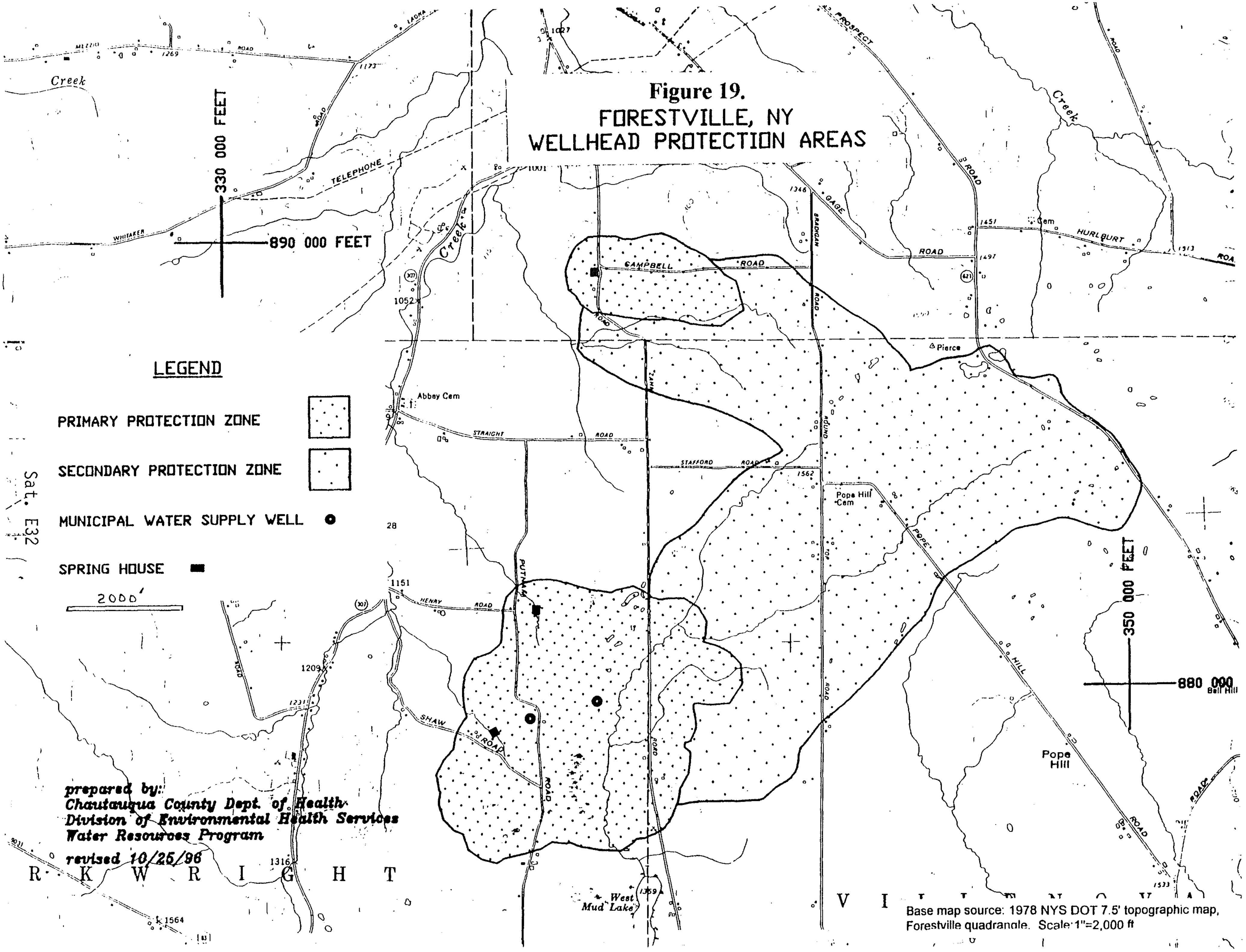


Figure 19.
FORESTVILLE, NY
WELLHEAD PROTECTION AREAS

prepared by:
Chautauqua County Dept. of Health
Division of Environmental Health Services
Water Resources Program
revised 10/25/96

Base map source: 1978 NYS DOT 7.5' topographic map, Forestville quadrangle. Scale 1"=2,000 ft added to the outer perimeter of this area to create the final zone. This is shown in Figure 19 along with the primary protection zone for Bradigan spring, delineated in a similar fashion.

The secondary protection zone for the spring and well system is included for the protection of surface water that recharges the aquifers. The delineation is based on watershed limits beginning at a point on the West Branch of Conewango Creek, down stream of the primary protection zone, and encompassing the entire drainage basin up-gradient from that point.

SINCLAIRVILLE WELLFIELD

Hydrogeologic Setting

The Sinclairville wellfield is located on a fan-shaped gravel deposit flanking a ridge along one side of a glaciated valley (Figures 20 and 21). The deposit consists of coarse-grained fluvial sediment (sand and gravel) originating in the uplands and deposited in a late Wisconsin-age glacial lake. This lake has subsequently filled with sediment to form the present-day Cassadaga Valley. The sand and gravel overlies and is interbedded with, valley-filling sediments (Muller, 1963; Crain, 1966). A portion of the underlying stratified drift is a regional aquifer (Lower Cassadaga Valley Aquifer, also known as the Jamestown Aquifer) extending down-valley.

The aquifer, identified in both production well logs, consists of alluvial fan sand and gravel grading downward into delta sand and gravel. The wells were drilled through approximately 60 ft of various sand and gravel layers overlying a layer of sandy clay. The depth to bedrock at the well field is unknown. The aquifer is unconfined with static water levels varying seasonally from about 9 to 22 ft below ground (saturated thickness ranges from 38 to 51 ft). The fan-delta is 1 mi^2 in area, bounded to the north and east by till covered bedrock, and to the south and west by lake sediments. Based on other well logs in the Sinclairville area, the fan-delta deposit thins or pinches-out approaching the bedrock hills. The delta gravel also dips westward as it becomes interlayered with the Jamestown Aquifer. The Jamestown Aquifer is thought to be outwash, 20 ft thick underneath about 100 ft of lake silt.

Municipal Wells

Sinclairville currently uses two vertical wells drilled adjacent to Mill Creek (Figure 20). The water system serves about 772 people and provides water to commercial and light industrial users. Their average and maximum daily water demands are 130,000 and 180,000 gpd respectively.

Well 1 was drilled in 1956 to a depth of 59 ft and screened from 54 to 59 ft. Well 2 was drilled in 1974 and is located closer to Mill Creek. It is 60 ft deep and is screened between 50 and 60 ft. The annuli of the wells are properly sealed with concrete and both wells are enclosed in separate buildings with concrete floors. The wells are both pumped at an average rate of 130 gpm with maximum pumping rates of 150 gpm for well 1 and 187 gpm for well 2. The wells are pumped one at a time, 17 to 23 hours per day depending upon demand. It is common practice to

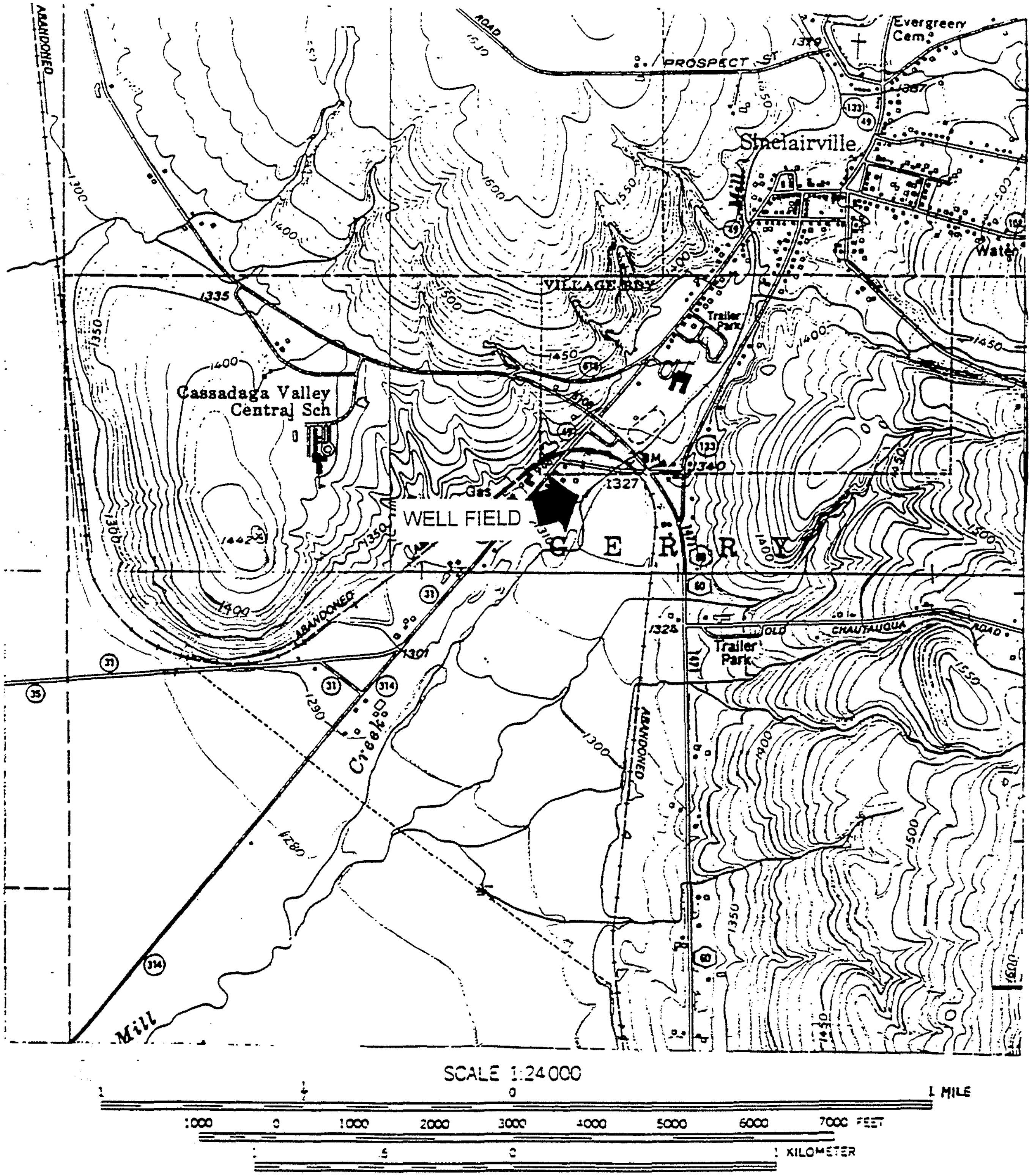
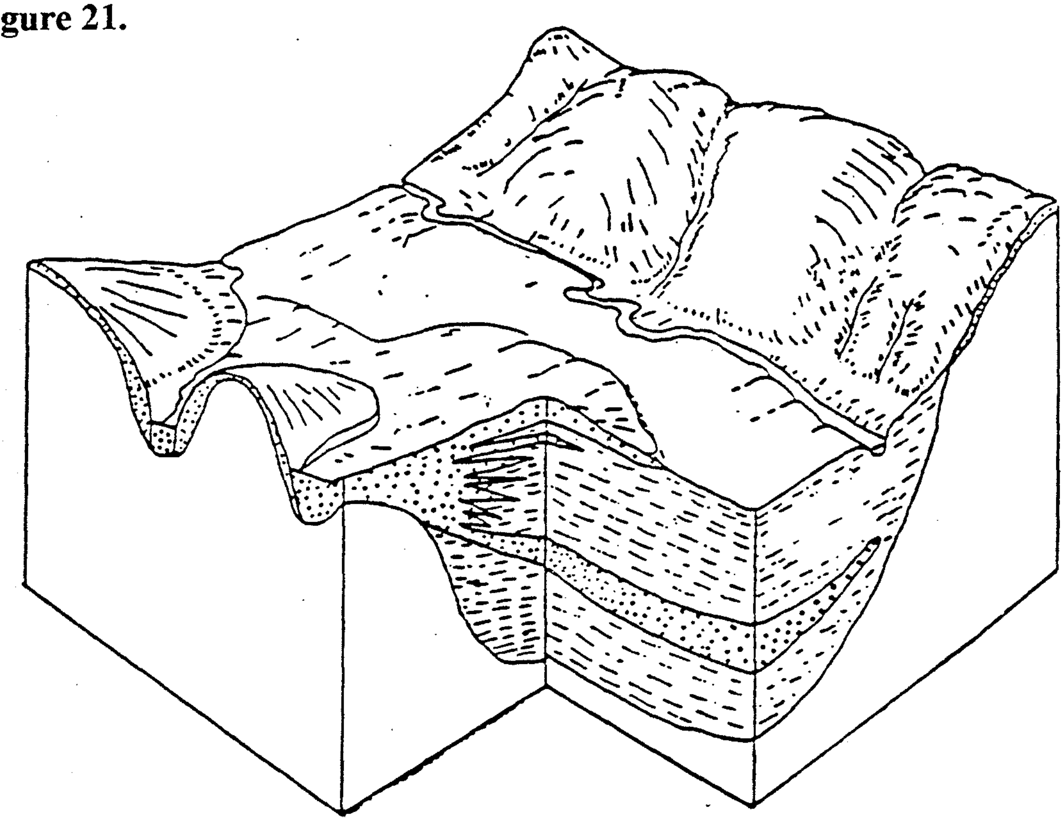
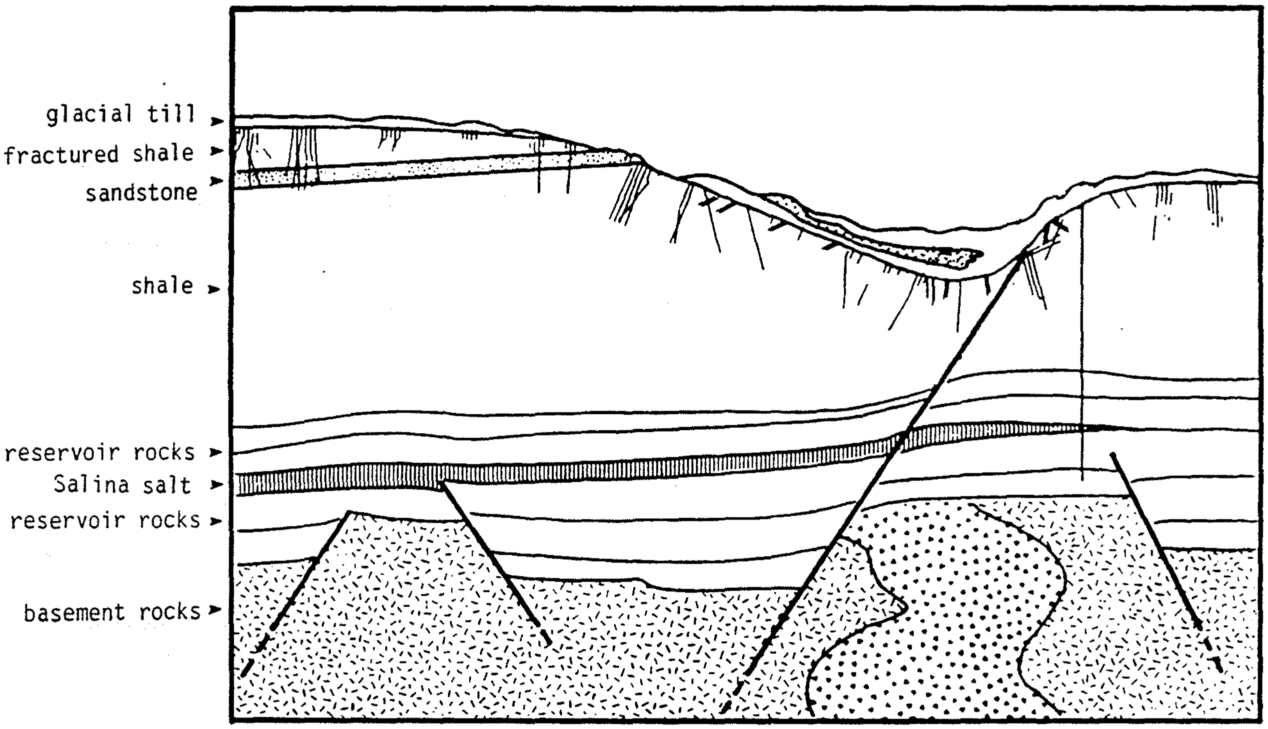


Figure 20. Location of the Sinclairville well field (Source USGS 7.5' topographic map - Cassadaga and Ellery quads, scale: 1"=2,000 ft).

Figure 21.



21a Block Diagram of Mill Creek Fan and Cassadaga Valley
(modified from Crain, 1966)



21b **Deep Section** **(not to scale; Wilson 1985)**

alternate the wells every two to three days in order to distribute wear, although it is not uncommon for each well to be run for a week at a time.

Original pump test data for either well is not available. Documentation by the well driller indicates that well 1 was continuously pumped for 5 days at 150 gpm with only 1.6 ft of drawdown. No information is available for well 2. A pump and recovery test was performed on well 1 on 8/13/91 as part of an American Water Works Association Research Foundation (AWWARF) project to characterize microparticulate recharge and associated phenomena (Wilson and others, 1996). Water level data was collected from well 2 and a monitoring well 75 ft away from well 1. The monitoring well is a 2 in. steel pipe, the top of which is buried about 2 ft below grade. Water level data collected from the monitoring well was analyzed using the AQTESOLV computer program (Geraghty & Miller, 1989) by both the Theis and the Cooper-Jacob method for evaluating unconfined aquifers. Transmissivity and storativity of the aquifer are approximately 5,000 ft^2/day and 0.65 respectively; hydraulic conductivity is about 151 ft/day.

Ground-Water Flow

Water table elevation data is limited, preventing the determination of actual flow directions and gradients. But since the aquifer is unconfined, surface topography can be used to approximate them. Based on local topographic maps, regional flow is from approximately north 35 degrees east. Water drains off the till covered hills, entering the aquifer through the porous sediments of the delta, and flows toward the center of Cassadaga Valley. The gradient of ambient ground-water flow, based on both topographic maps and streambed surveys, is between 0.005 and 0.010. The majority of the upland watershed drains into Mill Creek which flows across the delta. Towards the center of the valley, the delta deposit merges with the fine grained lake sediments (silts and clays) thereby restricting horizontal flow as the ground-water moves downward into the Jamestown Aquifer. This being the case, it is likely that hydraulic gradients in the delta aquifer are steeper than predicted by surface topography.

Water available to the wells is from water stored in the saturated sediments of the aquifer, as well as from recharging precipitation, Mill Creek infiltration, and hillslope runoff to the delta margin. The total land area of the delta aquifer up-gradient of the wells is approximately 0.32 mi^2. Using an average saturated thickness of 20 feet and a porosity of 20%, a conservative estimate of water available to the wells in storage is 267 million gallons. Additional storage may occur in the upland till areas. Mill Creek, which flows directly across the delta and into Cassadaga Creek, is a major source of recharge to the aquifer. The delta watershed is approximately 20 mi^2. The maximum amount of water available for recharge from runoff (precipitation: 42in. – evapotranspiration: 23in.) on an annual basis, averages 6.6 billion gallons. Only a portion of this would actually recharge ground water; the majority would contribute to stream flow. Although no actual streamflow data is available for Mill Creek, it has been observed that flow routinely diminishes during middle to late summer with all or a majority of streamflow disappearing as it flows across the delta (Wilson and others, 1996). This is typical of valley-fill aquifer systems in western New York State (Crain, 1966; Randall and Johnson 1987).

A distance-drawdown graph for the well field (Figure 22) shows that the cone of depression extends approximately 400 feet. The water level in the well never stabilized during the pump test, therefore the cone was still growing when the test was terminated. When this pump test was conducted, Mill Creek was dry immediately adjacent to the wells. Upstream, creek flow was observed to be very low with flow completely disappearing about 1,000 feet up-gradient of the well field. Drawdown in the well was greater than usual due to the depletion of water from storage. The cone of depression was, therefore, extending up-gradient towards the flowing portion of the stream and inducing recharge. It should also be pointed out that the water table elevation in the delta aquifer may be reduced by ground-water withdrawals from the Jamestown aquifer.

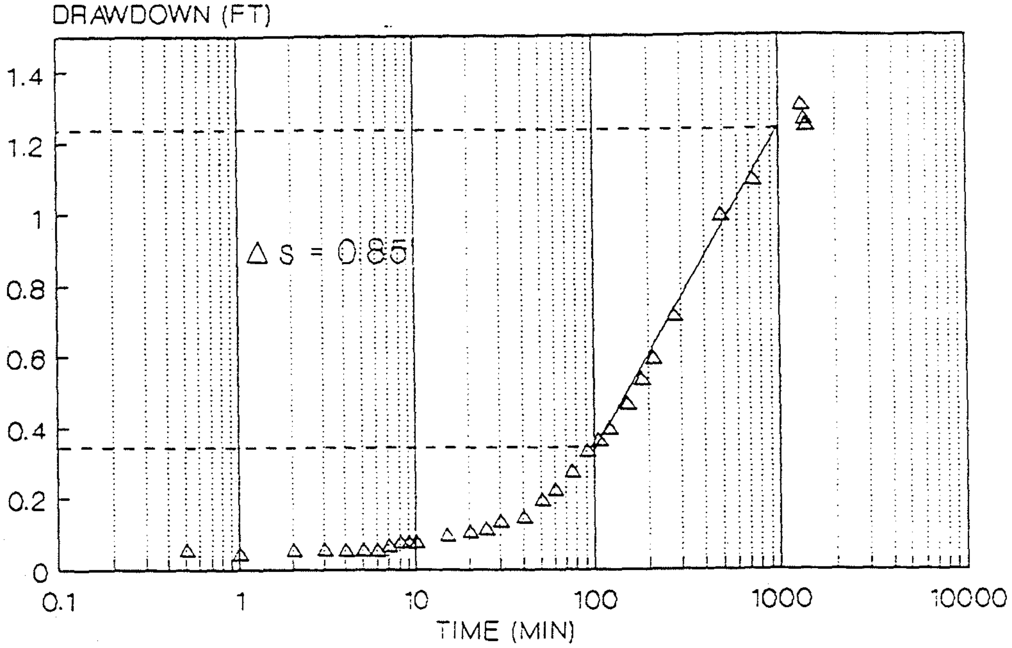
Time of Travel

Periods of induced surface water recharge to the aquifer were estimated utilizing surface water and ground-water temperature and conductivity data (Figure 23). During the early part of the year, there was sufficient precipitation to maintain water in storage in the aquifer. The ground-water temperatures did not vary significantly above or below the ambient air temperature (9.5^0C for this area), signifying that most of the water was in the aquifer for several months or longer. In May, ground-water temperatures began to increase to above the ambient air temperature after a one-month dry period. This condition continued through the summer and into the fall, most notably in well 2 which is closer to the stream. The warmer ground-water temperatures are due to stream water recharging the aquifer up-gradient of the well field. The onset of ground-water warming began in mid-May, two months after the onset of surface water warming. This difference in times for the onset of warming suggests a time-of-travel from the creek to the well of about 60 days. The temperature peaks for stream water and ground water nearly coincide and indicate travel times of 20 days or less during mid-summer. That the amplitudes on the ground water temperature graph are so small indicates that induced stream water is a small portion of flow to the wells. The amplitude of the ground-water graph is about 10 or 20% of the surface water graph. Conductivity data (Figure 23) also provide recharge and travel time information. Ground-water conductivity is relatively stable until mid-April, then declines (receives amounts of creek recharge). Between mid-June and mid-July, the well water conductivity rises as does Mill Creek conductivity. Base flow dominates the upper basin of Mill Creek, making Mill Creek more conductive; then lower Mill Creek infiltrates the aquifer, raising the conductivity of ground water at the wells.

Computer Modeling

Several WHPA computer modeling runs were conducted for the Sinclairville well field using various hydraulic parameters. The well field was modeled using a single well pumping at 130,000 gpd (average demand) since both wells are similar and do not run concurrent. ZOCs (zones of contribution) were computed for wet periods (late fall-winter-spring when storage in the aquifer is at or near maximum capacity) and also for dry periods (summer-early fall when storage is at a minimum). For wet period simulations, the maximum saturated thickness (51 ft), minimum estimated hydraulic gradient (0.005), and ambient flow direction (58^0 above an east-west line) were used. For dry period simulations, the minimum saturated thickness (38 ft) and maximum

SINCLAIRVILLE WELL 1
TIME-DRAWDOWN



DISTANCE-DRAWDOWN

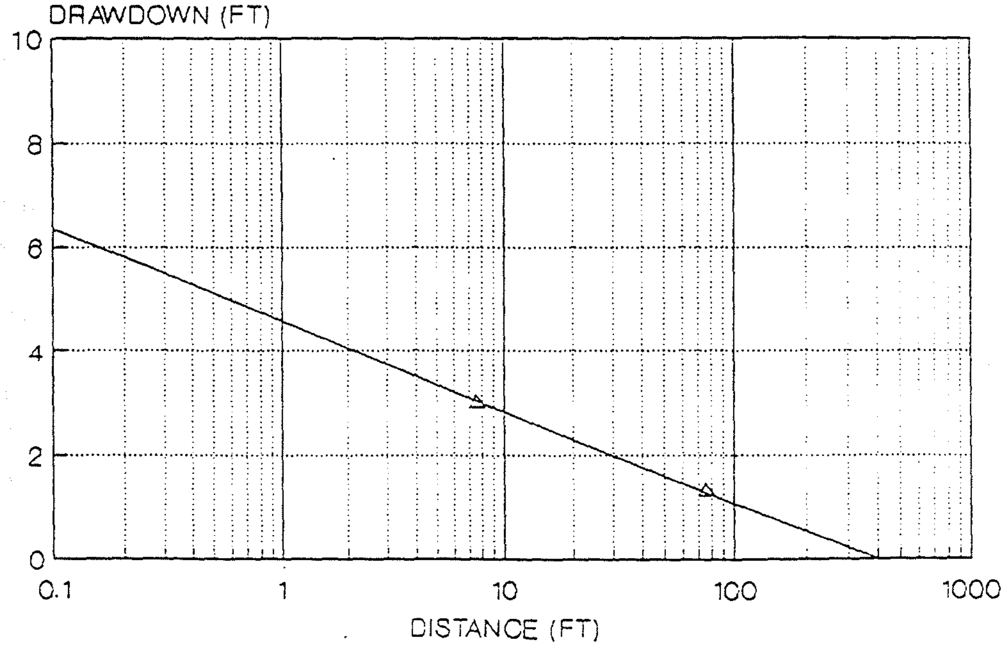


Figure 22. Distance-Drawdown graph for well 1 (bottom) at time = 1310 minutes into the 8/13/91 pump test. One point is the drawdown measured in a monitoring well 75 ft from well 1, the second point was calculated using the equation from Driscoll (1986): drawdown = 2 X Δs (over 1 log cycle), where Δs is computed from the Time-Drawdown graph (top). This identifies the cone of depression extends approximately 400 ft from well 1, but since the well did not stabilize during the pump test, the cone of depression was still growing.

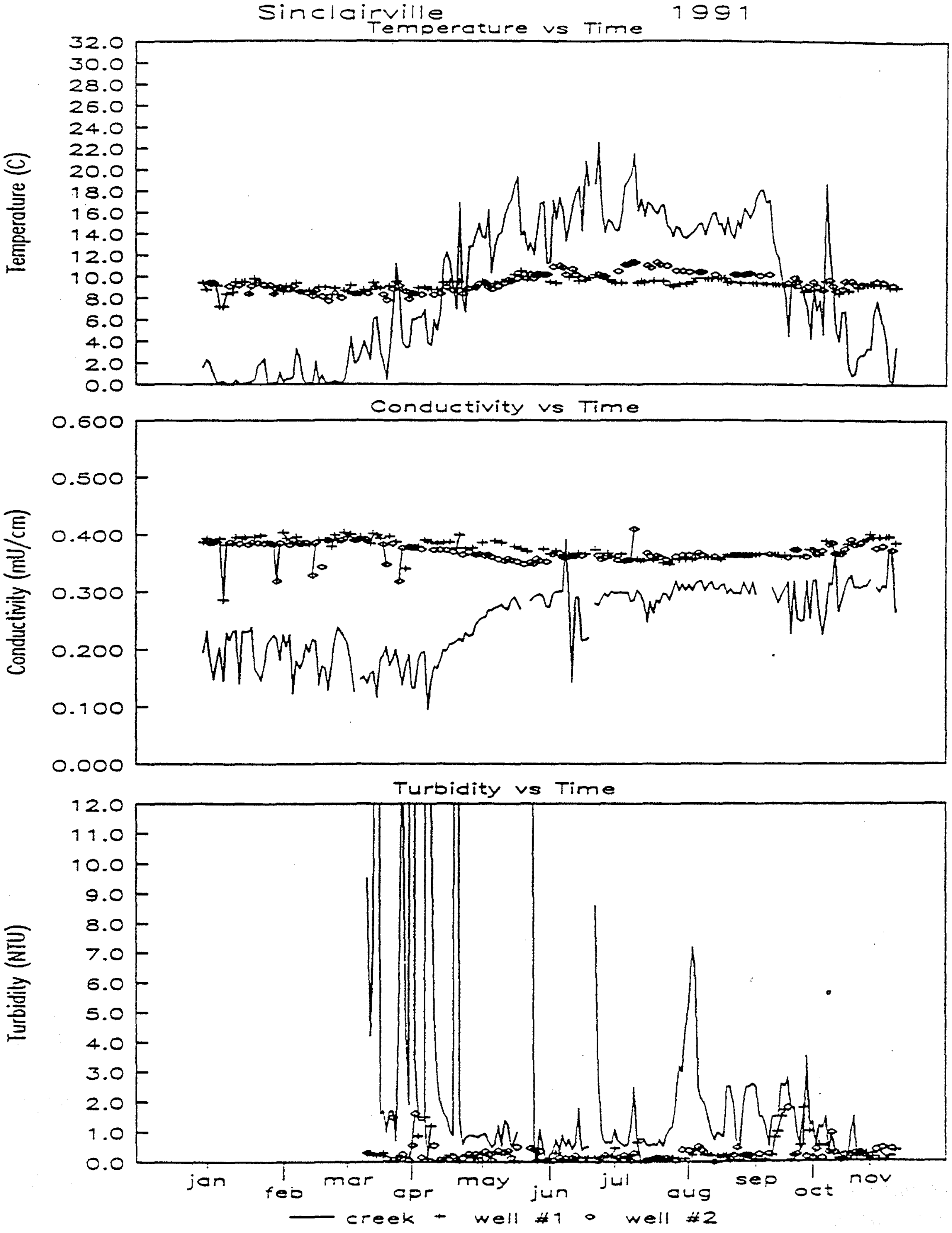


Figure 23. Water quality graphs for wells 1, 2, and nearby Mill Creek.

estimated hydraulic gradient (0.010) were used. During dry periods, the direction or ambient ground-water flow would be skewed towards the stream, therefore, a flow direction of 46^0 above an east-west line was used. The other parameters and results of the modeling are shown in Figures 24 and 25. Note that during the dry period simulation, the ZOC is much longer and thinner, intersecting a portion of the stream bed. It is speculated that as aquifer water is depleted, the ZOC makes a gradual transition from that shown in Figure 24b to that shown in Figure 24a and begins to induce surface water recharge through pumping. Otherwise, natural stream loss and precipitation are the primary sources of recharge.

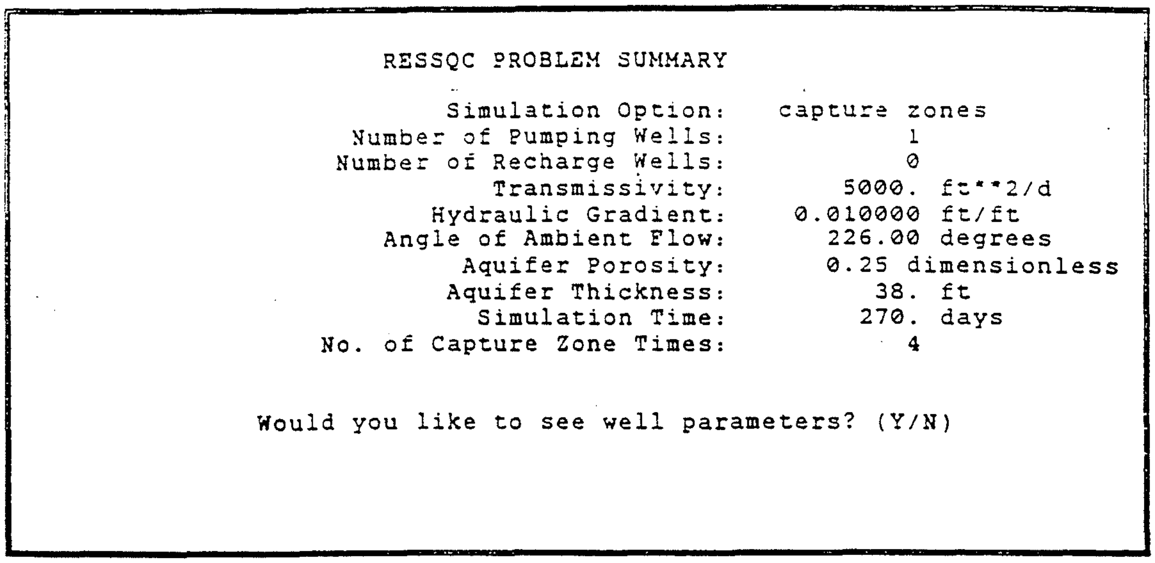
Times-of-travel were also estimated using the WHPA computer model. The shortest possible travel time between the stream and well 2 (the well closest to the stream) was estimated to be from 10 to 20 days (Figure 25). This computer model run is based upon a relatively steep gradient being created between the high stream stage and increased drawdown in the well due to a lack of stored water. This situation would occur at or near the end of a dry period during a storm event. The model simulates ground-water flow to be from a point in the stream closest to the well, in an east to west direction, using a gradient of 0.22. The MWCAP module was used to perform this run which allowed the simulation of induced recharge from a stream, the other runs were performed using the RESSQC module.

Microscopic Particulate Recharge

Because of concerns for giardiasis, cryptosporiodosis, and other surface water diseases that may move as particulate matter from surface waters into ground waters, we evaluated microparticulate recharge using utility in-kind support and resources from grants. Lines of evidence included temperature dilution, conductivity dilution, turbidity data, bacteria data, and microscopic particulate analysis (MPA) test results. In prior sections above, we already established that aquifer geometry, pump tests, and water observations indicated hydraulic connection and a time of travel less than the viability period of giardia cysts (90 days) for example.

As previously stated, relative magnitudes of the ground-and-surface-water temperature amplitudes suggest a significant dilution of creek water by ground water. In these sand and gravel deposits, hydraulic conductivities are high but not so high as to be like cavernous limestones. Therefore, dilution is essentially dispersion; turbulent or diffusive mixing is negligible. During the summer, 9.5^0C ambient ground water is raised to 10 or 11^0C by 16^0C-average surface water. While this comparative approach is highly simplified, a mix of 20% surface water (that is, 7^0C above ambient ground water) with ambient ground water yields 10.8^0C ground water. In winter, ground water is 0.39 mU/cm; in summer it's 0.36 to 0.37 and surface water is 0.30 to 0.32. If the well water is composed of 30% of 0.31 conductivity and 70% of 0.39, then the late summer mix is the observed 0.366 conductivity.

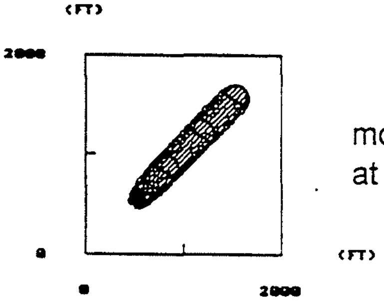
Figure 24.



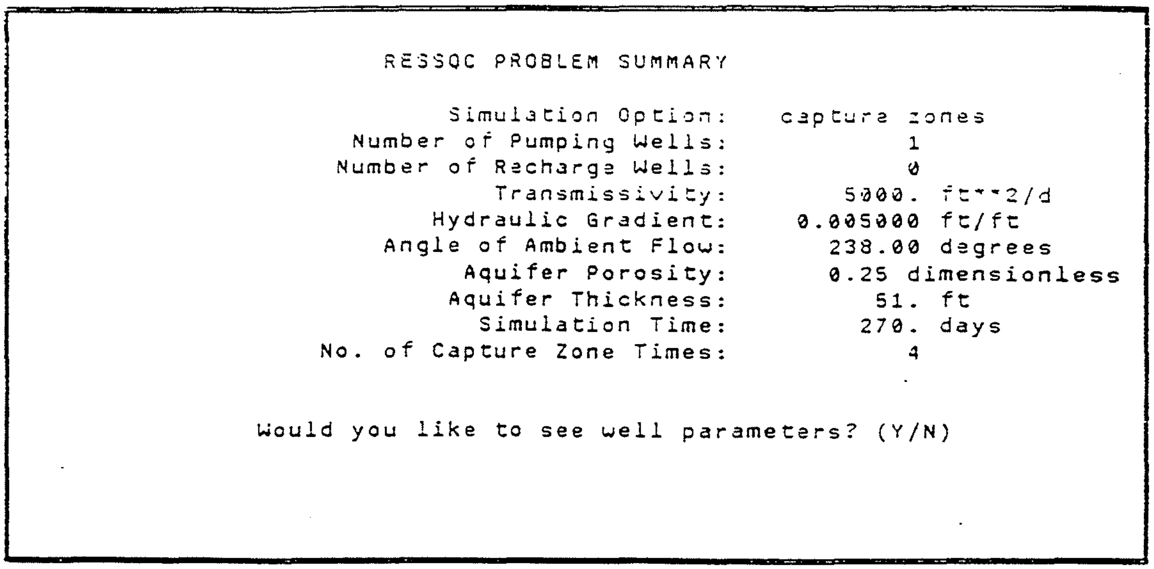
```
                    RESSQC PROBLEM SUMMARY

            Simulation Option:    capture zones
      Number of Pumping Wells:          1
     Number of Recharge Wells:          0
               Transmissivity:       5000. ft**2/d
           Hydraulic Gradient:    0.010000 ft/ft
        Angle of Ambient Flow:      226.00 degrees
             Aquifer Porosity:        0.25 dimensionless
            Aquifer Thickness:         38. ft
              Simulation Time:        270. days
     No. of Capture Zone Times:           4


    Would you like to see well parameters? (Y/N)
```



WHPA computer modeling results for a 9 month "dry period" simulation with a single well pumping at 130,00 gpd. Scale of ZOC plot is 1" = 2,000 ft.



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                    RESSQC PROBLEM SUMMARY

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     Number of Recharge Wells:          0
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           Hydraulic Gradient:    0.005000 ft/ft
        Angle of Ambient Flow:      238.00 degrees
             Aquifer Porosity:        0.25 dimensionless
            Aquifer Thickness:         51. ft
              Simulation Time:        270. days
     No. of Capture Zone Times:           4


    Would you like to see well parameters? (Y/N)
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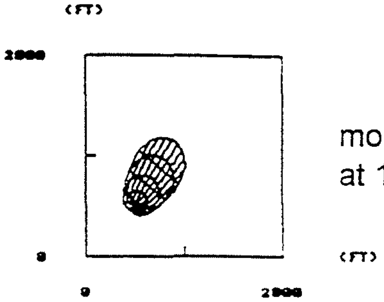
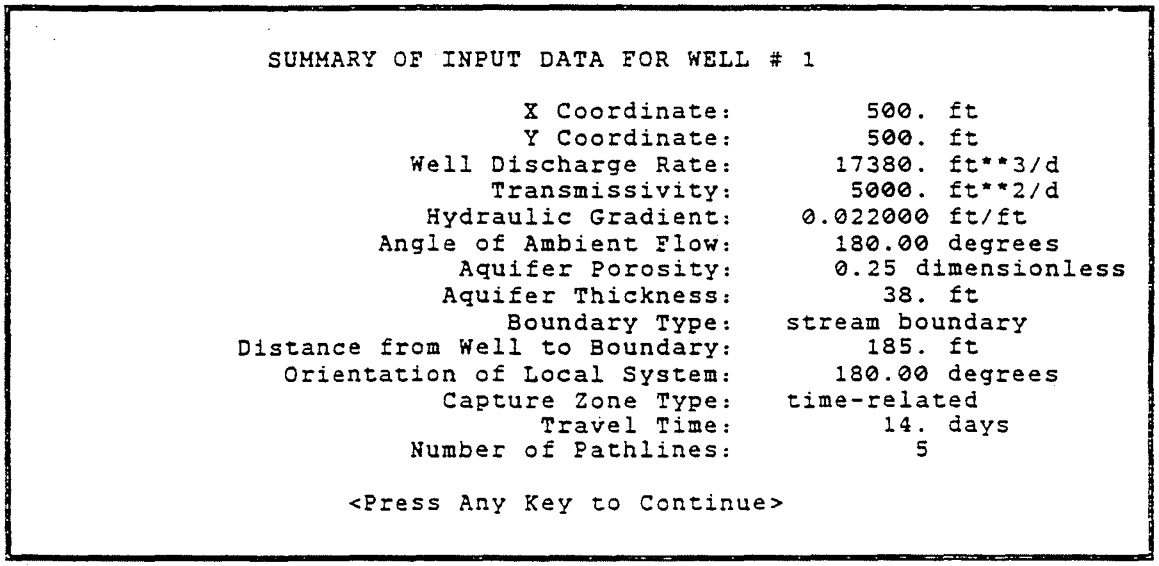


WHPA computer modeling results for a 9 month "wet period" simulation with a single well pumping at 130,00 gpd. Scale of ZOC plot is 1" = 2,000 ft.



```
                SUMMARY OF INPUT DATA FOR WELL # 1

                               X Coordinate:        500. ft
                               Y Coordinate:        500. ft
                        Well Discharge Rate:      17380. ft**3/d
                             Transmissivity:       5000. ft**2/d
                         Hydraulic Gradient:    0.022000 ft/ft
                      Angle of Ambient Flow:      180.00 degrees
                           Aquifer Porosity:        0.25 dimensionless
                          Aquifer Thickness:         38. ft
                              Boundary Type:   stream boundary
                Distance from Well to Boundary:        185. ft
                   Orientation of Local System:      180.00 degrees
                          Capture Zone Type:   time-related
                                Travel Time:         14. days
                        Number of Pathlines:          5

                     <Press Any Key to Continue>
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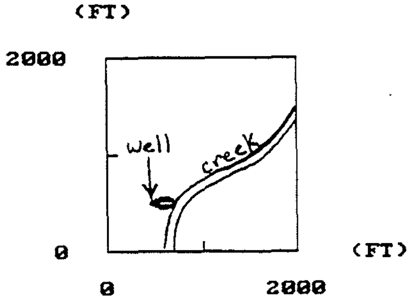


Figure 25. WHPA computer modeling results using the MWCAP module of the program. This run simulates the shortest possible time-of-travel within the aquifer assuming all ground water pumped from the well is from induced surface-water recharge from nearby Mill Creek. This situation could occur during a storm event (when Mill Creek is at high stage) at the end of an extended dry period (late-summer or early fall) when the aquifer is depleted. Travel times from the creek to the wells would be between 10 and 20 days under these conditions.

Turbidity data collected in 1991 indicates 90% of the values for the wells were below 0.3 NTU and all were below 2.0 NTU (Figure 23). Surface waters varied widely from 0.5 to over 12 NTU. Ground-water turbidity variations were minimal and not correlative with other parameters or events. Weekly coliform and heterotrophic bacteria levels were zero for the twelve months of 1991 in the two wells, while nearly always present in Mill Creek.

MPA was performed during the summer months on creek water and ground water from both wells (Table 2). Also, we determined natural reduction (filtration plus dilution) efficiency by comparing the number of surface water particulates and ground-water particulates. An apparent near-total removal of particulates in March and July suggested an extremely high natural reduction efficiency through the aquifer.

A second MPA was performed on creek water and ground water from well 1 in December. The well was pumping during an identified major recharge period. A number of surface water indicators (Table 2) were identified in the ground water at this time. The resulting high EPA relative risk score indicated direct surface water influence. Natural filtration efficiencies for diatoms and "other algae" were calculated at 5-log and –2-log removals respectively. These results represent a period of cold wet conditions following drought. The negative log reduction of the "other algae" likely reflects the effect of TOT on the measurement, i.e., TOT was not fully accounted for in the choice of measurement dates for the surface samples vs. the well sample.

Conclusion: although Sinclairville wells experience periods of short TOT, these periods are infrequent and particulates from the stream water face reduction by dilution and natural filtration in the ground as well as some inactivation during their 10 or 20 day subsurface transport. There is further dilution in the holding tank and distribution pipes. There is also extended contact time with chlorine in the distribution system.

Delineated Wellhead Protection Areas

Primary recharge to the aquifer is from precipitation falling on permeable aquifer (delta) sediments along with stream loss occurring along segments of Mill Creek. Additionally, during dry periods, well pumpage induces surface water recharge from the creek.

Due to the nature of this aquifer, ground-water protection is best accomplished using the geologic extent of the delta formation. The primary protection zone for wells 1 and 2 was delineated using the areal extent of the aquifer up-gradient of the well field. The 500 ft buffer was then added to the outer perimeter of this area to create the final primary protection zone shown in Figure 26.

A secondary protection zone is included for the protection of surface water that recharges the aquifer through both overland flow and stream loss. The delineation is based on watershed limits beginning at a point down stream from well 2 and encompassing the entire drainage basin up-gradient from that point. A portion of the secondary protection zone is shown in Figure 26.

Table 2. Sinclairville - MPA DATA

Device	Source Type	Filter ID#	Date	Giardia	Coccidia	Diatoms	Other Algae	Insects/ larvae	Rotifers	Plant Debris
*	Surface Water	1640	12/09/91	0	0	4,000,000	1	0	0	0
*	Surface Water	1438	07/09/91	0	0	90,000,000	3,000,001	0	0	0
*	Surface Water	1334	03/28/91	0	0	2,000,000	4,000,000	1	0	0
Well 1	Drilled Well	1337	03/28/91	0	0	0	1	0	0	5
Well 1	Drilled Well	1440	07/11/91	0	0	0	0	0	0	0
Well 1	Drilled Well	1641	12/10/91	0	0	20	60	0	0	0
Well 2	Drilled Well	1439	07/10/91	0	0	0	0	0	0	0

* Sample results relate spatially to both wells

- MPA DATA (cont'd.)

Device	Source Type	Nematodes	Crustaceans	Amoeba	Non-Photo. flagellates & ciliates	Photo-synthetic flagellates	Other: iron bacteria	EPA TOTAL RISK	EPA RELATIVE RISK
*	Surface Water	0	0	0	0	0	0	20	High
*	Surface Water	0	0	0	0	0	0	30	High
*	Surface Water	1	0	0	0	0	0	33	High
Well 1	Drilled Well	0	0	0	0	0	0	4	Low
Well 1	Drilled Well	0	0	0	0	0	0.3	0	Low
Well 1	Drilled Well	0	1	0	0	0	0	20	High
Well 2	Drilled Well	0	0	0	0	0	0	0	Low

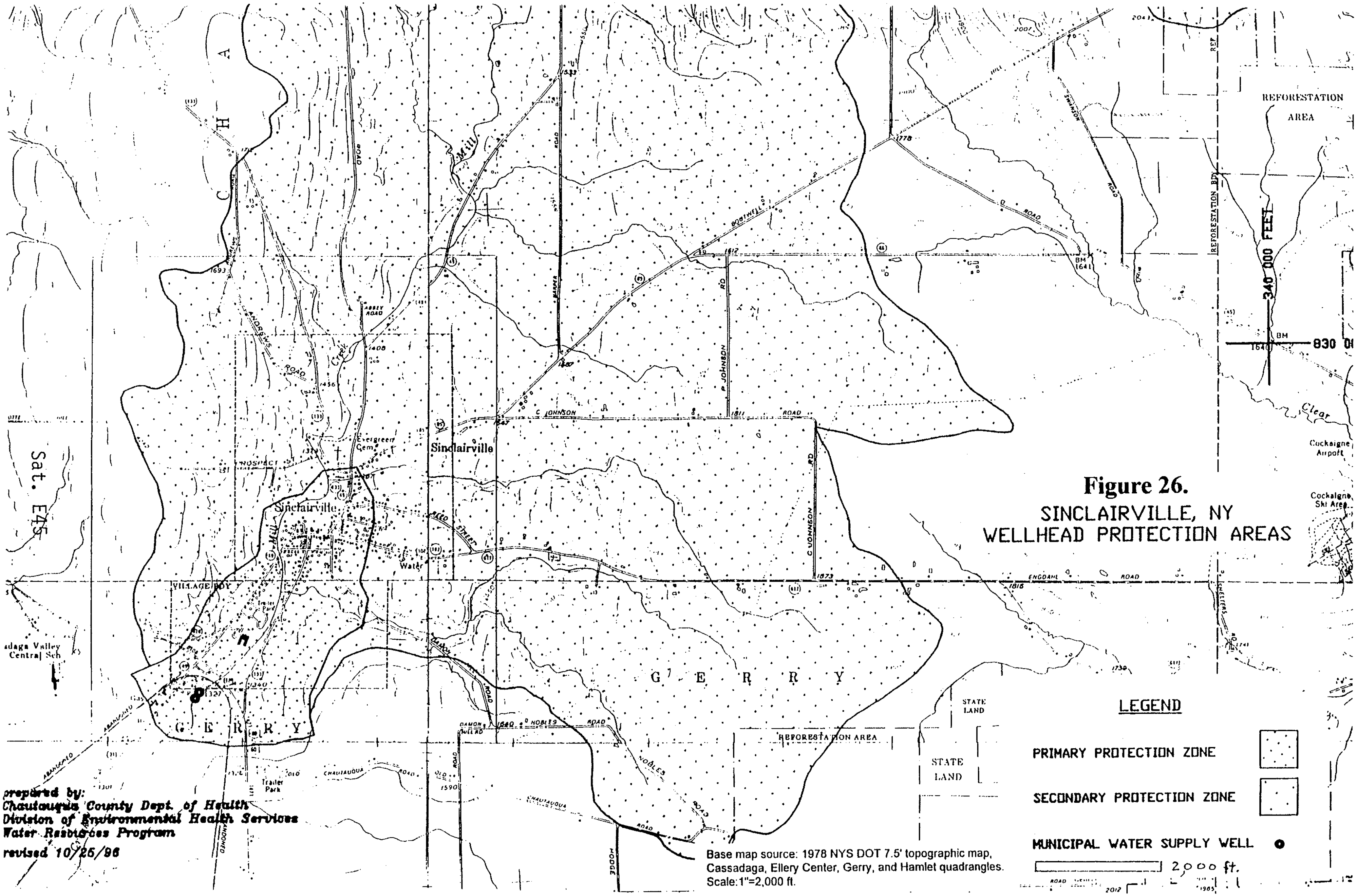


Figure 26.

SINCLAIRVILLE, NY
WELLHEAD PROTECTION AREAS

LEGEND

PRIMARY PROTECTION ZONE

SECONDARY PROTECTION ZONE

MUNICIPAL WATER SUPPLY WELL ●

2,000 ft.

prepared by:
Chautauqua County Dept. of Health
Division of Environmental Health Services
Water Resources Program
revised 10/25/96

Base map source: 1978 NYS DOT 7.5' topographic map, Cassadaga, Ellery Center, Gerry, and Hamlet quadrangles.
Scale:1"=2,000 ft.

DRINKING WATER TURBIDITY AND RESERVOIR SEDIMENTATION, BROCTON, NY

System Description

The Village of Brocton is located in north central Chautquaua County, southwestern New York (Figure 27). The village is served by a system of three reservoirs and a filter plant. Water is distributed to about 1,500 residential customers, area businesses, and the Lakeview Correctional Facility. The reservoirs are fed by Slippery Rock Creek, a north flowing stream that drains from the north edge of the Allegheny Plateau. West Branch Slippery Rock Creek drains into Burr Reservoir (built 1897), East Branch drains into Risley Reservoir (1918), and the outlets for each of these reservoirs drain north into Brocton Reservoir (1953). Burr Reservoir currently has a capacity of 6,000,000 gallons (6MG); Brocton Reservoir is 70 MG and Risley is less than 1 MG. Risley and Brocton Reservoirs function by direct stream through-flow while Burr Reservoir receives water from occasional stream diversion through an artificial inlet channel roughly 50 ft in length. The Village owns 625 of the 2000 acre watershed.

Background and Purpose

Village water plant operators prefer to utilize water from Burr Reservoir because of its low turbidity. However, West Branch stream replenishment of Burr Reservoir is insufficient to replenish the level of this reservoir during summer and early fall. Consequently, Burr Reservoir water supply must be augmented by the Brocton Reservoir during summer and early fall. The high turbidity of the Risley and Brocton Reservoirs is often visually obvious from poor clarity when compared to the Burr Reservoir. And, Risley Reservoir is filled with sediment such that its surface is mostly exposed sediment, and there is essentially no water capacity. Fine suspended sediments that reach the Brocton Reservoir overload filter beds at the treatment plant compromising the treatment process, creating turbid finished water, and posing a potential health threat to the public.

The problems of the Brocton reservoirs came to the attention of several members of the Chautauqua County Water Quality Task Force in 1996. Several initial site reviews were conducted by USDA (Larry Brown), County Soil and Water Conservationist (Dave Wilson), SUNY-Fredonia (Mike Wilson), and County Health Department personnel (Steve Johnson and Bill Boria). The importance of the landslide area as a sediment source was determined during initial visits by this group.

The purposes of this guidebook article are to summarize investigations of: (1) the disparity in water clarity between West Branch (less turbid) and East Branch (more turbid); and (2) the sedimentation of Risley Reservoir. The importance of the landslide area as a source of turbidity is confirmed and quantified.

The purpose of our investigation was to further evaluate turbidity causes prior to constructing site renovations. The previously planned site renovations were: First and foremost the landslides and creek channel were to be stabilized by dewatering the slope, removing debris

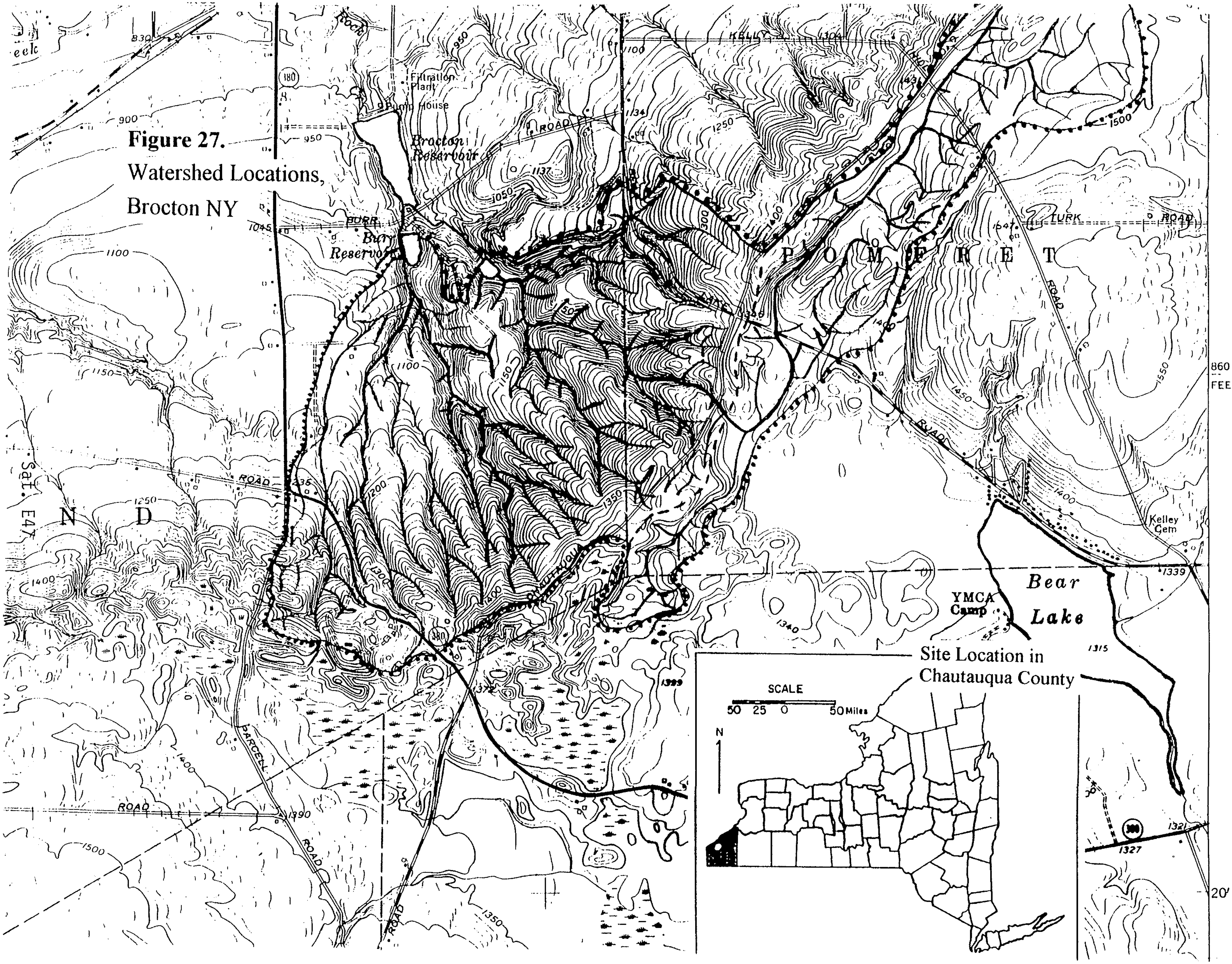


Figure 27.
Watershed Locations, Brocton NY

dams, and placing gabions along both sides of approximately 200 ft of creek bed. Secondly, both sides (a total of 200 ft) of Chautauqua Road at the culvert were to be stabilized with gabions and rip-rap. Finally, an access road was to be built leading to the Risley Reservoir which would be dredged and used again as a water supply.

However, partly because of the findings reported herein, practicality and costs of the above three-phase plan were reconsidered. Landslide and channel stabilization is being given further thought and not being implemented immediately. A massive Chautauqua Road culvert stabilization was completed. And, Risley Reservoir will be dredged and is being referred to as a "sedimentation basin". With good access, this sedimentation basin can be maintained yearly by the Village, removing creek bed-load material that would otherwise settle in the Brocton Reservoir.

Participants

The Geomorphology class (GS 330) from SUNY-Fredonia consisted of 26 students from sophomore to senior level. These students conducted much of the work reported herein. Wilson and Boria organized the investigation. Brian Mentley and Marty Terrell were Teaching Assistants. Much of the field data collection was accomplished by dividing the class into 4 teams of about 6 students each. Wilson, Boria, Mentley and Terrell each worked with one team in a different portion of the watershed. Also, lab and computational work was routinely divided among teams and re-checked by teams. Student reports ranged from about 50 to 150 pages.

Boria was liaison to the Village and made arrangements for test drilling, records review, historic information on treatment plant operation, and finance for items such as water sample analysis.

Sub contractors on the project were Earth Dimensions, Inc. (Buffalo, NY) and Microbac Labs (Erie, PA). Earth Dimensions provided drilling and soil sampling services. Microbac analyzed water samples for total suspended solids (TSS). Additionally, Wanda Gustafson of Chautauqua County Emergency Management supplied sandbags used by us to temporarily dam very small streams when we were measuring flow and sampling.

Summary of Methods

We investigated the history of the site concerning reservoirs construction, operations and maintenance. Muller's Pleistocene geology map of Chautauqua County (1963) was reviewed. Likewise, we converted the USDA Soil Survey maps to parent materials maps (i.e., surficial geology maps) throughout and adjacent to the drainage basins. A generalized cross-section of bedrock and sediment was constructed from the Lake Erie plain through the reservoir area and into the Allegheny Plateau near Bear Lake. The 7.5 minute Brocton quad topographic map was enlarged and copies highlighted for: drainage patterns, gully patterns, flat-topped inter-fluves, morphologic features (such as eskers or moraines), watershed boundaries, etc. We computed morphometric properties such as stream orders, drainage densities, stream lengths, watershed areas, stream profiles, relief and relief ratios. We began outdoor work by driving and walking through the watershed with the above materials at hand.

We took field notes of watershed and reservoir conditions including description of exposed sediment and rock materials, general locations of landslides, and appearance of eroded areas and other landscape features. This fieldwork and all succeeding fieldwork was supplemented and documented with photography.

Test borings were completed at four locations in the vicinity of the landslide area near Chautauqua Road. These four borings were sited above the landslides and drilled to below the ravine bottom so that cross-sections could be drawn through the slides, hills, valleys, and surface and subsurface materials. The cross-sections could be drawn utilizing drilling observations, standard penetration test results, water levels, topography, notes and photographs of surface conditions, and soil parent materials maps. To improve the drawings, the continuous split spoon samples were taken to the College at Fredonia and sub-sampled. The sub-samples were sorted for observation in custom-cut wood trays placed side by side relative to sampled elevations. Elevations of tops of borings and points along the nearby streambed were surveyed by transit. These data and drawings allowed for documentation and interpretation of subsurface material types, aquifer geometries, and general pore pressure conditions.

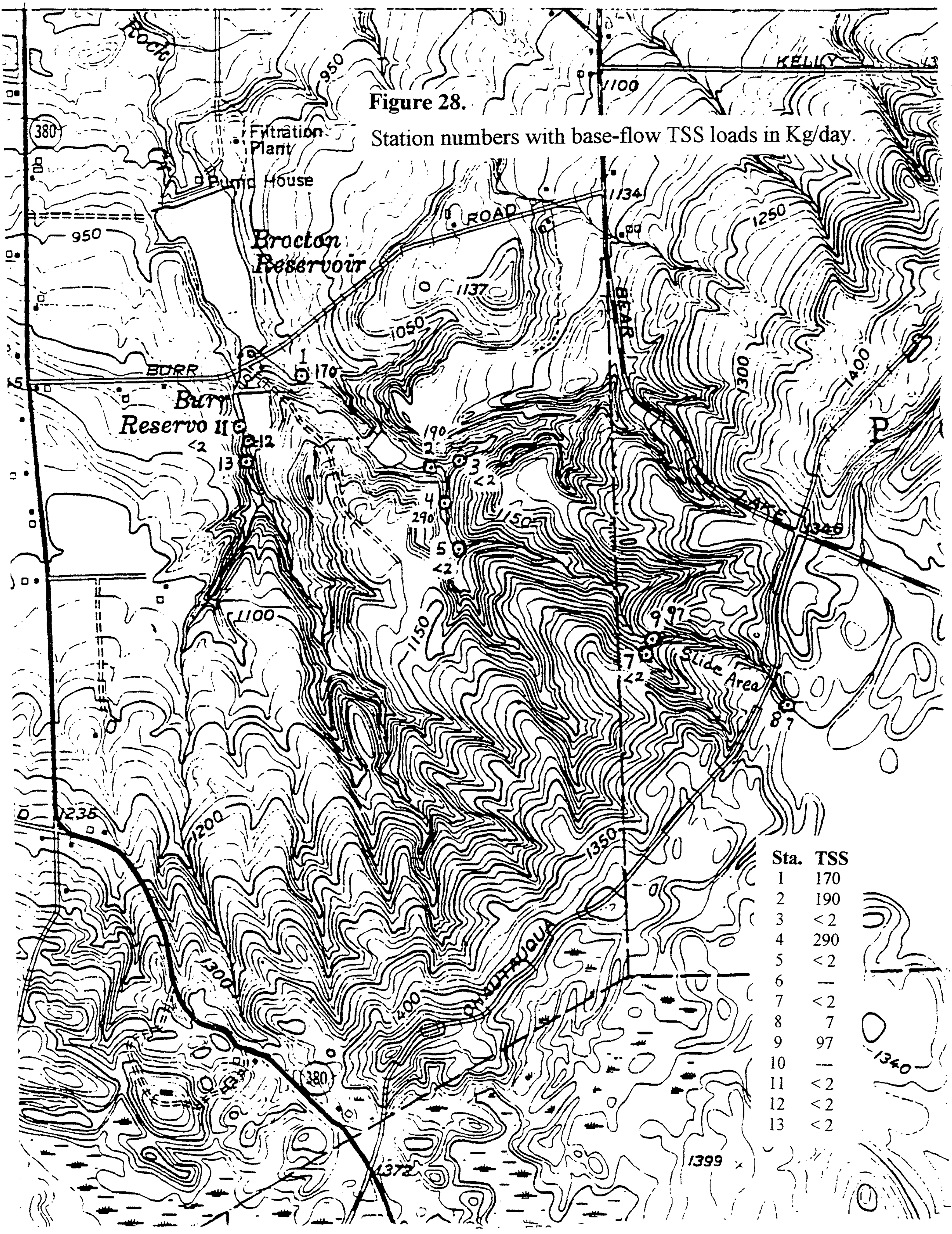
Below Chautauqua Road we sketched, photographed, sampled and measured the slide masses. Measurements were made with high quality tape measures and the clinometers on Brunton compasses (slope angles). Fluvial conditions including erosion scars, deposits, knick points (upstream migrating water falls), and vegetative debris jams were reviewed. Landslide failure planes were investigated and then scarps, fractures and exposed-toe slip-planes noted. For the largest landslide we calculated the approximate maximum average-soil shear-strength by solving the Factor-of-Safety equation for the Ordinary Method of Slices for shear strength when the slip circle is known and the soil weight is estimated.

Erosion and sediment transport were investigated in moderate detail at about a dozen locations (Figure 28). With tape measures, wading rods, and flow meters, we measured stream cross-sections and subsection velocities and discharges. At several locations, water depth or velocity were too low to measure accurately with a flow meter. At these locations, the stream was sandbagged to create a temporary weir and discharge was measured by stop watch and bucket. Water samples were taken from high velocity subsections at each location. Chain of custody records were kept and Microbac, Inc. analyzed the samples for Total Suspended Solids (TSS). A blind duplicate sample was included; it yielded good reproducibility of results. The TSS concentrations were multiplied by stream discharge to obtain sediment loading. These results were a measure of baseflow sediment transport above and below the landslides, into each reservoir, and from several tributaries.

Additionally, high flow conditions were estimated by collecting TSS samples during high flows of Spring 1998 (all other measures described above were from Fall 1997). These TSS values were multiplied by bank-full discharge estimates in order to approximate flood sediment transport (Table 3). The bank-full discharges were estimated using the Manning equation to estimate velocity. Variables in the Manning equation were measured by tape measure and rod (slope, hydraulic radius from cross-section). Manning's *n* was determined from channel

Figure 28.

Station numbers with base-flow TSS loads in Kg/day.



Sta.	TSS
1	170
2	190
3	< 2
4	290
5	< 2
6	—
7	< 2
8	7
9	97
10	—
11	< 2
12	< 2
13	< 2

comparison to US Geological Survey Water Supply Paper No. 1849 (Barnes, 1967). Bank-full water levels were estimated from bank shape and high water marks.

Results

This section of the report presents a summary of the main results. Details of results and methods were given to the Mayor of Brocton in an Appendix of approximately 150 pages. Most of the appendix was a copy of one of several outstanding student participant reports. This report by Cynthia Pettit included all of the project generated data (mostly group generated).

Figure 29 gives the change in reservoir volumes through time. The sedimentation rates (reservoir capacity losses) are: Burr 2,900 ft^3/yr, Risley 27,100 ft^3/yr, and Brocton 40,800 ft^3/yr. These data suggest that the rate for sedimentation in Risley Reservoir was fairly consistent throughout its existence. Either or both of two factors may account for the low sedimentation rate in Burr Reservoir: (1) lower sediment transport rate along West Branch Slippery Rock Creek; or (2) operation of Burr Reservoir in a way that allows sediment to bypass the reservoir.

Baseflow TSS loading measurements (Figure 28) into Burr Reservoir and in the bypass channel around the reservoir were less than 2 kg/da on 11/6/97, while Risley Reservoir received between 190 and 290 kg/da and Brocton Reservoir received 170 kg/da. Thus, the baseflow sediment loads to Brocton Reservoir were diminished by Risley Reservoir. Baseflow particle sizes were clay-silt dominated as indicated by qualitative settling observations in our labs. These East Branch loads were about 100 times the West Branch baseflow loads.

Numerous casual observations of stream colors and clarity agree. East Branch is commonly grayish. Also, pH measurements collected in 1938 were 7.5-7.8 in Risley and 7.0-7.2 in Burr. High clay concentrations in Risley would cause these pH differences.

Another set of TSS samples was collected at 3 locations on 4/21/98 during high flow storm water conditions. Table 3 gives the TSS concentrations at locations (Figure 28): #13 (above Burr), #8 (Chautauqua Rd.), and #2 (below the landslides and above Risley Reservoir). The discharges are those estimated by use of the Manning equation for bank full conditions. Consequent hypothetical bank full storm water loads for West Branch are 9,000 kg/da (200 ft^3/da); 22,000 kg/da for East Branch at Chautauqua Rd.; and 226,000 kg/da (5,000 ft^3/da) into (or through) Risley. Thus, it appears that the disparity in sediment load between East Branch and West Branch is about 2 orders of magnitude for **either** baseflow **or** storm conditions. Therefore, the operation of Burr reservoir with a bypass channel may aid water clarity in Burr Reservoir, but does not account for disparity of sediment transport between East and West Branches of Slippery Rock Creek.

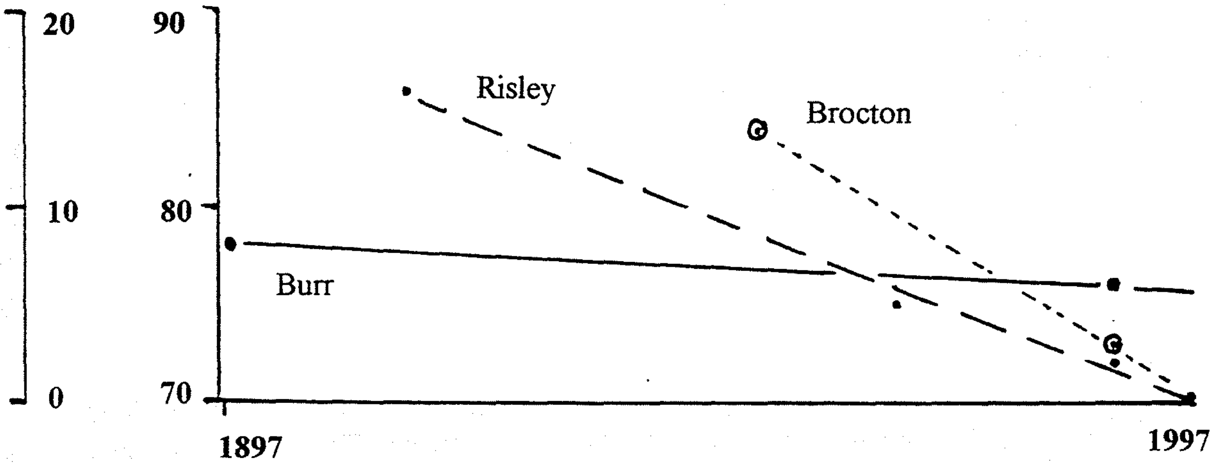
East and West Branches of Slippery Rock Creek carry very different sediment loads. Why? What is similar and what is different about the two systems? There are several similarities. Both became fourth order streams a short distance before entering Burr or Risley reservoirs and have drainage densities about 9 mi/mi^2. Both have dendritic patterns below Chautauqua Road. Each has a similar trunk stream profile below Chautauqua Road, which is concave-up with

Table 3. **Storm Water TSS**

Location #	Site	TSS (mg/L)	Discharge (L/s)	Load (kg/da)
13	Burr	20	5.000	9.000
8	Chaut. Rd.	52	5,000	22.000
2	Risley	262	10,000	226.000

Figure 29. Reservoirs Capacities Through Time.

Millions of gallons



possible knickpoints (water falls). Below Chautauqua Road, they have similar shaped watersheds, share a common drainage divide, and have the same climate and similar vegetation.

But there are also striking differences between the two watersheds. The East Branch (Risley) has a large additional watershed above Chautauqua Road (Figure 27). The portion of the East Branch sediment load from above Chautauqua Road is by itself greater than the West Branch load. The stream profile for East Branch (Figure 30) indicates extreme disequilibrium because the profile is not fully smooth or concave-up. The East Branch is composed of two separate drainage systems. The system above Chautauqua Road is separate, developed parallel to the glacial end moraines, and could have once flowed into Bear Lake (Figure 27). This upper drainage system literally falls into the head of the main gully of East Branch at Chautauqua Road. Considering our measured erosion rates and the scale, we expect one to several thousand years of intense erosion in the Chautauqua Road area.

Steep side slopes of gullies are apparent in Figures 27 and 28. The east portion of the West Branch watershed is highly gullied, and the whole of East Branch watershed is highly gullied. These areas coincide with surficial mapping of extensive sands, silts and clays, while surrounding areas are dominantly glacial till and minor amounts of exposed bedrock. Thus, the extensive gullying in East Branch is in response to easily eroded sediments.

On the main East Branch channel just below Chautauqua Road (Figure 28, between stations 8 and 9) is an area of extensive landslides. In addition to landslides, we observed several instances of erosive seepage (sapping creating a new tributary gully head and several locations of piping in the main stream bank wall). As already noted, the landslide area is responsible for about half of the baseflow sediment load and also is an important contributor during storms. However, the landslides themselves are not the sole contributor. Without the landslides, this reach would still be an important contributor of sediment due to gully head advance aggravated by the water and sediment contribution from drainage above Chautauqua Road, and due to sapping and piping (erosive ground-water seepage).

The hillside materials in the landslide area are composed of glacial till, gravel, sand, silt and clay deposited originally by streams flowing on, in or under glacial ice. These deposits generally coarsen northward, toward the former ice position. As the ice melted away, the deposits partly collapsed. Consequently, the geometry of the depositional layers is complex: water level observations in the test borings indicate one instance of ground-water confinement. Occasional aquifer confinement could result from obstructions of coarse layers caused when the glacier melted or from movements of modern landslide blocks.

Landslide blocks are of two types at this location: (1) fairly large (10's meters across), up to two or three slices, rotational failures with well defined slip circles, top scarps, back rotated vegetation, slide faults and scarps, and toe slip planes exposed in banks of the streambed (with no apparent uplift of the opposite bank); and (b) small (meters across), vegetated, translation failures, where the failure surface is the base of the root zone (a meter or less thick). In both cases, recent failure surfaces are very smooth. Sediments along the recent surfaces are very wet. Sediment along the recent translation slip surfaces appears liquid-like. Using the Ordinary Method of slices

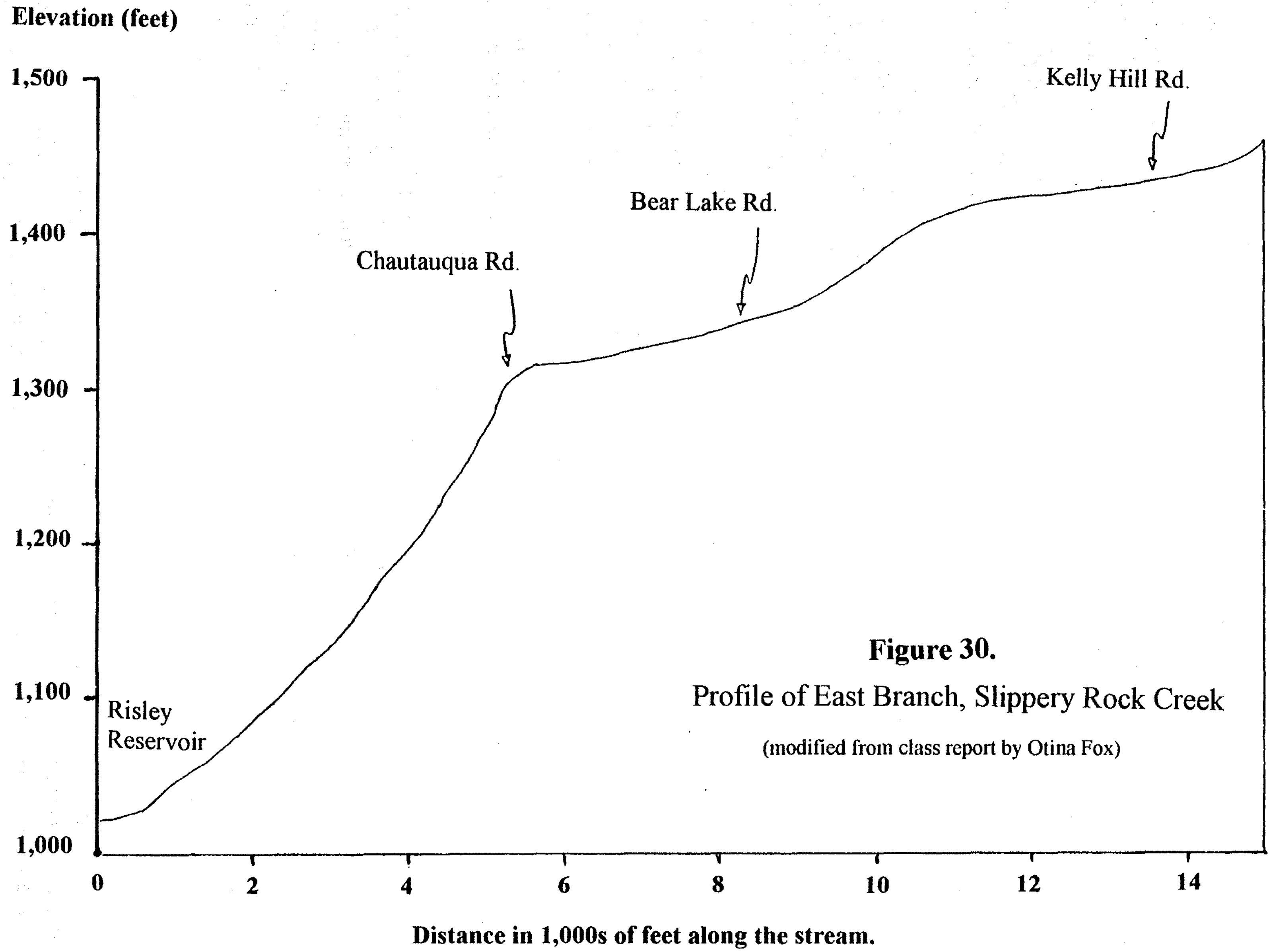


Figure 30.

Profile of East Branch, Slippery Rock Creek

(modified from class report by Otina Fox) approach for rotational landslides, and estimating a soil density of slightly less than 2 g/cc and measuring the approximate top and toe of the exposed slip circle, we calculated the consequent average maximum shear strength of the hillside soils as 5 lb/in^2. (i.e., 700 lb/ft^2) for the time of failure.

There is a very dynamic balance here between the stream and its hillslope process. As fast as the stream down cuts, the landslides will occur due to low strength and steep slopes. However, the stream can only downcut to the extent that it is not overfilled with landslide debris. These processes are aggravated and complicated by sapping and piping and the large water flow off the watershed area south of Chautauqua Road.

The sub-grade fill of Chautauqua Road played no apparent role in any of the stream or slope processes except that floods built up behind the embankment and washed away the road and its fill approximately once per decade. We estimated that the road embankment routinely lost about 6,000 ft^3 per year to the stream and lost its full volume (37,500 ft^3) once per decade. This combined to give an average roadway sediment yield of about 10,000 ft^3/year. This is approximately 15% of the annual combined loss of volume of Risley and Brocton Reservoirs. The road embankment erosion is therefore an important source of reservoir loss, although not the primary cause.

Conclusions

The Brocton and Risley Reservoirs suffer from excessive turbidity and sediment infilling (loss of capacity). About 15% of the volumetric (capacity) loss was due to repeated erosion of the Chautauqua Road embankments. Most of the problem, however, is due to natural erosion at the head of the gully below Chautauqua Road. This area is subject to erosive ground-water seepage and landslides and excess stream flow from above Chautauqua Road that falls into the top of the gully.

Reservoir capacity can be re-established by dredging and the costs figured into long-term maintenance. **Turbidity, however, is a dilemma**. Unless the stream flow above Chautauqua Road is diverted to Bear Lake (likely politically difficult but inexpensive), turbidity will continue. Even if flow is diverted, erosive seepage in the gully head may yield turbidity. Attempts to stabilize landslides in the gully head will be hampered by low strength soils, erosive seepage, and stream down cutting. Stabilization may last only 1 to 5 years.

If the watershed is maintained for drinking water, future activities should include improved timber management practices, especially reduction of logging road erosion. Only one dairy farm (potential source of cryptosporidium) is present.

TURBIDITY REMEDIATION AT SOURCE AREA AND TREATMENT PLANT, WESTFIELD, NY

Water Use

The Village of Westfield water supply (Figure 31) serves about 4,000 people, a number of commercial businesses, three fruit processing plants, the Westfield Central School and the Westfield Memorial Hospital. The village is situated along the Lake Erie plain on and between glacial Lake Warren and Lake Whittlesey beach ridge deposits. Micro-climates created by the proximity of Lake Erie, along with the presence of the sand and gravel beach ridge deposits, make this part of the Lake Erie plain an excellent grape growing location. Drinking water for the village is obtained from the Chautauqua Creek watershed, tributary to Lake Erie. Average daily production at the water treatment plant ranges from 0.5 to 0.8 MGD but, in the fall during grape packing season, production increases to approximately 1.3 MGD.

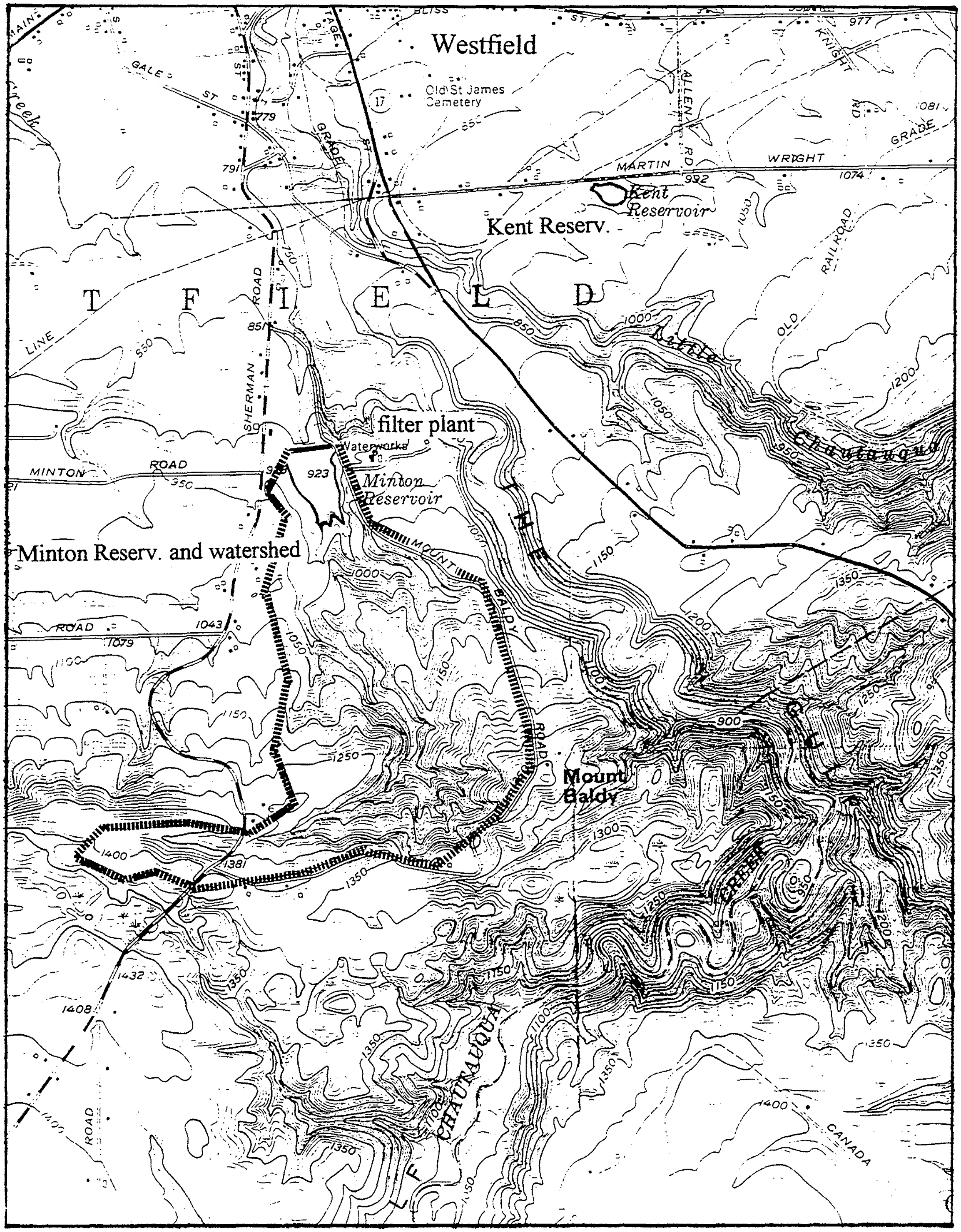
Water Supply History

The first public water supply and distribution system to serve the Village of Westfield was constructed in the early 1890s. The original system conveyed water from Chautauqua Creek to the village through a gravity pipeline whose intake was located several miles upstream from the present-day water treatment plant. Much of the pipeline was laid along the creek bank and was subject to breaks caused by stream erosion, making it a high maintenance system. Water flowed from the source, into a sedimentation basin, and then through the village distribution system. The old 7 MG Kent Reservoir stored water for emergency use. The drinking water received no disinfection until 1915, when a water-borne typhoid fever outbreak occurred in the village creating a serious need for chlorination.

This system was unable to meet the Village's water needs so, in 1939, the Minton Reservoir was built on a tributary to Chautauqua Creek (Figure 31). While a complete and detailed history of the Westfield water supply is not available at this time, information suggests that an original reservoir capacity of 45 MG was augmented in 1962 to 50 MG by raising the spillway, and in 1992 to 55 MG by partial dredging (Wayne Cardy, 1999, personal communication). The watershed area of this reservoir is only 0.7 square miles; Minton Reservoir was designed to provide only a portion of demand. Since before Minton Reservoir was built, a low-flow diversion dam in Chautauqua Creek was fitted with a pump and used to supplement the supply. Up until 1977, all of the above mentioned sources were used by the Village. The method of operation in recent decades was to rely primarily on Chautauqua Creek, especially when creek turbidity was below 20 NTU and when creek discharge was above a permitted base flow.

In 1951, a conventional 2.0 MGD filtration plant was constructed which used ferric sulfate coagulation with lime softening, sedimentation and rapid sand filtration using anthracite as the filter media. These down-flow filter beds consisted of a layer of anthracite coal on top of a porous Carborundum plate, which kept the coal in place. Backwash water, used to clean the filters, was discharged to the creek. After filtration, the water was disinfected with chlorine gas and fluoridated prior to distribution.

Figure 31. Westfield Water Works



Increasingly stricter drinking water turbidity standards have occurred (prior to 1962 10.0 NTU; 1962 to 1976 5.0 NTU; 1977 to 1988 1.0 NTU; and from 1988 onward the current standard of 0.5 NTU 95% of the time). These increasingly stringent standards along with sporadic high turbidity in the raw water caused the village drinking water to be frequently out of compliance with the turbidity regulation.

We estimated from CCDOH records that by the mid-1980s the Minton Reservoir had lost about 15% of its original capacity to sedimentation. Thus, capacity loss was a problem, in addition to high raw water turbidities in both Chautauqua Creek and Minton Reservoir. Two approaches were taken to address these issues. The first was improved watershed management; the second was construction of a new filtration plant.

Reducing Turbidity Sources

Several approaches to improved watershed management were taken. Activities within the Minton Reservoir and Chautauqua Creek watersheds that contributed to the problem (i.e., logging, oil and gas exploration, etc.) are now carefully managed, especially on the extensive areas of land in the source watersheds owned by the Village. The Village has upgraded its Watershed Rules and Regulations, Part 105 of the New York State Health Law, to address changes in land uses and modern issues unforeseen when the original regulations were enacted in the early 1900s. These regulations give the Village legal authority to address violations discovered during watershed inspections. Causes (i.e. landslides and stream down-cutting) in the creek feeding the Minton Reservoir were also treated with direct structural responses (channelization with check dams).

In 1993, the Village initiated a stream bank stabilization project in the main tributary to Minton Reservoir. With assistance from the Chautauqua County Soil and Water Conservation District, the USDA-NRCS and FORECON, Inc. (the Village's forestry consultant), plans were developed to reduce stream bank erosion and control stream down-cutting.

Active landslides and extensive gullying along the Minton Reservoir tributary compounded erosion and sediment transport problems. These areas coincided with surficial mapping of sands, silts and clays, while surrounding areas are dominantly glacial till. The Minton tributary is quite different from much of Chautauqua Creek, whose banks and bed are primarily Devonian shale and siltstone. The hillside materials in the landslide area were a complex mix of glacial till, gravel, sand, silt and clay deposited originally from streams flowing on, in or under glacial ice. Landslides here were triggered mainly by stream down-cutting. Fresh slides transported easily eroded sediment to the active creek channel, where it was subsequently transported down stream.

Access to the stream was the first problem to overcome. A 500 ft access road was constructed from Mount Baldy Road to the stream at a cost of approximately $10,000. Stream bank stabilization consisted of placing gabion baskets longitudinally along both sides of the stream at problem areas. Care was taken to anchor starting and ending gabions securely into the stream bank so water could not flow between gabions and the bank. In addition, the first tier of gabions was buried at least one foot below the existing stream bed and geotextile placed under and behind all gabions. Several check dams or sills were constructed across the stream channel to control stream down-cutting and decrease stream velocity. These too were securely anchored into both banks and geotextile used as above. Splash pads made of gabion baskets were placed on the down stream side of each check dam to prevent bed erosion (Figure 32).

Each gabion basket was placed in position then filled with local rock by hand. Close inspection reveals very tight packing of rock and nice straight sides on exposed gabion faces. This is critical to achieving the desired stability and long lasting results.

With the aide of a backhoe and operator, a prison crew from the Lakeshore Correctional Facility in Brocton spent approximately 10 months on the project. Prison inmates worked 25 to 30 hours each week placing each gabion basket by hand, then packing them tightly with rock in layers. Correctly installing gabion baskets is very labor intensive. Key to a quality job was having a conscientious prison guard, who was trained for this specific project. The project was successful and within budget because of the opportunity to have the same guard throughout the entire project. The project cost approximately $15,000 to complete, plus labor.

Improved Turbidity Filtration

In 1995 major upgrades and additions were made to the water filtration plant and the Minton Reservoir intake. Three modular Microfloc Trident package treatment units each containing an upflow clarifer and multi-media filter were installed next to the existing treatment plant building, inside a new steel building. The plant, rated at 3 MGD, is capable of fully automatic operation. One of the three clarifer-filter units is rested while the other two are being used. As raw water enters the plant, ferric chloride is added as a coagulant in a mixing chamber followed by the addition of activated carbon in a second mixing chamber. Pre-treated water then flows through an upflow absorbent clarifier containing buoyant plastic media, then down through a multi-media filter containing anthracite coal and several layers of various sized graded gravel. Chlorine gas is added for disinfection after the filters, followed by fluoridation in the clearwell. Finished water is stored in an underground storage tank adjacent to the water plant.

Conclusions

Reduction of stream erosion, improved watershed management and major upgrades to the Westfield Water Treatment Plant have dramatically reduced raw and finished water turbidity. Prior to 1995, finished water turbidities often violated the NYS Health Department MCL. This situation increased the risk of exposing water customers to microbiological contaminants, requiring the Village to initiate intense public notification of the violations to its water customers as required under New York State law.

Since watershed and filter plant improvements have been made, the Village has been in complete compliance with turbidity standards. Finished water turbidity is now consistently below 0.1 NTU, which may soon be the new MCL for turbidity nationwide. The old plant finished-water ranged from 1.0 to 4.0 NTU while the new plant values range from 0.03 to 0.08 NTU.

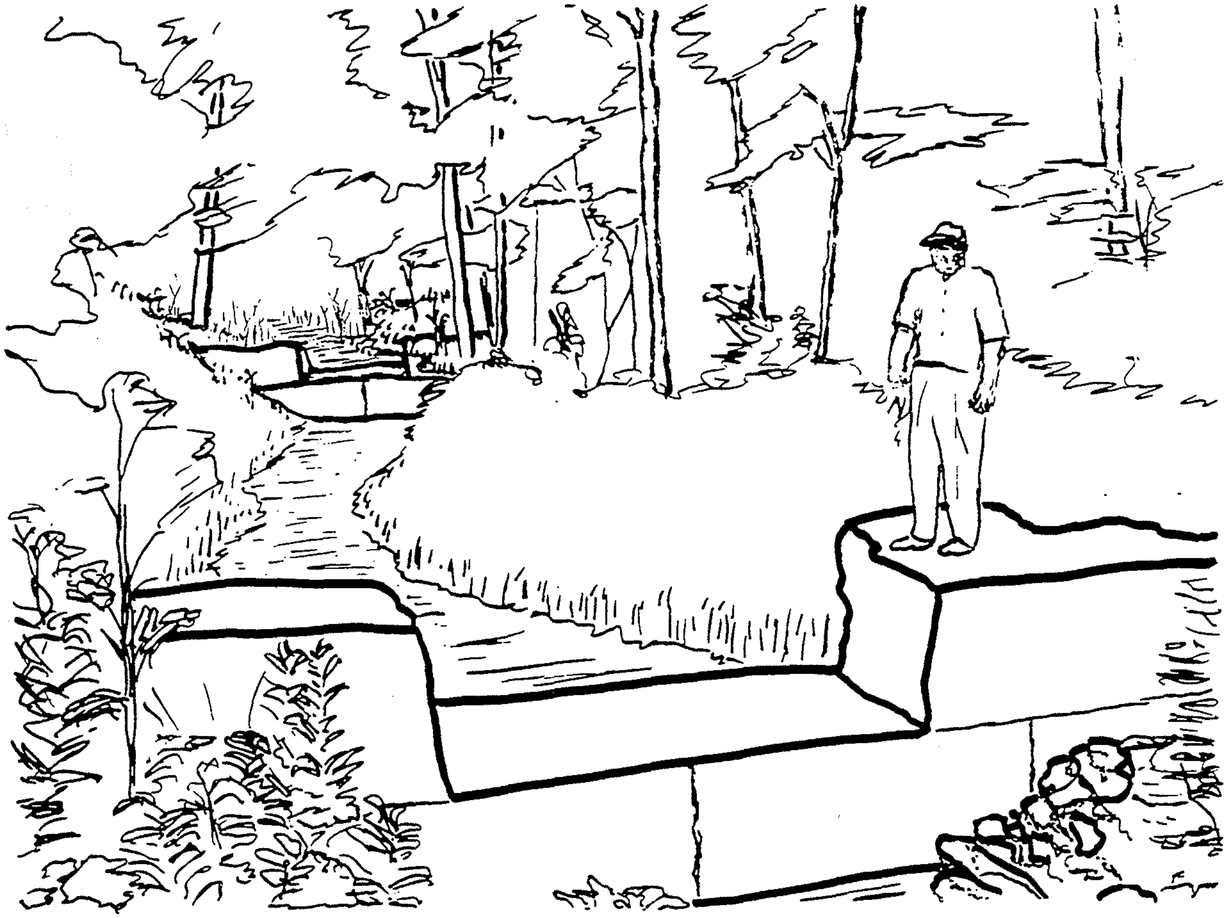
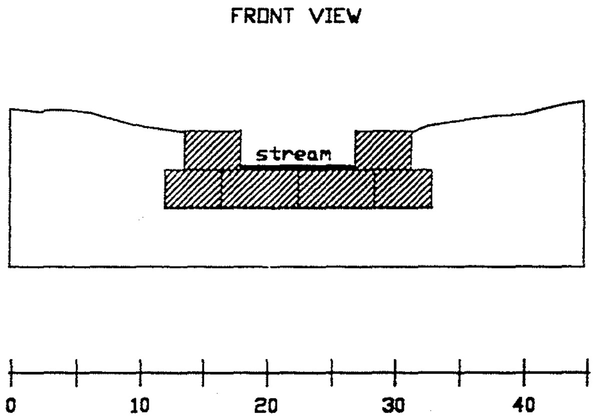
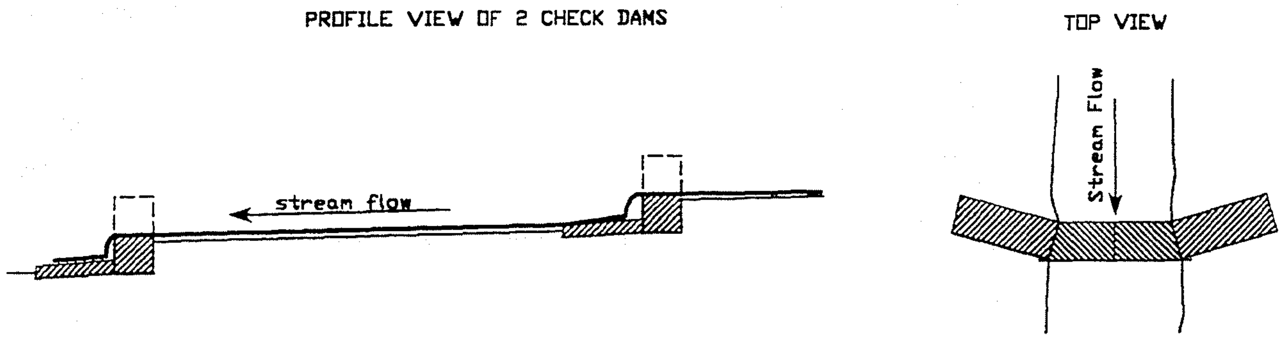


Figure 32.
Gabion-basket
Check Dams





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Illustrations for our guidebook article were modified from:

CCDOH, 1998, Village of Forestville Non-Point Source Pollution Abatement Program, 47p.

CCDOH, 1996, Chautauqua County Wellhead Protection Program, Phase II: Delineation of Wellhead Protection Areas, 158p.

CCDOH and SUNY-Fredonia, 1998, Investigation of Drinking Water Turbidity and Reservoir Sedimentation, Brocton, NY, 171p.

ACKNOWLEDGEMENTS

In addition to participants already described in the article and the references cited above, we wish to thank several other contributors. Water supply operators provided invaluable support. Wayne Cardy (Westfield Water Works) helped reconstruct the history of the Westfield water supply and operating methods of their filter plants. He generously agreed to provide a tour of their new "package" filter plant. Harold Richter collected water quality data on a daily basis for nearly three years (1991 and 1995-97), for the Forestville springs and wells. Richard Smith collected similar data at the Sinclairville wellfield for one year (1991).

David Wilson (District Conservationist, County Soil and Water Conservation District) and Lawrence Brown (USDA Natural Resources Conservation Service) provided erosion control planning for Hall Spring (Forestville), Chautauqua Road stabilization (Brocton), and the Minton Reservoir inlet-stream gabions. Brian Bullard of FORECON, Inc. reviewed with us the history of renovations to the Minton Reservoir inlet stream (FORECON is a forestry management company that consults on the watersheds owned by the Village of Westfield). Steven Johnson (CCDOH Public Health Engineer) reviewed the designs for the Hall Spring renovation and Robert Brown (independent consulting engineer) prepared specifications and bid packages for the Hall Spring renovation.

Road Log

Quaternary Geology and Water Supply Issues

Total miles	Miles from Last Point	Route Description
0.0	0.0	Leave the SUNY Fredonia campus at the Temple Street exit. Turn Left (south) onto Temple Street
0.7	0.7	Turn Left (north east) onto State Route 20. The village of Fredonia lies mostly on Glacial Lake Warren shoreline and Canadaway Creek delta and terrace sand and gravel.
4.2	3.5	Turn Right (east) onto State Route 39.
		Cross Glacial Lake Whittlesey shoreline. We will drive slowly in this area, **possibly stopping but not exiting vehicles,** in order to regroup vehicles. At mile 5.1 see "beach ridge" through the front and right vehicle windows approx. 1500 feet away. Cross the "beach ridge" at 5.4 miles. At 7.5 miles, view left is Lake Erie and the Canadian shoreline (40 to 50 miles weather permitting).
9.1	4.9	Turn Right (south) onto Water Street (County Rt. 85), as you enter the Village of Forestville.
12.9	3.8	Turn Left (south east) onto Henry Road.
12.9	0.0	Turn Immediate Right onto Shaw Road.
13.9	1.0	**STOP 1.** Hall Springs, Village of Forestville. Park on side of Shaw Road. We will walk eastward on the gravel entry road for about 100 meters. After returning to vehicles from Stop 1, continue southeast on Shaw Road.
14.1	0.2	Turn Right (south) on Putnam Road.
14.3	0.2	**STOP 2.** Brief look at Hall Spring source water area. Park on side of Putnam Road.
14.3	0.0	Continue south on Putnam Road. A water well drilled near the intersection of Putnam Rd. and Route 83 penetrated 324 feet of sediments without encountering bedrock. Depth to

		bedrock near this road intersection was estimated at 450 ft using a high-precision gravity survey.
15.1	0.8	Turn Right (west) onto State Rt. 83.
15.6	0.5	Turn Left (south) onto County Rt. 85.
18.0	2.4	Turn Right (west) onto County Rt. 72.
19.3	1.3	Turn Left (south) onto County Rt. 77.
26.7	7.4	Continue...Leave County Rt. 77 by continuing straight ahead onto County Rt. 66. Enter Village of Sinclairville driving southwest on County Rt. 66 and leave the Village by continuing driving southwest on County Rt. 66.
27.9	1.2	Continue driving on County Rt. 66 under State Rt. 60.
28.0	0.1	Turn Left (east) onto Bloomer Street.
28.1	0.1	Turn Right (south) into water supply property. Park left (north) of the first well-house, on the lawn.
28.1	0.0	**STOP 3**. Village of Sinclairville wellfield.
28.2	0.1	Turn Left onto Bloomer Street, when leaving the Sinclairville wellfield.
28.2	0.0	Turn Right onto County Rt. 66, heading in the reverse direction (northeast), approximately 0.1 mile.
28.3	0.1	Turn Right (east) onto the access road for State Rt. 60.
28.4	0.1	Turn Left (north) onto State Rt. 60.
35.6	7.2	Turn Left (west) onto County Rt. 58 at the Cassadaga Village stop light. Due to the sometimes heavier traffic on Rt. 60, the vehicle group may become disaggregated between Sinclairville and Cassadaga. Consequently, we will drive slowly through the Cassadaga Village portion of County Rt. 58, possibly stopping but not exiting vehicles, near or at the:
36.4	0.8	Cassadaga Water Works (wells) and maintenance buildings. Cassadaga Lakes are on the right (north) side of the road. The lakes are kettle lakes between the Lake Escarpment Moraines to the north and the Lavery Moraine

		to the south. Rt. 58 that we are traveling is on outwash between the moraines. If the Lavery Moraine dates at 16,000 BP and the Lake Escarpment dates at 14,000 BP, were the kettles formed from Lavery ice buried by Lake Escarpment outwash?
38.8	2.4	Continue westward on County Rt. 58 through Village of Stockton stop light.
39.0	0.2	Turn Right (north) onto Mill Street.
39.1	0.1	Turn Left (west) onto Dean Road. Dean Road passes through a small Amish community. A large Amish community is found about 30 miles to the east in the Conewango Valley.
44.4	5.3	Turn Right (north) onto Thayer Road.
45.6	1.2	**STOP 4.** Turn Right (east) into Luensman Overview Park. Lunch and rest stop at the park. The park is located on the Mississippi River-Great Lakes drainage divide. A brochure is available in the pavilion. There is a short nature trail. Weather permitting, features of the Canadian shoreline 40 miles and more distant may be observed. A faint pale yellow or tan haze is often in the lower atmosphere. This haze is the drifting air pollution from the mid-western U.S. In spite of our somewhat pristine surroundings, the nearby National Atmospheric Deposition Program station sometimes registers the highest acidity and deposition. The acid portion of deposition is buffered by the calcareous glacial till.
45.9	0.3	Turn Left (south) onto Thayer Road (backtrack), when leaving Luensman Park.
47.0	1.1	Turn Left (east) onto Dean Road (backtrack).
48.4	1.4	Turn Left (northeast) onto Frances Road. Note the kame and kettle topography of the Lake Escarpment Moraines.
50.1	1.7	Continue northeast on Chautauqua Road (road name changes from Frances to Chautauqua as road crosses County Rt. 380). Note kame and kettle topography. Chautauqua Road is often perched on one of the moraine ridge crests. For about 0.6 mile the moraine ridge under the road is the St. Lawrence – Mississippi watershed divide

50.9	0.8	Note the lack of gully erosion in the ravines to the left as we drive along Chautauqua Road.
51.4	0.5	**STOP 5.** In the Brocton Reservoirs drainage basin. Parking on roadside.
51.4	0.0	Continue northeast on Chautauqua Road.
51.7	0.3	Turn Left (north) onto Bear Lake Road.
52.5	0.8	Turn Left (west) onto Burr Road.
53.3	0.8	Drive slowly. The largest of the three reservoirs supplying the Village of Brocton (Brocton Reservoir) is north, on the right side of Burr Road. The sloped bank on the left (south side of the road) is the earthen dam of Burr Reservoir. A third small reservoir (Risley Reservoir) is out of view on the left (south).
53.3	0.0	Continue on Burr Road.
53.7	0.4	Turn Right (north) onto County Rt. 380.
55.7	2.0	Turn Left (west) onto State Rt. 20. Rt. 20, again, as at the beginning of the trip, follows mostly on top of the Glacial Lake Warren shoreline (gravelly sand).
55.9	0.2	Continue (west) through the Village of Brocton; then about 8 miles, through the Village of Westfield and over the long bridge over Chautauqua Creek on the immediate west side of the center of the Village of Westfield.
64.8	8.9	Turn Left (south) onto Chestnut Street.
66.0	1.2	Turn Left (east) onto Mt. Baldy Road.
66.4	0.4	Drive slowly past Minton Reservoir on left.
66.7	0.3	**STOP 6**. Renovated gully draining into Minton Reservoir. Park on roadside. We will enter the forest at the gated dirt road to the right. This road was cut to give access to the gully so gabions could be placed for erosion prevention.

		CAREFULLY: Please turn vehicles around and drive back into the Village of Westfield Water Works on right.
66.9	0.2	**STOP** 7. Westfield Water Works.
84.9	18.0	Return: drive back down the hill to Westfield, then right (east) onto Rt. 20 to Fredonia; at the intersection of Temple Street and Rt. 20 (at Barker Common), turn left onto Temple Street, then right onto campus.

Total Trip Approximately 84.9 Miles

GEOLOGY OF THE ZOAR VALLEY GORGE OF CATTARAUGUS CREEK CATTARAUGUS AND ERIE COUNTIES, NEW YORK

by

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NEW YORK STATE DEPARTMENT OF ENVIRONMENTAL CONSERVATION

Abstract

The Zoar Valley Gorge of Cattaraugus Creek cuts west for 7.5 miles through up to 400 feet of Late Devonian shales and siltstones of the Canadaway Formation, part of the Portage Facies of the Catskill Delta. The Laona Siltstone and Shumla Siltstone members of the Canadaway Formation, reported to pinch out west of the gorge, are projected to crop out in the stream bed and in the gorge wall, respectively, where two siltstone units occur. Surface expressions of the Alleghenian Bass Island Trend, reported to occur in the South Branch, a left-bank tributary gorge, are exposed in the main branch as joints and a pop-up fold trending NE. Other joint sets trend N, ENE and NW. The E, ENE and NE features exert significant influence on streambed orientation until cut by a strong NW fracture zone, which then controls streambed orientation. Five instances of continuous strong joint sets bending through 20°-50° of arc occur in the main branch or the South Branch, possible pre-NW tear fault indicators of complex stress distributions. Zoar Valley Gorge incises the bedrock beneath the trace of an ice marginal meltwater channel parallel and adjacent to the Valley Heads Moraine. Subsequent ice recession allowed Cattaraugus Creek to breach the moraine and occupy the pre-glacial Allegheny River Valley in Gowanda, New York. Surficial deposits and landforms provide clues to the sequence of events leading to gorge formation, but present more mysteries. Although flowing parallel to strike, Cattaraugus Creek is not a typical subsequent stream. The stream traverses at least three pre-glacial north-flowing obsequent stream valleys dammed by the Valley Heads Moraine. A curious erosional remnant at the Confluence of the main branch and the South Branch defies explanation. Cattaraugus Creek drops at an average gradient of 0.3% from the head of the gorge to the first rapid, 0.6% from the first rapid to the mouth of the gorge and 0.4% to the end of the rapids one mile downstream of the mouth. Practically all of the drops occur in 19 rapids. A strong correlation exists between rapids, siltstone beds, joints and cross channel cobble and boulder deposits called rock gardens. It is proposed that classic pool and riffle morphology occurs in the bedrock streambed, modified by more resistant siltstone beds and fracture zones. More study is required.

Introduction

"Paper? What paper? It's a raft trip..."

Thus began the collection of observations, ideas, theories, thoughts and random musings presented here on the geology of Zoar Valley Gorge along Cattaraugus Creek, east of Gowanda, New York (Figure 1). Mysteries lurk throughout the stratigraphy, structures, glacial history and geomorphology of the 7.5-mile long, up to 400-foot deep, bedrock gorge. More questions than answers have resulted from this investigation. Whether or not stream flow allows a raft trip or requires a hike, we will have an adventure. Several rapids in the gorge are referenced throughout the paper. Please refer to Figure 2 for their locations.

Stratigraphy (A Classic Floating Section or The Case of the Missing Laona)

Cattaraugus Creek cuts west through Late Devonian (Chautauquan) shales and siltstones of the Canadaway Formation. The Canadaway Formation is included in the Portage Facies of the Catskill Delta (Figures 3 and 4 from Geology of New York, a simplified account, Educational Leaflet No. 28, NYS Museum/Geological Survey 1991). The sediments were eroded from the Acadian Mountains to the east and were deposited along the mid-to-outer shelf, slope and basin edge of a westward deepening inland sea. A series of black shales extending eastward serves as marker beds for time correlations of rapid sea level rises.

Tesmer (1975) states: "The Canadaway Formation in Cattaraugus County contains gray to black shales, various zones of concretions and septaria, and many gray siltstone beds. Black shales are largely confined to the older Dunkirk, South Wales and Gowanda members." Tesmer (1955, pp. 9-10) also includes the Laona, Westfield, Shumla and Northeast Members in the Canadaway Formation. Van Duyne, et al. (1994) interpreted the Laona to be "mid-shelf tempestites deposited during a minor shallowing of the Devonian shale basin."

The original Gowanda type locality occurs along the right bank of Cattaraugus Creek just upstream of Grand Finale Rapid, Gowanda, New York (B4, C4; Gowanda 7½' quadrangle) (Chadwick, 1919, p.157) and Figure 1. Although Pepper and DeWitt (1951) relocates the standard reference section to Walnut Creek, Hanover Township, Chautauqua County, New York (Silver Creek and Forestville 7½' quadrangle), the original type locality fixes the section at the downstream end of Zoar Valley gorge at elevation 750± feet above sea level (asl).

From here, it gets murky.

According to Tesmer (1975), the Gowanda member is 270-280 feet thick. The Corell's Point Goniatite Bed, corresponding to the zone *Cheiloceras amblylobum*, occurring in a ledge of concretions up to 18 inches thick at the type locality (Kirchgasser 1974), is identified in the South Branch of Cattaraugus Creek at elevation 965 feet asl (D5: Gowanda 7½' quadrangle) (House

1967, p.1066 in Tesmer, 1975) and Figure 1, approximately 8000 feet south of the original Gowanda type locality.

Regionally, the bedrock dips less than 40 feet per mile (0.8%) to the south or south-southwest (Tesmer 1975). Therefore, the Corell's Point Goniatite Bed projects from the South Branch north to elevation 1025 feet asl at Grand Finale Rapid (Table 1). Unfortunately, bedrock is missing above elevation 880 feet asl at that location, so its location cannot be verified. If the projection is accurate, then the original Gowanda type locality represents the base of the unit and the Corell's Point bed represents the top, to maintain the reported 270-280 foot thickness.

However, a similar projection from the Corell's Point type locality, Corell's Point, Portland township, Chautauqua County (Brocton 7½' quadrangle) to the Laona Siltstone type locality, Canadaway Creek, Laona, Chautauqua County, New York (Dunkirk 7½' quadrangle) at elevation 800 feet asl places the Corell's Point bed about 190 feet below the Laona Member (Table 1).

Tesmer (9175) states: "At Corell's Point the *Cheiloceras* zone is found in the lower Gowanda but rises higher in the unit when traced eastward into Erie and Cattaraugus Counties." However, Tesmer (1963, p.18) earlier warns: "Some concretionary zones may be traced for distances of several miles, but cannot be used for long-distance correlations." Also, House (1966) identifies two separate Goniatite-bearing concretionary layers in the Gowanda Shale. The above projections support Tesmer's interpretation of a rising zone, but lead to the following questions:

1. How can one sedimentary bed climb through a section of flat-lying conformable sedimentary beds and remain the same bed?

2. Is the bed identified in the South Branch of Cattaraugus Creek the Corell's Point Goniatite Bed or simply a later replication of a similar environment as the Corell's Point environment?

3. Has structural displacement occurred?

Analysis of the Laona Siltstone's reported locations and character raises further questions. According to Tesmer (1975), the Laona "extends from Lake Erie shore in Chautauqua County eastward into western Cattaraugus County where it apparently pinches out near Gowanda."

Based on gas and oil well logs, Van Tyne, et. al. (1980) traces a northeast-trending structure from southwest Chautauqua County, New York through Zoar Valley Gorge and into Erie County, New York with approximately 150 feet of upward vertical displacement at the base of the Dunkirk Shale within the two-mile wide structure at Zoar Valley Gorge. Van Tyne (1999, personal communication) states that the Laona Siltstone is correlative with the base of the Bradford First Sand and that the Shumla Siltstone is correlative with the basal Glade Sandstone.

Finlayson and Ebert (1991) report that the Laona crops out in the South Branch of Cattaraugus Creek at elevation 980 feet asl, based on the occurrence of the Corell's Point

Goniatite bed at the lower falls. The basal contact of the Laona is disconformable on top of the Gowanda shale and "a displacement of 10's of meters of the units in the Canadaway Group is clearly visible on a (normal?) fault within the gorge of the South Branch." The strike of the fault is not reported.

Unpublished work by Mr. Ray Vaughn suggests that the Laona crops out south of the main gorge on the north side of Wickham Road, one mile west of North Otto Road, at the confluence of two ravines flowing toward the gorge at elevation 1330 feet asl.

Projection of the Laona at elevation 800 feet asl from the type locality a distance of 15 miles to the outcrops along Big Indian Creek at elevation 1015-1030 feet asl (Figure 1) supports Tesmer's observations of a very gentle southward dip. However, projection of the Laona from Big Indian Creek another 6.8 miles to Zoar Valley Gorge places the Laona at 835-850 feet asl, the elevations at several of the rapids in the streambed, about 150 feet below the Corell's Point Bed when projected from the South Branch (Table 1). All of the rapids at the intersections of the streambed and the projected Laona occur where the stream flows across jointed siltstone beds.

Could this be the Laona? If so, the bedrock upstream of Pinball Rapid would be the Westfield Shale and the goniatite bed in the South Branch could not be the Corell's Point Bed.

Field investigation by the writer (who strolled up the South Branch to beautiful 5-foot high and 25-foot high waterfalls) revealed at least two concretionary layers and sporadic thin siltstone beds separated by weak shales south of the confluence, below a pyritic siltstone-capped waterfall at elevation 900 feet asl and two siltstone-capped waterfalls at elevation 980 feet asl. About 45 feet above the upper falls, a 30-foot thick siltstone package crops out in the gorge wall at elevation 1025-1055 feet asl. An admittedly brief search produced no goniatites.

At least one strong 130°-145° trending joint set, a small reverse fault and two 20°-30° trending pop-up folds are exposed at stream level. One of the pop-ups may be the feature interpreted by Finlayson and Ebert (1991) as the normal (?) fault. Exceptionally low water revealed continuous beds on both limbs and across the fold axis in the streambed. No significant displacement of beds on the gorge walls was observed.

Projection of the siltstone beds capping the waterfalls and exposed in the gorge walls above the upper falls north a distance of 10,000 feet to the main gorge places the siltstone beds at elevation 1080-1155 feet asl, approximately 210-285 feet above Unnamed Rapid, close to the stratigraphically highest siltstone-capped rapid in the main branch of the Zoar Valley Gorge. Field measurement (Brunton compass) locates a siltstone package at elevation 1060-1150 above Unnamed Rapid, 190-280 feet above the siltstone forming the rapid (Table 1).

As an additional test, a siltstone bed at stream level at the first bend upstream of Forty Bridge on the South Branch occurs at elevation 920 feet asl. When projected 550 feet north to the Confluence, the bed should crop out at elevation 975 feet asl, about 130 feet above stream level. In fact, a siltstone bed does occur at that height above the Confluence, supporting the accuracy of the previous projection.

Projection of the Shumla Siltstone from the type locality at elevation 950 ft. asl on Canadaway Creek (Figure 1) north a distance of 13,000 feet to the Laona Siltstone type locality on the same creek places the Shumla at elevation 1080 feet asl, approximately 280 feet above the Laona Siltstone, found at elevation 800 feet asl. A similar projection of observed Shumla to observed Laona in Big Indian Creek produces approximately 210 feet of separation (Table 1). None of the projections reference known points (top, bottom, marker beds, etc.) within the identified members. Therefore, it is here proposed that 210-280 feet is a reasonable range of separation distances between the Laona and Shumla Siltstones.

Applying the KISS Principle, the projected 210-285 foot separation and measured 190-280 foot separation between the top of the rapids in the main branch and the siltstones of the South Branch suggest that the siltstone unit exposed at and above the upper waterfalls on the South Branch of Cattaraugus Creek may be the Shumla Siltstone, and the siltstone unit exposed along the main branch of Cattaraugus Creek between Pinball and Canoe Eater Rapids is the Laona Siltstone, if the concretionary bed exposed below the upper falls on the South Branch is a later replication of the Corell's Point Goniatite Bed depositional environment, and if the shallow shales absorbed the energy such that no significant structural displacement has occurred at the surface, and if the members of the Canadaway Formation remain relatively flat and consistently thick.

However, if the vertical displacement identified by Van Tyne, et. al. (1980) carries to the surface, then the pyritic siltstone capping the lower falls above Forty Bridge on the South Branch could be the Laona.

Lots of ifs.

Careful stratigraphic section descriptions and measurements, petrographic analyses and structural observations may solve the Mystery of the Missing Laona.

Structural Geology

Zoar Valley Gorge owes some of its sinuousity to cracks and crenulations associated with the Late Paleozoic Alleghenian Orogeny. As previously noted, Van Tyne, et. al. (1980) traces a northeast-trending structure through the gorge. The Bass Island Trend (BIT), a northeast-bearing fracture zone traces the leading edge of the detachment structure at the end of the Allegheny Plateau décollement in Chautauqua County, New York (Beinkafner, 1983), and has been identified in the South Branch of Cattaraugus County (Jacobi, et al., 1999).

At depth the BIT occurs as several sigmoidal thrust/reverse faults rising above the pinchout of a salt zone in the Vernon Formation through Silurian and Devonian sediments to apparently steepen and die out in the weak shales of the Hamilton Group (Beinkafner, 1983).

However, detailed studies of the South Branch of Cattaraugus Creek by Jacobi, et al. (1999) have discovered "clear evidence for faulting in Late Devonian deposits. Steeply-dipping bedding, thrusts with fault gouge and breccia, mesoscopic duplexes, asymmetric kink folds associated with thrusts, and "pop-ups", all striking NE, indicate that thrusts of the Bass Island Trend ramp up to the surface units.

A second set of faults, called here the South Branch Fault System (SBFS), strikes N-S. These high angle faults and monoclines localize hydrocarbon seeps. Stratigraphic offset is on the order of 1-3 m. At least 3 parallel N-S fault zones are evident in the valley and to the east. The faults are segmented by widely-spaced NW-striking fracture intensification zones. NW-striking pop-ups and high-angle faults, with small stratigraphic offset, also occur." Gravity, magnetic and landset data suggest Pre-Cambrian origins for the N and NW-striking features (Jacobi, et al., 1999).

Baudo and Jacobi (1999) note that the "length and height of the NW master fractures is an order of magnitude greater than the NE fractures" in the South Branch.

Beinkafner (1983) identifies a northwest-trending tear fault between adjacent blocks above the BIT thrust fault sole in Chautauqua County. "The significance of the tear fault is that it indicates that the regional arcuate pattern of the structural trends (strike of faults or fold axes) on the Allegheny Plateau is created by differential movement of blocks bounded by strikeslip faults."

Zhao and Jacobi (1997) propose fold-axis-parallel elongation associated with arcuate fold and thrust belts as a mechanism for propagation of syn-orogenic cross-fold joints in the Appalachian Plateau. Their study area in Allegany County, New York focussed on 3 systematic point sets trending 280°-305°, 312-310°, and 322-340°, respectively. Zoar Valley Gorge lies to the west and slightly north of their study area.

Review of several logs of gas wells drilled close to the gorge has revealed a thin salt zone at depth, supporting Beinkafner's model of BIT structures above a thin to absent salt-zone (Dahl, 1999, personal communication).

Field investigation by the writer (more strolls along the South Branch and the main branch of Cattaraugus Creek) have revealed five distinct fracture trends, N (350°-10°), NE (20°-40°), ENE (60°-70°), E (80°-110°) and NW (310°-330°) (Figure 5). Personal communication with R. Jacobi (1999) suggests the following sequence from oldest to youngest: NE/ENE, E, N and NW. NW, NE/ENE, N? and E? The fractures either control the streambed as parallel-flow chutes or cross the streambed as ledges in the rapids or simple fractures between rapids. Table 2 summarizes the orientations of joints in the rapids in the main branch. A NE pop-up fold occurs at the head of Curly, Larry and Moe Rapid. A N70E15SE thrust fault(?) with minimal displacement occurs at the first sharp bend, upstream of Pinball Rapid.

In the South Branch, an E joint forms a chute in the streambed approximately 2000 feet upstream of the Forty Bridge. ENE joints control the stream channel for 1000 feet above the confluence. Strong NE features control the stream bed as joints between the confluence and the Forty Bridge, and as a tight fold between the easternmost bend and the upper falls. A NE joint set occurs in the Main Branch on strike with the tight fold between the easternmost bend and the upper falls. A NE pop-up fold occurs downstream of the easternmost bend. N joints control the streambed immediately downstream and upstream of Forty Bridge, at the confluence, and downstream of the easternmost bend. NW joints cut the channel downstream of Forty Bridge and upstream of the easternmost bend, and control the streambed between the second and third bends above the Confluence and upstream of Forty Bridge to the big bends.

In summary, E, ENE and NE features exert significant influence on streambed orientation in the main branch until truncated by a strong NW fracture zone as Cattaraugus Creek leaves the gorge to occupy the ancestral Allegheny River Valley. In the South Branch downstream of the falls, NE and N features control the channel except where cut by a strong NW fracture zone.

In eight curious instances the streambed follows continuous strong joint sets as they bend though 20°-50° of arc. In the main channel, from the first sharp bend to Pinball Rapid, strong joint sets bend from 25° to 45°, 60° to 80° and 275° to 290°. Above Turtle Rock Rapid, the joint set and streambed bend from 40° to 70°. In the South Branch between Forty Bridge and the confluence, the joint sets and streambed bend from 355° to 15° back to 25°, then 0° to 330°, then 25° to 75° just above the confluence. The bending joints cut both shale and siltstone, but predominate in shale. In all five cases, the bending joints are cut by strong NW joints.

Here are some questions:

1. What types and sequence of stresses would cause both clockwise and counterclockwise rotation on continuous joints?
2. If the NW zone is a tear fracture associated with the Bass Island Trend, are the bending joints pre-tear indicators of complex stress distributions across a weakening zone in fissile shales and thin siltstones or curving perpendicular intersections, indicating that the NW fractures came first?

Glacial History

Zoar Valley Gorge incises the bedrock beneath the trace of an ice marginal meltwater channel parallel with, and adjacent to, the Valley Heads Moraine (VHM). Subsequent ice recession allowed the young Cattaraugus Creek to breach the moraine and occupy the pre-glacial Allegheny River Valley in Gowanda. Surficial deposits and landforms provide clues to the sequence of events leading to gorge formation, but present more mysteries.

Fairchild (1932) worked out a progressive sequence of Pleistocene meltwater channels across Cattaraugus County. Proglacial lakes occupied a series of north-flowing pre-glacial (Tertiary?) valleys dammed by the VHM. Progressively lower outlets were exposed as the ice receded, draining the lakes and cutting three gorges along Cattaraugus Creek. The presently studied gorge is the furthest downstream. The middle gorge occurs due north of East Otto. The upper gorge occurs south of Springville and can be viewed from U.S. Route 219 (Figure 1). All three gorges lay beneath meltwater channels cutting uplands between ice-or moraine-dammed north-flowing valleys (Fairchild, 1932).

A lake in the valley east of Zoar Valley Gorge and in the Skinner Hollow section of the South Branch drained through an outlet at Persia (el. 1320), until a mid-valley rise (moraine?) was exposed at elevation 1340 feet asl (Cuthbert, 1937). A further recession allowed the north half of the lake to join the Skinner Hollow section of the South Branch via a channel between the VHM and the bedrock upland, as indicated by the soils present (Figure 6).

A Chenango gravelly loam terrace straddles the Forty Road/Wickham Road intersection at elevation 1340 feet asl east of the South Branch, and terraces of Mentor fine sandy loam are distributed east of the South Branch about elevation 1340 feet asl between Forty Road and Skinner Hollow Road. The Soil Survey of Cattaraugus County, New York (1940) describes Chenango gravelly loam as stratified sand and gravel subsoil, deposited by water as stream terraces, outwash plains and deltas.

Mentor fine sandy loam is described as gravel-free fine sand subsoil, deposited as terraces and deltas in glacial lakes, underlain by heavy blue lake clay at a depth of 8-10 feet. Arkport very fine sandy loam occurs along the north rim of the gorge. The Soil Survey of Erie County describes Arkport (very fine sandy loam) as very fine to fine sandy loam subsoil deposited in sandy deltaic and lacustrine sediments.

Thus, water flowed west along the trace of the present main gorge and south along the trace of the presently north-flowing South Branch gorge, lazily depositing fine sands between the bedrock upland and the VHM, as it drained through the Persia outlet into the Conewango Valley. The Conewango Valley, itself once occupied by the pre-glacial north-flowing Allegheny River, previously diverted at Steamburg, New York by an earlier glacial advance (Tesmer, 1975), drained through Kennedy, New York to the Allegheny River. Later ice retreat opened progressively lower outlets northwest of Perrysburg, allowing deeper incision through the overlying sediments into the bedrock until the present day.

This seems straightforward, but there's a twist.

The Persia outlet is bounded on the north by a multiple looping moraine composed of reworked (?) lacustrine clay that extends east to the Big Bend of the South Branch and west to Dayton, New York (Figure 6). Tesmer (1975) noted lithologic similarities between the moraine and the Defiance (?) moraine in Chautauqua County. However, the upstream drainage system described above developed in response to the VHM. Also, the looping moraine is the largest topographic barrier across the northern Conewango Valley, characteristic of the VHM across the state. Furthermore, a large commercial sand and gravel mine occurs within a mile of the outer loop of the moraine, also characteristic of the VHM. It would seem that the looping moraine is the VHM.

However, if the moraine is composed of reworked lacustrine sand and clay, then the clay must have been bulldozed by the ice, requiring recession from the outer loop and a subsequent re-advance sufficient to plow up clay 100 feet above the valley floor. A second loop segment occurs west of the outer loop. This raises a question: To where did the lake waters drain prior to the re-advancement?

Two commercial gravel pits, located north of the Forty Road/Point Peter Road intersection in Cattaraugus County and south of the Vail Road/Allen Road intersection in Erie County, respectively, (Figure 6) may provide clues. The Point Peter Pit exposes well graded sands and gravels apparently dipping 15° NW in a delta-like geometry with surface elevation of 1270 feet asl. The Vail Road Pit exposes a similar deposit apparently dipping 30° NW with a surface elevation of 1140 feet asl. Both deposits are capped with a five-foot thick layer of stony till (?), suggesting later ice re-advancement. Since the only outlets low enough to establish base levels for the deltas are west of Perrysburg, perhaps recession allowed westward drainage.

The apparent dips of the sand and gravel beds raises another question: why do outwash-like deposits dip toward the ice? Perhaps the deposits grew as inwash from the captured drainage of the Cattaraugus Creek and South Branch meltwater channels. First the South Branch could have built the Point Peter deposit after breaching the outer loop moraine or pouring through a void left by retreating ice, reversing its flow from south to the Persia outlet to north to build the

Point Peter delta, then west past Perrysburg. A series of patches mapped as Chenango soils near elevation 1200-1250 feet asl arcing across the Conewango Valley from the Point Peter delta toward Perrysburg may trace one or more meltwater channels. Further field work is necessary (an understatement). Further recession could have lowered base level sufficiently to allow Vail Road delta deposition by the main branch, or by the South Branch.

Subsequent ice resurgence reworked the tops of the Point Peter and Vail Road deposits, which raises other questions: Where's the resurgent moraine? Some summit alignment east of Point Peter Road and south of Forty Road may mark the moraine, but north of Forty Road, the South Branch flows north where one would expect the moraine. Why weren't the apparent meltwater channels arcing across the valley destroyed? Do they represent post-resurgence drainage?

Now here's a puzzling one: why did the South Branch cut across the head of the Point Peter delta to join the main branch, instead of flowing west around the delta, presumably down gradient, as base level declined? Did resurgent ice push the stream east? If so, how could base level be low enough to encourage downcutting? Did a buried ice block melt after delta deposition and resurgence? No kettles or other stagnant ice features have been found. However, unpublished soils data from the U.S.D.A. Natural Resources Conservation Service show Valois gravelly silt loam to occur east of the South Branch from elevation 1100 feet asl to the bedrock upland. The Soil Survey of Erie County describes Valois gravelly silt loam to occur on undulating reglaciated outwash moraines and other moraines. If an ice block was buried by inwash gravels, subsequent melting could leave an undulating slope as found. Are tectonic forces at work? The streambed of the South Branch closely follows NW joints to Forty Bridge, then N to NE joints to the confluence with the main branch. Jacobi, et al. (1999) reference six seismic events along the N-S trend, with three located at intersection with NW lineaments. Could a buried ice block have filled a pre-existing structural depression? Is there another, completely different explanation?

The writer doesn't know, but will pursue these questions as time allows.

Geomorphology

Cattaraugus Creek flows west across very slightly (less than 1%) south-dipping Late Devonian Canadaway Formation shales and siltstones of the Allegheny Plateau. Although the physiography of upstate New York is cuestaform, with resistant escarpments separated by weak fine-grained sediments, Cattaraugus Creek is not a typical subsequent stream. The stream traverses at least three pre-glacial north-flowing obsequent stream valleys dammed by the VHM to the north at Sardinia, Springville and north of East Otto, then crosses the moraine and re-occupies the pre-glacial Allegheny River Valley at Gowanda until it discharges into Lake Erie (Figure 1). In crossing the VHM moraine east of Gowanda, Cattaraugus Creek is the only stream in western New York, other than the Genesee River, to breach the continental divide between the Mississippi River and the St. Lawrence River watersheds. The stream connects the pre-glacial valleys via meltwater channels across intervening uplands. Zoar Valley Gorge is the westernmost of the channels.

Fairchild (1932) describes the trace of Zoar Valley Gorge as "intrenched meanders" in the bedrock, inherited when lowering base levels allowed incision through the overlying glacial sediments into the soft shales and thin siltstones of the Canadaway Formation. While probably true throughout the slightly meandering upper miles of the gorge, structural control appears to exert increasing influence downstream.

The first significantly larger and sharper meander occurs about 10,000 feet west of the head of the gorge, on strike with a major NE fold/joint set observed in the South Branch. Unfortunately, the writer's strolls did not reach the first large meander at the time of this writing. Perhaps by meeting time, more data will be available. Alternatively, if sufficient water flow allows a raft trip, the participants can look for NE joints or other trends as we paddle.

Continuing downstream, the amplitude of the meanders increases. Strong joint sets, trending E and NW at Unnamed Rapid, NW, E and ENE at Refrigerator Island, NE at Lunchstop Hole, NE and NW at Confluence, NW at Curly, Larry and Moe, and E at Canoe Eater Rapids in the gorge, and NW at Turtle Rock, N at Shotgun Ledge, NW at Redline Slot, NW at Glue Factory and NW at Grand Finale Rapids downstream of the gorge, form chutes that channel streamflow. The sharp bends at Unnamed Rapid, Refrigerator Island and Confluence follow strong joint sets. Practically the entire reach of the South Branch from the upper falls to the Confluence follows strong NE, N, NW and ENE joint sets, either as chutes, at stream bends, or both.

Therefore, it is here proposed that pre-existing joints have exercised increasing influence over stream channel direction after erosion exposed bedrock. The young Cattaraugus Creek meandered across the essentially flat-lying rocks until flow concentrated erosion at zones of weakness, as suggested by the plateau north of Valentine Flats Road (Figure 2).

Valentine Flats itself piques curiosity. The gorge walls are roughly twice as far apart at the Flats as they are upstream or downstream. Relict meanders along the west wall do not well match the east wall. At the upstream end of the Flats at Curly, Larry and Moe Rapid rises the Pyramid, an impertinent pinnacle 120 feet high beveled on all three sides similar to the gorge walls (Figure 2). All the walls have been eroded to the same elevation. And so, the inevitable questions:

1. Did the South Branch once flow between the Pyramid and the west wall, joining the main branch downstream of the Pyramid? Perhaps a thin wall separating the branches upstream of the Pyramid eroded away, allowing confluence further upstream and creating the Pyramid.

2. Why don't the relict meanders match?

3. How was the west wall carved obliquely to the Pyramid?

4. Did the main branch once flow between the Pyramid and the west wall? If so, how can the present configuration be explained?

Weird stuff. The writer will pursue these questions, too.

Rapids

Cattaraugus Creek drops approximately 40 feet from the head of Zoar Valley Gorge to the top of Pinball Rapid over a stream distance of 15,000 feet at a gradient less than 0.3% with no rapids. From Pinball Rapid to the mouth of the gorge above Turtle Rock Rapid, the stream drops approximately 100 feet over a stream distance of 16,000 feet at an average gradient of 0.6%. Practically all of the 100 feet of drop occurs in twelve sections of rapids comprising approximately 5425 feet of stream distance at an average gradient of 1.8%. From the mouth of the gorge above Turtle Rock Rapid to the bottom of Grand Finale Rapid, the stream drops approximately 40 feet over a stream distance of 9000 feet at an average gradient of 0.4%. Practically all of the 40 feet of drop occurs in seven sections of rapids comprising approximately 3104 feet of stream distance at an average gradient of 1.3%.

Table 1 summarizes various characteristics of the nineteen individual rapids. Several general observations can be made.

1. Of the fifteen rapids across bedrock, ten are capped by siltstone.

2. Thirteen rapids are strongly influenced by joints, either as cross-flow ledges or parallel-flow chutes.

3. Seven rapids occur at bends.

4. Twelve rapids cross “rock gardens”, cross channel cobble/boulder bars.

5. Eight rapids combine rock gardens and bedrock chutes or ledges.

6. Six rapids at bends have rock gardens at the top of the rapid with pools immediately upstream, and bedrock ledges and/or chutes downstream of the rock gardens.

7. With the exception of Redline Slot, the steepest drops occur across the four rock gardens not visibly associated with bedrock.

8. Five rapids occur around mid-channel islands.

9. E, ENE or N joints strongly influence the upper rapids.

10. NW joints strongly influence the lower rapids.

What do these observations mean?

There is a strong correlation between rapids, siltstone beds, joints and rock gardens. While rapids, resistant beds and fractures make sense, the occurrence of rock gardens at the heads of rapids seems contradictory: as the gradient increases, velocity increases, as does stream competence. Why does deposition occur instead?

The occurrence of upstream pools suggest that classic pool and riffle stream morphology is at work, even though the streambed is bedrock. Glacial erratics are common constituents of the rock gardens, indicative of a large bedload expected so close to upstream moraines and outwash plains. During high water times, perhaps Cattaraugus Creek scours the soft shale in the streambed, then deposits the bedload as the current meanders upward through the water column. If, on the following downward flex, the current encounters more resistant siltstone, lateral migration and erosion of shales exposed in the bank would be encouraged, spreading the flow and encouraging further bedload deposition as mid-channel islands, point bars, or rock gardens. When a fracture zone is encountered in the siltstone, downward erosion could re-commence, focussed along the fracture zone in a chute or into the softer underlying shale once the siltstone has been removed downstream of the fracture, leaving a ledge. Unnamed, Refrigerator Island, Confluence, Canoe Eater, Turtle Rock and Redline Slot Rapids are examples. More study is required.

Flow direction and bedrock dip creates a unique situation. In two reaches, Pinball to Unnamed and Refrigerator Island to Lunchstop to Confluence, the stream flows consequently across siltstones. As a result, the stream may cut the same siltstone bed two or three times in a pool and riffle pattern. Detailed petrographic analysis and section measurement is necessary to verify these occurrences.

The writer will also pursue these investigations.

Acknowledgments

The writer sincerely thanks field partners Ms. Wendilorion Meyers, Ms. Amanda Joy Meyers and Mr. Rick White for their sweat and laughter while surveying the rapids, Dr. Robert Jacobi, Dr. James Ebert, Dr. Gordon Baird, Mr. Art Van Tyne and Mr. Ray Vaughn for providing references and insights, Mr. Jack Dahl, Mr. John Hoffman and Ms. Tracy Johnson, NYS DEC, for providing insights and technical support, Mr. Keith Scheetz and Mr. Rich Pecnik, Gernatt Asphalt Products, Inc. for providing information on area gravel deposits, JWS for teaching skepticism, DCM for teaching professionalism and most of all, my wife, Ms. Laura Kay Meyers, for putting up with me.

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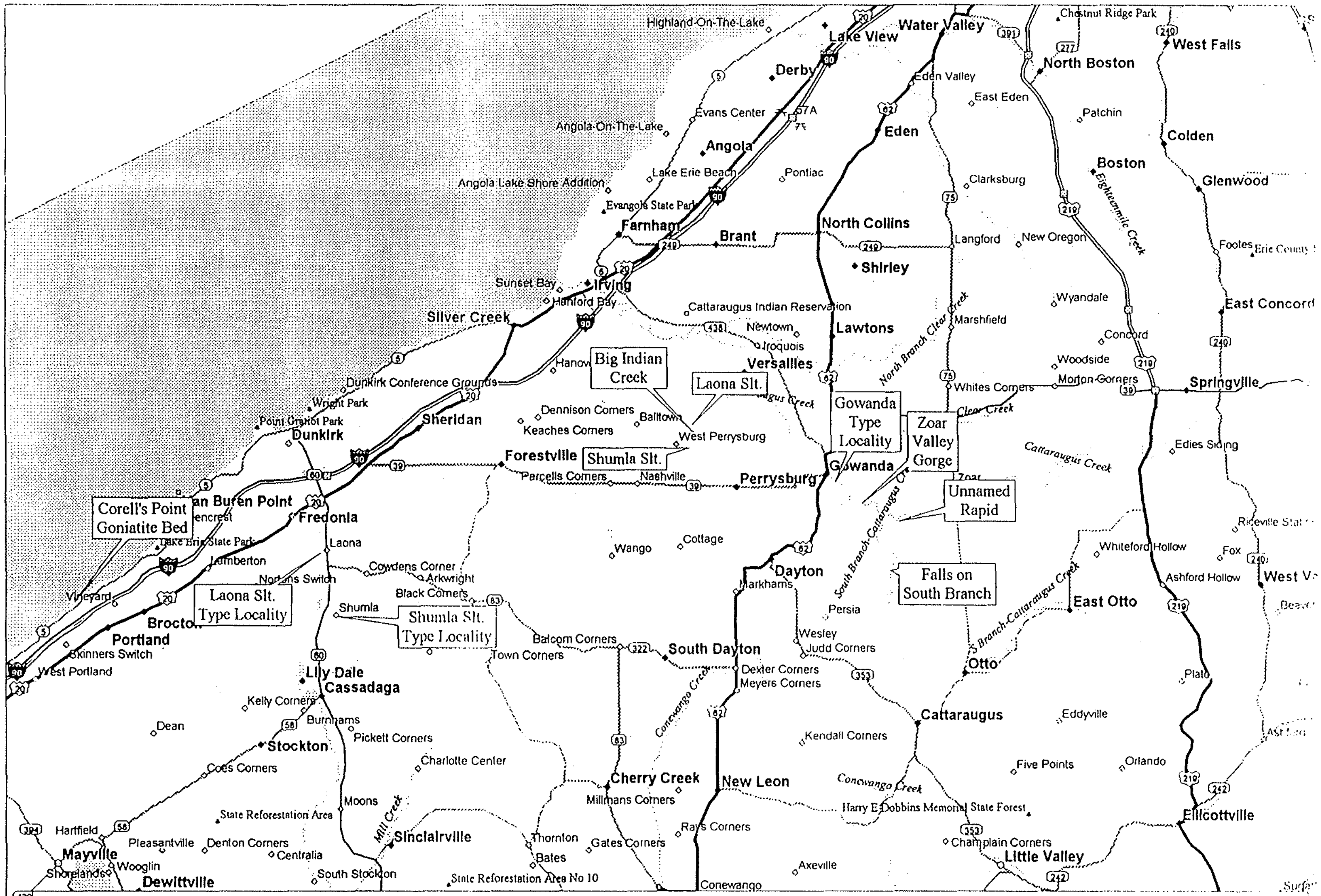
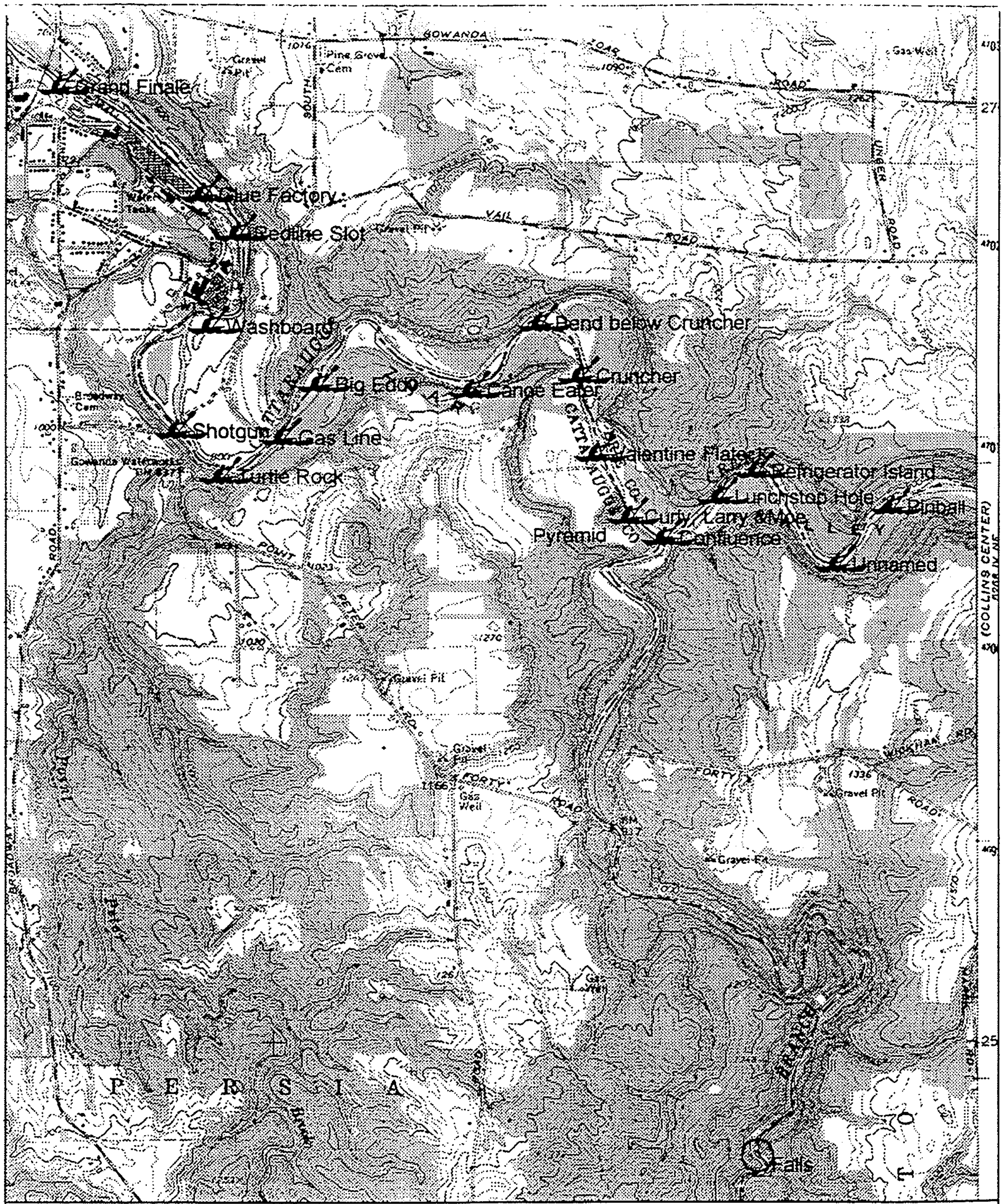


Figure 1. Location Map



Name: GOWANDA
Date: 8/2/99
Scale: 1 inch equals 2000 feet

Location: 042° 26' 10.2" N 078° 54' 11.1" W
Caption: Figure 2. Rapids of Zoar Valley Gorge, Cattaraugus Creek, NY

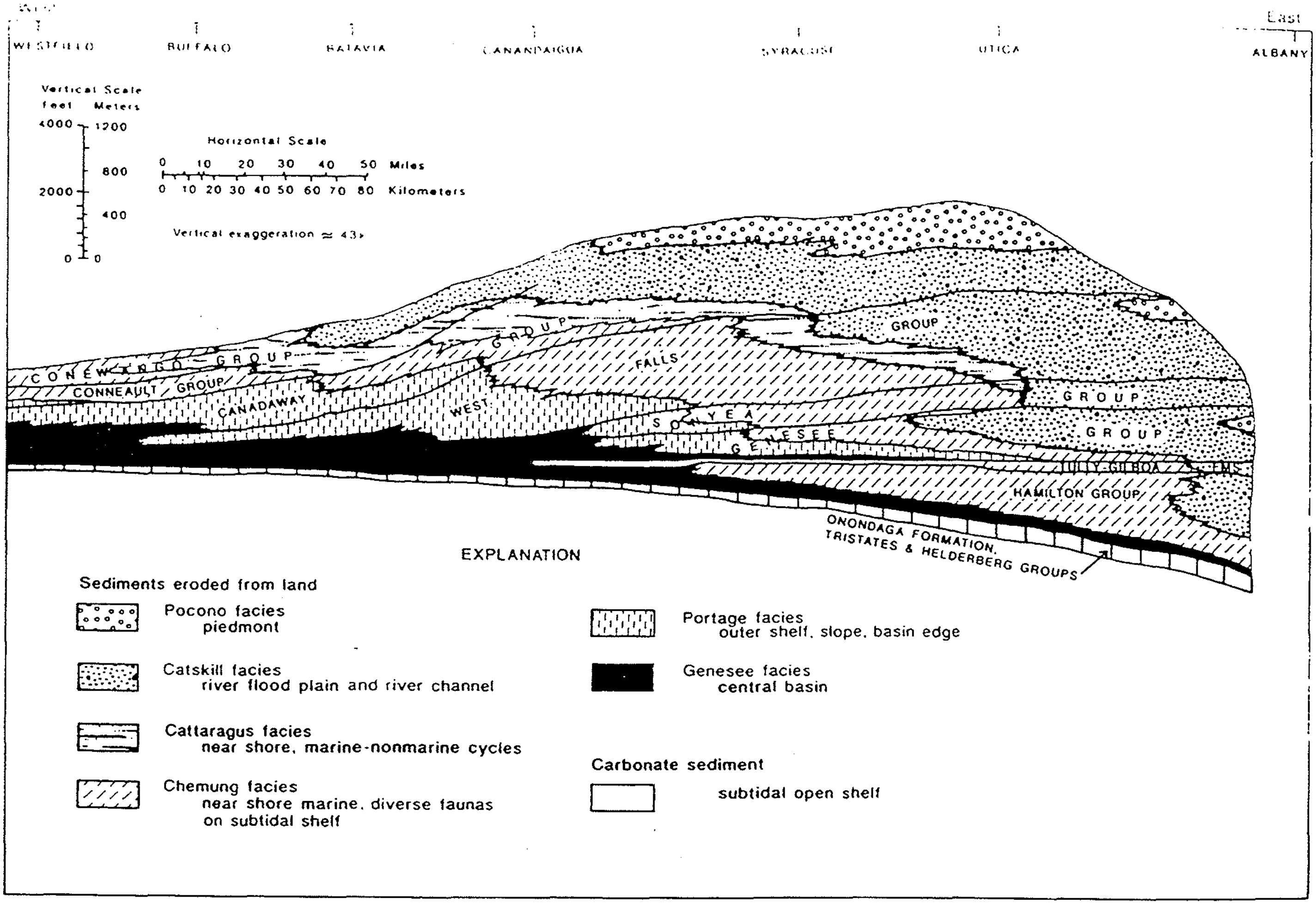


Figure 8.16. Diagrammatic cross section of the "Catskill Delta" east-west across New York State. This diagram is a composite that uses information from the outcrops in New York and in northern Pennsylvania. The cities listed across the top of the diagram generally are north of the main body of the cross section. A line drawn south from a city will cross the facies shown below it, starting with those facies at the bottom of the diagram. The "delta" deposits are divided into groups. Each group includes several facies. Figure 8.15 shows the environments where the different facies developed. Each group records an episode of the "delta's" construction. For example, as the Genesee Group was deposited, the shore zone moved from east to west as the sediment filled in the sea. An abrupt increase in the depth of the water moved the shore zone back toward the east, and deposition of the Sonyea Group began. The opposing processes eventually built the complex of sedimentary rock we call the "Catskill Delta." Notice that this diagram is distorted because the vertical scale is much larger than the horizontal scale. This vertical exaggeration is necessary to show details. However, it gives a false impression because it exaggerates the thickness relative to the width of the units shown.

Figure 3: From Geology of New York, A Simplified Account, 1991,
Educational Leaflet No. 28, SUNY State Education Department

Figure 4: From Geology of New York, A Simplified Account, 1991, Educational Leaflet No. 28, SUNY State Education Department

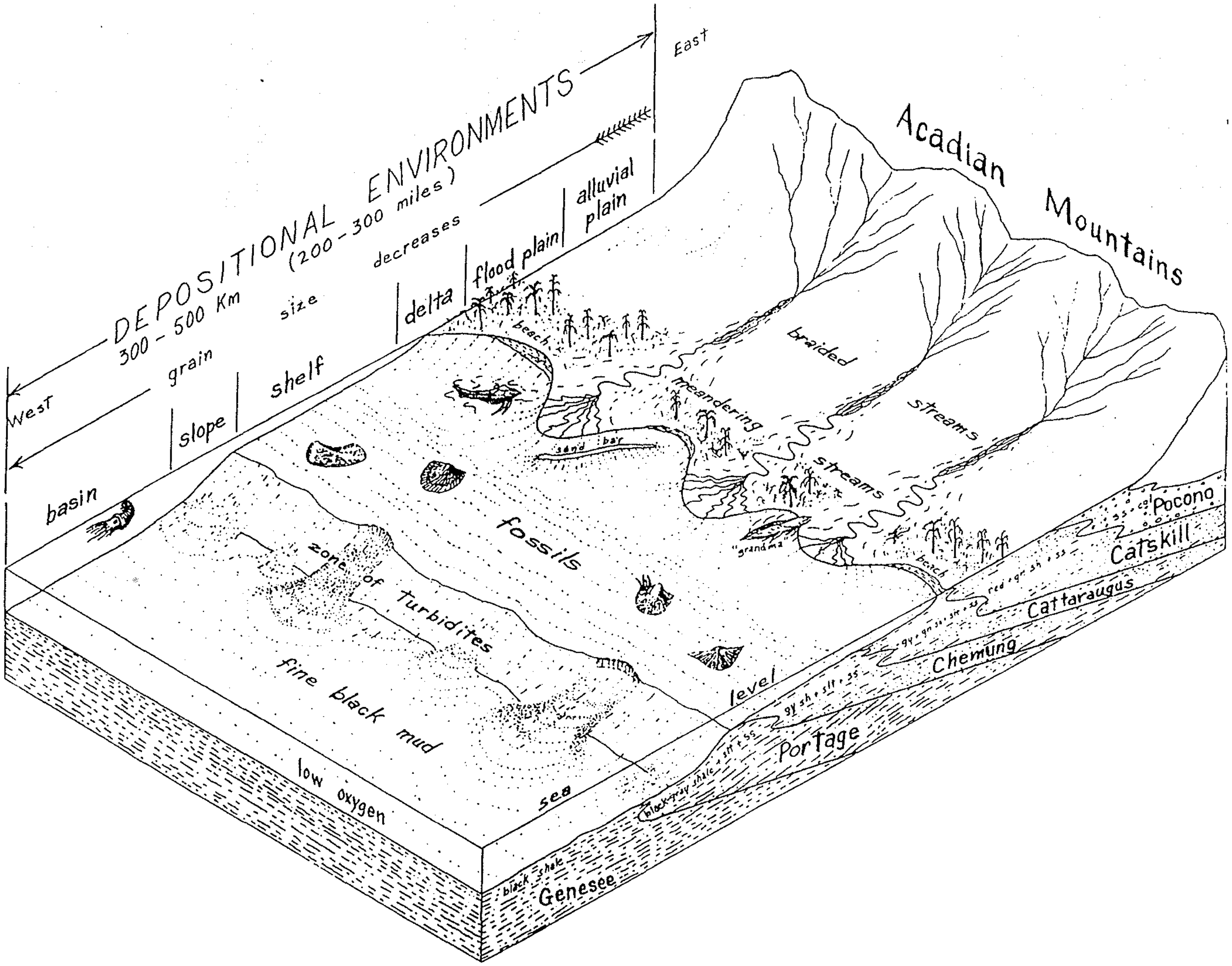
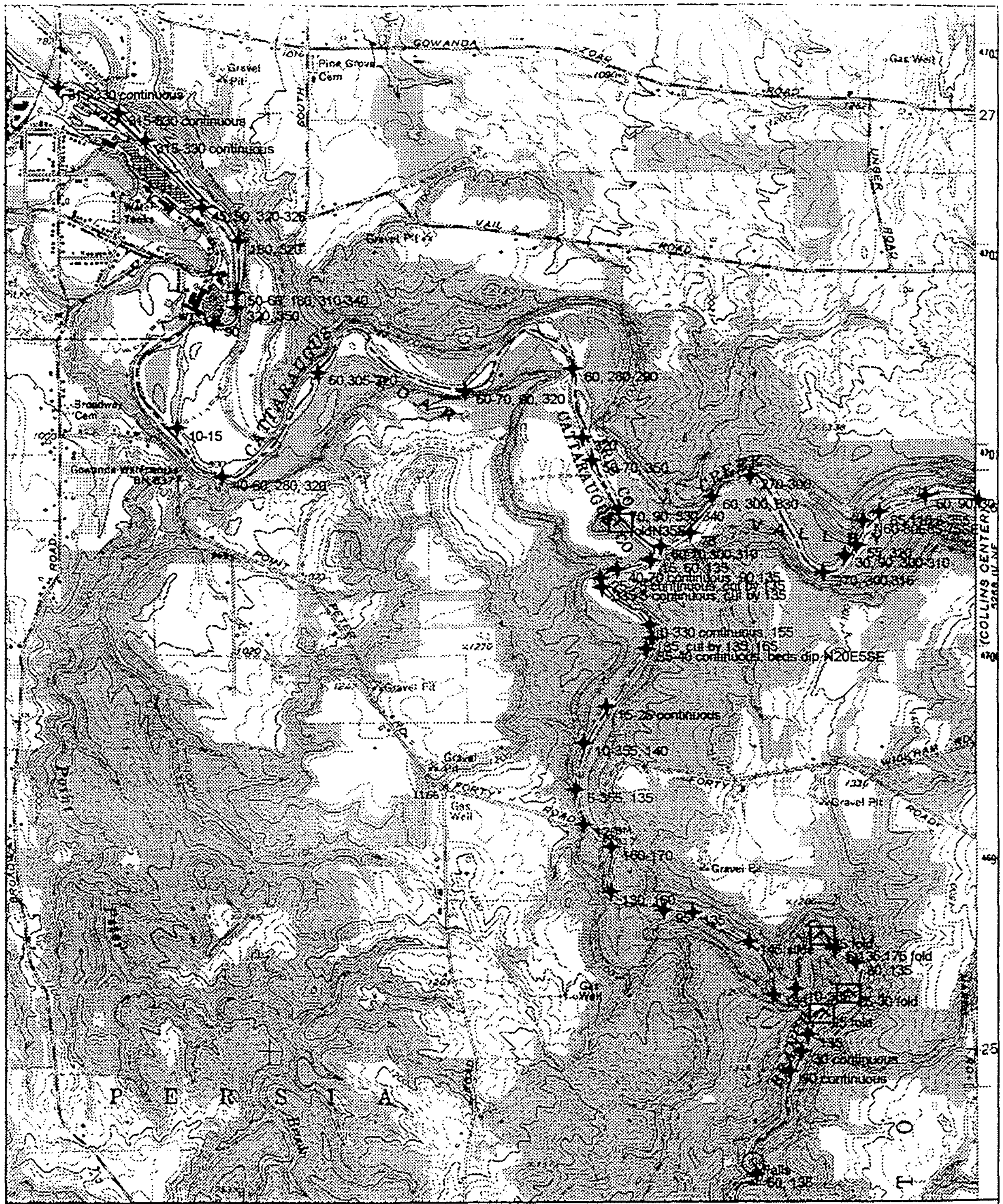
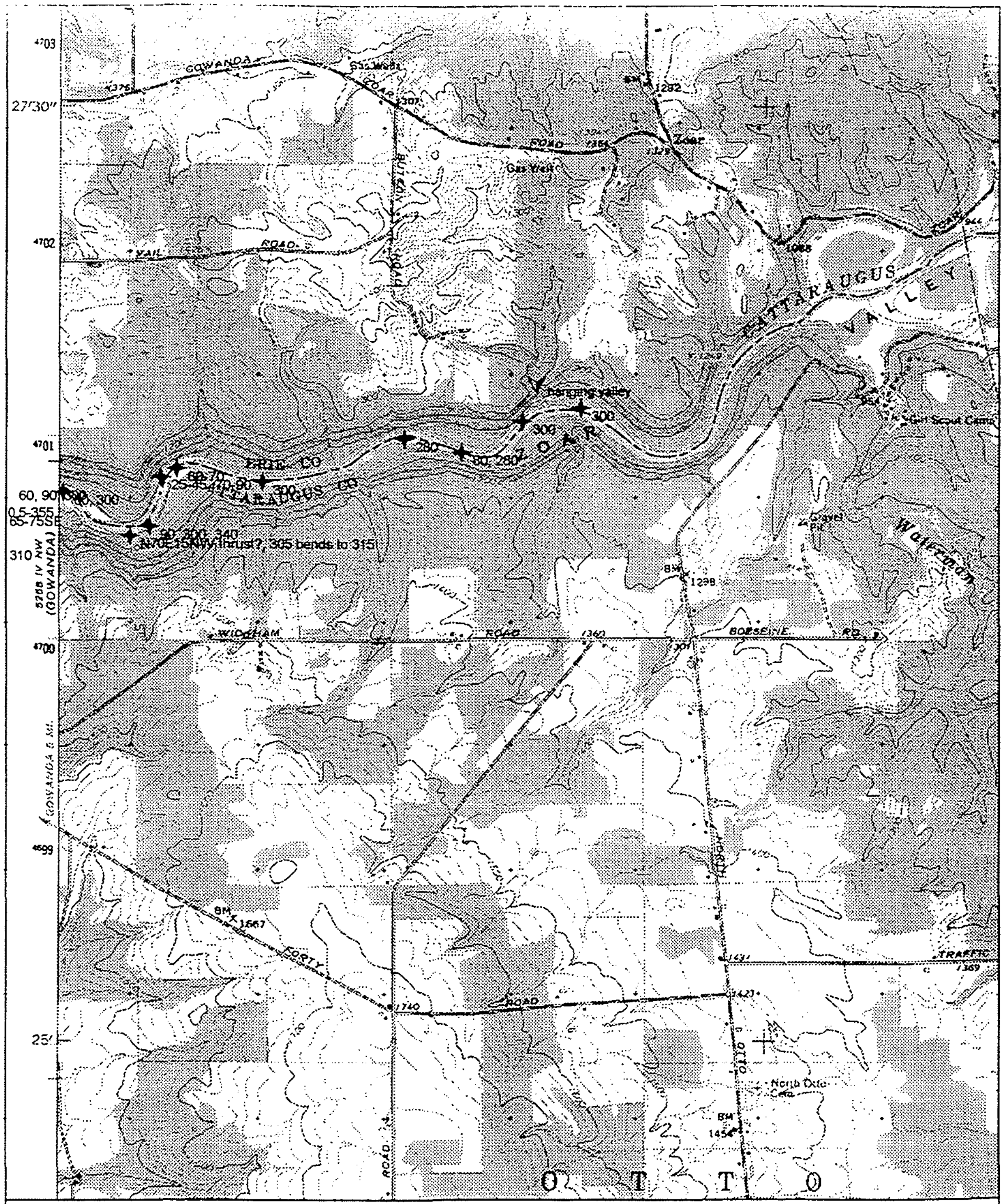


Figure 8.15. Diagram of the depositional environments of the "Catskill Delta" and the facies that were deposited in them. The arrangement of the facies (Genesee-Pocono) shows that the environments have moved from right to left through time as the sediment has filled in the edge of the sea. This process could be reversed by a rise in sea level, which would move the shore zone toward the right. (In this oversimplified diagram, the Pocono facies looks as if it were underneath the Acadian Mountains. It was actually deposited at the foot of the mountains.)



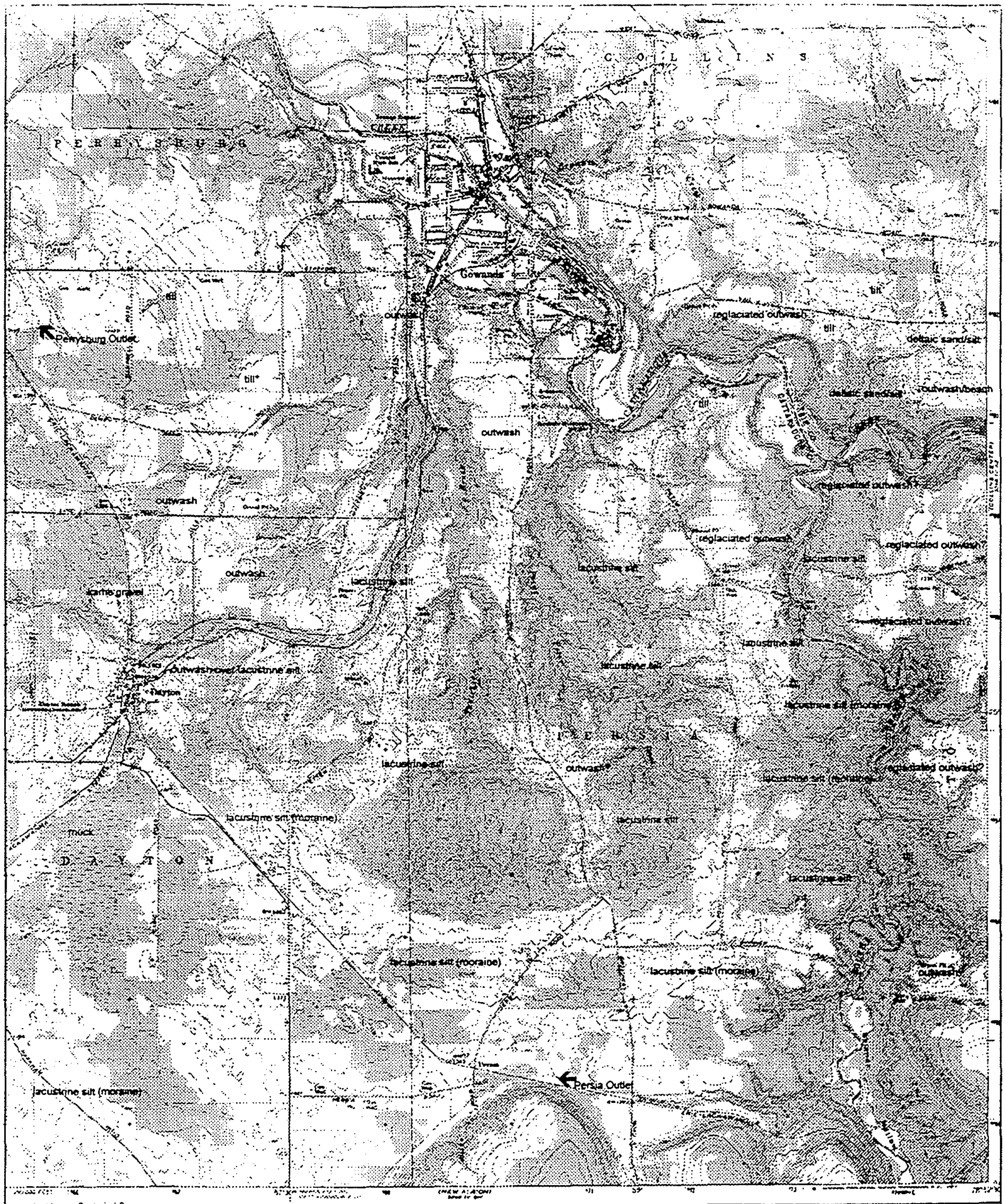
Name: GOWANDA
Date: 8/9/99
Scale: 1 inch equals 2000 feet

Location: 042° 26' 11.6" N 078° 54' 11.1" W
Caption: Figure 5. Joint and Fold Orientations, Zoar Valley and South Branch Gorges, Cattaraugus Creek, NY (west)



Name: COLLINS CENTER
Date: 8/9/99
Scale: 1 inch equals 2000 feet

Location: 042° 26' 10.6" N 078° 50' 55.4" W
Caption: Figure 5. Joint and Fold Orientations, Zoar Valley and South Branch Gorges, Cattaraugus Creek, NY (east)



Name: GOWANDA
Date: 8/17/99
Scale: 1 inch equals 4000 feet

Location: 042° 25' 35.4" N 078° 55' 55.9" W
Caption: Figure 6. Preliminary Surficial Geology Near Zoar Valley Gorge, Cattaraugus and Erie Countie, NY

TABLE 1
PROJECTION OF SHUMLA SILTSTONE, LAONA SILTSTONE AND CORELL'S POINT GONIATITE BED FROM TYPE LOCALITIES TO ZOAR VALLEY GORGE

	CORELL'S POINT		**SHUMLA**		**LAONA**		**BIG INDIAN CREEK**		**SOUTH BRANCH GORGE CATTARAUGUS CREEK**			**ZOAR VALLEY GORGE CATTARAUGUS CREEK**		
UNIT	LAT/LONG	ELEV.[1]	LAT/LONG	ELEV.	LAT/LONG	ELEV.	LAT/LONG	ELEV.	LAT/LONG	ELEV.		LAT/LONG	ELEV.	
										(proj.)	(loc.)		(proj.)	(loc.)
Shumla Siltstone	---	---	42°23'11"/ 79°17'56"[2]	950[2]	---	1080[2]	42°28'19"/ 79°1'28"[3]	1185[3]	42°24'42"/ 98°53'17"[7]	1040[6]	980-1055[7]	42°26'15"/ 78°53'2"[7]	1140[6]	1060-1150[7]
Laona Siltstone	---	---	---	---	42°25'15"/ 79°18'37"[2]	800[2]	42°29'26"/ 79°1'52"[3]	1015-1030[3]	42°24'42"/ 78°53'17"[5]	980[5]	---	42°26'15"/ 78°53'2"[7]	860[6]	840-870[7]
Corell's Point Goniatite	42°24'51"/ 79°26"57"	550	---	---	---	690[6]	42°30'54"/ 79°2'37"[3]	800[4]	42°24'43"/ 78°53'18"[4]	650[6]	965 [4]	---	---	---

(1) elevation in feet above sea level
(2) from Tesmer, 1963
(3) from Tesmer, 1975
(4) from House, 1967
(5) from Finlayson and Ebert, 1991
(6) projected in this study from type locality assuming 1% dip to south, uniform thickness of beds
(7) siltstone outcrop located in this study

Sat. F24

TABLE 2
ZOAR VALLEY GORGE RAPIDS

				GRADIENT (%)				
RAPID	TYPE	DROP (FT)	LENGTH (FT)	AVE.	IN CHUTE	JOINTS	ROCK TYPE	COMMENTS
1. Pinball	l/rg	9.1	698	1.3	2.0	85-110, 5-355	slt	90° l at top; chute cuts across mid-channel rg
2. Unnamed	rg/l	9.4	544	1.7	2.1	90, 300, 315	slt	rg at top; 90° l at bend; 90° joints form chute
3. Refrigerator Island	rg/l	11.9	916	1.3	1.9	80-90, 300	slt	rg at top; 90° l at inside bend around mid-channel island
4. Lunchstop Hole	chute	6.2	249	2.5	2.5	60, 300, 330	slt	60° joints form chute along straight stretch
5. Confluence	rg/l	6.6	302	2.2	2.2	60-70, 80-115, 300, 310	slt	rg at top; 70° l's cut by 315° joint
6. Curly, Larry & Moe	chute	8.9	488	1.8	2.2	35, 70, 90, 330-340	slt	35° pop-up at top; 330-340° joints form chute along straight stretch
7. Valentine Flats	l	6.3	595.9	1.1	--	45, 310	sh	310° l's across weak shales along straight stretch
8. Cruncher	l/rg	11.8	516	2.3	--	60, 100-110	sh	60° l above rg
9. Bend Below Cruncher	rg	3.0	62	4.9	--	--	--	rg at bend
10 Canoe Eater	rg/l	12.9	775	1.7	1.9	60-70, 90, 320	sh	rg at top; 90° l at outside bend, forms chute around mid-channel island
11. Big Eddy	rg	7.5	135	5.6	--	--	--	rg at top of mid-channel island
12. Gas Line	rg	7.8	145	5.4	--	--	--	rg at bottom of mid-channel island
13. Turtle Rock	rg/l	7.7	508	1.5	1.5	0, 40-60, 100, 320	slt	rg at top; 100°, 320° joints form chute
14. Shotgun (Upper)	l	4.8	276	1.7	1.7	10-15	sh	10°-15° joints form chute
15. Shotgun (Lower)	rg	4.3	156	2.8	--	--	--	rg adjacent to mid-channel island
16. Washboard	roll	3.0	114	2.6	--	--	sh	stream flows over N55E10NW monocline
17. Redline Slot	rg/l	2.5	35	7.1	7.1	315	slt	rg at top; 315° joints form chute
18. Glue Factory	l	5.5	407	1.4	1.4	45, 90, 320-325	slt	45° l; 320° joints form chute
19. Grand Finale	l	12.0	1608	0.7	2.3	315-330	slt	315°-330° joints form chute

ROAD LOG
GEOLOGY OF THE ZOAR VALLEY GORGE OF CATTARAUGUS CREEK, CATTARAUGUS AND ERIE COUNTIES, NY

MICHAEL J. MEYERS
NEW YORK STATE DEPARTMENT OF ENVIRONMENTAL CONSERVATION

Enroute to Zoar Valley Gorge, we will visit the type localities of the Corell's Point Goniatite Bed of the Gowanda Shale Member and the Laona Siltstone Member of the Canadaway Formation. We will also pass a sand and gravel pit in a glacial Lake Whittlesey beach deposit, with excellent concurrent reclamation to a vineyard, climb from the Lake Erie Plain onto the Allegheny Plateau, cross the Valley Heads Moraine (VHM) and pass another sand and gravel deposit located downgradient of the VHM on top of the lake sediment-filled pre-glacial Allegheny River Valley, now occupied by Conewango Creek. We will re-cross the VHM and drop into Gowanda through deeply dissected lake sediments, then visit the type locality of the Gowanda Shale Member of the Canadaway Formation, located at Grand Finale Rapid on Cattaraugus Creek, stop at a gravel pit with stratified sands and gravels dipping back toward the ice, then park at Forty Bridge on the South Branch of Cattaraugus Creek. We'll hike a total of three miles through the South Branch gorge to observe surface expressions of the Bass Island Trend, rapids along the main branch of Cattaraugus Creek, possible outcrops of the Laona and/or Shumla Siltstones and other natural beauty in the spectacular Zoar Valley Gorge.

The above itinerary assumes insufficient flow for a white water raft trip. If we are blessed with water, then we'll skip the Corell's Point, Laona and Shumla type localities and the gravel pits, drive to Gowanda to Zoar Valley Canoe & Rafting Co., Water Street, change into wetsuits (remember dry clothes, towel and shoes), pick up paddles & life jackets, catch the bus to the put-in, paddle the gorge and experience Zoar Valley the way we should. So pray for rain...

TOTAL MILES	MILES FROM LAST POINT	ROUTE DESCRIPTION
0.0	0.0	Leave the Fredonia campus at the Temple Street exit. Turn right (north) onto Temple Street.
0.4	0.3	Y-Junction; turn right (north) on Brigham Road.
0.9	0.6	Cross New York State Thruway.
1.5	0.6	Enter City of Dunkirk.
1.7	0.2	Pass Al-Tech Corp. factory (to right).
2.7	1.0	Junction with Route 5; turn left (southwest).
2.9	0.2	Turn right onto Point Drive North.
3.9	1.0	Cross Canadaway Creek.
7.5	3.6	County Fly Ash Dump to the left.
8.6	1.1	Bridge over Little Canadaway Creek.
9.4	0.8	Entrance to Lake Erie State Park.
11.3	0.9	Bridge over Slippery Rock Creek. Exposures include the South Wales Member at the lake shore level and Gowanda Member at the bridge and upstream.
12.2	0.9	Bridge over Corell Creek. Exposures are in the Gowanda Shale Member. The Corell's Point pyrite-goniatite bed is exposed approximately 120 feet upstream from the bridge.
13.3	1.1	Turn right (northwest) onto property of trailer court. Proceed 0.1 mile. Park at beach by boat ramp and proceed on foot across small creek and along shore for approximately 100 yards.

IMPORTANT: The landowner requests that no turtle rocks be whacked on or removed.

STOP 1: CORELL'S POINT PYRITE-GONIATITE BED IN GOWANDA MEMBER (description from Baird and Lash, 1990)

The Corell's Point Pyrite-Goniatite Bed, encompassing two regionally mappable levels of calcareous septarian concretions, is present at several creek localities in this county but this shore exposure is the best place to examine fossils and sedimentary structures (Fig. 4 B,C.). At least two, laterally discontinuous beds rich in pyrite nodules and locally abundant pyritized cephalopod steinkerns can be traced within the lower septarian concretion zone along the shore and around the small headland. Goniatites include Cheiloceras amblylobum, tornoceras concentricum, and Aulatornoceras bicostatum (Fig. 4C); these belong to the zone of Cheiloceras (II) in the amennian (see House, 1966; Kirchgasser, 1974). Orthoconic cephalopods are also common; these are commonly encrusted by a reptate auloporid coral. Slightly-curved conical shells less than one inch in length may be bactitid cephalopods or coleolid tubes. Bivalves, including Lunulicardium eriense, Praecardium multicostatum and Loxopteria corrugata occur with the cephalopods but these are usually preserved as non-pyritic composite molds often with a faint organic patina which may be a remnant of the periostracum layer. Driftwood, usually partly carbonized and partly permineralized by pyrite, occurs with the other fossils. Spectacular large Zoophycos spreiten in the Corell's Point Bed indicate that this trace had become important in offshore, dysoxic facies by the Famennian.

Babcock (1982), believed that the fauna of this bed was selectively preserved by turbiditic smothering events; some beds in this unit have shallow sole marks and display lamination similar to those in flaggy siltstone beds elsewhere in the Canadaway Formation. However, evidence of periods of reduced sediment influx is shown by intense biotrubation at some levels and by the tendency for auloporid corals to not only colonize partly-buried cephalopods but to extend colonial growth onto the adjacent seafloor. The history of this unit is complex and the presence of so many fossils at this level is suggestive of an episode of increased bottom oxygenation and reduced average turbidity.

The Corell's Point Bed is well exposed in Corell's Creek, Slippery Rock creek near Brocton, Little Canadaway Creek near Lamberton, Canadaway Creek upstream from Route 20, and Walnut Creek at Forestville (House, 1966, 1968).

Examine the Gowanda strata both below and above the Corell's Point Bed; notice the numerous brown-black shale beds which alternate with grey-green mudstone to produce the conspicuous striped banding along the shore (Fig. 4B).

Return to the vehicle(s). Leave trailer park and turn left (northeast) onto Route 5.

TOTAL MILES	MILES FROM LAST POINT	ROUTE DESCRIPTION
14.5	12.0	Junction with Pecor Road. Turn right (southeast). Proceed across sandy lake sediments.
15.1	0.6	Cross NYS Thruway.
15.5	0.4	Cross railroad tracks. Climb onto glacial Lake Warren beach deposit.
16.0	0.5	Junction with U.S. Route 20. Continue straight onto Fay Street. Climb onto glacial Lake Whittlesey beach deposit.
16.5	0.5	Junction with Webster Road. Turn left (east).

TOTAL MILES	MILES FROM LAST POINT	ROUTE DESCRIPTION
17.3	0.8	Pass Benchley Gravel Pit. Exposed at the face are glacial Lake Whittlesey beach deposits. The mine floor has been reclaimed to a vineyard, an excellent example of reclamation concurrent with mining. The floor was ripped to alleviate compaction, covered with subsoil, then topsoil, and seeded to perennial grasses and legumes. Grapes were planted 2 years later. Continue on Webster Road along Lake Whittlesey beach deposits. After junction with Highland Road, pass onto thin lacustrine sediments, over till, then back onto beach deposits.
18.5	1.2	Junction with Chautauqua County Route 380. Bear left on C.C. Route 380.
18.6	0.1	Junction with continuance of Webster Road. Bear right to continue on Webster Road along the beach ridge. On either side of the road, sporadic thin lacustrine silts overlie thin tills. Meltwater draining the young Cattaraugus Creek watershed flowed southwesterly across this area, removing most of the previously deposited sediments.
21.5	2.9	Junction with Ellicott Road. Continue east on Webster Road across a former meltwater channel and back onto the beach ridge.
23.4	1.9	Junction with Y intersection. Bear right. Continue on Webster Road across thin till.
23.6	0.2	Junction with Chautauqua Road. Continue straight on Webster Road across thin till.
24.5	0.9	Junction with Seymour Road. Continue straight on Webster Road across thicker till. Drop into Canadaway Creek Valley across outwash(?) or beach(?) deposit.
25.2	0.9	Junction with Chautauqua County Route 73. Continue straight on Webster Road.
25.5	0.1	Cross Canadaway Creek and park on left.

Stop 2: LAONA SILTSTONE MEMBER (description from Baird and Lash, 1990)

Laona Siltstone over Gowanda Shale at waterfall 200 feet southwest of car park at bridge (Overlook Stop Only). Note the sharp contrast between the conspicuously banded ("zebra" facies) of the Gowanda and the massive nature of the overlying Laona. The Laona and the higher Shumla Siltstone are believed to be gravity-flow units which record downslope movement of silt or fine sand into the anoxic to minimally dysoxic lower slope-basin setting recorded by the Gowanda-Westfield-Northwest shale members.

Return to vehicle(s). Continue east on Webster Road.

TOTAL MILES	MILES FROM LAST POINT	ROUTE DESCRIPTION
25.8	0.3	Junction with NYS Route 60. Turn right (south).
26.3	0.5	Junction with NYS Route 83. Turn left (east). Climb up from the Lake Erie Plain onto the Allegheny Plateau and cross the Lake Escarpment Moraine, partly correlative with the Valley Heads Moraine, between the previous turn and Arkwright. According to the Chautauqua County Soil Survey, the first 0.6 miles from the intersection crosses a mixture of tills and reglaciated outwash, lateral and recessional moraines.
29.9	3.6	Junction with Center Road at Arkwright. Continue straight (east) on NYS Route 83 along moraine. Drop into moraine-blocked valley and at Chicken Tavern Corners cross outwash valley.
31.7	1.8	Junction with C.C. Route 85 at Chicken Tavern Corners. Note reclaimed gravel pit on NW corner reverting to successional field since Chautauqua County DPW closed the site in the late 1980's. Continue on NYS Route 83. Cross hummocky valley filled with outwash, lake plain and till sediments. To the north (left) lies the Lake Escarpment/Valley Heads Moraine.
33.3	1.6	Junction with Zahm Road. Stay on NYS Route 83 and bend south along valley wall on outwash? or kame terrace? sands and gravels.
34.6	1.3	Climb onto till.
36.1	1.5	Junction with Chautauqua County Route 72 at Hamlet. Turn left (east) and continue on NYS Route 83 across a moraine (possibly an earlier position of the Valley Heads Moraine).
36.7	0.6	Cross onto delta deposit and drop onto west arm of lake dammed by the Valley Heads Moraine in the Conewango Creek Valley. Prior to glaciation, the west arm may have been a left bank tributary of the ancestral Allegheny River. The valley floor is now covered with outwash sand and gravel.

TOTAL MILES	MILES FROM LAST POINT	ROUTE DESCRIPTION
38.4	1.7	Junction with NYS Route 322 at Balcolm Corners. Continue straight onto NYS Route 322 at Balcolm Corners. Drop onto lacustrine sediments upon entering the Village of South Dayton.
40.6	2.2	Cross railroad tracks in the Village of South Dayton. The train station on the left appeared in the movie "Planes, Trains and Automobiles", starring Steve Martin and the late John Candy. Continue on NYS Route 322 across lacustrine sediments.
43.0	2.4	Junction with U.S. Route 62. Turn left (north) onto U.S. Route 62.
43.5	0.5	Pass Country Side Sand and Gravel, Inc. on right. Several lakes have resulted from excavation of (mostly) sand buried beneath up to 4 feet of lacustrine sediments. The deposit grades into finer material at 25-30 feet of depth. The valley floor elevation is approximately 1294 ft. asl. A deep ENE trending channel filled with coarser gravels and cobbles cuts across the site and bottoms near elevation 1250 ft. asl (Keith J. Scheetz, Country Side Sand & Gravel, Inc., personal communication), suggesting that the Persia Outlet of the young Cattaraugus Creek and glacially dammed lakes contributed the sediments, at least during early deposition. However, if the Persia Outlet, at elevation 1320 feet asl, drained with sufficient competence to carry coarse sediment more than three miles in a distinct channel, to where did the stream discharge? The lowest present outlet to the south is south of Kennedy at elevation 1250 ft. asl, more than 18 miles away. If the Country Side channel was deposited when the Perrysburg Outlet was exposed, why wasn't the Persia Outlet abandoned by the South Branch and Cattaraugus Creek in favor of the lower channel?
44.7	1.2	Climb up the edge of the silt moraine (Valley Heads?). The fine-grained composition of the moraine suggests that the deposit was bulldozed into place by advancing ice, instead of being deposited by meltwaters or stagnant ice.
45.3	0.6	Cross onto outwash sand and gravel. Pass through Markham, climb briefly onto till on the valley wall, then drop back onto kame terrace sand and gravel and pass through Dayton.

TOTAL MILES	MILES FROM LAST POINT	ROUTE DESCRIPTION
47.9	2.6	Cross railroad tracks in Dayton. Junction with NYS Route 353. Turn left. Stay on U.S. Route 62. Descend along tributary of Thatcher Brook through deeply dissected lacustrine sediments to Gowanda. Sporadic sand and gravel deposits capping the uplands on either side of the road may trace sequential meltwater channels through the Perrysburg Outlet and lower outlets to the northwest.
50.9	3.0	Confluence with Thatcher Brook on right. Extensive outwash sand and gravel deposits capping the upland east of the stream may result from progressive dissection and re-deposition of higher deltas built by Cattaraugus Creek and the South Branch as lower outlets were exposed, or may result from a later glacial re-advancement (Gowanda?). More work is needed. About 2200 feet south, a gas well penetrated 575 feet of glacial sediments before hitting bedrock.
52.4	1.5	Junction with NYS Route 39 and Water Street in Gowanda. Turn right (south) onto Water Street. If sufficient flow allows a white water raft trip, proceed ½ block to Zoar Valley Canoe and Rafting Company on the right and park. If not, continue on Water Street.
53.0	0.6	Junction with Broadway Road. Park in bare area on left, opposite Broadway Road. Walk about 700 feet north to Cattaraugus Creek.

Stop 3: GOWANDA SHALE TYPE LOCALITY, GRAND FINALE RAPID, CATTARAUGUS CREEK

The Gowanda Shale Type Locality crops out across the stream. Interbedded medium light gray to grayish-black shales, silty shales and thin to thick-bedded ripple-marked light gray silt stones characterize the Gowanda at this location. Many zones of calcareous concretions and septaria occur elsewhere within the Gowanda. Cattaraugus Creek cuts Grand Finale Rapid through a siltstone cap upstream, then through weak shales along a strong NW joint set. At flood water levels, a series of 10 to 15 foot high standing waves form between the base of the chute and the railroad bridge downstream. At medium water levels, the joint intersection at the base of the chute forms a challenging hole for white water rafters. A note of caution: at medium to high water levels, only experienced paddlers should attempt Grand Finale Rapid, unless accompanied by a NYS licensed guide or other experienced paddler.

The odor in the air comes from the buried tannery landfill adjacent to the stream. Currently on the U.S.E.P.A. Superfund List, plans are being developed to permanently remediate the site. A short walk upstream will reveal orange liquid leaching from the rocks and beneath the retaining wall.

Also evident along the stream is the gorge formation in microcosm. Joints parallel to streamflow are preferentially eroded, focussing water and further increasing erosion.

Return to vehicle(s). Proceed south on Broadway Road.

TOTAL MILES	MILES FROM LAST POINT	ROUTE DESCRIPTION
53.4	0.6	Pass Gernatt Asphalt Products, Inc. gravel pit on right, excavating Gowanda(?) Moraine outwash or meltwater channel deposits.
53.7	0.3	Junction with Point Peter Road. Turn left (east) onto Point Peter Road and drop into outwash covered proglacial lake floor.
54.2	0.5	Cattaraugus Creek Overlook alternative stop. Park in bare area. Follow a very narrow trail with no handholds to observe imminent breaching of a knife edge meander core immediately upstream of the confluence of Point Peter Brook and Cattaraugus Creek, a possible analogy for the origin of the Pyramid at the confluence of Cattaraugus Creek and the South Branch within the gorge. Gas Line, Turtle Rock and Shotgun Ledge Rapids are visible along Cattaraugus Creek from this location.
54.7	0.5	Junction with Valentine Flats Road, an alternative access road into Zoar Valley Gorge. A parking lot and trailhead occur at the end of the road about 4500 feet north, then east. A spectacular view of Valentine Flats exists about 1200 feet north of the parking lot. This field trip will not stop there. Continue straight on Point Peter Road and climb distal face of outwash delta deposit.
55.4	0.7	Point Peter Road gravel pit on left. Turn into pit.

Stop 4: POINT PETER ROAD GRAVEL PIT

Stratified sand and gravel beds, overlain by stony till, dip NW toward the former ice front. Were these sediments deposited as a delta when retreating ice allowed the South Branch to abandon the Persia Outlet and discharge into a proglacial lake draining past Perrysburg? Did a re-advancement, indicated by the overlying till, divert the South Branch to join Cattaraugus Creek across the head of the delta? If so, upon subsequent retreat, why didn't the South Branch drain south of the delta, instead of eroding through the head of the delta at a higher elevation?

Return to vehicle(s). Turn left (east) and continue on Point Peter Road.

TOTAL MILES	MILES FROM LAST POINT	ROUTE DESCRIPTION
55.5	0.1	Junction with Forty Road. Bear left onto Forty Road. Cross outwash slope and drop into South Branch Gorge. The road is quite steep. Note the first appearance of bedrock shortly after beginning the steep descent.
56.1	0.6	Parking Area at Forty Bridge. Prepare for a three mile hike. Your feet and lower legs will get wet.

Stop 5: SOUTH BRANCH GORGE

Welcome to Zoar Valley Gorge. The bedrock is probably the Westfield Shale Member of the Gowanda Formation, unless Bass Island Trend vertical displacement at depth, noted by VanTyne, et al. (1980), carried to the surface. If so, then the Gowanda Shale Member crops out in the gorge walls. The South Branch of Cattaraugus Creek flows north past the abutments of Forty Bridge, visible upon hiking to the stream, and joins the main branch about one mile downstream (Figure 3). A strong NW joint set is visible on both walls and in the streambed just downstream of the abutments. The same(?) joint set occurs upstream to the southeast, controlling the streambed, along the scarp of a massive landslide where the stream undermined the weakened right wall just below the big bend, and further upstream in the streambed at the confluence with a small waterfall on the right wall above the big bend. A similar strong NW joint set occurs roughly on strike to the northwest in Cattaraugus Creek where it controls the streambed for about 3700 feet from Redline Slop to Grand Finale Rapids.

Downstream, continuous N, then NE, joint sets bend back and forth through 20° of arc, periodically cut by NW joints. Weakly developed concretionary layers crop out in the streambed, partly coated with iron oxide.

Below a gravel bar, continuous NE joint sets control the streambed. About 3500 feet downstream of Forty Bridge, the stream drops through a siltstone package cut by strong NE joints, providing an excellent example of "stairstep stratigraphy". Joints and a very slight SE dip concentrate erosion along the bases of miniature cuestas, formed by thin siltstones and thicker shales, observable at very low water levels.

As the stream bends to the northwest, so do the joints in the streambed. Similarly, as the stream bends to the northeast at the next bend, so do the joints in the streambed. Fracture intensity increases approaching the confluence, with strong NE, NW, N and E joint sets intersecting with various cross-cutting relationships.

The gorge widens considerably at the confluence with Cattaraugus Creek. Downstream about 400 feet, a 35° pop-up fold occurs in the left bank at the top of Curly, Larry and Moe Rapid. The pop-up is interpreted as a surface expression of the Bass Island Trend. The rapid drops through a chute following a strong NW joint set, forming a playful wave train.

At the confluence lies Confluence Rapid, with a rock garden at the top above a siltstone caprock cut into a ledge by a 70° joint. The ledge has migrated upstream about 140 feet in the past seven years. Formerly a dangerous "keeper hydraulic", due to very strong back currents in the hole at the base of the ledge, the rapid is now an exciting cascade.

Upstream about 1500 feet lies Lunchstop Hole, another chute following a strong joint set, this time trending 65° to 95°. A series of holes within the chute provide a roller coaster ride.

Around the bend is Refrigerator Island Rapid, with a rock garden at the top above siltstone caps cut into ledges by 80°-90° joints. This rapid can be dangerous if a rafter drifts too far to the left and gets tangled up in the downed trees along the bank.

The siltstones capping Refrigerator Island, Lunchstop Hole and Confluence Rapids may be the same unit cut three times as the stream flows obsequently, subsequently and consequently through the reach. Projected from the type locality, the Laona Siltstone would crop out at the elevation of these rapids, if no structural displacement occurred. The Shumla Siltstone would crop out roughly 210 feet up the wall. A siltstone unit does occur at the projected elevation. Detailed mapping and petrographic analysis may resolve the Mystery of the Missing Laona.

Some questions:

1. Do the joints determine the locations of the rock gardens above the rapids by controlling the streambed, slowing down the water at bends where the stream intersects, then follows, a strong joint set?

2. Alternatively, do the rock gardens grow in classic pool and riffle mechanics and force lateral migration when the streambed crosses resistant siltstones until an intersecting joint set is exposed, encouraging downward erosion again?

Detailed mapping and surveying of the stream features, bedrock and structures may answer these and other questions. As time allows, the writer will pursue these investigations.

Please enjoy the 1.5 mile hike back to the vehicle(s).

Return to Gowanda. Bill's Lair, an excellent watering hole, is located next to Zoar Valley Canoe & Rafting Company. Delicious chinese food is available across the street. At the junction with U.S. Route 62 and NYS Route 39, turn left (west) but bear right onto NYS Route 39. Proceed about 18 miles to the junction with U.S. Route 20. Turn left (southwest) onto U.S. Route 20. Proceed 3.5 miles to Temple Street in Fredonia. Turn right (north) onto Temple Street. Proceed 0.7 miles to the Fredonia campus.

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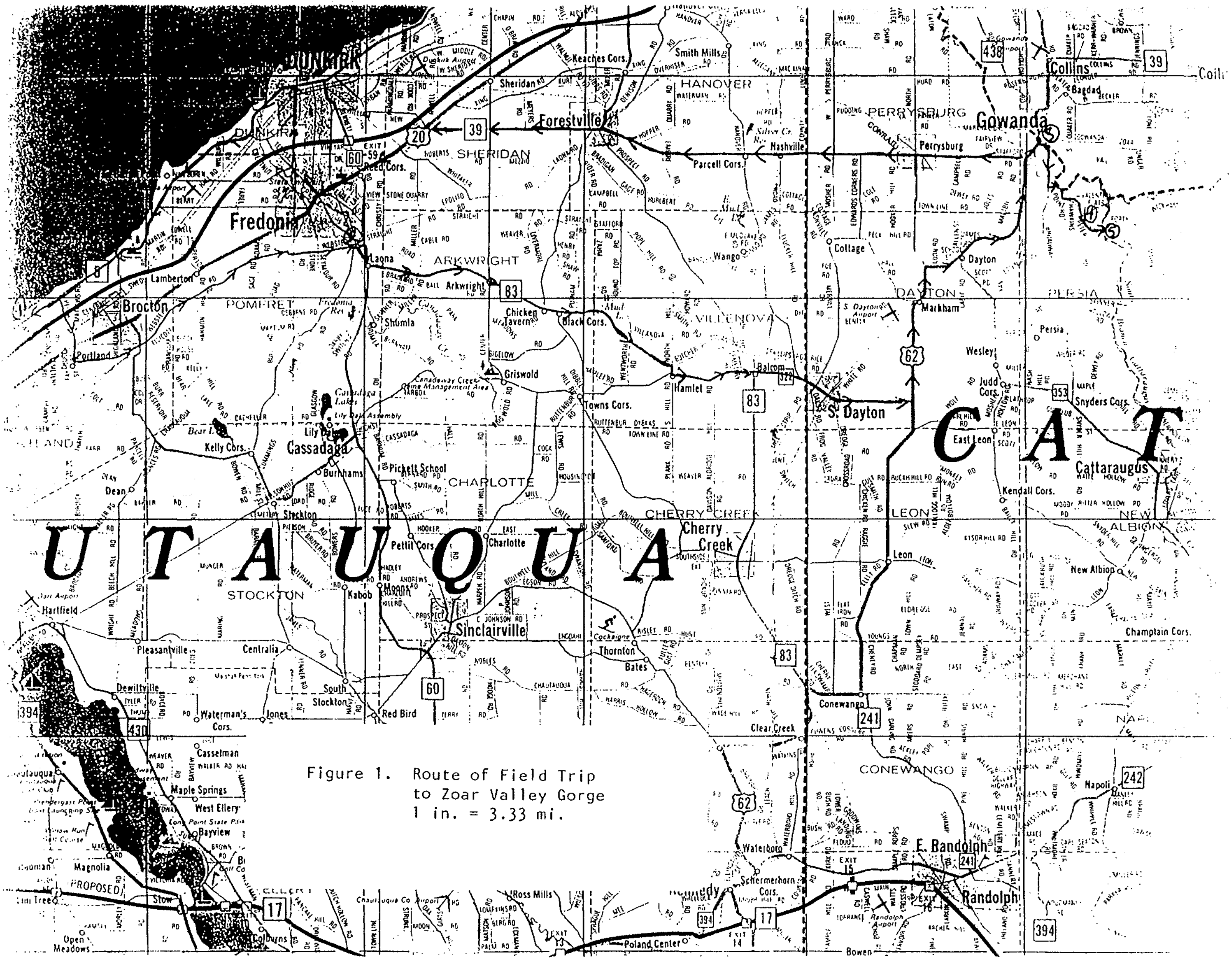
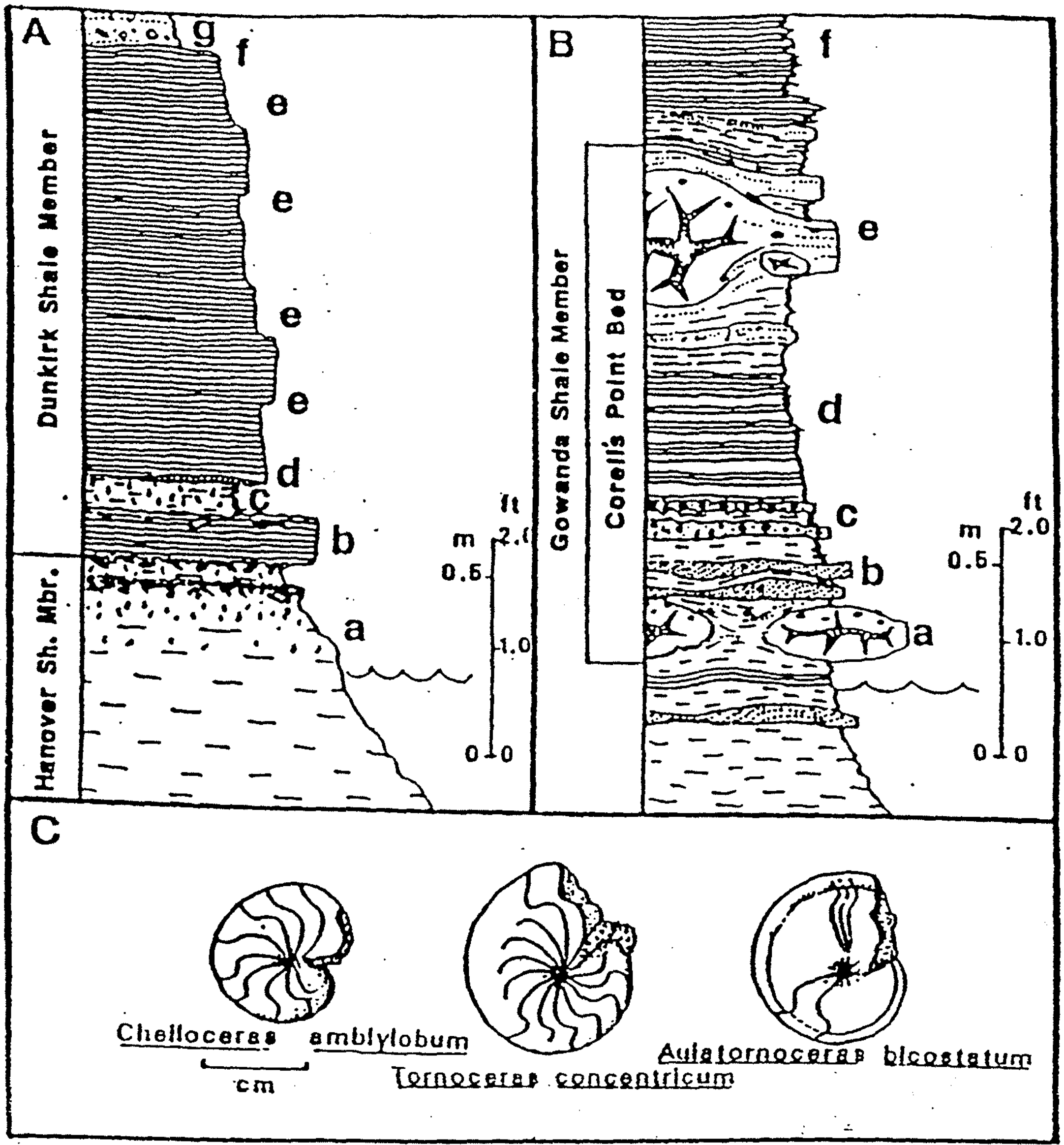
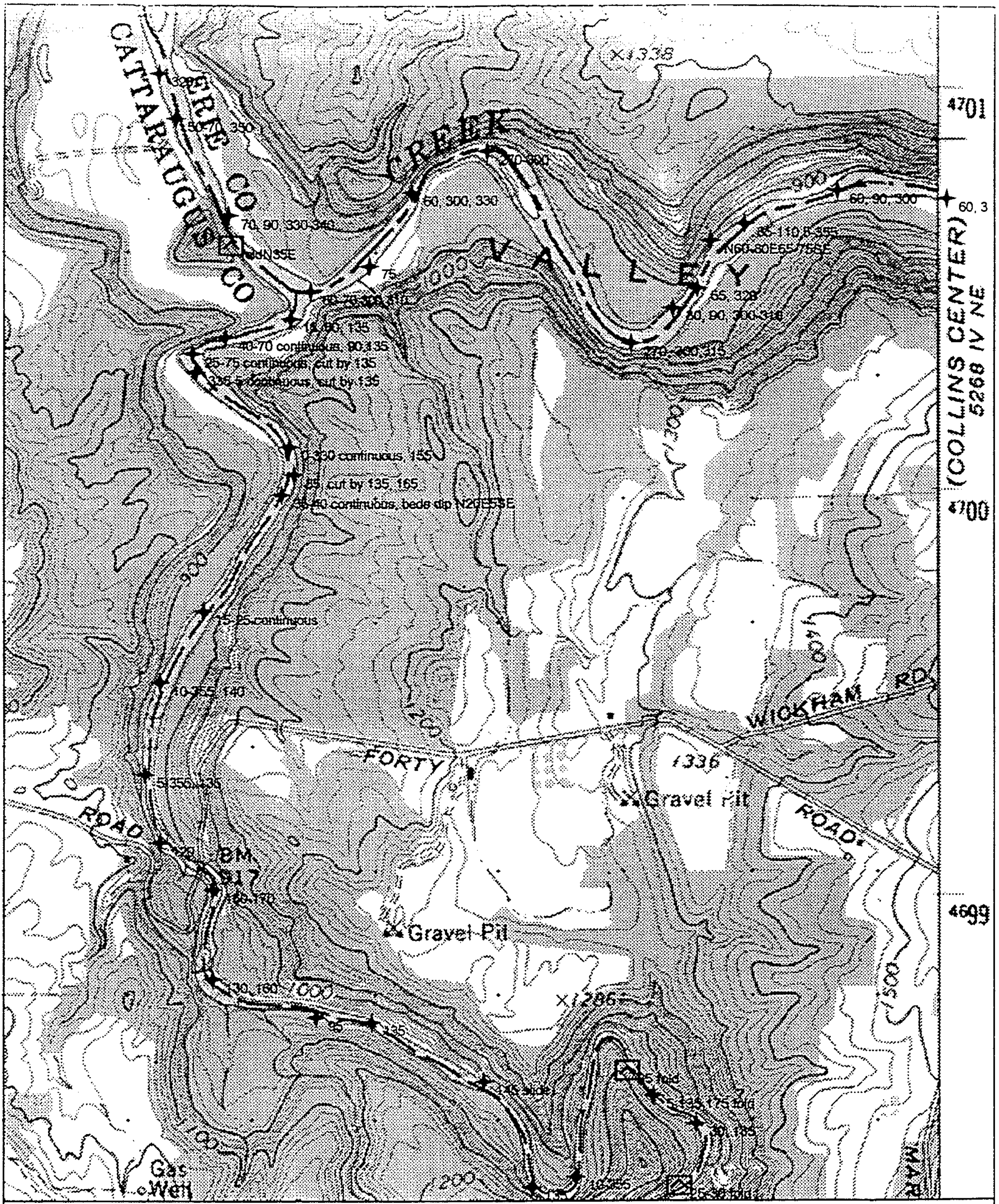


Figure 1. Route of Field Trip to Zoar Valley Gorge
1 in. = 3.33 mi.



Stratigraphic sections for the Point Gratiot and Corell's Point lake shore localities and key goniatite fossils from the Corell's Point Bed. A) Section at Point Gratiot . Lettered units include: a) intensely bioturbated grey-green mudstone; b) wood-and bone-bearing black shale bed; c) bioturbated grey-green mudstone bed; d) detrital pyrite lens along black shale-roofed discontinuity; e) laminated black shale; f) striated glacial scour contact; g) bedded glacial "till"; B) Section at Corell's Point (STOP/). Lettered units include: a) septarian concretions containing fossiliferous pyritic steinkerns; b) siltstone beds containing unfossiliferous pyrite nodules, c) bioturbated siltstone beds yielding numerous pyrite nodules, pyritic fossil steinkerns and non-pyritic fossils; d) interbedded black and grey-green shale ("zebra" facies); e) large septarian concretions with occasional pyritic steinkerns and abundant auloporid corals; f) black shale; C) Key zonal goniatites from Corell's Point Bed (After House, 1962, 1965; Kirchgasser, 1974).

Fig. 2. From Baird and Lash, in Lash, G.G. (ed) Field Trip Guidebook NYS Geol. Assoc. 62nd Annual Meeting, 1990.



Name: GOWANDA
Date: 8/17/99
Scale: 1 inch equals 1000 feet

Location: 042° 25' 55.4" N 078° 53' 16.8" W
Caption: Figure 3. Joint and Fold Orientations, Zoar Valley/South Branch Confluence, Cattaraugus Creek, NY

PENN DIXIE PALEONTOLOGICAL AND OUTDOOR EDUCATION CENTER:

Visit to a Classic Geological and Outdoor Education Center

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INTRODUCTION

The site of a former quarry operation in Hamburg, New York (Fig. 1), was once the source of calcareous shale excavated and used for cement aggregate by the Penn Dixie Cement Company. A majority of the 57-acre site was quarried from the early-to-late 1960s, during which time 9 to 10 feet of shale was removed from the surface. A gray, somewhat flat "lunar landscape-appearing" surface now occupies a majority of the site. After the quarry operations ceased, weathering forces began to reveal 380-million-year-old Devonian fossils preserved within the Windom Shale. This highly fossiliferous unit underlies the entire site and provides an inexhaustible supply of fossils. In addition to the Windon Shale, several limestone units (the Genundewa, North Evans, and Tichenor) that outcrop on the site are also fossiliferous.

Professional and amateur paleontologists began visiting the Penn Dixie Site, which has often been referred to as the Bay View Quarry, in the early 1970s on a regular basis. Classes from numerous regional universities and the Buffalo Museum of Science began to regularly visit the site to collect the well-preserved, diverse, and highly abundant numbers of invertebrate fossils. Fossil fish and carbonized plant remains have also been collected, but with more difficulty. During the 1970s, 1980s, and early 1990s, the Penn Dixie Site changed ownership, and at times it was difficult acquiring access. It was also during this time period that the former quarry served as a "playground" for all-terrain vehicle (ATV) driving, target-shooting, and youth parties, and as a dumping area for stolen cars and other materials. Many who visited the site during this time period will remember ducking for cover, jumping out of the path of ATVs, and avoiding the broken glass and debris left over from parties.

PRESERVATION OF THE PENN DIXIE SITE

In 1989 and 1990, the site was under the threat of light industrial development, but the community had other ideas for preserving it for future generations. A group of local citizens and geologists collaborated in 1990 to work on acquiring and preserving the site for future outdoor educational use. Initially, the plan was to acquire the property and leave it in its natural state for everyone to have an opportunity to study the local geology

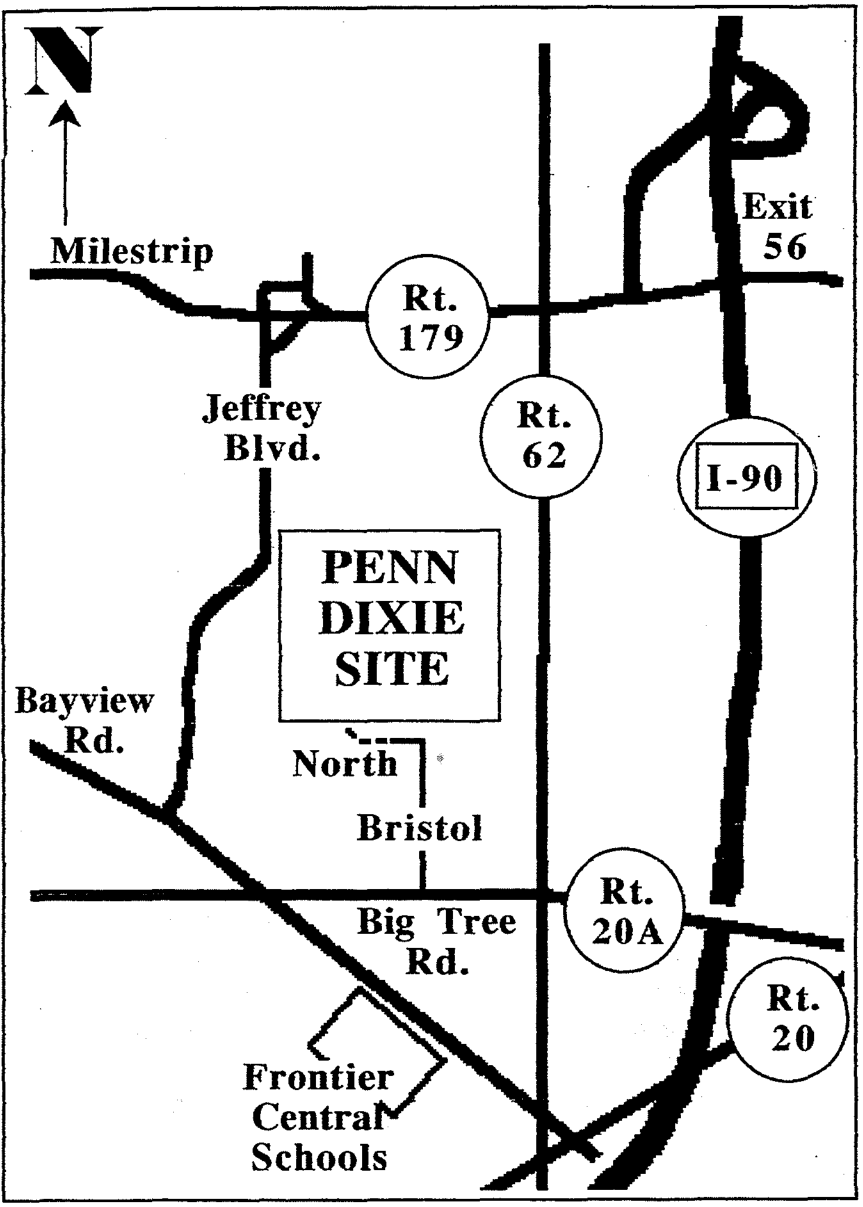


Figure 1. Penn Dixie Paleontological and Outdoor Education Center
Hamburg, New York

and paleontology. The Hamburg Natural Society, Inc. (HNHS)-a non-profit 501 (c) (3) organization-was formed in 1993 to help with the purchase and development of the former Penn Dixie Site. The Town of Hamburg, under the leadership of Councilman Mark Cavalcoli (then a biology teacher at the Frontier Central High School), worked with the HNHS to help buy the property. In December 1995, the Town of Hamburg successfully completed the purchase and deeded 32.5 acres to the HNHS in January 1996. The remainder of the acreage was deeded to the Hamburg Community Development Agency, which in turn used some of the land for affordable single-family homes. The development of the Penn Dixie Paleontological and Outdoor Education Center had begun. During two separate site cleanup efforts, one in 1996 and the second in 1998, five 30-yard dumpsters of garbage and debris, over 300 tires, five abandoned cars, two boats, a motorcycle, a golf cart, and a snowmobile were removed from the site.

Fossil collecting and the study of the local geology were the initial intent for the preservation of this former quarry. After acquisition of the property in early 1996, the HNHS reexamined the other resources available for outdoor education programs in other areas of the natural sciences. The Society hired a development consultant and an architect to generate specific plans for the development of the Penn Dixie Site. Figure 2 illustrates the 32.5-acre site, which includes a new entrance way (now in use); parking area (temporary parking area currently in place); plans for barrier-free nature trails (hard surface and boardwalks); excavation, reconstruction, and revegetation of the wetland areas; shelters and outdoor classrooms; information panels; facilities for an astronomy pad; a 10,000-square-foot outdoor education center building with classrooms and meeting rooms; and a commitment from the National Weather Service to install a complete climatological station on site upon completion of building construction. These exciting and ambitious plans continue to be the goal of the HNHS and are helping draw students of classic geology, stratigraphy, and paleontology and visitors to the site from all over the U.S., Canada, and the world.

GEOLOGY, STRATIGRAPHY, AND PALEONTOLOGY

The Penn Dixie Site contains an extensive exposure of 380-million-year-old fossiliferous Middle Devonian shales and limestones, serving as an excellent outdoor classroom for introducing students to the local geology and paleontology. The Genundewa Limestone, North Evans Limestone, Windom Shale, Tichenor Limestone, and Wanakah Shale at this site are readily accessible and have the most extensive exposure available for study in the Western and Central New York area. Figure 3 (Brett and Baird, 1982) illustrates the stratigraphic units present at the Penn Dixie Site. Prime exposures of these units are present (except for the West River Shale, which is mostly covered at the south end of the site). Brett (1974) and Brett and Baird (1982), along with Beuhler and Tesmer (1963), provide a detailed discussion of the stratigraphy and paleontology of these units. The warm tropical seas that covered this region of Western New York 380 million years ago, when the region was 20 to 30 degrees south of the equator, provided an environment conducive for a variety of invertebrate and vertebrate animals. The shales and limestones that formed during this time period preserved the remains of the diverse and abundant fauna that occupied these seas. The following brief discussion of the units present on the

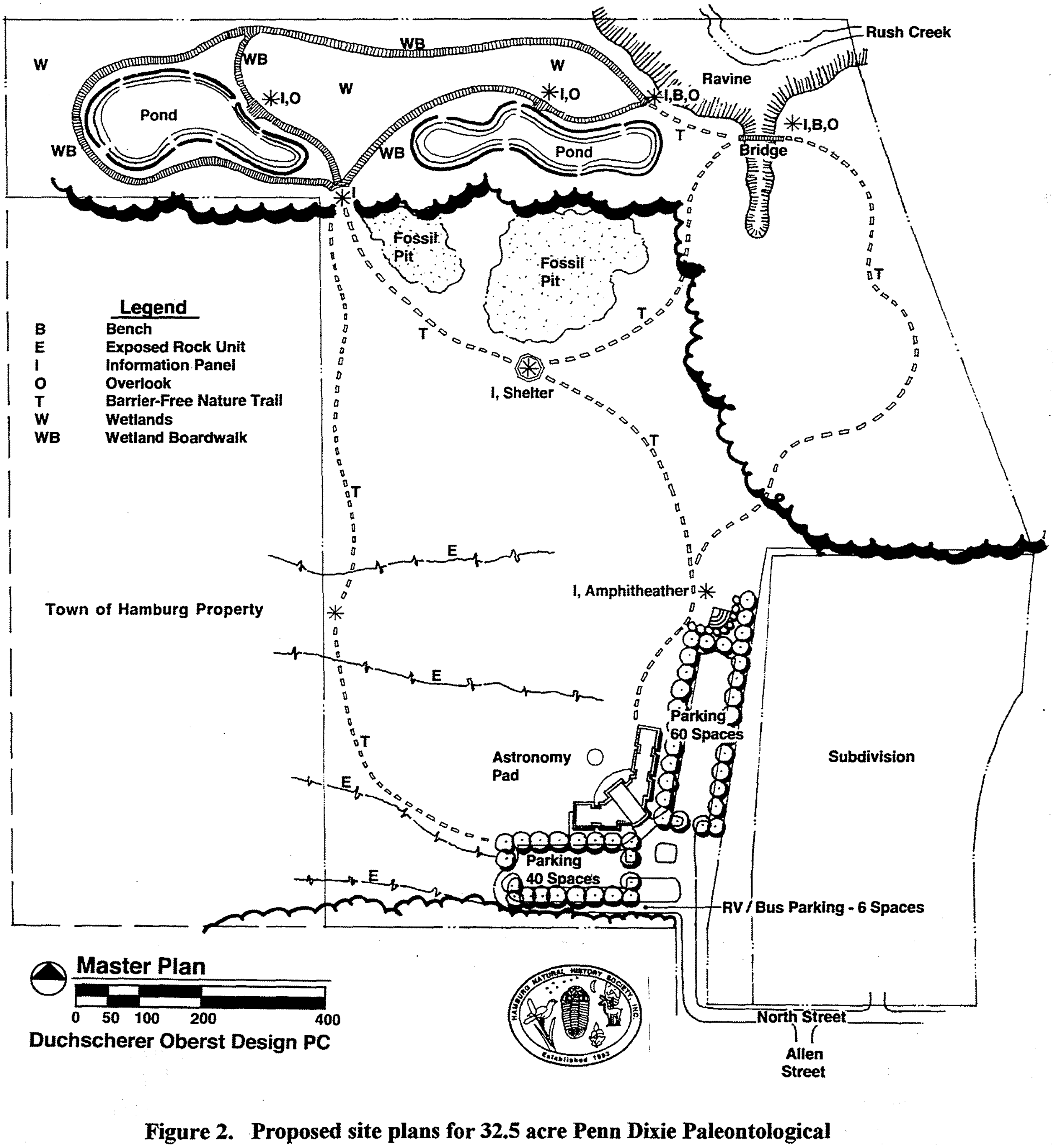


Figure 2. Proposed site plans for 32.5 acre Penn Dixie Paleontological and Outdoor Education Center in Hamburg, New York.

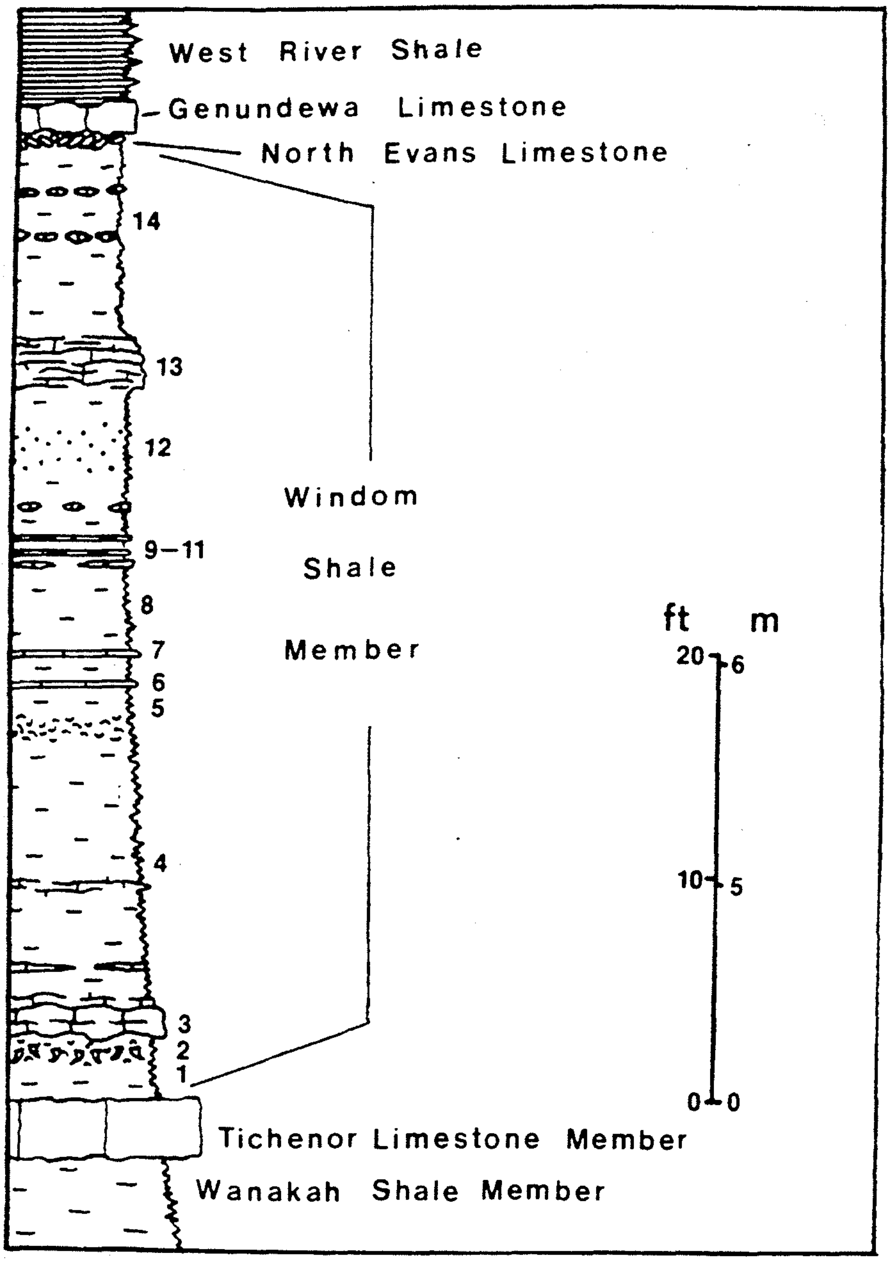


Figure 3. Stratigraphic units present at the Penn Dixie Site. Stratigraphic subdivisions of the Windom Shale Member; standard section at Penn Dixie and unnamed creek near Big Tree; Units include: 1) *Ambocoelia umbonata* beds; 2) Bay View coral bed; 3) Smoke Creek bed; 4) barren shale interval; 5) Big Tree bed; 6,7) A-B limestones; 8) Buffalo pyritic beds; 9-11) C, D, and E limestones; 12) Penn Dixie pyritic beds; 13) Amsdell bed; 14) upper *Ambocoelia*? *praeumbona*-bearing Shales. (Modified from Brett and Baird, 1982).

site begins with the lower Wanakah Shale at the north end through the West River Shale to the south.

Wanakah Shale

The Wanakah Shale is a medium gray to light-blue gray calcareous shale that weathers to a sticky clay. The Wanakah is exposed in the northeast section of the site in a tributary of Rush Creek and in the high banks on the south side of Rush creek. The tributary is a popular area for fossil collecting, as opposed to the steeper cliffs along Rush Creek. Brachiopods, bryozoans, trilobites, gastropods, pelecypods, echinoderms, corals, sponges, ostracodes, and some pyritized fossils may be found. Limited outcrop area in the tributary does not provide sufficient access for large groups.

Tichenor Limestone

The Tichenor Limestone overlies the Wanakah shale and outcrops at the northern end of the site. Pyrite coating the surface of the Tichenor has weathered, exhibiting a reddish-rusty color that stands out from the surrounding overlying gray Windom Shale. At the northeast section of the site, an unexplained domal feature of the Tichenor, with several feet of relief, is present. A large exposure of the eroded surface is adjacent to this feature and extends to the north to one of the on site ponds. This area is often referred to as "crinoid heaven" due to the countless number of pelmatozoan columnals that are found lying on the surface. The Tichenor Limestone contains corals, brachiopods, pelecypods, trilobites, bryozoans, and echinoderms, which are offer difficult to remove from the hard limestone. The Tichenor Limestone is approximately 1.5 to 2 feet thick and underlies most of the site, dipping to the south-southwest along with the other units on site.

Windom Shale

The Windom Shale is a medium to dark gray, variably calcareous mudstone with several thin argillaceous limestones, concretionary beds, and pyritic horizons (Beuhler and Tesmer, 1963). The Windom also weathers to a sticky clay. The Penn Dixie Site has the most complete and best exposure of Windom Shale in New York State, approximately 42 feet thick. Brett and Baird (1982) described 14 subdivisions within the Windom that could be recognized at this location (Figure 2). Fossil assemblage zones were described in Brett (1974) and Brett and Baird (1982). A disconformable basal contact with the Tichenor Limestone is exposed in the domal outcrop in the northeast section of the site. The upper Windom beds have been scoured, and shale clasts can be observed in the overlying North Evans Limestone. The Windom contains a variety of corals brachiopods, pelmatozoan columnals, bryozoans, trilobites, gastropods, pelecypods, cephalopods, and fish remains. The weathering of the shale exposes thousands of specimens lying on the surface, waitng to be found after 380 million years. Enrolled trilobites can be commonly found washed out of the shale after a good rain storm, along with horn corals, brachipods, and pelmatozoan columnals. Sections of the Windom are not as fossiliferous as others, but careful study of the stratigraphic subdivisions identified by Brett and Baird (1982) will yield some interesting discoveries.

North Evans Limestone

The North Evans Limestone is a buff-colored, weathered dark-gray crinoidal limestone that is 1.5 to 4 inches thick and contains angular clasts derived from the underlying Windom Shale. Erosional lag concentrations of hiatus concretions, pelmatozoan fragments, conodonts, fish plates, teeth, and mandibles, along with some brachipod valves, are present (Brett and Baird, 1982). Although a variety of fish remains have been found at the Penn Dixie Site, they are difficult to find even with the good exposure of North Evans present. The buff-colored weathered surface of the North Evans and bone material make this unit easily recognizable.

Genundewa Limestone

The Genundewa Limestone is a nodular, medium dark-gray, poorly bedded limestone that weathers to a light gray, which has been referred to as the "Styliolina Limestone" directly overlying the North Evans (Beuhler and Tesmer, 1963). This limestone unit is .5 to 1.2 feet thick, containing pelmatozoan columnals, cephalopods, brachiopods, wood fragments, and fish fragments (Brett and Baird, 1982). The carbonized wood can frequently be found, but other examples of the fauna are more difficult to obtain.

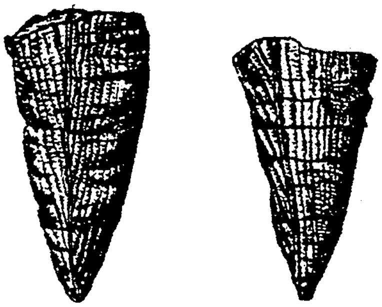
West River Shale

The West River Shale is dark gray to black in color and overlies the Genudewa Limestone. Most of this unit is covered by overburden at the Penn Dixie Site and Eighteen Mile Creek provides a better opportunity to view this unit. Conodonts, cephalopods, pelecypods, and fish remains have been reported from the West River Shale at other localities in Western New York (Beuhler and Tesmer, 1963).

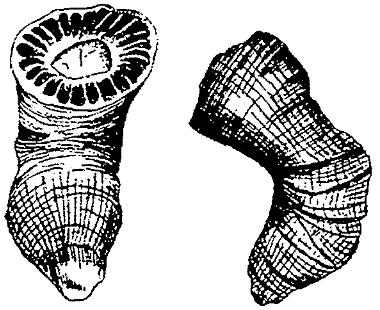
The preservation, diversity, and abundance of fossils at the Penn Dixie Site makes this an excellent site for students and amateur and professional paleontologists to be introduced to Western New York geology and paleontology. Plates 1 through 4 illustrate some of the more common fossils that can be found at the Penn Dixie Site. Weathering of the Windom Shale results in many corals, brachiopods, pelmatozoan columnals, and trilobites being continually exposed. Those who extend the effort to dig into the shale are rewarded with an extensive introduction to the variety of fossils preserved within the Windom. The northern section of the site provides an excellent outdoor classroom for students and visitors to be introduced to fossils and the local geology.

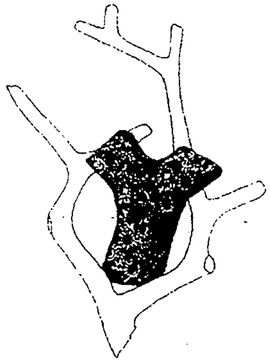
Plate 1
Fossils of the Penn Dixie Site

CORALS

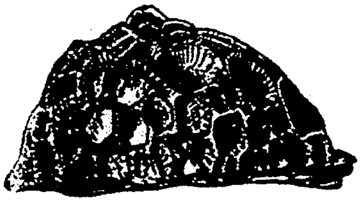

Sterolasma rectum


Cystophyllum americanum

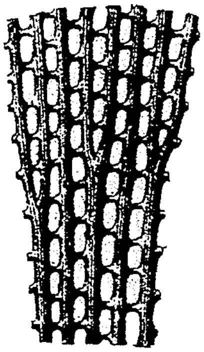

Amplexiphylum hamiltoniae

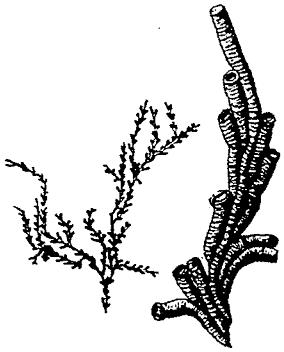

Trachypora sp.

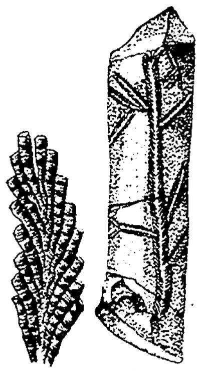

Favosites hamiltomiae


Pleurodictyum americanum

BRYOZOANS


Fenestella sp.


Hederella sp.

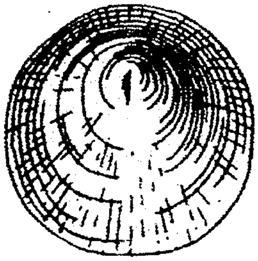

Reptaria stolonifera

Drawings from "Geology and Palaeontology of Eighteen Mile Creek" by Amadeus Grabau
Plates compiled by Scott Clark

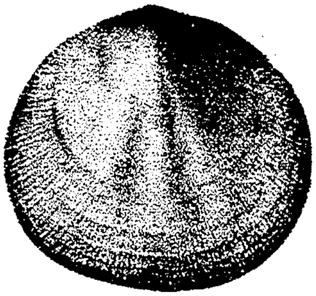
Plate 2

Fossils of the Penn Dixie Site

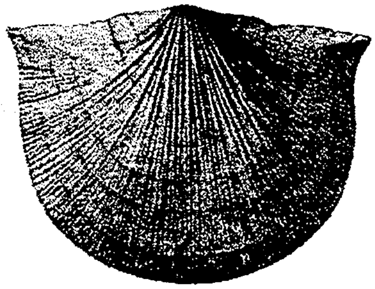
BRACHIOPODS



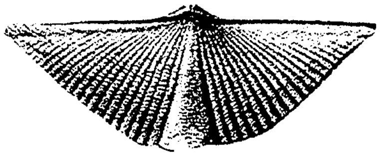
Orbiculiodea sp.



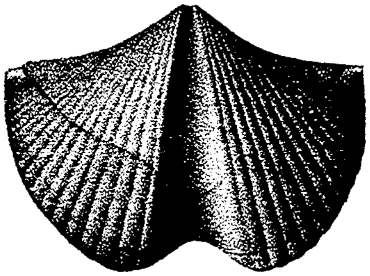
Rhipidomella sp.



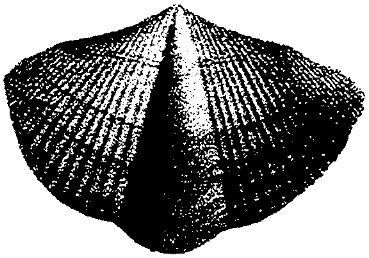
Stropheodonta demissa



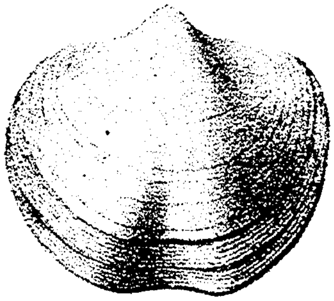
Mucrospirifer mucronatus



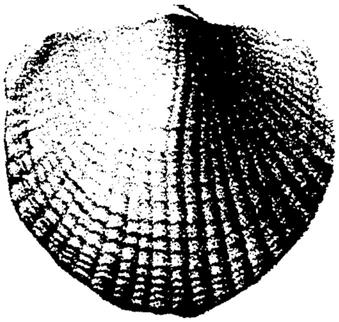
Spinocyrtia granulosa



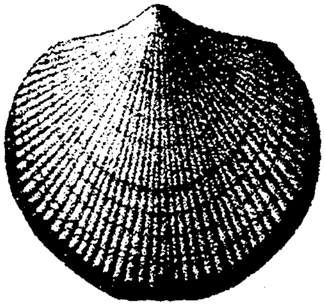
Mediospirider auduculus



Athyris spiriferoides



Spinatrypa spinosa

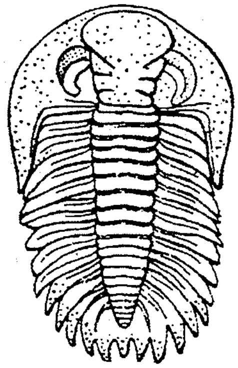


Pseudoatrypa devonica

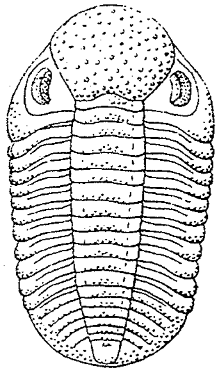
Drawings from "Geology and Palaeontology of Eighteen Mile Creek" by Amadeus Grabau
Plates compiled by Scott Clark

Plate 3
Fossils of the Penn Dixie Site

TRILOBITES

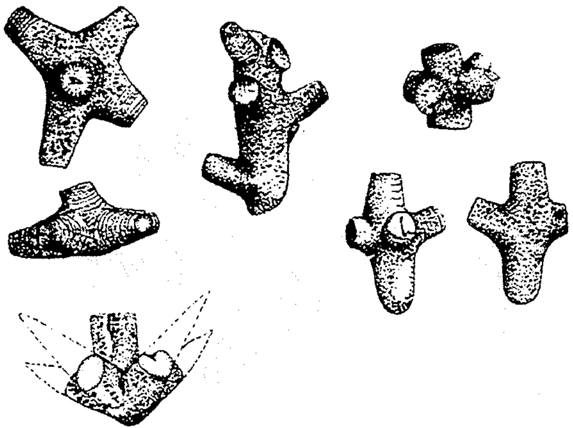


Greenops boothi

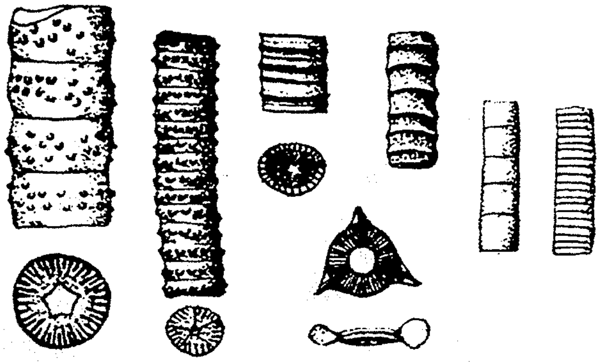


Phacops rana

CRINOIDS



Ancyrocrinus bulbosus

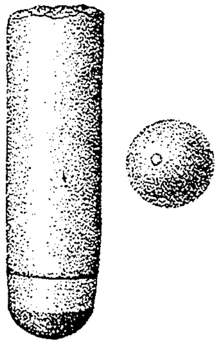


Various Crinoid segments

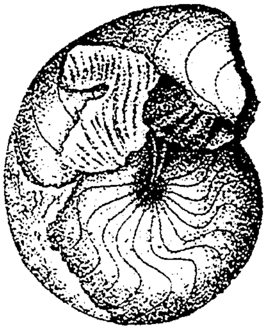
Drawings from "Geology and Palaeontology of Eighteen Mile Creek" by Amadeus Grabau
Plates compiled by Scott Clark

Plate 4
Fossils of the Penn Dixie Site

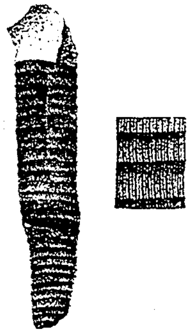
CEPHALOPODS



Michlenoceras sp.

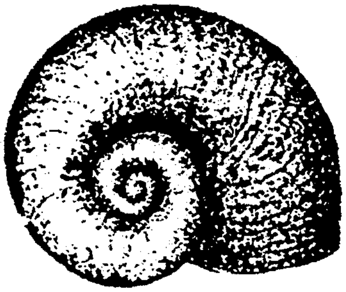


Tornoceras uniangulare



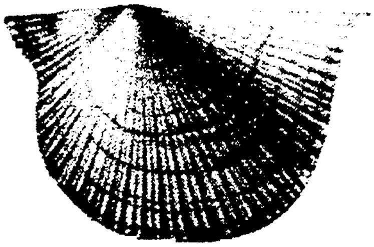
Spyroceras sp.

GASTROPODS

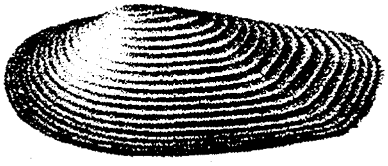


Naticonema lineata

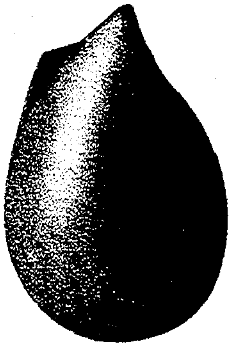
PELECYPODS



Pterinopecten sp.



Palaeoneilo sp.



Plethomytilus sp.

Drawings from "Geology and Palaeontology of Eighteen Mile Creek" by Amadeus Grabau
Plates compiled by Scott Clark

CURRENT PROGRAMS AT PENN DIXIE

The opportunity to actually find and collect ancient creatures that roamed the seas of Western New York 380 million years ago fascinates children and adults alike. The opportunity to collect and keep their fossil specimens amazes many visitors. The Penn Dixie Site provides an opportunity to open a whole new world of geology and paleontology to students, scouts, senior citizens, and the general public. It has also provided an outdoor educational experience for many hearing impaired, visually impaired, and physically disabled individuals. The preservation of this site has been extremely important. Commercial and residential development, along with landowners no longer permitting access to their property, have made many fossil collecting sites no longer accessible. In addition, the Penn Dixie Site can accommodate large groups, whereas many stream beds, road and railroad cuts, and shoreline exposures can not. Attempts to preserve collecting sites, such as Penn Dixie, must be made, or many classic collecting locations will be lost for future generations to visit and study.

The HNHS is an all volunteer organization that provides monthly "public day" programs to collect fossils and evening astronomy events at the Penn Dixie Site. In addition, birding programs were initiated in 1999 to view the more than 148 migratory and nesting bird species documented on site. Society volunteers provide weekday programs to school groups, introducing students to the local geology and fossil collecting. Weekend trips are also scheduled for scouts, families, birthday parties, universities, and amateur groups that regularly visit the site from Michigan, New York, Ohio, Pennsylvania, and West Virginia. Along with visitors who have come from all over the United States, individuals and families from Australia, Canada, Ecuador, England, Germany, and Japan have found the site exciting and educational. Visitors are provided a brief introduction to the local geology and the best collecting areas on site. Fossil identification cards, an illustration of what the area was like 380 million years ago, and a stratigraphic cross section are provided to visitors. First-time visitors and/or those who are just beginning to be introduced to paleontology and fossils learn quickly to develop their eyes to recognize the fossil forms. Once this is accomplished, they are amazed at how many specimens are lying on the surface. The volunteers also provide an introduction to the site, help everyone locate fossils, and encourage the visitors to think about what the environment was like during the Middle Devonian, when there was no land mass present in Western New York.

Several of the Society's public day programs have become very popular with the public, drawing from between 240 to 1,400 children and adults at an event. The June Children's Day program has, for the past few years, attracted 400 children and adults annually. Fossil contests to find the largest horn coral, the pelmatozoan columnals with the most articulated segments, and the total number of fossils in the jar grasp the children's interest. Prizes are awarded to the winners and then all the other children attending receive prizes. *Dieonychus*, a 70-millon year old dinosaur representative (Dr. Donald Birdd) and "Tilly the Trilobite" (Peg Hermann) welcome visitors. The solar system is

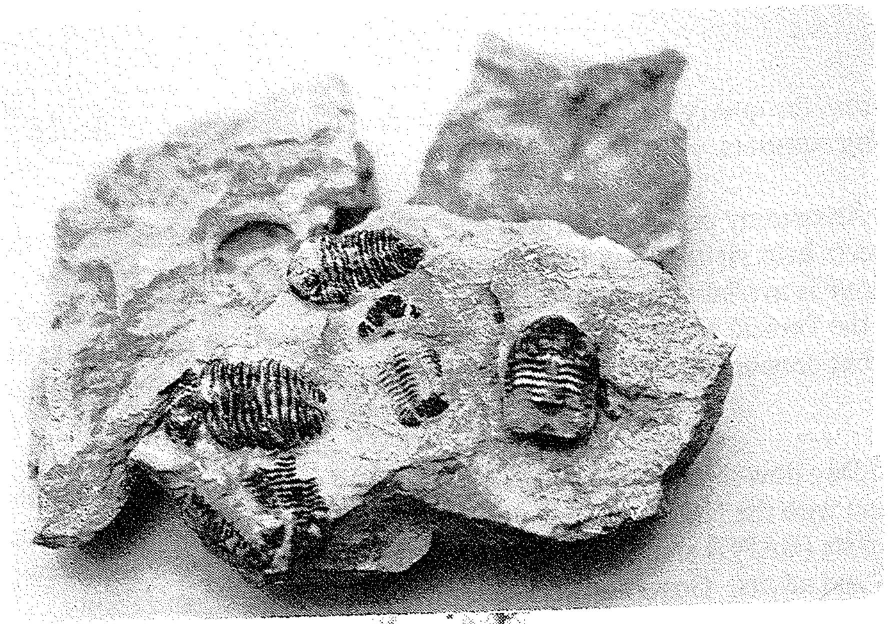


Figure 4.
Windom Shale slab containing 5 complete trilobites, *Phacops rana* (Green), collected in August 1996 by Lorraine Haibach of Pennsylvania at the Penn Dixie Site. (Photo by Candi Simmons of PA).

Figure 5.
"Spring Birding at Penn Dixie" group led by Michael Morgante and Micahel Turisk on April 18, 1999. (Photo by J. Bastedo).

Figure 6.
HNHS Board Member Dr. Thomas Kinsey introducing *Dieonychus* (Dr. Donald Birdd) and "Tilly the Trilobite"(Peg Hermann) at the Annual June Children's Day program.

laid out to scale across the quarry floor, and volunteers make a Dobsonian telescope available for viewing sunspots.

The August Fossil-Astronomy program starts in late afternoon during the cooler portion of the day. Volunteers help visitors find fossils and, prior to the evening astronomy program, the telescope is available to view sunspots. The main feature of the evening program is to view the Perseid Meteor Shower, which peaks in early to mid-August each year. The weather has cooperated for two of the four years, and meteors were seen each of those years.

The October Public Day now features the Western New York Earth Science Day, which is held in conjunction with the National Earth Science Week. The Buffalo Association of Professional Geologists (BAPG) and the HNHS co-hosted this event I 1998 and drew over 1,400 children and adults. Governmental agencies, companies, organizations, schools, universities, and businesses that employ earth scientists or geologists were invited to offer an exhibit to explain what geologists do and answer questions from the public. A local drilling company provided a drill rig and crew to demonstrate installation of a groundwater monitoring well and rock-coring procedures. The exhibits and drilling demonstrations were free. Fossil collecting was also available for a nominal charge to non-members of the HNHS. The 2nd Annual Earth Science Day is scheduled for October 16, 1999, at the Penn Dixie Site from 9 AM to 3 PM with over 21 groups exhibiting, a drill rig providing demonstrations at 10:30 and 1:30 PM, and fossil collecting.

During May, July, and September, public day programs are held for fossil collecting that are becoming very popular with the public and groups visiting Western New York. The HNHS attempts to accommodate as many groups and individuals as possible with the volunteers available. Many families request an opportunity to visit the site, and the HNHS attempts to combine their visit with other groups or individuals. All visits to the Penn Dixie Site must be scheduled through the HNHS.

Many professionals now working in public schools, at universities, in the oil and gas field, as environmental geologists, at museums, and a variety of earth science or geological positions have passed through the Penn Dixie Site in the early development of their careers. In addition, many individauls who took an introductory geology course in college frequently return to the site to introduce their children to the geologic past.

FUTURE PLANS

The Penn Dixie Site is owned and operated by the HNHS. Four officers and eight directors administer the Society and are supported by 50 to 60 active volunteers and over 300 members. Twenty percent of the membership is from out of state, with some members in Canada and Japan. Seven membership categories–Student, Individual, Family, Associate, Corporate, School, and Life–help support the operations of the Society. All life membership dues are placed in an endowment fund to be used for operating the Penn Dixie Site. All the programs and activities of the HNHS are provided

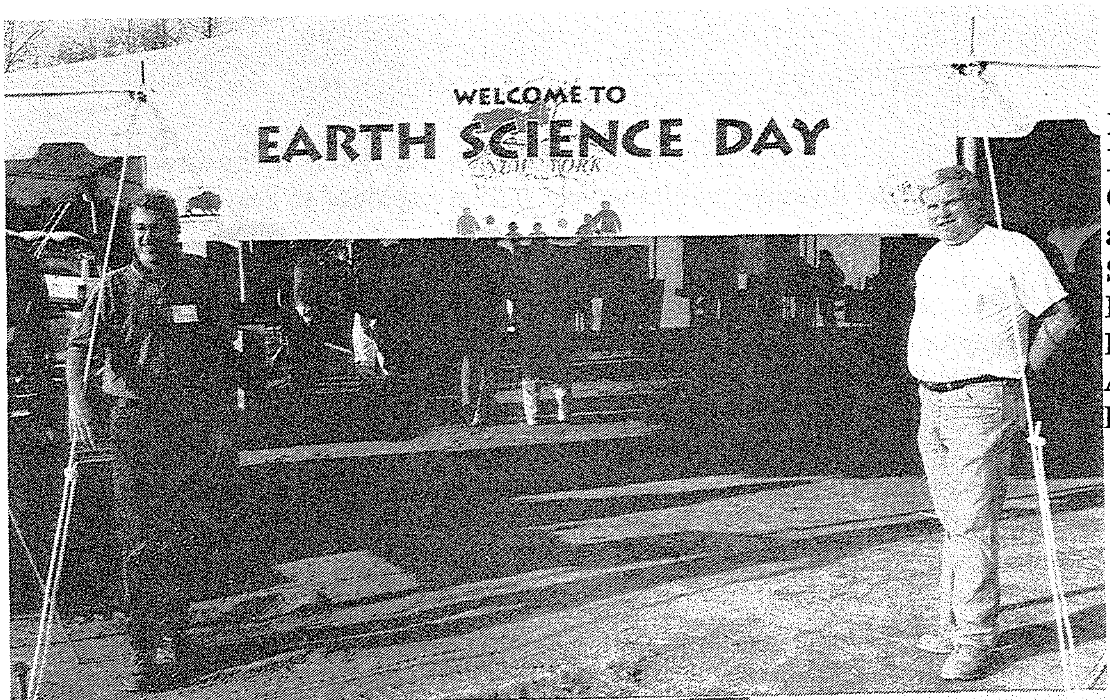


Figure 7.
Earth Science Day October 17, 1998 at the Penn Dixie Site. Co-Chairmen Richard Watt (L), BAPG President, And Jerry Bastedo, HNHS President.

Figure 8.
HNHS members Paul and Peg Zimmer insructing Bernadette Tomaselli on viewing sunspots at the October 17, 1998 Earth Science Day program.

Figure 9.
Maxim Technologies, Inc. demonstrating drilling & coring procedures on Earth Science Day. The drill rig is in the background and a direct push rig in the foreground.

by volunteers. In addition to the development of site facilities, the HNHS looks forward to the day when part-time and full-time staff members will be employed to help provide outdoor educational programs.

The HNHS employs a part-time development consultant to raise funds for the educational programming and capital development of the Penn Dixie Site. The Society also has a part-time accountant on retainer to assist with the annual financial review and provide financial advice.

In 1997, the HNHS contracted an architectural firm to provide a design and cost estimate for a parking area, barrier-free nature trail, outdoor education center, outdoor classroom areas, and an astronomy pad for evening programs (see Figure 2). A $1.75 million fund raising campaign began in November 1997 to raise funds for these capital improvements and provide the much-needed bathroom facilities. The Society initiated a $1,000 Club pledge, with installments to be made over three years, designated for the construction of the building. HNHS members, corporations, foundations, banks, governmental funding sources, amateur and professional geological groups, and other funding sources have been, and continue to be, approached to aid in attaining the Society's capital fund goal. The officers were aware that this would be an ambitious road to travel, but progress is being made. A new entranceway was installed in May 1998 off of North Street; a locking gate was installed to keep dumpers and ATVs off the site; site cleanups were conducted in 1996 and 1998; a Penn Dixie entranceway sign was installed in July 1999; funds have been acquired to install information panels and a covered outdoor classroom (plans are to have installation begin in Fall 1999); funds have been obtained in1998 and 1999 to help with educational programs; the barrier-free nature trail has been flagged; and in October 1999 the nature trail will be cleared through the leadership of an Eagle Scout candidate and his scout troop. Fund-raising efforts continue, and the officers are continually searching for additional opportunities to pursue funds.

Simultaneous with fund-raising efforts, educational programs for schools, scouts, families, public days, and amateur and professional geologists continue to increase every year. The Society anticipates expanding the educational programming with qualified volunteers, and eventually staff, to augment a variety of courses in the natural sciences. Upon completion of the outdoor education center building, the National Weather Service has committed to installing a complete climatological station at the Penn Dixie Site.

The HNHS appreciates the support it has received from volunteers, corporations, foundations, governmental agencies, and private individuals to offer outdoor educational programs and to develop the Penn Dixie Site. The HNHS has one of the finest and most dedicated groups of volunteers. The volunteers provide the programs, help develop and maintain the site, and provide the ideas that establish the future directions and goals of the Society. The HNHS is especially appreciative of the leadership efforts and support provided by Mark Cavalcoli, Hamburg Town Councilman, and the Hamburg Town Board for acquisition of the Penn Dixie Site. Their continued support of the educational programs and site development is greatly appreciated.

The HNHS was founded in 1993 to promote the study of the natural sciences with an emphasis on the field activities associated with the geological and biological sciences; to develop, administrate, and maintain the Penn Dixie Paleontological and Outdoor Education Center in Hamburg, New York; promote a regional fossil collecting site to foster and encourage a medium for the public to study and collect fossils; encourage and promote upper-level training of in-service and pre-service teachers; and to aid in obtaining and administering funds to promote the study of natural history in Western New York. The current plan for the Penn Dixie Site is to provide outdoor education programs in the natural sciences for students and visitors to have a hands-on experience. If you are interested in helping support the goals of the Society and visiting the Penn Dixie Site, contact the HNHS at (716) 627-4560 or P.O. Box 772, Hamburg, New York 14075. Your support of the outdoor educational programs offered by the HNHS will be greatly appreciated. As a non-profit organization, all donations are tax deductible.

ACKNOWLEDGEMENTS

I thank Julie Sacco Bastedo and Stephen McCabe for their critical review of this manuscript. Scott Clark compiled the fossil plates of specimens that may be found at the Penn Dixie Site and the Penn Dixie location map. I also thank the HNHS members and volunteers who have unselfishly provided their time and talents to the development of the Penn Dixie Paleontological and Outdoor Education Center.

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ROAD LOG FOR PENN DIXIE SITE VISIT

Total Miles	Miles from last point	Route Description
		Leave Fredonia Campus and take the NYS Thruway to Exit 56 where the road log begins.
0.0	0.0	BEGIN ROAD LOG AT INTERSECTION OF TOLL BOOTH EXIT & RT. 179.
0.2	0.2	At Rt. 179, turn right (north) to intersection of U.S. Rt. 62, South Park Avenue. Turn left (south) onto South Park Avenue.
1.3	1.1	Continue on South Park Avenue to intersection with Big Tree Rd. Turn right (west) onto Big Tree Rd.
1.6	0.3	Cross over single railroad track and at interesection of first road, turn right onto Bristol Road.
1.8	0.2	Continue north on Bristol Rd. to North St. Turn left (west) on to North St.
2.0	0.2	Continue west to entrance road of the Penn Dixie Paleontological and Outdoor Education Center and meet in the parking area on site. The field trip will begin with an introduction to the Penn Dixie Site and a visit to the important exposures and fossil areas present on the site. Representative fossils preserved in the Genundewa and North Evans Limestones, Windom Shale, Tichenor Limestone, and Wanakah Shale may be collected.

"Nunda Sandstone" Depositional Event in the Pipe Creek Black Shale, South Wales – Varysburg Area, New York

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ABSTRACT

The Upper Devonian (Frasnian) Nunda Member of the West Falls Formation is characterized by siltstones and sandstones of gravity flow origin, and is marked by distinctive, thick sandstone units at its top in southern Wyoming County, New York. Recent study of these thick, culminating beds shows that the shales and thin sandstones interbedded with most of the thick sandstones can be correlated westward with the Angola Shale Member, whereas the uppermost massive layers of the Nunda are interbedded with black shales of the Pipe Creek Member-succession. Hence, the Angola-Pipe Creek boundary extends eastward into the uppermost part of the Nunda succession; for this reason we herein refer to Angola-equivalent sandstones as Nunda and Pipe Creek-equivalent sandstones as "Nunda."

Both the Nunda and "Nunda" intervals thicken eastward and southeastward impressively near South Wales in eastern Erie County, and massive 3-6 m thick sandstone beds develop in the uppermost Nunda and "Nunda" in Wyoming County. "Nunda" facies is expressed as grey to brown, micaceous sandstone that can be laminated, massive or chaotic. The "Nunda" succession typically displays a sharp basal contact with silty grey, Angola-type mudstone beds as well as with the basal part of the Pipe Creek shale but has a complex interfingering relationship with overlying Pipe Creek shale deposits. Locally the "Nunda"-Pipe Creek lithologic boundary is characterized by disturbed bedding. Sharply defined olistoliths observed within the lower part of the "Nunda" in two localities are composed of Pipe Creek-type black shale clasts including one observed clast displaying what is probably the Angola-Pipe Creek contact. This evidence suggests that the "Nunda" records one or more large gravity flow events that occurred during the time of Pipe Creek black mud deposition and which, at least locally, scoured up the Angola Shale-Pipe Creek Shale contact.

INTRODUCTION

The Late Devonian (Upper Frasnian) Pipe Creek Member of the West Falls Group is an important correlational marker in sections mainly west of the Genesee Valley (Pepper and DeWitt, 1950; Pepper et al., 1956; Richard, 1975; Van Tyne, 1982). In Erie and northernmost Chautauqua County it overlies the Angola Shale Member, a heterolithic succession of nodular grey silty mudstone, grey mudstone with nodular pyrite horizons, and thin black shale units (Tesmer, 1963; Buehler and Tesmer, 1963). Thicker siltstone and sandstone beds appear in the upper Angola in the vicinity of West Falls in Erie County; this coarse facies (Nunda Member) rapidly thickens eastward from there, particularly in the vicinity of South Wales (Jacobi et al., 1990; Jacobi et al., 1994). Farther east, in the Java Village-Johnsonburg area in Wyoming County, a succession of turbiditic sandstone layers capped by massive (4-7m thick) sandstone beds occurs below the Pipe Creek black shale (Pepper et al., 1956; Jacobi et al., 1994). Jacobi et al., (1990, 1994) noted that the Nunda sandstone beds displayed abrupt terminations instead of grading distally into thinner turbiditic layers. Moreover, these same researchers showed that 1) higher sandstone beds distinctly thin over differentially thickened underlying beds, suggesting that the sand accumulations had positive relief on the seafloor, and 2) flow directions in the sandstone suggested a lobate geometry to these sand bodies. This information indicated to Jacobi et al., (1990, 1994) that the thick Nunda sandstones represent sand lobes on a submarine fan. These lobes were generated by sand-rich gravity flows characterized by inefficient, viscous internal hydraulics. These characteristics contrast with evidence for sand-poor, efficient flow in thin, turbiditic sandstones observed lower in the section (Jacobi, et al., 1990,1994).

One of us (Baird), while examining the regional basal contact of the Pipe Creek Shale, noticed the abrupt eastward appearance of "Nunda"-type sandstone within the basal part of the Pipe Creek beginning in gullies immediately west of the Village of South Wales. East of the village in a ravine north of Warner Hill Road (**Fig. 1**), thicker sandstone beds appears in the basal Pipe Creek, and contorted sandstone

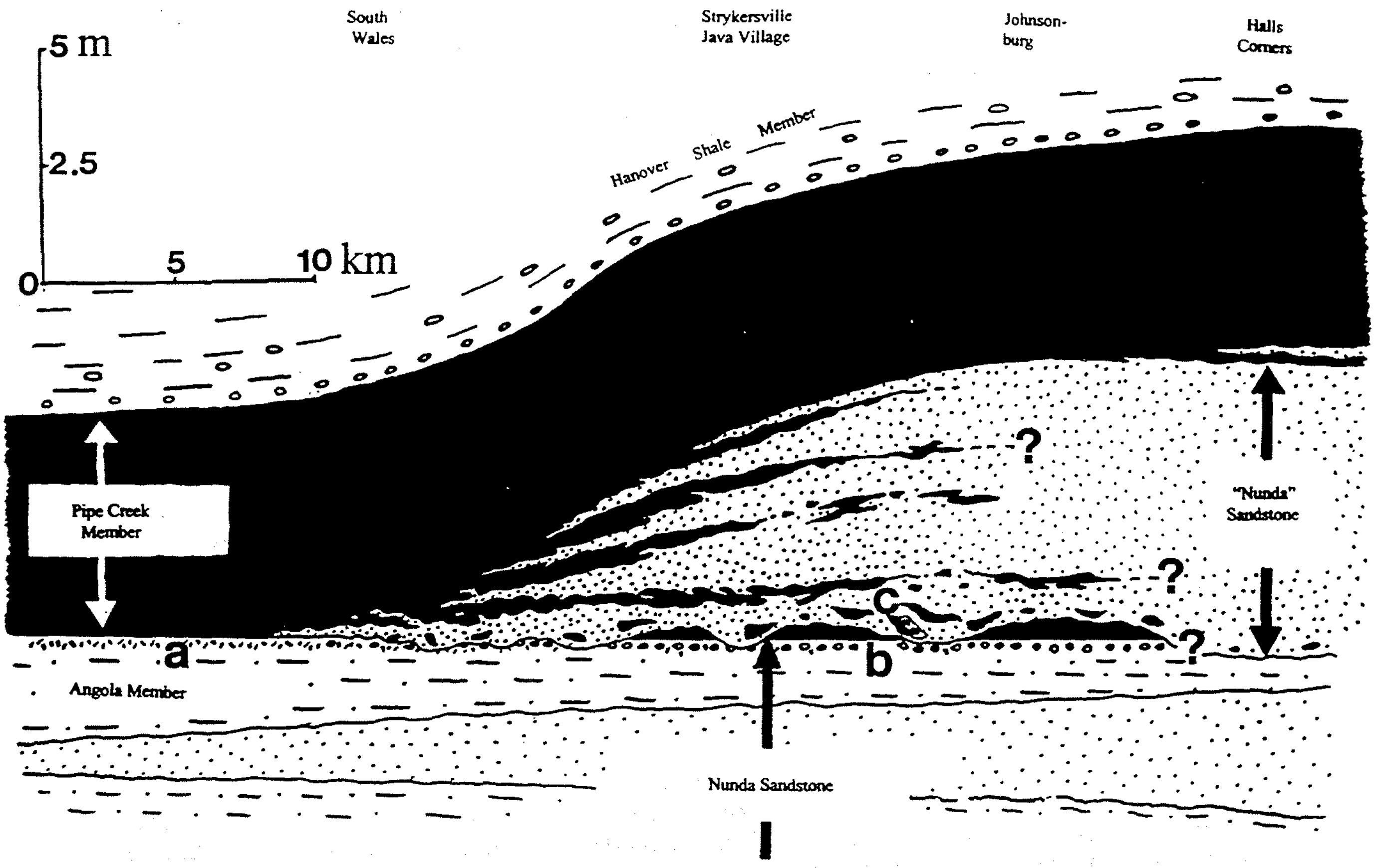


Figure 1. Generalized east-west cross-section of the Pipe Creek Member and associated stratigraphic units in the region between West Falls and Warsaw, New York. Note relationship between the Pipe Creek black shale and the complex "Nunda" sandstone which is interpreted to be the product of several major gravity flow events (see text). Lettered features include: a, pyrite-rich zone of Angola Shale below Pipe Creek member in eastern Erie County; b, carbonate nodule-rich zone below lower contact of probable Pipe Creek shale in non-eroded inlier below "Nunda" sandstone; c, olistolith showing exhumed Angola-Pipe Creek contact. Question marks denote uncertainty as to the position and character of the Nunda-"Nunda" contact where the sandstones appear to be juxtaposed southwest of Warsaw, and as to whether discrete "Nunda" beds within Pipe Creek in the Strykersville area amalgamate eastward to give the impression of a single massive flow event or whether the massive bed in the Johnsonburg-Halls Corners area is truly a single event.

intermixed with black shale appear above the basal sandstone. Similarly, Jacobi et al. (1990, 1994) noted disturbed beds in the "Nunda" at this locality as well as the rapid increase in underlying Nunda thickness in this area. To the east and southeast of the South Wales-Holland area, very thick, massive sandstones appear near the top of the Nunda interval with maximum observed bed thicknesses of several meters (**Fig. 1**). In the Strykersville-Johnsonburg area of Wyoming County, the thick, massive culminating beds usually number two to three in sections and they locally overly thin erosional remnant inliers of Pipe Creek black shale (**Fig. 1**).

It is significant that the base of the Pipe Creek shale can be traced eastward into the interval of thick sandstone development (Fig. 1). This means that there is an Angola-equivalent Nunda sandstone succession and a Pipe Creek-equivalent "Nunda" sandstone; for purposes of discussion herein we refer to all massive, laminated and contorted sandstone within the Pipe Creek sedimentary package as "Nunda" with quotation marks since this unit is, as yet, unnamed. This paper provides a brief description of the "Nunda" facies and a discussion regarding its regional significance with respect to surrounding facies.

"NUNDA SANDSTONE"

The base of the Pipe Creek Shale in the West Falls and Emery Park areas of Erie County is sharp, but apparently non-erosional; approximately 5m of hard Pipe Creek black shale rests abruptly on bioturbated silty green-grey mudrock of the Angola Shale in this area. One persistent Nunda sandstone layer extends westward to the west branch of Cazenovia Creek at West Falls, but much of the West Falls succession is mudstone in this region (Buehler and Tesmer, 1963; Jacobi, et al., 1990, 1994).

At Emery Park, however, the base of the Pipe Creek Shale contains a dilute fraction of micaceous sand above the upper Angola contact. In the gully paralleling Darling Road 1.5 km (0.9 mi) west of South Wales, the basal 8-10 cm of the Pipe Creek is marked by a mud-rich micaceous sandstone containing a breccia of black shale clasts (Fig 2c). This unit displays a sharp basal contact on the Angola, and appears to represent the northwestern limit of the "Nunda" as a recognizable unit. To the south and east of South Wales the "Nunda" sandstone thickens to a meter or more in tributary localities bordering the East Branch of Cazenovia Creek; typically it displays a sharp base on the Angola, displays horizontal internal lamination, and grades upward into the Pipe Creek through a transitional zone of micaceous, sandy black shale. However, in an unnamed ravine 0.25 km (0.15 mi) north of Warner Hill Road and 0.7 km (0.4 mi) east of South Wales, 0.5 m of "Nunda" sandstone is overlain by a 0.6 m zone of complexly interlayered and contorted black shale and sandstone blocks that pass upward into uniform black shale. At this locality the sand appears to have been injected into soft, but coherent black mud that peeled and rolled as the sand surged through it. The resulting "ice cream roll" fabric is a freeze-frame image of this deformation.

East of the East Branch of Cazenovia Creek, the "Nunda" thickens dramatically into a massive brown sandstone body that caps waterfalls on area creeks. In the Java Village, Strykersville, and Johnsonburg areas of Wyoming County, this sandstone interval can reach thicknesses of 6 and 7 m! (Fig. 1). The base of the "Nunda" is sharp both on Angola-type grey, nodular, silty mudrock facies and on thin intervals of basal Pipe Creek shale that are locally present, whereas the upper boundary grades complexly into the Pipe Creek. For example, at Angel Falls in Java Village (**STOP 2**) the massive "Nunda" facies at the falls rests abruptly on a 8-9 cm-thick black shale unit that appears to be a basal erosional remnant of the Pipe Creek Member. However, the "Nunda" grades upward into the Pipe Creek succession. Examination of the highest sand-rich interval at this locality reveals sheets and pods of brown sandstone complexly intermingled with black shale clasts and masses through an interval of approximately 75 cm-thickness. Much of the black shale occurs in brecciated pieces ("broken formation"), but some of the texture suggests a soft-sediment condition for both the black mud and sand (Fig. 2a, b).

On a small, west-flowing tributary of Cayuga Creek that borders the east edge of the Bryncliff resort (0.4 km [0.25 mi] south of U.S. Route 20 east of Parsons Corners), the "Nunda" reaches the greatest overall complexity of any section so far observed. It is expressed as two or more brown sandstone units complexly interlayered with darker sandy Pipe Creek shale. The basal "Nunda" sandstone unit displays a sharp base on the grey (Angola-type) mudstone lithology. Although the Pipe Creek shale is not observed to underlie this basal sandstone at this locality, clasts of Pipe Creek shale and carbonate nodules typical of the uppermost Angola Member occur reworked at the base of the "Nunda". In adjacent sections where the basal Pipe Creek contact is intact, these same nodules characterize the intensely bioturbated 15 cm interval of underlying Angola-type facies. Within the thick basal sandstone are coherent olistoliths of Pipe Creek-type black shale. Below the "Nunda" interval on this creek are two lower Nunda sandstone beds that overlie Angola Shale at the base of the section. Above the 6-7m "Nunda" interval is a 6-7m succession of black Pipe Creek shale.

In creeks near Johnsonburg, still farther east, the "Nunda" sandstone becomes even thicker (Fig. 1). In a ravine below the Hickory Hill Camp (1.6 km [1.0 mi] northwest of Johnsonburg), the "Nunda" sandstone is approximately 6 m-thick. In this section at the base of the "Nunda" interval is 0.5 m of Pipe Creek shale that rests abruptly on nodular grey mudstone. Downstream from the nodular mudstone level is a thick Nunda sandstone bed and still lower, less thick sandstones and associated silty grey mudstone layers.

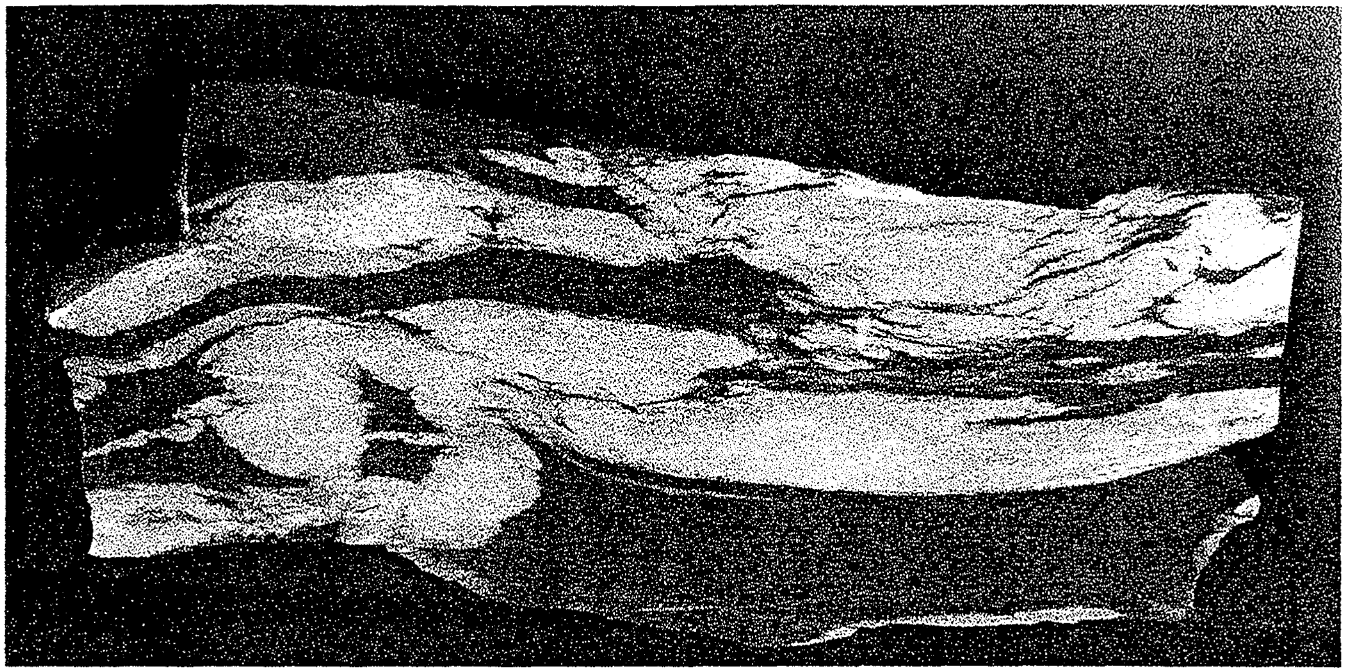
"NUNDA" DEPOSITIONAL EVENT

Most siltstone and sandstone beds in the Nunda succession have been attributed to gravity flow processes associated with westward-northwest progradation of the Late Devonian Catskill Delta (Sevon and Woodrow, 1985; Broadhead, et al., 1982; Jacobi, et al., 1990, 1994). Most observed layers are relatively thin C- and D- starting turbidites that are tabular in outcrop, many displaying sole mark features consistent with a turbidite origin. The thin beds are numerous and appear to be the products of efficient, highly fluidized gravity flows associated within a probable radial turbiditic fan system (Jacobi, et al., 1990, 1994).

In contrast to the thin turbiditic beds are the aforementioned massive sandstone units that are far less common in outcrop. These typically display non-graded, laminated to structureless interiors and often spall into conchoidal pieces in outcrop. As noted above, the "Nunda" sandstone displays local disturbed bedding features and is quite complex. Jacobi, et al. (1990, 1994) believed that the massive beds were the products of inefficient, sand-rich density flows and that such flow events were probably distinct in origin from those responsible of the thin, graded siltstone and fine sandstone beds elsewhere in the section.

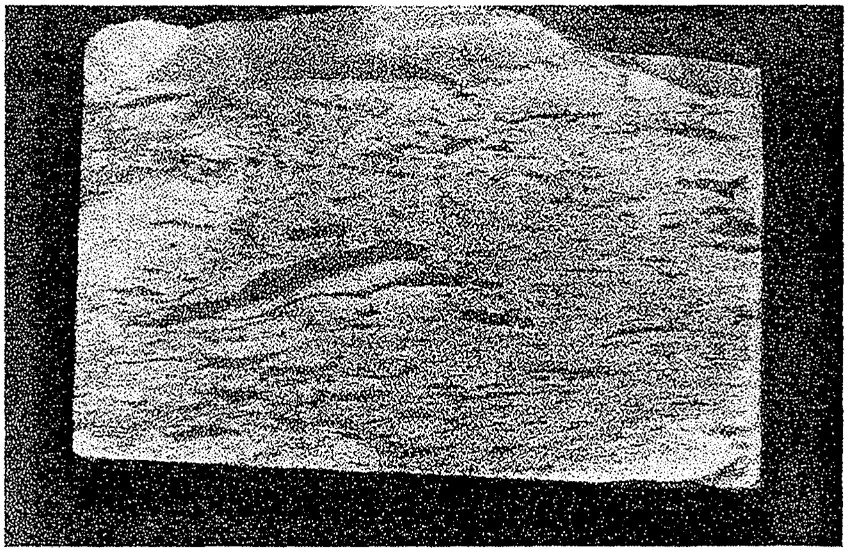
A key question concerns the timing of the "Nunda" gravity flow events relative to the onset of Pipe Creek black mud deposition. Were the "Nunda" events synchronous with the earliest black mud accumulation or did they occur well after that time? We believe that initial deposition of the "Nunda" sand flow events occurred well after onset of black mud deposition because "Nunda" sandstone apparently overlies the basal part of the Pipe Creek in several sections. In particular, we observe olistoliths of, at least, partly lithified Pipe Creek black mudstone within the "Nunda". These indicate that the already deposited black mud had been sheared off of the seafloor during one or more "Nunda" flow events. Most significantly we observe in a ravine 1.0 km (0.6 mi) north of Java Village a detached olistolith of Pipe Creek lithology displaying a bedding contact with Angola-type mudstone adhering to it. This suggests that the Angola-Pipe Creek contact, once present in the region, was sheared off and incorporated into the flow system at least locally (Fig. 1). Although soft-sediment interaction of the higher "Nunda" sands with minimally consolidated Pipe Creek deposits may be the result of later, minor flow events emplaced onto water-rich Pipe Creek muds, large sand fluid-escape structures (sand blows) suggest that some of the deformation may be related to liquefaction resulting from ground shaking. The events that triggered emplacement of the Nunda and "Nunda" massive beds can only be conjectured. However, it is likely that such events were of a seismic nature.

Figure 2 (facing page). Disturbed bedding associated with Pipe Creek shale – "Nunda" Sandstone contact. 2A, B show injections of "Nunda" Sandstone within Pipe Creek lithology, top of "Nunda" interval at Angel Falls in Java Village, N.Y.; 2C shows breccia of Pipe Creek black shale clasts in thin marginal "Nunda" sandstone deposits, creek immediately south of Darling Road west of South Wales, N.Y. All figures X1 and oriented top-up.



A) ANGEL FALLS, JAVA VILLAGE

B) ANGEL FALLS, JAVA VILLAGE



C) DARLING ROAD

To summarize, questions that remain after our preliminary work include the following.
1) Is the deformation we observe in the "Nunda" sands primarily the result of sand flow transport or from essentially in-place liquefaction?
2) The usual model for transgressive and highstand systems tracts is that little coarse clastic sediment reaches the basin. Yet here, where the black shales are assumed to mark a relative sea level rise, the clastic input did not switch off immediately, as if the sand transport and deposition are not tightly yoked to the sea level change. Does this lag in the cut-off time of sand deposition (relative to sea level rise) imply that some factor other than relative sea level rise locally controlled sand deposition (e.g., reworking of older Nunda sands exposed through fault block activity)? Or does it merely indicate that the end of sand deposition in the basin does not occur instantaneously when a sea level rise occurs?
3) What happens to the "Nunda" to the east and southeast of the Warsaw area?

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Frasnian (lower Upper Devonian) geology of western New York as seen along Eighteenmile Creek and Route 20A: submarine discontinuities, gravity flows, and mass extinction

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Gordon C. Baird – Department of Geosciences, SUNY-Fredonia, Fredonia, New York
William T. Kirchgasser – Department of Geology, SUNY-Potsdam, Potsdam, New York

Road Log

0.0	0.0	Begin at I-90 Angola Exit (Interchange 58), at the toll booth, 15 miles from SUNY-Fredonia. Turn right (northeast) on US 20 East toward Buffalo (Irving).
0.9	0.9	Cattaragus Creek and Erie County, at signal proceed to right on US 20.
13.6	12.7	Turn left (northwest) on South Creek Road before crossing bridge over Eighteenmile Creek. Proceed through village of North Evans.
14.6	1.0	Cross under railroad overpasses and park in gravel pull-off. This is a popular fishing access site. Proceed northeast on the abandoned railroad grade under power lines to the path on the right which leads down to the creek.

Stop 1 – Eighteenmile Creek between NY 5 and North Evans, Erie Co., NY. Tichenor Limestone and Windom Shale of the Hamilton Group; North Evans Limestone, Penn Yan Shale, Genundewa Limestone, and West River Shale of the Genesee Group; and Middlesex Shale and Cashaqua Shale of the Sonyea Group.

The gorge of Eighteenmile Creek, formed by the resistant cliff forming Rhinestreet Shale of the West Falls Group, exposes Givetian (Middle Devonian) and Frasnian (Upper Devonian) strata that can also be seen on the shore of Lake Erie. North of the stone railroad bridge to the mouth of the creek the upper Hamilton Group and Genesee Group strata are exposed (Figure 1).

The oldest unit exposed along Eighteenmile Creek is the Wanakah Shale Member of the Ludlowville Formation (Figure 2). The Wanakah consists of soft fossiliferous medium gray calcareous shale. Decimeter scale cycles within the Wanakah record facies and sea level shifts (Batt, 1996; Batt, 1999, herein).

The Tichenor Limestone ("Encrinal Limestone" of Grabau, 1899) rests disconformably on the Wanakah Shale and marks the base of the Moscow Formation. The base of the Tichenor is sharp and irregular, characterized by prod marks and hypichnial burrows. This erosion surface is a cut down that includes over 5 m of strata present to the east in the Genesee River Valley (Figure 3a). The Tichenor at Eighteenmile Creek is a 30 to 40 cm thick medium to pinkish gray pyritic biowackestone-grainstone. It contains reworked pyrite and shells from the Ludlowville, as well as large rugose corals, favositids, crinoid columnals, brachiopods, trilobites, and bivalves. The top of the Tichenor is also disconformable, representing a submarine hard ground surface with crinoid holdfasts, encrusting corals, and mineral crusts of phosphate and pyrite. Key taxa visible on the upper surface of the Tichenor include large rugose corals and *Favosites*, numerous brachiopods including: *Spinocyrtia granulosa*, *Orthospirifer marcyi*, *Mediospirifer audaculus*, *Pustulatia pustulosa*, and *Elthyra fimbriata*. Also present are the bivalves *Plethomytilus* and *Actinopteria*, platyceratid gastropods, and large trilobites of the genus *Phacops*. Immediately

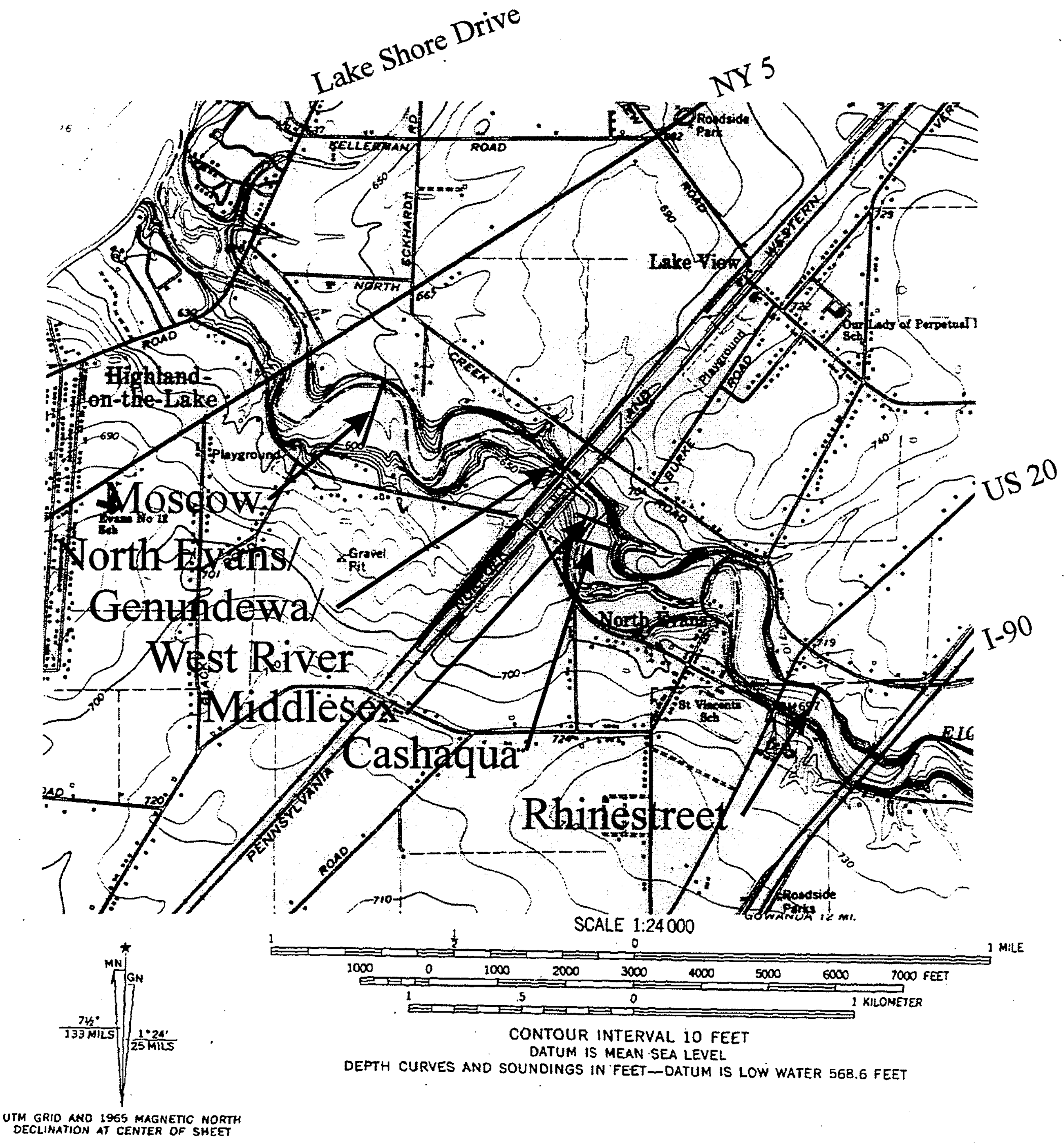

Figure 1. Topographic map of lower Eighteenmile Creek (Eden, NY 71/2' Quadrangle) showing base of formations at creek level. The upper Moscow through Rhinestreet are exposed in the high cliffs of the creek north of the rail road bridges.

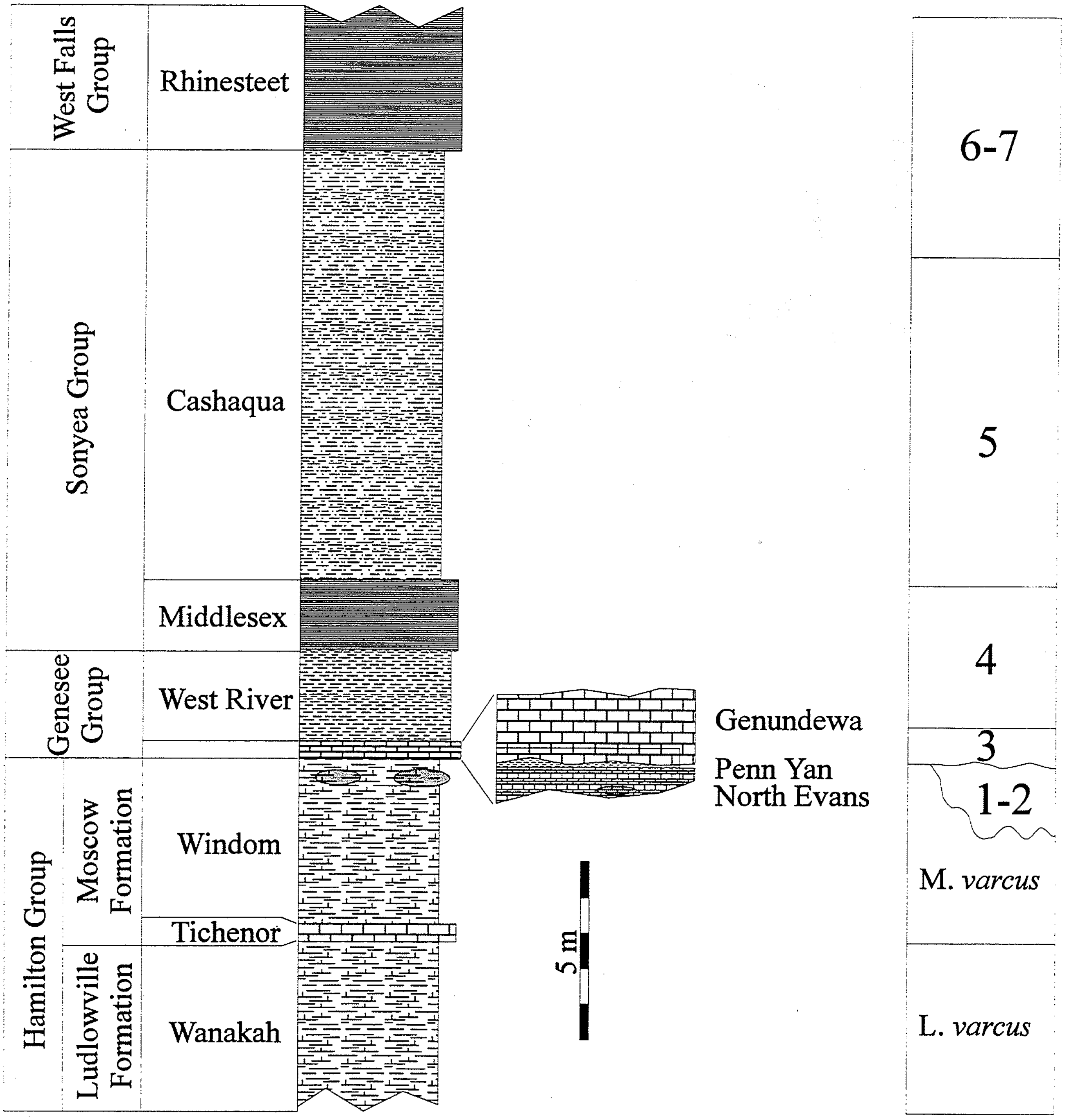

Figure 2. Schematic lithologic section and conodont zonation of Middle and Upper Devonian strata exposed along Eighteenmile Creek between NY 5 and US 20.

above the Tichenor is a thin (6 cm-thick) bed believed to be a condensed erosional remnant of the Kashong Shale Member, which can easily be confused as part of the Tichenor. This bed yields *Tropidoleptus carniatus* in association with *Spinocyrtia* and *Orthospirifer*.

Above the Tichenor and condensed Kashong Shale is the Windom Shale Member of the Moscow Formation. The Windom is 4.3 m thick along Eighteenmile Creek, bounded by discontinuities (Figure 3b; Baird and Brett, 1986), consisting of soft fossiliferous medium to dark gray calcareous shale, calcareous mudstone, and muddy carbonates. Soft shale at the base, with an abundance of *Ambocoelia umbonata*, is overlain by the Bayview Bed, a unit yielding a diverse fauna, including patchy concentrations of the large rugose coral *Heliophyllum* and *Cystiphylloides*, the brachiopods *Spinotrypa*, "*Mucrospirifer*" *consobrinus*, *Mediospirifer*, and abundant bryozoans. This bed is interpreted as a relative regression compared to adjacent Windom strata (Baird and Brett, 1983). The Bayview Bed is 36 cm above the Tichenor and offers the best opportunity for collection of macrofossils. Above the Bayview Bed is the Smoke Creek Bed, a 20 cm thick calcareous mudstone (Brett and Baird, 1994). The Smoke Creek Bed is characterized by an abundance of the small solitary rugose corals *Stereolasma* and *Amplexiphyllum*, the brachiopods *Pseudoatrypa* and "*Mucrospirifer*" *consobrinus*, and abundant *Phacops*, both whole individuals and molt assemblages. This bed lacks large corals and *Spinatrypa*, both common in the underlying Bayview Bed, and is believed to mark a transgressive transition into the fossil-poor mid-Windom facies (Brett and Baird, 1994).

Above the Smoke Creek Bed is a 2.5 m interval of unfossiliferous gray mudstone that correlates eastward to a sparsely fossiliferous interval designated the "Bear Swamp Interval" (Brett and Baird, 1994). Above the Bear Swamp equivalent is a concretionary limestone unit containing *Emanuella praeumbonata*. This layer correlates to the base of the mid-Windom dark-gray transgressive shale interval designated the Fisher Gully beds (Brett and Baird, 1994). The uppermost Windom at Eighteenmile Creek yields sparse *E. praeumbonata* and small concretions that correspond to the main part of the Fisher Gully beds in the Finger Lakes region (Figure 3b). The Windom succession on Eighteenmile Creek is condensed and truncated. Only the upper part of the *Ambocoelia* beds are present, and all of the upper-Windom succession (Tauton beds, Spezzano Gully beds, Gorge Gully beds, and newly discovered higher Windom strata in east central New York) is beveled (Figure 3c).

The North Evans Limestone ("Conodont Bed" of Hinde, 1879; Grabau, 1899), the basal stratum of the Genesee Group at Eighteenmile Creek, disconformably overlies the Windom Shale and represents a condensed and reworked bed at the great Taghanic Unconformity, a compound unconformity of several disconformities within the upper Hamilton and lower Genesee groups. To the east this erosive on lap is marked by the Leicester Pyrite, but here this major disconformity cuts out the upper Windom Shale, the Tully Limestone and its equivalents, most of the Geneseo and Penn Yan shales, and the lower Genundewa Limestone. The North Evans Limestone is lenticular, up to 15 cm thick, medium dark gray pyritic, glauconitic biograinstone. The limestone is rich in crinoid ossicles, fish plates, shark teeth, brachiopods, styliolinids, and abundant conodonts, including *Polygnathus linguiformis, P. dengleri, P. dubius, P. pennatus*, *Klapperina cristatus*, *K. disparalvea*, *Icriodus latericrescens*, *Ancyrodella rotundaloba*, and *A. recta*, a mix of upper Givetian and lower Frasnian taxa. The North Evans Limestone likely represents multiple reworking events; locally thin black shale partings, lithologically similar to the Geneseo and Penn Yan shales, are present.

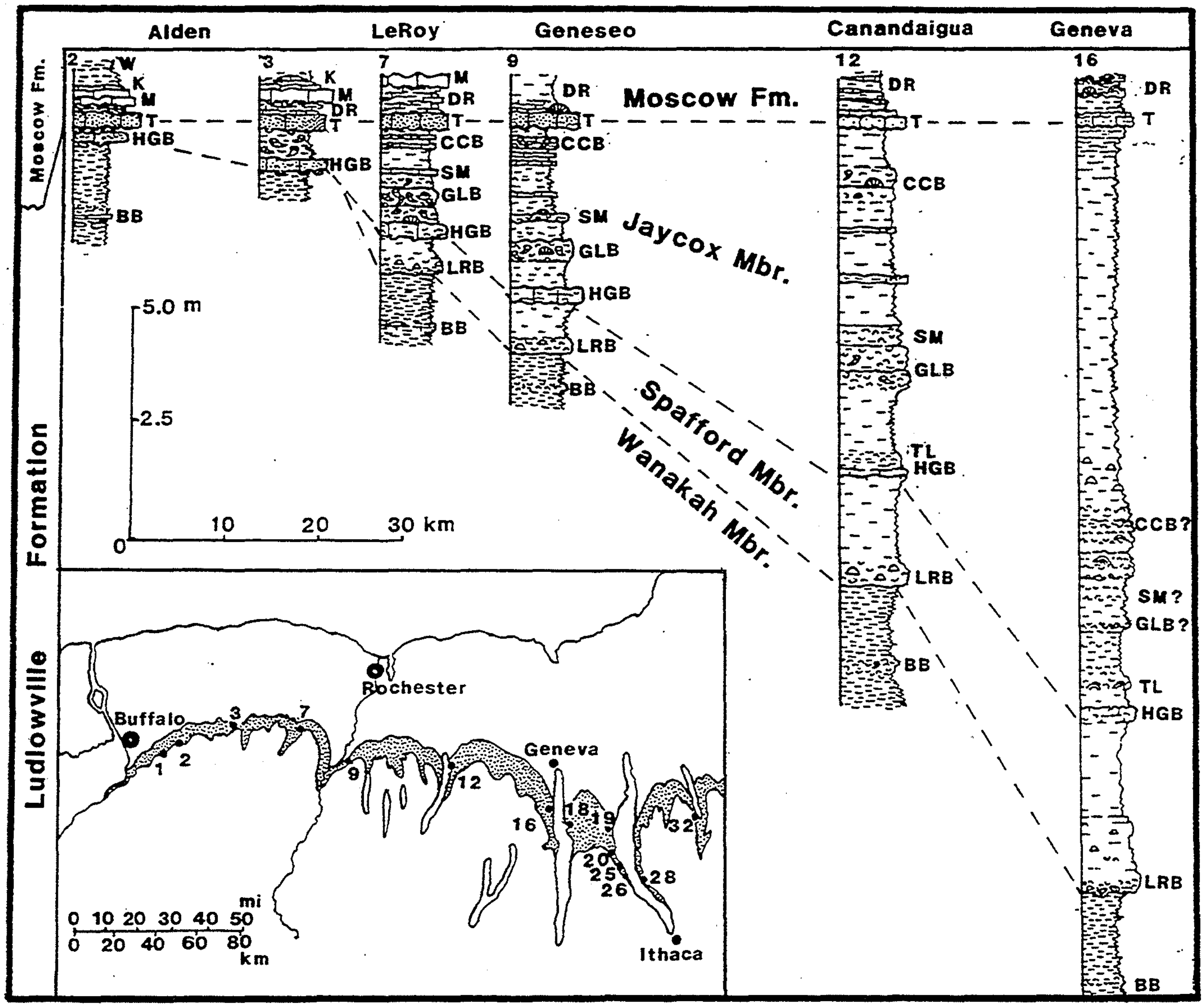

Figure 3a. Correlation of Tichenor, sub-Tichenor, and facies divisions of the upper Ludlowville and lower Moscow formations across western New York. Note prominent westward condensation, erosional truncation, and correlation of units that include: BB = Bloomer Creek Bed; CCB = Cottage City Coral Beds; DR = Deep Run Shale Member; GLB = Green's Landing Coral Bed; HGB = Hill's Gulch Bed; K = Kashong Member; LRB = Limerick Road Bed; M = Menteth Member; SM = Demosponge-*Megastrophia* Bed; T = Tichenor Limestone; TL = *Tropidoleptus-Longispina* mudstone interval; and W = Windom Member. From Mayer (1994).

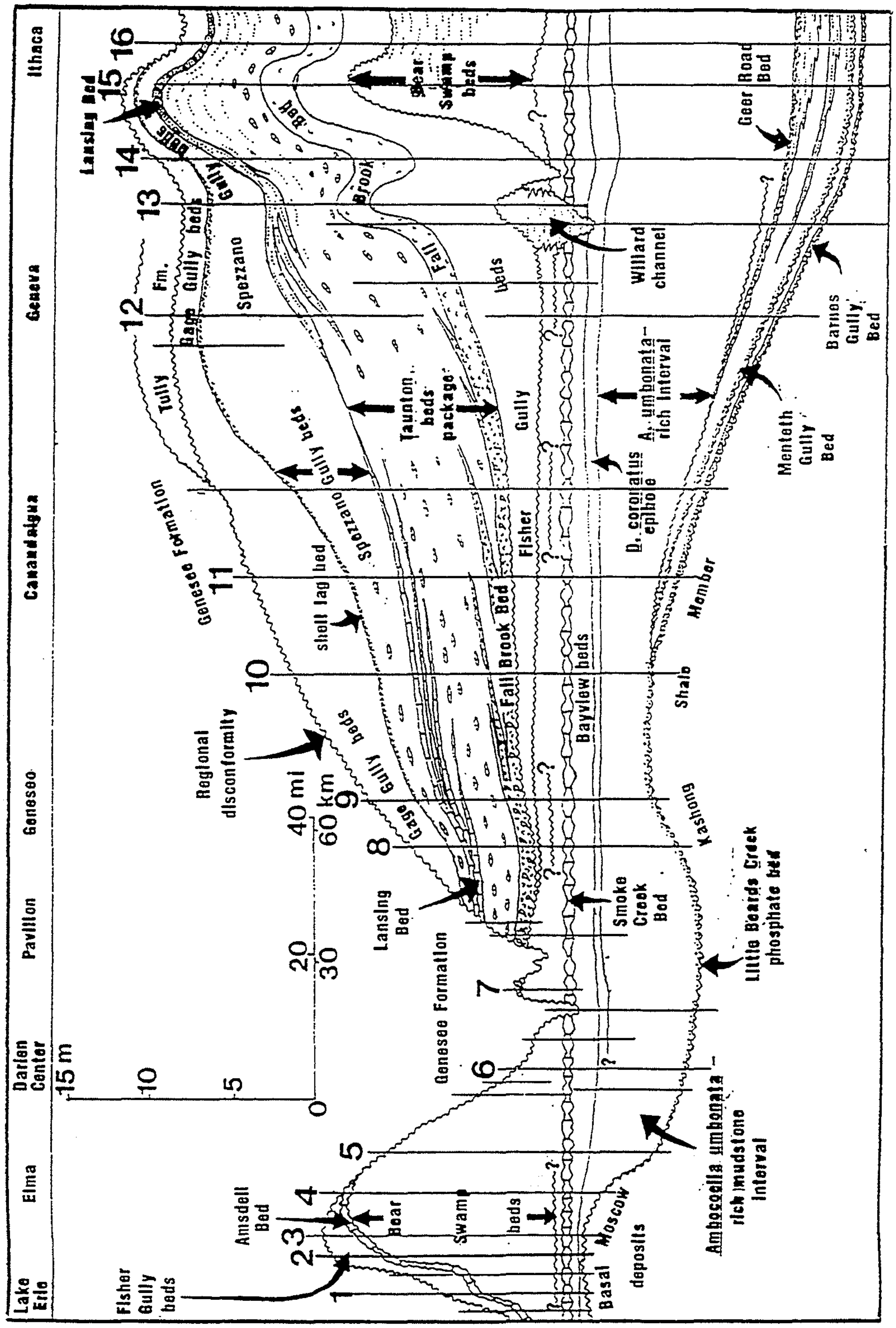

Figure 3b. Regional stratigraphy of the Windom Shale Member across western New York State. Datum is Smoke Creek Bed. Numbered localities include: 1, Eighteenmile Creek; 2, Penn Dixie Quarry; 3, Smoke Creek, 4, Cazenovia Creek; 5, Buffalo Creek; 6, Eleven Mile Creek; 9, Fall Brook; 10, Frost Hollow north of Honeoye; 11, menteth Gully; 12, Kashong Glen; 13, Simpson Creek at Willard; 14, Bloomer Creek; 15, Paines Creek; 16, Minnegar Brook near Lansing. From Brett and Baird (1994).

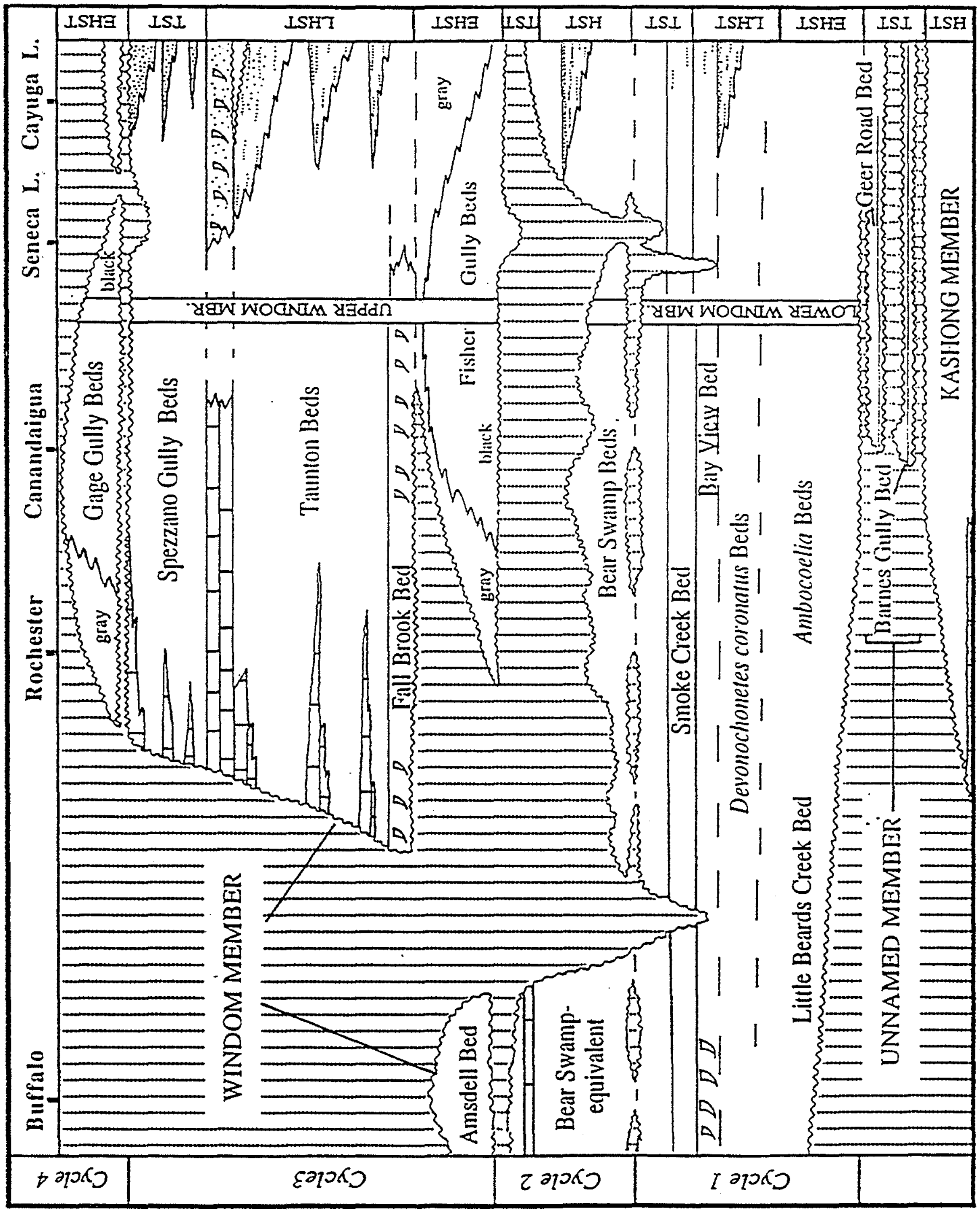

Figure 3c. Chronostratigraphic chart and sequence interpretation of the upper part of the Moscow Formation. Abbreviations for phases or system tracts (ST) include: TST = transgressive; EHST = early highstand; LHST = late highstand. Vertical ruling indicates unconformity; cornicopia = rugose corals; zig-zag lines indicate facies transitions. From Brett and Baird (1994).

A lenticular, up to 3 cm thick, dark gray styliolinid-rich shale overlies the North Evans Limestone. This shale is lithologically similar to the upper Penn Yan Shale, which to the east underlies the Genundewa Limestone and reaches a thickness of 11 m in the Genesee River Valley.

The Genundwa Limestone ("Styliolina Limestone" of Grabau, 1899) is a thin and wavy bedded medium gray bio-grainstone approximately 20 cm thick, and represents a starved basin "cephalopod kalken" dominated by a pelagic fauna of styliolinids, conodonts, locally cephalopods, and terrestrial derived wood. This bed is believed to be the uniformly-bedded upper Genundewa Limestone of the Genesee River Valley and Canandaigua Lake region. The nodular lower Genundewa of eastern exposures, with the ammonoids *Koenites* and *Tornoceras*, is missing here. Conodont dating of the Genundewa is complicated by occurrences of reworked and transported elements of the North Evans fauna at the disconfomity between the lower and upper Genundewa. The fauna of the lower Genundewa includes the late form of *Ancrodella rotundiloba* and *Ancyrodella recta*, indicating lower Frasnian MN Zone 2. The fauna of the upper Genundewa, also with *A. recta*, marks the entry of the early form of *Ancyrodella rugosa* indicating MN Zone 3 (Kralick, 1994). In the Genesee RiverValley the upper Genundewa marks the entry of the key Frasnian ammonoid genus *Manticoceras*.

The West River Shale on Eighteenmile Creek is 2.5 m thick, consisting of dark gray shale interbedded with thin siltstone beds and a concretion zone. *Styliolina* and the pelecypod *Pterochaenia* are both common. To the east, in the Genesee Valley and Canandaigua Lake region, thin limestones in the lower West River mark the entry of *Ancyrodella alata* (MN Zone 3). Concretions in the middle West River contain *Palmatolepis transitans* and mark the start of MN Zone 4 (*transitans* Zone). Here at Eighteenmile Creek the Williamsburgh Bed, a thin lenticular styliolinid-rich grainstone rich in wood, pyrite, and conodonts is tentatively recognized 0.5 m above the top of the Genundewa. This bed represents a sea level rise and recurrence of sediment starvation similar to the Genundewa Limestone. The conodont fauna of the Williamsburgh Bed includes *A. alata*, *A. rugosa*, *Icriodus nodosa*, *Mesotaxis asymmetricus*, *M. ovalis*, and *P. transitans*. The upper 2 m of the West River Shale at Eighteenmile Creek is correlated to the upper three meters of the West River in the Genesee River Valley where the entire formation is over 10 m thick. Individual beds of dark shale, siltstones, and concretions are recognizable. The lower West River is highly condensed or missing entirely in the westernmost exposures.

The Middlesex Shale, a black finely laminated pyritic and petroliferous shale, is 1.8 m thick at Eighteenmile Creek, and marks the base of the Sonyea Group. Millimeter and centimeter scale rhythmic laminations indicate small scale cycles (see Algeo and Woods, 1994), but their cause is problematic. Concentrations of wood and conodonts indicate intervals of even greater sediment reduction. The occurrence of *Ancyrodella gigas* (transitional to *A. nodosa*) and possibly *Palmatolepis punctata* indicate a position at or near the boundary between MN Zone 4 and MN 5 (*punctata* Zone).

The Cashaqua Shale, 12.8 m thick at Eighteenmile Creek, consists of light to dark green-gray shales and numerous concretion intervals. Concretion horizons, relatively evenly spaced through the Cashequa, represent lower sedimentation rates and relatively greater carbonate accumulation and mobility after deposition, but before final compaction. The ammonoid cephalopods *Manticoceras sinuosum* and *Probeloceras lutheri* occur in the shales and concretions at several levels associated with the conodonts *Ancyrodella gigas*, *A. nodosa*, *Mesotaxis asymmetricus*, and

Palmatolepis punctata, indicating MN Zone 5. The prominent concretion horizon in the dark shale band near the top of the Cashaqua is the Shurtleff Septarian Horizon; it lies just below the base of the black Rhinestreet Shale. To the east this bed contains baritized ammonoids, including *Manticoceras sinuosum* and *Prochorites alveolatus*, as well as the conodonts *Palmatolepis punctata*, *Ancyrodella nodosa*, and *Ancyrognathus ancyrognathoideus*, indicating MN Zone 6.

14.6	0.0	Continue north on South Creek Road.Continue north on North Creek Road.
15.5	0.9	At junction with NY 5, turn right (northeast) onto NY 5 East toward Buffalo, cross Eighteenmile Creek.
16.0	0.5	At intersection with North Creek Road turn right (southeast) onto North Creek Road.
17.5	1.5	At junction with US 20, turn left (northeast) onto US 20 East.
24.9		Town of Hamburg water tower and US 62 (proceed on US 20)
25.8	8.3	At five corners turn right (east) onto US20A toward Orchard Park and East Aurora.
35.7	9.9	NY 78 meets US 20A at traffic circle in East Aurora, continue east on NY 78/US20A.
39.8	4.1	Turn right (south) on NY 78 South toward Strykersville.
47.2		Strykersville US Post Office.
49.6	9.8	Cross Beaver Meadow Creek when entering Java Village and park on west side of road near post office. Creek and falls are east of NY78. Please respect the land owners along the creek.

Stop 2 – Angel Falls on Beaver Meadow Creek at Java Village, Wyoming Co., NY. Upper portion of Nunda Sandstone, basal Pipe Creek Shale, "Nunda" Sandstone and the medial and upper Pipe Creek Shale.

Two thick bedded sandstone units are visible in Angel Falls on Beaver Meadow Creek in Java Village (Figure 4). This is the uppermost part of the greater Nunda Sandstone succession characterized by light gray thin to thick bedded cross-laminated and bioturbated coarse silt – very-fine quartz sand. The gray sandstones and silty mudstones at the base of the falls are separated from the upper sandstone that forms the top of the falls by a thin (10 cm-thick) black shale that marks the base of the Pipe Creek Shale Member. The lower and medial part of the Nunda Member interfingers and grades westward into the Angola Shale. The upper sand is stratigraphically distinct, designated "Nunda," as it interfingers and toes out westward within the Pipe Creek Shale (Baird and Jacoby, 1999, herein, Fig. 1). The base of the "Nunda" sharply overlies the thin basal black shale bed; the top is interbedded and mixed with black shale.

The brownish lumpy sandstone of the topmost "Nunda" and superajacent Pipe Creek Shale show chaotic bedding, irregular sandstone masses, and complex swirly interlayering of micaceous sandstone and sandy black shale. Diffuse breccia clasts of black shale within brown sandstone matrix suggests emplacement of fluidized sand into variable water-rich, surficial black mud deposits. The thick "Nunda" sandstone seems to be a major fan lobe sand unit (Jacobi et al., 1994; Baird and Jacobi, herein). The "Nunda" flow event scoured the lowest Pipe Creek Shale as indicated by olistoliths of Pipe Creek Shale within the massive unit at several localities. The uppermost chaotic and diffuse "Nunda" Sandstone may represent later, smaller flow events.

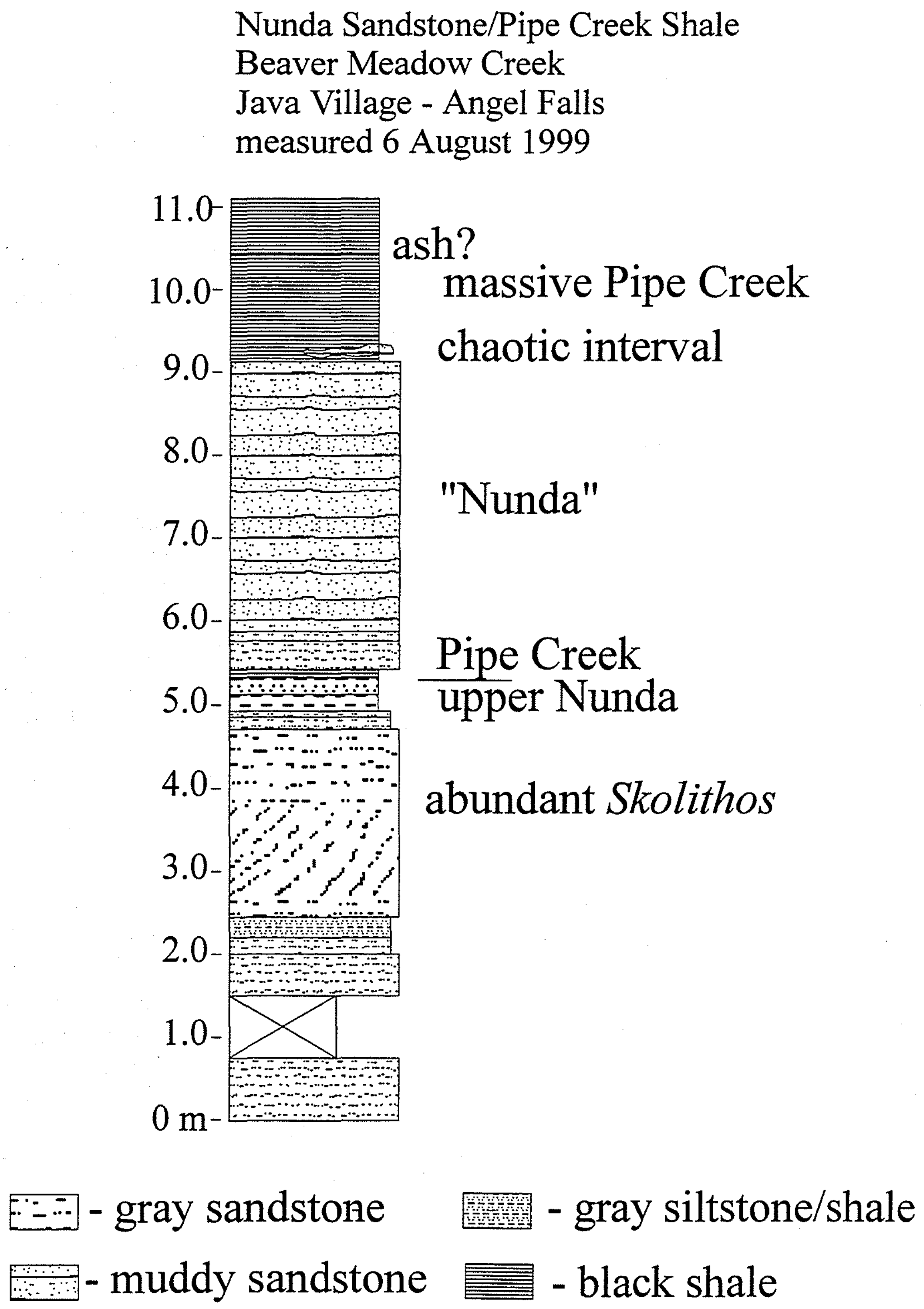

Figure 4. Schematic diagram of upper Nunda Sandstone, "Nunda" Sandstone, and lower Pipe Creek Shale at Angel Falls on Beaver Meadow Creek in Java Village.
between MN Zone 12 and Zone 13. In the lower Hanover Shale, just above the top of the Pipe Creek Shale, there are nodular beds which yield baritic specimens of *Mantiococeras cataphractum* associated with conodonts of MN Zone 13.

The Pipe Creek Shale is the northern Appalachian Basin equivalent to the Lower Kellwasser Horizon in Europe (Over et al., 1997; Over, 1997). Conodonts in the Pipe Creek Shale include *Palmatolepis winchelli*, *P.* aff. *P.* hassi, and *Polygnathus samueli*, indicative of the boundary

49.6	0.0	Turn around and head north on NY 78 to Strykersville.
52.0	2.4	Turn right (east) on Perry Road (just past post office).
53.6	1.6	Turn left (north) on Bartz Road.
54.3	0.7	Pull off on road side on south side of Glade Creek. This is private property and visiting the site is contingent on permission from the land owner. Walk west down the farm lane, right at implement shed and down to the creek.

Stop 3 – Glade Creek, Wyoming Co., NY. Hanover Shale, Frasnian-Famennian boundary mass extinction, and Dunkirk Shale.

The Hanover Shale in the Buffalo Creek Valley is predominantly green-gray pyritic silty shale. Dark organic-rich shale, muddy limestones, siltstones, and calcareous concretions are common (Figure 5). Three distinctive black shale intervals and numerous thinner black shales correspond to deepening phases or circulation changes and preservation of organic material in the substrate. The upper Hanover Shale is characterized by numerous black shale interbeds, indicative of deepening and a reduction in coarser clastic influx, as well as reduced oxygen levels in the substrate. The black shales amalgamate or are truncated westward (Baird and Lash, 1990), as a result of sediment reduction and/or submarine erosion. Black shales and calcareous concretions contain carbonized plant material, gastropods, crinoid debris, pteriacid bivalves, cephalopod aptyci, and an abundant and diverse conodont fauna. The upper Hanover at this locality is the source of the large goniatite *Sphaeromanticoceras rickardi* the last known manticoceratid of the New York Frasnian (House and Kirchgasser, 1993). A radical change in the conodont fauna marks the Frasnian-Famennian.

The Frasnian-Famennian boundary is one of the major biotic events in the Phanerozoic, recognized by the extinction of shallow water corals, most stromatoporoids, and numerous species and higher groups of trilobites, cephalopods, brachiopods, and conodonts. The mass extinction is associated with sea-level fluctuations and deposition of organic-rich fine-grained sediments in tropical seas. In Europe the Kellwasser horizons, two distinct organic-rich intervals, mark the onset and culmination of the extinction. It is estimated that 22 percent of extant families and 65 percent of extant genera went extinct (Hallam and Wignall, 1997). There is no compelling evidence for the single impact of a large bolide as the cause of the extinction (Walliser, 1995; Over et al., 1997).

The thick black shale corresponding to the Upper Kellwasser horizon is characterized by a diverse and abundant nektic and planktic fauna. Locally there are numerous homoctinids, pteriacid bivalves, *Sidetes* (cephalopod aptycus), current aligned orthocone nautiloids and conodonts, articulated fish, and carbonized plant remains. The conodont fauna is characterized by *Palmatolepis bogartensis*, *P. winchelli*, *Ancyrodella* sp., *Ancyrognathus* sp., *Icriodus alternatus* ssp., and *Polygnathus* sp. The concentration of fossil remains in the top of the bed indicates relatively slow sedimentation, that in association with the finely laminated pyrite-rich shale, suggests a relative sea level rise and submarine erosion. Numerous graded and current oriented silt laminae indicate turbidity flows or other bottom currents during black shale

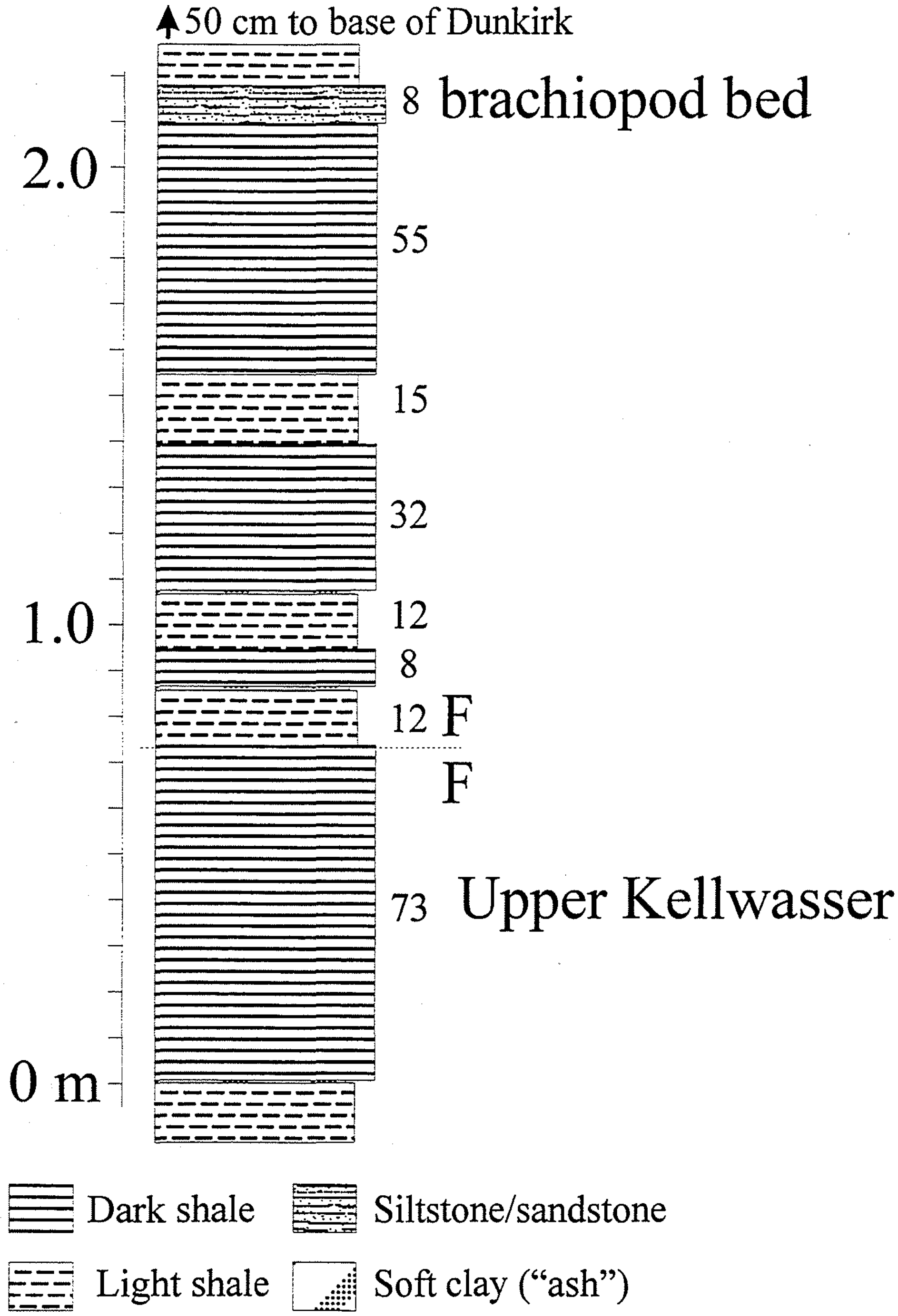

Figure 5. Schematic lithologic section of Frasnian-Famennian boundary interval in the upper Hanover Shale at Glade Creek, Bartz Road, Wyoming County, New York.

deposition. Hummocky cross laminated siltstones in the boundary interval indicate that these strata were deposited near storm wave base.

Fossil abundance drops precipitously above the Upper Kellwasser black shale, corresponding to the Frasnian extinction horizon. Recovery of conodont and benthic fauna is evident in the overlying meter of the Hanover. A ripple laminated 5-8 cm thick, medium gray coarse siltstone, that consists of three fining upward intervals, 1.2 m above the extinction boundary, contains a diverse offshore shelf brachiopod fauna that represents a concentrate from the underlying greenish mudstones. The fauna consists of *Schizophoria* sp., *Thiemella* cf. *T. leonensis* (Hall), *Whidbornella* cf. *W. lachrymosa* (Hall), "*Chonetes*" cf. "*C.*" *setigera* (Hall), *Evanoscirostrum*? sp., *Athryis angelica* (Hall), *Tylothyris* aff. *T. mesacostalis* (Hall), *Cyrtospirifer* cf. *C. inermis* (Hall), and *Linguloides*? sp. These are taxa that carry over from the Frasnian, and suggest a relatively high survival rate for deep shelf brachiopods. This bed also contains numerous specimens of *Palmatolepis triangularis*, fish remains, and bivalves. Brachiopods are present in the under- and overlying strata, but are only concentrated in a single interval in the middle of the bed, developed in a coarser and more pyritic zone over clay-rich and bioturbated laminae. The pyrite and shell interval overlies a low relief scour surface, indicating a concentration of coarser and denser material during higher energy conditions. The shell-bearing bed is characterized by low amplitude ripple marks that have a 6-7 cm frequency where the ripple crests are oriented NNE-SSW. Brachiopods, and in a lesser abundance crinoids, ostracodes, bryozoa, fish remains, and conodonts, cover the entire surface of the shell horizon. Many brachiopod valves are disarticulated and convex up, but otherwise there is little shell abrasion or other evidence of transport. Some of the larger brachiopod shells are at the top of the bed and concave up, possibly the result of suspension and settling. Abundant lingulid valves (n = 184) have a preferred, but not pervasive, long axes alignment in a NW-SE orientation, perpendicular to the current ripple crests.

The Dunkirk Shale, the lowest formation in the Canadaway Group, overlies the Hanover Shale. The Dunkirk is defined by the first occurrence of massive black shale above the green-gray shales and thin black shale interbeds of the Hanover, and is equivalent, at least in part, to the lower part of the Huron Shale in Ohio. The type section of the Dunkirk Shale is at Pt. Gratiot, Town of Dunkirk, on the Lake Erie shoreline. The basal Dunkirk yielded *Palmatolepis triangularis*, *P. subperlobata*, *P. delicatula delicatula* and *P. clarki*, characteristic of the Middle *triangularis* Zone. These species range into succeeding zones, but with the exception of juvenile specimens suggestive of *Palmatolepis perlobata* ssp. or *P. tenuipunctata*, conodonts indicative of the Upper *triangularis* Zone or younger were not recovered. *Palmatolepis glabra*, *P. perlobata, P. quadrantinodosalobata, P. subperlobata,* and *Ancyrognathus bifurcatus* were reported by Hass (1958) from the South Wales and Gowanda formations, which overlie the Dunkirk. This fauna is characteristic of a position no lower than the *crepida* Zone.

54.3	0.0	Continue north on Bartz Road through crossroad of Sheldon where St. Cecelia (large church at cross road) is the dominant feature. Continue north to US 20A.
58.2	3.9	Turn left (west) on to US 20A toward East Aurora, I-90, and Fredonia.

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FOSSIL FAUNAS AND MICROSTRATIGRAPHY OF THE UPPER LUDLOWVILLE FORMATION: SMALL-SCALE SEA LEVEL FLUCTUATIONS AND CONVERGING UNCONFORMITIES

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INTRODUCTION

The Middle Devonian (uppermost Eifelian-Givetian) Hamilton Group of New York State has long been known for its abundance and diversity of well-preserved marine fossils. Sands and muds eroded from the Acadian Mountains that rose to the east (present directional sense) in response to the collision of Laurussia with Avalonia accumulated at the northern end of the Appalachian Foreland Basin, a northeast-trending trough that subsided as the crust isostatically adjusted to the weight of the growing mountain range. A steep siliciclastic-dominated slope descended westward from a nearshore sandy platform into the deep, axial part of the basin, which at the time passed through the present-day Finger Lakes region (Brett and Baird, 1990). Beyond that a western muddy carbonate shelf rose gently toward the shoaling Findlay-Algonquin Arch.

Western shelf sequences include intervals of gray to black mudrock punctuated by thin, laterally persistent bioclastic and diagenetically enhanced limestone beds and calcareous concretion horizons. The carbonate horizons were long known as widely-traceable marker beds; the intervening, seemingly monotonous mudrock intervals have only recently been shown to consist of distinct and widely traceable "depositional units." For example, Batt (1996) distinguished more than 190 depositional units comprising the 20.6 m thick Wanakah Shale Member (Ludlowville Formation) exposed along Rush Creek in Erie County.

Each depositional unit includes two major parts: a basal fossil-rich horizon ("shell bed") overlain by a relatively fossil-poor shale or mudstone. The basal part includes the remains of organisms that accumulated during periods of time (perhaps hundreds or thousands of years) when little if any mud was transported across the deep basin to this offshore shelf setting (Fig. 1). The overlying fossil-poor mudrock represents mud that had been re-suspended from nearshore areas and transported into the area during major storm events. The mud blanketed large areas of sea floor, burying accumulated remains and living communities to promote excellent fossil preservation. A given layer of storm-transported mud (mud tempestite of Brett et al., 1986) is an isochronous bed which, when considered with the underlying shell bed, may be correlated on the basis of lithology and fossil content. The widespread correlation of these depositional units allows the creation of a highly refined chronostratigraphic framework that facilitates the testing of various concepts of paleoecology and sequence stratigraphy on a regional and temporal basis.

The current investigation examines the fossil faunas and "microstratigraphy" of the upper part of the Ludlowville Formation of the Hamilton Group in western and west-central New York State.

Cyclic vertical (up-section) lithologic and faunal changes suggest that deposition was affected by sea level fluctuations of various magnitude. The upper part of this interval also contains several unconformities which may with detailed correlation be shown to merge westward into a single erosion surface separating what remains of the Ludlowville Formation from the overlying Moscow Formation.

STRATIGRAPHY OF THE STUDY INTERVAL

The upper part of the Ludlowville Formation includes the Wanakah Shale, Spafford Member, and Jaycox Member (Fig. 2). Grabau (1917) named the Wanakah Shale for an exposure of 20 m of medium gray shale with thin carbonate horizons at Wanakah Cliff along the Lake Erie shore in Erie County. The unit grades eastward into dark gray to black shales in the western Finger Lakes region (basin center). Further east, equivalent rocks belong to the silty Ivy Point Formation (Kloc, 1983).

Three meters of calcareous shale exposed in the Genesee Valley area, placed by Cooper (1930) in the overlying Tichenor Member of the Ludlowville Formation, were included by Grasso (1973) in the Wanakah Shale. Baird (1979), however, designated this interval as the Jaycox Member and placed the Tichenor Member in the overlying Moscow Formation by correlation with the Portland Point Member and the recognition of a regional sub-Tichenor unconformity that truncates successively older Ludlowville units when followed westward. The uppermost meter of the newly-refined Wanakah Shale at Jaycox Run, an interval of silty mudstone and shale immediately below the Jaycox Member, was then determined by Mayer et al. (1994) to represent the westernmost equivalent of the Spafford Member described in the Owasco and Skaneateles Lake valleys of central New York (Smith, 1935).

The Wanakah Shale as presently defined may be divided into four submembers (Fig. 2). Miller (1991) designated the highly fossiliferous lower 5 m of the unit, which due to its numerous diagenetically enhanced marker beds may readily be traced across western and central New York, as the Darien Center Submember. Batt (1996) used lithologic and faunal dominance trends to subdivide the remainder of the member into three additional but unnamed submembers. The lowest of these, here designated as the Idlewood Cliffs Submember, includes 8.5 m of dark gray to nearly black fossil-poor shale with widely spaced bundles of thin limestone bands at Idlewood Cliffs, along the Lake Erie shore within 0.5 km north of the mouth of Eighteenmile Creek (Town of Hamburg, Erie County). The overlying Highland-On-The-Lake Submember, named here for exposures along the Lake Erie shore 0.5 to 1 km south of the mouth of Eighteenmile Creek (Town of Evans, Erie County), includes 5 m of dark gray shale with bundled concretion horizons. The remainder of the Wanakah Shale includes fossiliferous gray shales and is here designated as the Buffalo Creek Submember for exposures along Buffalo Creek at Bullis Road in the Town of Elma, Erie County. There the submember is 3.25 m thick and includes all of the marker beds contained in the interval in the shallower western shelf setting as well as key beds that mark the top of the submember from Buffalo Creek eastward but were erosionally removed from western sections.

The study interval in the present investigation (uppermost Highland-On-The-Lake Submember through Jaycox Member) contains numerous marker beds (Fig. 2), most of which actually include several depositional units. Some marker beds were originally named by Grabau (1898-99) for dominant fossils, but most have been re-named after type localities. The bundle of concretion horizons marking the top of the Highland-On-The-Lake Submember is Kloc's (1983) Spring Brook Interval (Grabau's "Upper *Athyris spiriferoides* bed"). The lower part of the Buffalo Creek Submember contains a thin dark gray shale interval with abundant styliolinids and (in western sections) a prominent horizon of calcareous concretions. This interval, which includes Grabau's "Tentaculite Bed," is here designated as the Milestrip Road Bed for an exposure immediately north of where that road crosses Smoke Creek in the Town of Orchard Park. The most highly fossiliferous part of the Buffalo Creek Submember, locally containing limey lenses or concretion horizons, was designated as the Blasdell Bed by Kloc (1983). The lower part of this interval includes Grabau's "*Demissa* Bed" and "*Stictopora* Limestone" in western sections. The Bloomer Creek and Romulus beds mark the top of the submember in eastern sections (Baird, 1981). Mayer (1989) designated a medium gray fossiliferous silty mudstone at the base of the Spafford Member as the Limerick Road Bed. The base of the Jaycox Member, ranging from limestone in western sections to calcareous siltstone in the Finger Lakes region, was named the Hills Gulch Bed by Kloc (1983). The Jaycox Member also includes two prominent coral-rich horizons, the Greens Landing Coral Bed and the Cottage City Coral Bed (Mayer, 1989).

METHODS

The study interval was measured and sampled at nine sections spaced along the Ludlowville Formation outcrop belt (Fig. 3), spanning a distance of more than 140 km. The entire Wanakah Shale was examined in five closely-spaced sections in Erie County by Batt (1994), but only the trilobite beds interval of the Darien Center Submember (Batt, 1995) and the Rush Creek section (Batt, 1996) have been discussed in publication. The addition of the four eastern sections extends the line of transect from the western shelf into the foreland basin, and the addition of the Spafford and Jaycox members completes the study interval.

Centimeter-scale measurement and description of each section revealed that the study interval everywhere consists of distinct depositional units. The relatively close spacing of the sections facilitated detailed correlation of these beds along the length of the transect in spite of basinward facies changes (Figs. 4-7). Basinward thinning and decrease in resolution in some intervals appear to reflect a number of factors including the increasing rarity of recognizable shell beds in deeper, less oxygenated settings, restriction of significant diagenetic enhancement to shallower parts of the western shelf, and decreased sediment influx into the deeper basin.

All sections were sampled for fossils, with at least 300 specimens collected from each depositional unit. The number of specimens of each macrofossil species was recorded for every sample, and after adjusting for disarticulated remains relative abundances were calculated (it should be noted that while crinoid remains were noted, they were not included in the counts due to their highly disarticulated nature).

Miller (1986) noted that the fauna contained in any given bed (depositional unit) actually represents a "time-averaged fauna," an assemblage averaged over perhaps hundreds of years as skeletal debris accumulated on the sea floor before storm-related burial. Even so, the relative abundances of the faunal components do reflect overall (averaged) environmental conditions during a given bed's history, conditions which may have been significantly different from the conditions under which the overlying bed was deposited perhaps a thousand years later. Thus bed-to-bed changes in faunal dominance may reflect changes in environmental parameters such as general water depth, turbidity, and oxygenation through time at a given locality.

For each sample, species with similar life habits and general environmental tolerances (depth, turbidity) were assigned to faunal categories. The data were then plotted on faunal frequency diagrams to illustrate up-section changes in the relative abundances of these categories which are interpreted to reflect changes in environmental conditions through time. Figures 8-13 are examples of faunal frequency diagrams constructed for the study interval at some of the sections discussed in the text.

These diagrams, introduced by Batt (1995) in an investigation of the trilobite beds of the Darien Center Submember, are a modification of a cumulative frequency graph developed by Bandy (1953) to interpret dominance trends for foraminifera. Percent abundance is indicated along the horizontal axis while beds are numbered from the bottom upward along the vertical axis (see Figs. 8-13). Each bed is represented by a single horizontal line (not drawn) rather than an interval of proportional thickness, because the fauna within a recognized bed is a time-averaged association and individual bed thickness is therefore insignificant. The space between the bed lines in essence represents the contact between synjacent beds in the outcrop (zero thickness). This in reality more closely reflects the relative time represented by beds and contacts. Brett et al. (1990) suggested that chemical and biological destruction of skeletal material on the sea floor would result in loss of identifiable remains of all but the last few generations of a fauna living prior to burial by storm-transported mud. During the non-represented times (between major storm-events), faunal associations changed in response to changing conditions (such as depth and/or turbidity). The changing widths of faunal categories from bed to bed thus represent the net changes in dominance between preserved time-averaged faunas.

In the present investigation, the faunal categories shown on these diagrams are arranged with those believed to be most characteristic of shallower bottoms to the left and deeper bottoms to the right. Also, since at any given depth different turbidity levels may affect the fauna represented (see Brett et al., 1990 for a discussion), categories representing higher turbidity are placed to the left of those representing lower turbidity.

DISCUSSION

The Spring Brook Interval (beds H1-H3) at the top of the Highland-On-The-Lake Submember includes numerous horizons of calcareous concretions in western (shallower) sections (Fig. 4) where sufficient calcareous debris was available to promote diagenetic enhancement. The fauna in this and synjacent intervals is dominated by the diminutive spiriferid brachiopod *Ambocoelia umbonata* (Figs. 8-11), characteristic of relatively clear (non-turbid) water deeper than maximum storm wave base (Brett et al., 1990). Common *Athyris spiriferoides* within the Spring Brook interval itself, while this form is lacking above and below, as well as the presence of small rugose corals, bryozoans, and larger spiriferids such as *Mediospirifer* in the interval in western (shallower) sections, indicates that the Spring Brook Interval represents a small-scale shallowing episode superimposed on an overall deepening trend recorded by the upper part of this submember (Batt, 1996).

Beds B1 through B6 of the Buffalo Creek Submember comprise one meter of fossil-poor dark gray (western sections) to black shale that records the greatest depths for the study interval. A three-fold division reflecting superimposed smaller-scale cycles is indicated by faunal trends, with even smaller-scale cycles discernable in western sections where bed resolution is greatest. Deep bottoms are indicated by the high relative abundance of the rhynchonellid *Eumetabolatoechia multicosta* in the upper part of the interval in eastern sections; Brett et al. (1990) considered this form to characterize deep, dysaerobic conditions.

The Milestrip Road Bed (beds B7 and B8), a thin (to 0.5 m) interval of dark gray to nearly black shale with bedding planes covered by styliolinids and (except at Kashong Glen) a sparse *Mucrospirifer*-dominated macrofauna, records bypass-related condensation during a shallowing pulse. Calcareous concretions are found in this interval in western sections, where shallower bottoms are indicated by the presence of the orthid *Tropidoleptus* and small rugose corals. An up-section increase in *Athyris* and chonetid brachiopods in the overlying dark gray to black shale (beds B9-B11) signals a small-scale deepening pulse superimposed on overall lower Buffalo Creek Submember shallowing; in western sections even smaller-scale subcycles may be discerned.

The Blasdell Bed, with a highly diverse shallow-bottom fauna, records peak Buffalo Creek Submember regression. Western sections include as many as 20 beds of somewhat calcareous gray shale totaling 1.5 m in thickness (Fig. 4), but the interval thins dramatically eastward and the number of recognizable beds decreases. Faunas and lithology divide the Blasdell Bed into lower and upper parts (see Fig. 9), each representing a superimposed smaller-scale regressive-transgressive cycle.

The lower part of the Blasdell Bed (beds B12-B16) includes three cyclic packages discernable in western sections. The basal one contains a diverse fauna with small rugose corals, bryozoans, large spiriferids, *Mucrospirifer*, and *Athyris*. The middle one was named the "*Demissa* Bed" by Grabau (1898-99) for *Stropheodonta demissa*, a common species in this bed as far east as Genesee County. The upper package includes diagenetic limestone bands and concretions as far east as Cazenovia Creek. Grabau named this interval the "*Stictopora* Limestone" for the abundance of the bryozoan *Sulcoretipora* (*Stictopora*), which may indicate increased turbidity levels associated with sea level fall. The "*Stictopora* Limestone" marks the top of the Wanakah Shale at Lake Erie (Fig. 4) where all overlying beds, as well as the entire Spafford and Jaycox members, are absent in the sub-Tichenor unconformity.

The upper Blasdell Bed (beds B17-B20) records the shallowest bottoms during upper Wanakah deposition, with common *Spinocyrtia granulosa* (a large spiriferid typical of depths close to normal wave base), *Sulcoretipora*, and diverse pelecypods in western sections and the appearance of the small tabulate coral *Pleurodictyum* to the east. Miller (1990) suggested that this coral may have favored higher turbidity levels, so its occurrence may be a good indicator of shallowing conditions and associated increased turbidity. This interval includes three superimposed subcycles, the tops of which are marked by concretion horizons at Rush Creek. The upper Blasdell Bed marks the top of the Wanakah Shale at Rush, Smoke, and Cazenovia creeks, where it is unconformably overlain by Spafford-equivalent shales.

Dark gray shale of the Bloomer Creek Bed (beds B21 and B22), present from Buffalo Creek eastward (Fig. 5), records a small-scale shallowing-deepening cycle during overall transgression. The upper part locally contains corroded, reworked concretions (Baird, 1981) associated with a maximum flooding surface (Brett and Baird, 1994). The lower part of the overlying Romulus Bed (beds B23-B30) contains black shale with numerous pavements of the diminutive spiriferid *Crurispina nana*. Its basal contact is everywhere marked by a sharp lithologic and faunal break, and east of Elevenmile Creek a thin (less than 1 cm) clay may represent a bentonite. The Romulus Bed appears to be conformable with beds above and below at Hopewell Gully and Kashong Glen, but significant condensation of the lower part is evident westward. The upper two beds contain relatively few *C. nana* compared to other faunal components and in western sections appear to be separated from beds below by a sharp hiatus. The uppermost bed in turn appears to have been erosionally removed in western sections prior to deposition of the Spafford Member.

The Spafford Member in its type area in east-central New York records a cycle of sea level change of at least the same magnitude as the Buffalo Creek Submember (Brett, pers. comm.), but much of the upper part appears to have been removed in the study area. The Limerick Road Bed (beds S1-S4) is a medium gray silty mudstone containing a shallow-water fauna with large spiriferids, gastropods, pelecypods, *Pleurodictyum*, and *Reptaria*-encrusted orthoconic nautiloids. *Mucrospirifer*, *Tropidoleptus*, and chonetids become prominent west of Hopewell Gully. The bed appears to be traceable at least as far west as Jaycox Run; Brett (pers. comm.) noted its erosional truncation near East Bethany. The upper part of the Spafford Member (beds S5-S8) in the study area includes silty gray shale deposited at greater depths than the Limerick Road Bed. All but two basal beds of the upper Spafford were removed by pre-Jaycox erosion at Jaycox Run. Further west, a few beds of silty bluish gray mudstone containing a very sparse *Mucrospirifer*-dominated fauna rests sharply on the beveled upper surface of the Wanakah Shale (Fig. 6) and appears to correlate with the Spafford Member. More work is needed to determine whether this thin interval belongs entirely to the upper part of the Spafford (indicating an erosion interval that removed the Limerick Road Bed) or may include a localized westward reappearance of part of the Limerick Road Bed.

Overall regression apparently followed deposition of the upper part of the Spafford Shale preserved in the study area, but rocks recording this appear to have been removed during sea level lowstand prior to deposition of the overlying Hills Gulch Bed. The Jaycox Member appears to record a single major sea level rise/fall cycle with a scale comparable to the Spafford Member or Buffalo Creek Submember cycles. This unit thins dramatically westward from Kashong Glen due to the removal of progressively older beds by pre-Tichenor erosion (Fig. 7).

The Hills Gulch Bed (bed J1), deposited during early transgression, is a prominent marker traceable westward into Erie County before it disappears in the pre-Tichenor unconformity. Its westward gradation from massive calcareous siltstone through silty limestone to bluish gray encrinal limestone reflects an upslope facies change. The fauna is dominated in eastern sections by mollusks (Figs. 12, 13); large rugose (*Heliophyllum*, *Eridophyllum*) and tabulate (*Favosites*) corals dominate to the west. The bed is represented at Smoke Creek by a thin (to 5 cm) limestone immediately underlying the Tichenor; it is only locally present and much thinner at Rush Creek.

Deepening after Hills Gulch deposition is recorded by a thin dark gray *Zoophycos*-swirled mudstone with *Mucrospirifer* and *Tropidoleptus* (bed J2), overlain by a thin dark gray to black shale interval (bed J3) with pavements of *Tropidoleptus* and the chonetid *Longispina deflecta*. A meter-thick dark gray shale interval (beds J4 and J5) with a fauna dominated by bryozoans (*Sulcoretipora* at Kashong Glen; fenestellids to the west) records a smaller-scale shallowing-deepening cycle. West of Jaycox Run, the shales above the Hills Gulch Bed are represented by whatever survived beveling prior to deposition of the Greens Landing Coral Bed. At Elevenmile Creek, 25 cm of shale are present; at Buffalo Creek only 2 to 4 cm. Further west, the Hills Gulch Bed (where present) is directly overlain by the next limestone bed.

The Greens Landing Coral Bed (beds J6 and J7) records temporary shallowing. It is nearly 0.5 m in the two easternmost sections, where it contains three fossil-rich intervals dominated by bryozoans (*Sulcoretipora* at Kashong Glen; fenestellids at Hopewell Gully) with common small rugose corals (*Amplexiphyllum*, *Stereolasma*), pelecypods, and *Mucrospirifer* (Fig. 13). The interval is represented at Jaycox Run by a 30-cm bed of hard, medium gray calcareous shale with a diverse fauna including large rugose corals (*Heliophyllum*, *Eridophyllum*), small favositids, and *Pleurodictyum*. At Buffalo Creek, the Greens Landing Coral Bed is a massive bluish gray limestone that rests on beveled remains of the underlying shale; it rests directly on the Hills Gulch Bed at Cazenovia Creek. Rapid lateral variations in thickness (from 0 to 12 cm) at these localities reflect irregular erosional scour on the shallow western shelf. The bed is absent at Elevenmile Creek and west of Cazenovia Creek.

Up to 40 cm of gray shale (bed J8) records post-Greens Landing deepening, but above this a bed (bed J9) with large spiriferids, *Pentamerella*, *Megastrophia concava*, small rugose corals, and crinoid debris ("Sponge-*Megastrophia* Bed" of Mayer, 1989) represents a smaller-scale regressive pulse. The greatest depths during Jaycox Member deposition may be represented by dark gray shales (beds J10-J14) with a diverse fauna and abundant crinoid debris. Faunal trends indicate smaller-scale subcycles. Most of the shale above the Greens Landing Coral Bed was removed by erosion in Erie County; a maximum of 5 cm was recorded at Buffalo Creek, and less than 2 cm at Cazenovia Creek.

The Cottage City Coral Bed (beds J15-J17) includes 70 cm of dark gray silty shale at Kashong Glen, where three fossil-rich beds contain a *Sulcoretipora*-dominated fauna with *Tropidoleptus*, small rugose corals, and crinoid debris (Fig. 13). The interval thins to 50 cm at Jaycox Run (Fig. 7), where the fossil beds are limey to concretionary and contain abundant large rugose corals. At Buffalo and Cazenovia creeks, the equivalent interval is a single massive bluish gray limestone that (where present) reaches a maximum thickness of 12 cm.

The remainder of the Jaycox Member (beds J18-J22) includes 7.5 m of *Zoophycos*-swirled silty mudstone at Kashong Glen where it records continued shallowing. There the fossil-poor upper few meters were not accessible for sampling, but the lower part contains a fauna with *Mucrospirifer*, chonetids, gastropods, and *Pleurodictyum*. Faunal dominance trends indicate at least one superimposed subcycle. This upper Jaycox thins dramatically westward beneath the pre-Tichenor erosion surface (Fig. 7); at Hopewell Gully, less than 1 m remains. At Jaycox Run, only about 45 cm of shale separates the Cottage City Coral Beds from the Tichenor, and 0 to 8 cm of dark gray shale represents this interval at Buffalo Creek and Cazenovia Creek.

CONCLUSIONS

Lithologic and faunal patterns reveal a hierarchy of cyclic packages in the upper part of the Ludlowville Formation (Fig. 14). Superimposed on an overall regression are several member- or submember-scale cycles. Numerous smaller-scale subcycles can be traced across most of the study area. An even smaller-scale cyclicity is observed where bed resolution is greatest. Comparison of the cyclic packages with the correlation-derived chronostratigraphy suggests that they are isochronous, with peak transgressions peak regressions recorded in the same bed along the 140-km transect. The cyclicity thus appears to reflect sea level fluctuations responding to regional or perhaps global controls. For a discussion of magnitudes, durations, and causal mechanisms of cycles recorded in Hamilton Group rocks, the reader is referred to papers by Batt (1996), Brett (1995, 1998), and Miller (1990).

Microstratigraphic correlation and cyclic interpretations allow a detailed reconstruction of events prior to deposition of the Tichenor Member, including at least seven distinct episodes of erosional scour and/or condensation (Fig. 15). The top of the Bloomer Creek Bed is believed to represent a maximum flooding surface associated with submember-scale transgression accompanied by basin-wide starvation as sediment was trapped in newly flooded embayments. Condensation of the lower Romulus Bed from Jaycox Run westward may record sediment bypass affecting shallower areas during subsequent sea-level fall.

Each of the five erosion surfaces in the remainder of the study interval records scour during a lowstand event. In each case, successively older beds were beveled in a westward direction where progressively shallower bottoms were more directly influenced by storm waves during sea level fall. Pre-Spafford erosion removed the uppermost Romulus Bed from Jaycox Run to Buffalo Creek; further west, the entire Bloomer Creek through Romulus interval is absent. The unconformable base of the Hills Gulch Bed from Jaycox Run westward reflects erosion during lowstand associated with the Spafford cycle, even though a thin interval of mudstone probably equivalent to part of the Spafford Member persists as far west as Rush Creek. The erosional bases of the Greens Landing and Cottage City coral beds also represent lowstand events, with westward removal of progressively older underlying shales until, at Cazenovia Creek (and locally at Buffalo Creek), the coral bed rests directly on remnants of the limestone of the previous cycle. The intermittent persistence of these limestones as far west as Cazenovia Creek suggests that they may have been locally indurated prior to re-exposure on the sea floor as somewhat resistant hardgrounds.

Erosion during final pre-Moscow lowstand affected the entire area of study. The sub-Tichenor unconformity not only truncates successively older beds but also oversteps older erosion surfaces to create a westward merging of unconformities until only one is present at the Lake Erie shore, where the Tichenor Member rests directly on a beveled surface near the top of the lower Blasdell Bed (Fig. 15). This overall pattern is very similar to that noted by Brett and Baird (1982) for the top of the Hamilton Group in western and central New York.

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ROAD LOG AND STOP DESCRIPTIONS

The road log begins at the first stop, at Jaycox Run. From Fredonia: New York State Thruway (I-90 E) to Exit 48 (Batavia) (68 mi); Rt. 98 S to Batavia (2 mi); left (S) on Rt. 63. Pass through Pifford in 24.5 mi; 2.4 mi further turn left onto Court Street in Geneseo. In 0.5 mi turn left (N) onto Rt. 39. Pass Nations Road on left in 2 mi. White Devon Farm 0.5 mi further; turn around and park across from farm on shoulder near gateway into pasture. Walk straight west from gate through the pasture to a cluster of oak trees along the south branch of Jaycox Creek.

Note: Section descriptions for stops are arranged from the top bed downward. Corresponding depositional units discussed in text are provided for each interval described. Prominent fossils are listed for each bed; these are not complete faunal listings.

STOP 1: JAYCOX RUN

Exposures along the south fork of Jaycox Creek, on the property of William P. Wadsworth (White Devon Farm), about 0.8 km (0.5 mi) north of Nations Road, Geneseo, Livingston County, NY. This site is PRIVATE PROPERTY; in order to collect, PERMISSION MUST BE OBTAINED.

This section, the eastern-most one we will visit, illustrates all of the members and major marker beds of the study interval. Some of the beds present in sections further east have already been removed here in various unconformities.

SECTION DESCRIPTION:

J15-J17 94 cm COTTAGE CITY CORAL BED
Three limey, fossil-rich beds, each overlain by an interval of less fossiliferous shale. Corals: *Heliophyllum, Eridophyllum, Cystiphylloides, Amplexiphyllum, Stereolasma, Favosites.* Bryozoans: fenestellids, *Sulcoretipora, Lichenalia.* Brachiopods: *Pentamerella, Parazyga, Mesoleptostrophia, Protodouvillina, Athyris, Devonochonetes, Rhipidomella.* Trilobites: *Phacops, Monodechenella.* Abundant crinoid debris. > 20 species identified from these beds.

J10-J14 77 cm Several beds of hard shale with two prominent fossil-rich horizons. Corals: *Amplexiphyllum, Stereolasma, Aulocystis*; bryozoans: fenestellids, *Sulcoretipora, Lichenalia*; brachiopods: *Devonochonetes, Stropheodonta, Mesoleptostrophia, Protoleptostrophia, Protodouvillina, Mucrospirifer, Mediospirifer, Pentamerella, Parazyga*); mollusks, trilobites, abundant crinoid debris. Beds contain more than 30 species.

J9 31 cm "SPONGE-*MEGASTROPHIA* BED"
6 cm shell bed overlain by 25 cm shale. Corals: *Eridophyllum, Amplexiphyllum*; bryozoans: fenestellids, *Lichenalia*; brachiopods: *Megastrophia, Mesoleptostrophia, Stropheodonta, Orthospirifer, Parazyga, Pentamerella*; trilobites: *Phacops, Greenops.* Abundant crinoid debris. 22 species.

J8 29 cm Medium gray hard fissile shale with crinoid debris. 16 species noted, dominantly fenestellids, *Stereolasma, Protodouvillina, Phacops, Monodechenella.*

J6-J7 30 cm GREENS LANDING CORAL BED

Hard medium gray shale with abundant crinoid debris. More than 30 species noted. Corals: *Heliophyllum, Cystiphylloides, Cyathophyllum, Eridophyllum, Thamnoptychia, Favosites, Pleurodictyum*; bryozoans: fenestellids, *Sulcoretipora, Lichenalia*; brachiopods: *Protodouvillina, Orthospirifer, Pentamerella, Parazyga*. *Phacops* the dominant trilobite.

J2-J5 50 cm Three beds hard fissile medium gray shale; more than 35 species. Corals: *Amplexiphyllum, Cyathophyllum, Favosites, Pleurodictyum*; bryozoans: fenestellids, *Sulcoretipora, Lichenalia*; brachiopods: abundant *Tropidoleptus* and chonetids; also *Mediospirifer, Orthospirifer, Rhipidomella, Pentamerella, Athyris*. Various gastropods and pelecypods. Trilobites: *Phacops, Dipleura*. Crinoid debris rare.

J1 28 cm HILLS GULCH BED

Hard massively fissile bed at top of waterfall. More than 30 species. Corals: *Amplexiphyllum*, aulocystids; bryozoans: fenestellids; brachiopods: *Orthospirifer, Athyris, Parazyga*; pelecypods: *Pseudaviculopecten, Actinopteria, Mytilarca, Pterinopecten, Grammysioidea, Gosseletia, Cypricardella, Modiomorpha*; gastropod: *Mourlonia*; cephalopod: *Nephriticerina*; trilobite: *Phacops*. Crinoid debris very rare.

S5-S6 45 cm Upper part of Spafford shale. Two beds of hard bluish gray, massively fissile shale with few fossils. 12 species noted. Coral: tiny *Pleurodictyum*; brachiopods: *Mucrospirifer, Tropidoleptus, Euschuchertella*, chonetids, *Mediospirifer, Cupularostrum*; pelecypod: *Nuculoidea*; gastropod: *Euryzone*; orthoconic nautiloid.

S1-S4 37 cm LIMERICK ROAD BED

Represented here by two beds of hard medium gray, *Zoophycos*-swirled shale with more than 20 species. Coral: *Pleurodictyum*; brachiopods: *Mucrospirifer, Tropidoleptus, Protoleptostrophia, Mediospirifer, Orthospirifer, Athyris, Cupularostrum*; mollusks (*Nuculoidea, Nuculites, Grammysioidea, Palaeozygopleura, Euryzone, Mourlonia*, orthocones. Crinoid debris rare.

B29 18 cm UPPER ROMULUS BED

Soft dark gray shale with less than 20 species. Brachiopods: *Mucrospirifer, Athyris, Mediospirifer, Orthospirifer, Cupularostrum*; gastropods (*Mourlonia, Palaeozygopleura*; cephalopods (orthoconic nautiloids, *Agoniatites*. Base marked by prominent granular pavement of *Crurispina nana* (condensed upper part of lower Romulus Bed).

B23-B25 49 cm LOWER ROMULUS BED

Represented here by 2 beds of hard dark gray fissile shale with several closely-spaced pavements of *Crurispina nana* (>90% of fauna). Also chonetids, *Mucrospirifer, Eumetabolatoechia, Euryzone*. Thin (<1 cm) clay at base may represent bentonite.

B21-B22 7 cm BLOOMER CREEK BED

Hard medium gray fissile shale with 14 species: *Mucrospirifer*, chonetids, *Cupularostrum*, gastropods (*Euryzone, Retispira*), trilobites (*Phacops, Greenops*).

B17-B20 19 cm UPPER BLASDELL BED

Two beds of hard medium gray fissile shale, more than 20 species. Corals: *Stereolasma*, *Pleurodictyum*; bryozoan: *Sulcoretipora*, brachiopods: *Mucrospirifer*, chonetids, *Orthospirifer*, *Athyris*, *Eoschuchertella*, *Rhipidomella*; mollusks (*Euryzone*, *Mourlonia*, *Palaeozygopleura*, orthocones); *Phacops*. Rare crinoid ossicles.

B12-B16 24 cm LOWER BLASDELL BED

Represented here by two beds of softer medium gray fissile shale, more than 20 species. Corals: *Stereolasma*, *Aulocystis*, small *Pleurodictyum*; bryozoans: *Sulcoretipora*, fenestellids; brachiopods: *Mucrospirifer*, chonetids, *Orthospirifer*, *Athyris*, *Ambocoelia*, *Pseudoatrypa*; mollusks (*Paleoneilo*, *Pterinopecten*, orthocones); abundant *Phacops*, rare crinoid ossicles.

B9-B11 14 cm Represented here by single bed hard dark gray shale with 7 species dominated by *Mucrospirifer*, *Sinochonetes*, with *Cyrtina*, common orthocones, *Phacops*. No crinoid debris.

B7-B8 23 cm MILESTRIP ROAD BED

Two beds hard dark gray thinly fissile shale with <10 species: *Eumetabolatoechia*, *Mucrospirifer*, *Sinochonetes*, orthocone, *Palaeozygopleura*, *Phacops*. Abundant blastoid stem material in lower part. Bedding planes covered with *Styliolina*.

B1-B6 67 cm Several beds of soft dark gray thinly fissile shale with <10 species. Brachiopods: *Eumetabolatoechia*, *Ambocoelia*, *Mucrospirifer*, *Sinochonetes*. Also *Palaeozygopleura*, orthocones, *Phacops*. Abundant styliolinids.

H1-H3 23 cm SPRING BROOK INTERVAL

Hard dark gray thinly fissile shale with 5 species. *Ambocoelia* dominant, with *Mucrospirifer*, *Sinochonetes*, *Phacops*.

Return to vehicles and CONTINUE SOUTH ON RT. 39

MILEAGE:		INSTRUCTIONS:
0.0	0.0	White Devon Farm at Stop 1.
0.5	0.5	Nations Road on right. Continue south on Rt. 39.
2.0	2.5	Court Street in north Geneseo (by courthouse). Turn right.
0.5	3.0	Jct. with Rt. 63. Turn right.
2.4	5.4	Pass through Pifford.
1.5	6.9	Retsof mine site. Continue on Rt. 63.
0.8	7.7	Griegsville Corners. Turn right (north) onto Rt. 36.

2.8	10.5	York Road in York. Turn left.
1.1	11.6	Turn right onto Limerick Road.
0.2	11.8	STOP 2. Limerick Road site.

STOP 2: LIMERICK ROAD SITE (Optional)

Creek on the property of Robert Walton, York, Livingston County, NY.

This stop, not included in the investigation, provides an additional exposure of the Spafford and Jaycox members. Section similar to that described for Jaycox Run.

Return to York.

MILEAGE:		INSTRUCTIONS:
1.4	13.2	Turn left in York onto Rt. 36, proceed north.
4.0	16.2	Turn left (west) onto US 20.
4.2	20.4	Turn left (south) onto Asbury Road.
0.45	20.85	Turn right (west) onto Murry Road.
0.15	21.0	Turn right onto driveway.
0.1	21.1	Stop at house.

STOP 3: HILLS GULCH

Creek on the property of Carl Hume, Union Corners, Genesee County, NY.

This site, not included in the investigation, exposes the interval from the upper part of the Buffalo Creek Submember through the Tichenor Member. The general section is described below (thicknesses approximate):

SECTION DESCRIPTION:

(not meas.)	Tichenor Member at top of waterfall.
17 cm	Cottage City Coral Bed. Only the lowest of the three coral beds remains after pre-Tichenor erosion.
130 cm	Middle part of Jaycox Member between coral beds.

30 cm	Greens Landing Coral Bed. Numerous large, often elongate and constricted *Heliophyllum*, also *Eridophyllum*, *Favosites*.
17 cm	Shale between Greens Landing Bed, Hills Gulch Bed
25-30 cm	Hills Gulch Bed. Hard silty mudstone with abundant fossils: *Mucrospirifer*, large spiriferids, *Phacops*.
30 cm	Upper part of the Spafford Member. Hard light gray massively fissile, poorly fossiliferous shale.
25 cm	Limerick Road Bed. Bluish gray silty mudstone, *Pleurodictyum*, large spiriferids.
27 cm	Upper Romulus Bed. Soft fissile shale.
75 cm	Lower Romulus Bed. Several beds of soft, thinly fissile shale; pavements of *Crurispina*.
25 cm	Bloomer Creek Bed. Hard fissile shale with *Athyris*, *Mucrospirifer*.
50 cm	Blasdell Bed. Fissile shale with *Sulcoretipora*, *Phacops*, diverse brachiopods.
30 cm	Shale below Blasdell Bed to creek level.

Return to vehicles and return to Jct. Asbury Road and US 20.

MILEAGE:		INSTRUCTIONS:
0.7	21.8	Turn left (west) onto US 20 from Asbury Road.
5.0	26.8	Texaco Town, Jct. Rt. 63 and US 20. Continue on US 20.
3.3	30.1	Old Telephone Road at Bethany Center. Continue on US 20.
6.4	36.5	Jct. US 98, Alexandria. Continue on US 20.
4.9	41.4	Darien. Continue on US 20.
1.9	43.3	Jct. 77, Darien Center. Continue on US 20.
1.7	45.0	Cross Elevenmile Creek.
0.5	45.5	Entrance to Darien Lake State Park on right. Continue on US 20.
2.7	48.2	Pass John and Mary's on left.

0.3	48.5	Crittendon Road in Alden. Continue on US 20.
0.3	48.8	Fork in Alden; stay on US 20 (bear left).
2.9	51.7	Two Rod Road (Marilla sign). Turn left (S).
2.5	54.2	Clinton Street (stop sign). Continue on Two Rod Road.
0.7	54.9	Enter Marilla.
0.4	55.3	Bullis Road. Turn right (west).
2.1	57.4	Stolle Road. Continue on Bullis Road.
0.1	57.5	Turn left onto access to old bridge over Buffalo Creek (closed), just before Bullis Road bridge. Park before barricade. DO NOT BLOCK DRIVEWAY! If there is not enough room, continue on Bullis Road across creek, turn sharp left onto access road to other end of old bridge. Walk down to east end of old bridge, take path downstream, then down to creek bank at base of waterfalls.

STOP 4: BUFFALO CREEK AT BULLIS ROAD

Buffalo Creek beneath and downstream of Bullis Road bridge, Marilla, Town of Elma, Erie County, NY.

This exposure illustrates the continued westward removal of successively older beds during lowstand events. Most dramatic is the removal of almost all of the shale overlying the Hills Gulch Bed, Greens Landing Coral Bed, and Cottage City Coral Bed. Each of these beds is here represented by a massive fossiliferous limestone characteristic of this shallower western shelf setting. This section also marks the westernmost occurrence of the Bloomer Creek Bed and Romulus Bed of the Buffalo Creek Submember.

SECTION DESCRIPTION:

Note: The Jaycox Member was not sampled for fossils in this investigation, so bed prefixes were not assigned.

TICHENOR LIMESTONE. Massive gray limestones. To 50 cm.

Hard bluish gray shale: remains of Jaycox Member above the Cottage City Coral Bed. Locally absent. 0-8 cm.

COTTAGE CITY CORAL BED. Variable thickness over short distances. Massive bluish gray limestone with large corals (rugose and *Favosites*), crinoids, other fossils. 0-12 cm.

Hard bluish gray shale (escaped pre-CCC Bed erosion). 0-5 cm.

GREENS LANDING CORAL BED. Thickness varies over short distances. Locally the lowest limestone in the waterfall. Fossils similar to Cottage City Coral Bed. 0-15 cm.

Hard bluish gray shale (escaped pre-GLC Bed erosion). 0-8 cm.

HILLS GULCH BED. Massive bluish gray limestone with abundant fossils: crinoid debris, bryozoans, brachiopods (*Elita, Parazyga, Protodouvillina, Pholidostrophia, Megastrophia*), mollusks (*Actinopteria, Platyceras*), corals (*Heliophyllum, Favosites, Pleurodictyum*). 0-16 cm.

S1?-S6? 95 cm PROBABLE SPAFFORD EQUIVALENT
Top two beds (locally absent) massively fissile bluish gray shale with few fossils (*Mucrospirifer*, chonetids, *Agoniatites*). Lower beds hard, thinly fissile dark gray shale with *Mucrospirifer*, *Cupularostrum*, chonetids, tiny *Tropidoleptus*, *Cyrtina*, nuculids.

B29 16 cm UPPER ROMULUS BED
Soft dark gray thinly fissile shale dominated by *Devonochonetes* and *Mucrospirifer*. Also tiny *Tropidoleptus*, *Crurispina nana*, orthocones, *Agoniatites*. 10 species.

B23-B24 23 cm LOWER ROMULUS BED
Two horizons of widely-spaced irregular concretions studded with *Crurispina nana* in hard, dark gray thinly fissile shale. *C. nana* comprises >80% of fauna of <10 species. Also chonetids, small *Tropidoleptus, Mucrospirifer*, *Cupularostrum*.

B21-B22 16 cm BLOOMER CREEK BED
Hard fissile medium gray shale with 15 species. Fauna dominated by *Mucrospirifer* and chonetids, with common *Athyris* and *Tropidoleptus*. Also *Cyrtina, Mediospirifer*, *Pseudoatrypa*, *Grammysioidea*, various pelecypods, *Phacops*, rare *Stereolasma*.

B17-B20 45 cm UPPER BLASDELL BED
Four beds of hard fissile dark gray shale, >40 species. Coral: *Stereolasma*; bryozoan: *Sulcoretipora*; brachiopods: *Mucrospirifer, Devonochonetes, Rhipidomella, Tropidoleptus*, *Spinocyrtia, Mediospirifer*, *Nucleospira, Athyris*; *Phacops*. Crinoid debris rare.

B12-B16 68 cm LOWER BLASDELL BED
Five beds of hard fissile to thinly fissile shale, >40 species. Coral: *Stereolasma*; bryozoans: *Sulcoretipora*, fenestellids; brachiopods: *Mucrospirifer, Rhipidomella, Protodouvillina*, *Megastrophia, Stropheodonta, Mediospirifer, Spinocyrtia, Cyrtina, Pseudoatrypa, Athyris*; various mollusks, trilobites. Crinoid debris rare compared to sections to west.

B9-B11 26 cm Three beds of thinly fissile dark olive gray shale, <15 species. Dominantly *Mucrospirifer* but *Athyris* quite abundant. Also chonetids, *Mediospirifer, Cyrtina, Nucleospira*, trilobites. Rare *Stereolasma*. No crinoid debris.

B7-B8 49 cm MILESTRIP ROAD BED
Hard dark gray thinly fissile shale, styliolinid-covered surfaces. Widely spaced calcareous concretions at base. <10 species. Dominantly *Mucrospirifer* and *Sinochonetes*, with *Cyrtina*, *Eumetabolatoechia*, *Nuculoidea*, *Grammysioidea*, *Phacops*.

B1-B6 87 cm Several beds of hard fissile to thinly fissile dark gray shale. Fauna in upper part dominated by *Mucrospirifer*, with chonetids, *Cyrtina*, *Phacops*. *Ambocoelia* dominant in lower beds. <15 species.

H1-H3 82 cm SPRING BROOK HORIZON
Represented here by several beds of hard fissile shale. One horizon of flattened calcareous concretions near top; two horizons of larger concretions in lower part. Beds contain up to ten species. Dominated by *Ambocoelia*, with *Mucrospirifer*, *Sinochonetes*, *Athyris*, *Phacops*; rare *Sulcoretipora*, *Stereolasma*, *Spinocyrtia*, blastoid stems.

Return to vehicles, continue west on Bullis Road.

MILEAGE:		INSTRUCTIONS:
0.4	57.9	Girdle Road. Continue on Bullis Road.
1.6	59.5	Bowen Road. Continue on Bullis Road.
3.0	62.5	Transit Road (US 20/Rt. 78). Turn left (S).
0.4	62.9	Jct. Rt. 400. Turn right (Rt. 400 W).
5.0	67.9	Jct. NY State Thruway. Take I-90 West.
11.3	79.1	Exit 57 (Hamburg). After toll, take Rt. 75 North.
1.0	80.1	Jct. US 20. Turn left.
4.4	84.5	Detour (US 20 bridge closed). Turn Right onto Lakeview Road.
1.5	86.0	Jct. Rt. 5. Turn Left.
1.1	87.1	Cross Eighteenmile Creek.
0.2	87.3	Jct. South Creek Road. Turn left and park in lot on right. Cross South Creek Road and follow fishing trail under bridge to creekbed (steep). Exposure immediately upstream.

STOP 5: EIGHTEENMILE CREEK AT ROUTE 5

South bank of Eighteenmile Creek immediately upstream of Route 5 bridge, Town of Evans, Erie County, NY. This section, Grabau's Section 6, is similar to the Lake Erie Shore section exposed less than 1 mi to the west. It was chosen because of accessibility. NOTE that the exposures along the creek on the north bank, west of the Route 5 bridge, are on private property and are off-limits.

Here the Tichenor can be seen to rest directly on a beveled surface near the top of the lower part of the Blasdell Bed. The entire Jaycox, Spafford, and upper Wanakah down through the upper part of the Blasdell Bed has been removed by pre-Tichenor erosion. Also visible at this locality is the unconformity separating the Tichenor Member from the overlying Windom Shale, with the intervening Deep Run Shale, Menteth Limestone, and Kashong Shale removed during similar lowstand erosion events.

SECTION DESCRIPTION:

NOTE: Numbered beds referred to in the study were defined at the type locality for the Buffalo Creek Submember. Because resolution is greater at the Lake Erie Shore section, several beds here may correspond to one bed at Buffalo Creek. Example: B15 is represented here by four.

B16 23 cm "*STICTOPORA* LIMESTONE"
Three hard limey beds packed with fossils (>50 species). Prominent fossils include *Sulcoretipora, Mucrospirifer, Nucleospira,* fenestellids, *Phacops, Pseudoatrypa,* crinoids, chonetids, *Stereolasma, Lichenalia, Rhipidomella, Spinocyrtia, Stropheodonta,* mollusks.

B15 22 cm "*DEMISSA* BED"
Four beds of slightly softer medium gray fissile shale with abundant fossils (>50 species). Prominent forms include *Mucrospirifer, Sulcoretipora,* fenestellids, *Stereolasma,* chonetids, *Stropheodonta, Megastrophia, Spinocyrtia, Mediospirifer, Athyris, Pseudoatrypa,* diverse gastropods and pelecypods, orthoconic nautiloids, *Nephriticerina, Phacops, Greenops,* crinoids.

B12-B14 42 cm Shale of basal Lower Blasdell Bed subcycle. Four beds, *Zoophycos*-swirled. >50 species. Brachiopods: *Mucrospirifer, Nucleospira,* chonetids, *Cyrtina, Cupularostrum, Rhipidomella, Pseudoatrypa, Athyris* (abundant), *Spinocyrtia, Megastrophia, Stropheodonta.* Also *Stereolasma,* mollusks.

B9-B11 48 cm Four beds of fissile shale, up to 20 species. Dominated by chonetids and *Mucrospirifer.* Also *Mediospirifer, Athyris, Cyrtina, Nucleospira, Stereolasma* (few), *Greenops, Phacops,* orthocones.

B7-B8 30 cm MILESTRIP ROAD BED
Two beds, each with calcareous concretions at base. Abundant styliolinids. Up to 20 species. *Mucrospirifer, Athyris* (abundant), *Stereolasma, Aulocystis, Protoleptostrophia, Cyrtina,* chonetids, *Phacops, Greenops.*

B1-B6 78 cm Seven beds of fissile dark gray shale. <15 species. *Mucrospirifer* dominates in upper part; *Ambocoelia* in lower part. Also chonetids, small *Tropidoleptus*, *Cyrtina*, *Athyris*, *Eoschuchertella*, *Aulocystis*, *Stereolasma*, *Phacops*.

H1-H3 76 cm SPRING BROOK HORIZON
Six beds of hard dark gray thinly fissile shale, including three horizons of large concretions. <20 species. *Ambocoelia* dominant, with abundant *Athyris*, also *Sulcoretipora*, *Rhipidomella*, chonetids, *Protoleptostrophia*, *Mediospirifer*, *Mucrospirifer*, *Phacops*.

To return to Fredonia, follow South Creek east to US 20, turn right (west), turn left onto Evans Center/Eden Center Road, get on NY Thruway at Angola exit (57A).

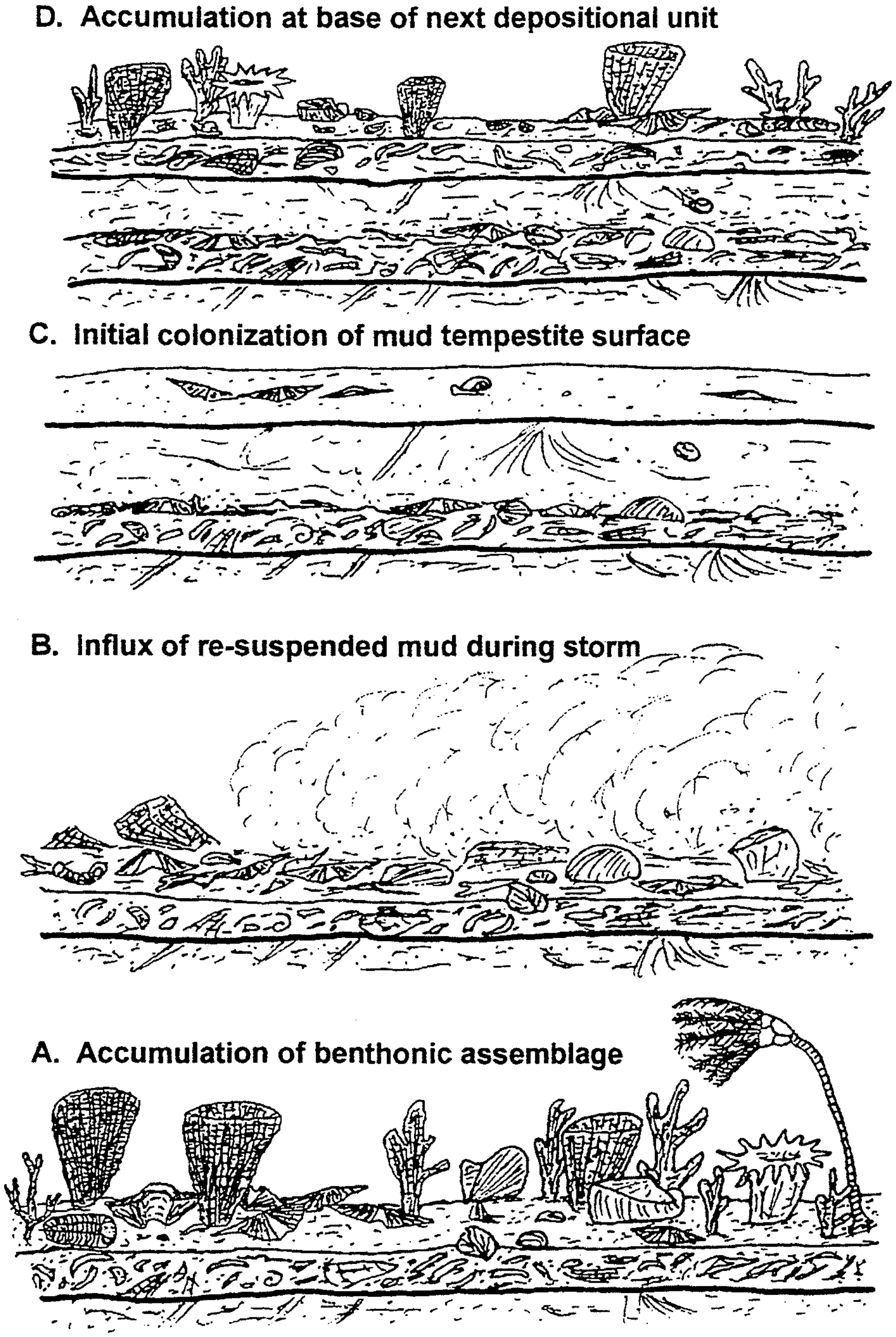


FIGURE 1. Steps in the formation of a typical depositional unit.

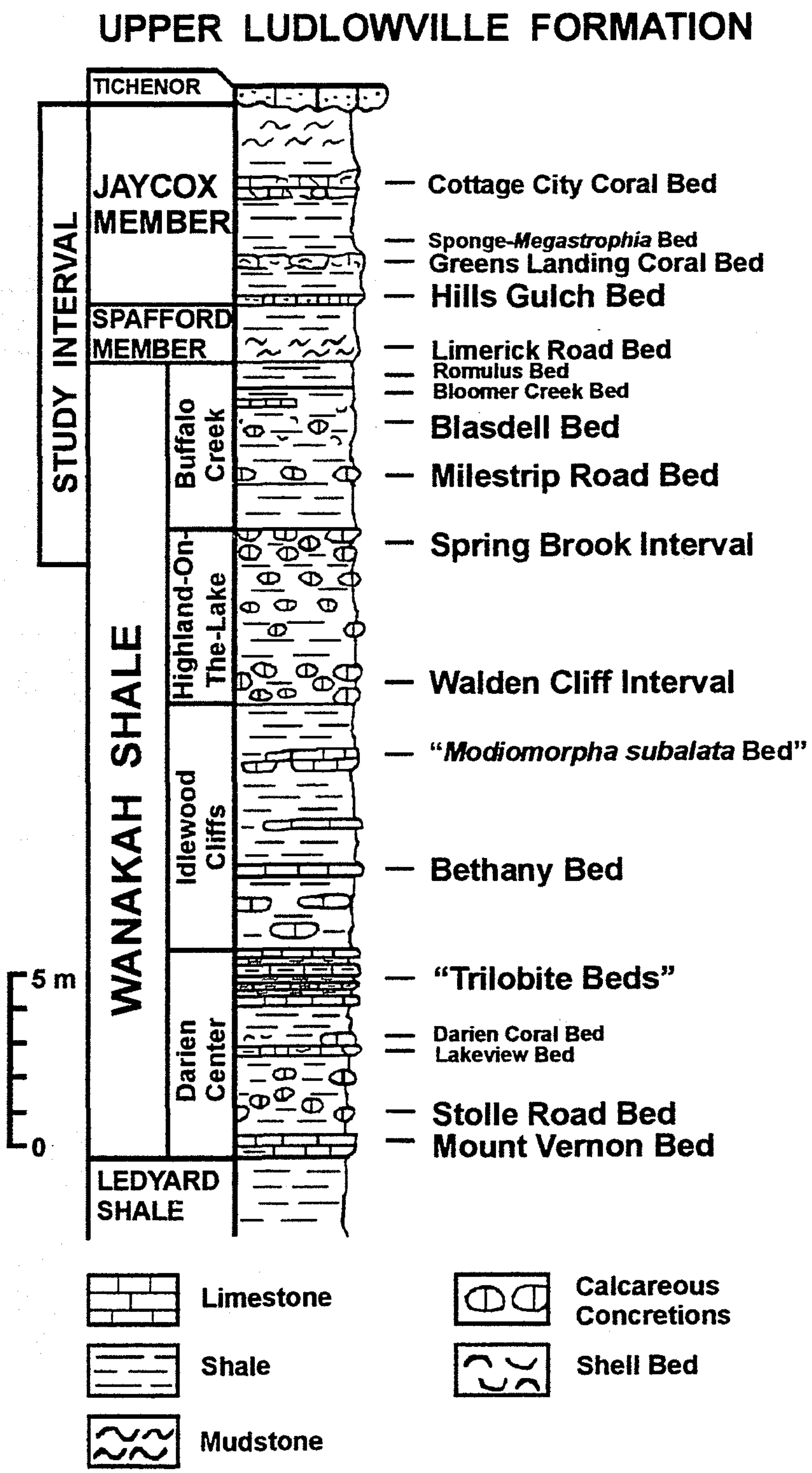


FIGURE 2. Stratigraphic section for the upper part of the Ludlowville Formation. Study interval includes the Spring Brook Interval (uppermost Highland-On-The-Lake Submember), Buffalo Creek Submember, Spafford Member, and Jaycox Member.

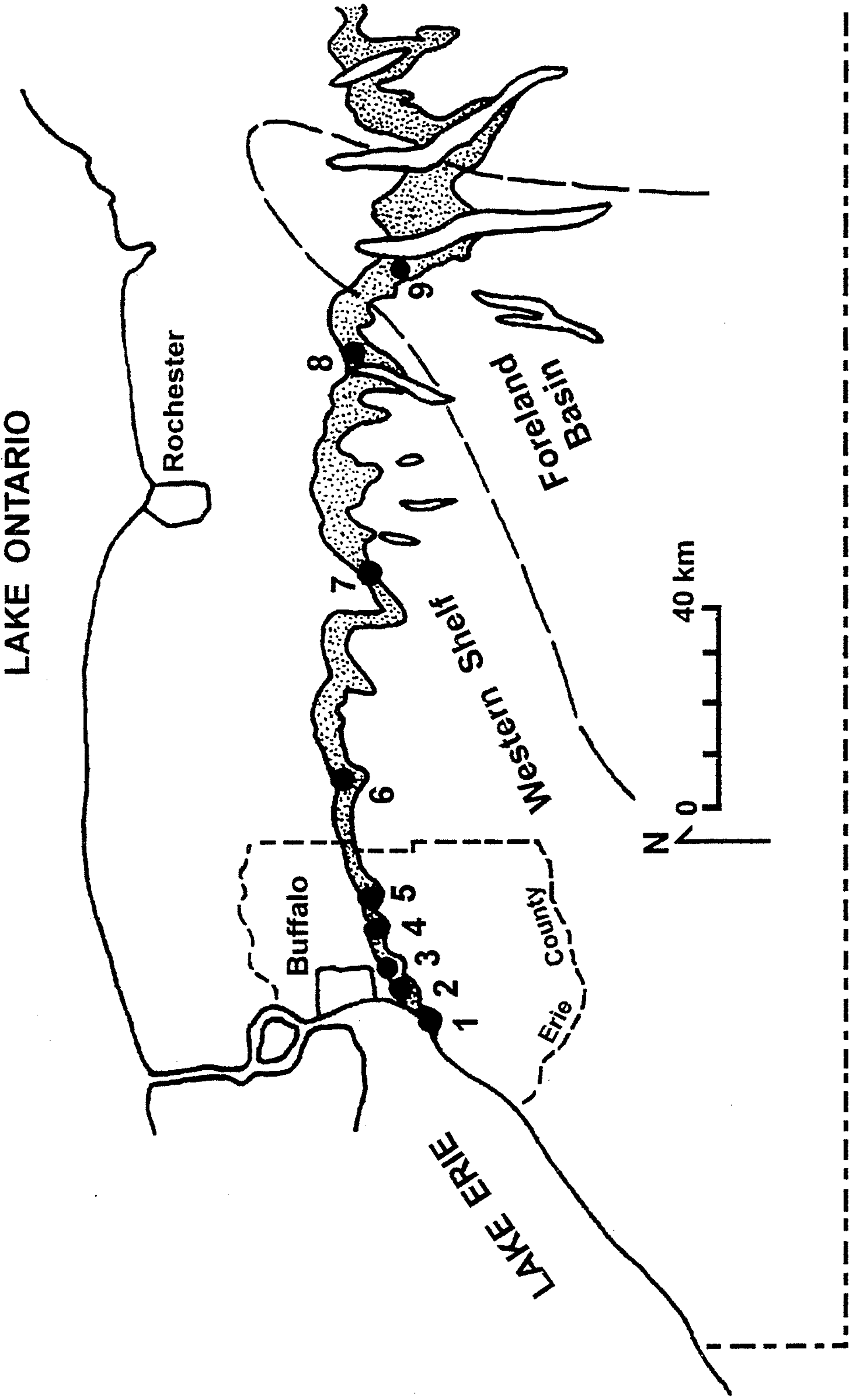


FIGURE 3. Map of study area showing outcrop belt of Ludlowville and Moscow formations (stippled pattern), major paleogeographic features, and location of measured sections: 1) Lake Erie Shore near mouth of Eighteenmile Creek; 2) Rush Creek near Blasdell; 3) Smoke Creek near Windom; 4) Cazenovia Creek near Spring Brook; 5) Buffalo Creek near Elma; 6) Elevenmile Creek near Darien; 7) Jaycox Run near Geneseo; 8) Hopewell Gully near Canandaigua; 9) Kashong Glen near Geneva.

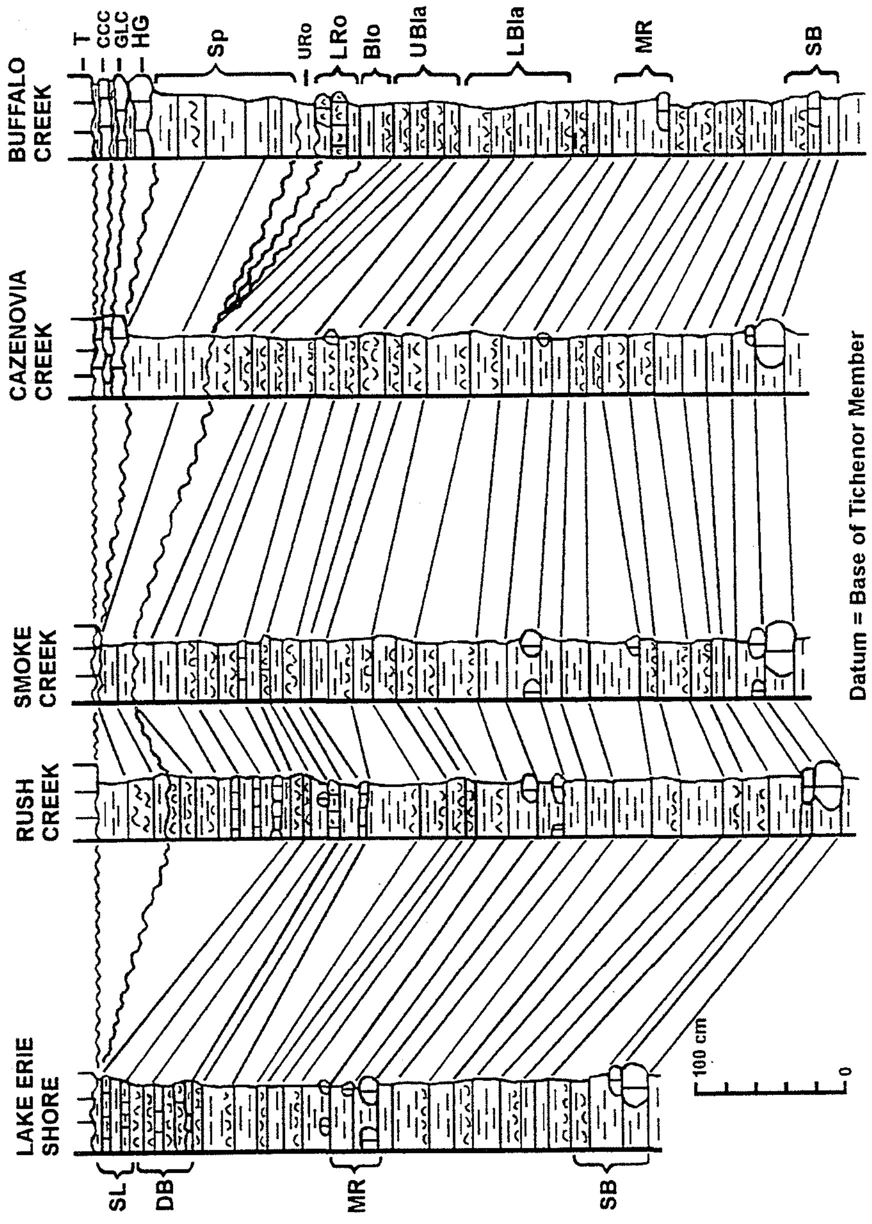


FIGURE 4. Correlation of measured sections through the study interval in Erie County (Lake Erie shore to Buffalo Creek). Marker beds: SB Spring Brook Interval; MR Milestrip Road Bed; LBla lower Blasdell Bed; UBla upper Blasdell Bed; Blo Bloomer Creek Bed; LRo lower Romulus Bed; URo upper Romulus Bed; Sp Spafford Member; HG Hills Gulch Bed; GLC Greens Landing Coral Bed; CCC Cottage City Coral Bed; T Tichenor Member; DB "*Demissa* Bed"; SL "*Stictopora* Limestone".

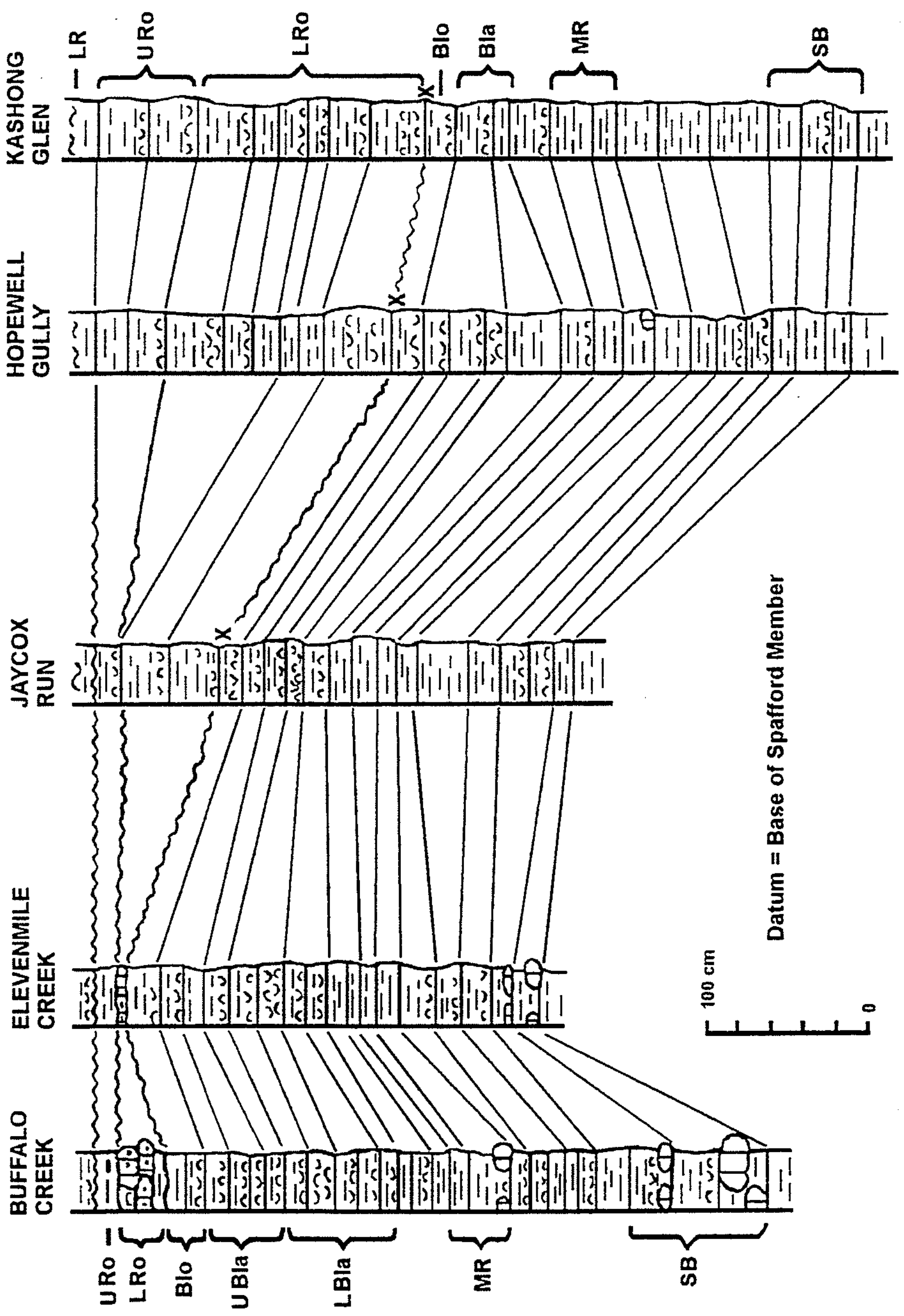


FIGURE 5. Correlation of measured sections through the Wanakah Shale part of the study interval from Buffalo Creek to Kashong Glen. Marker beds defined in Figure 4 caption (Bla represents undifferentiated Blasdell Bed in eastern sections). Position of possible bentonite indicated by "X".

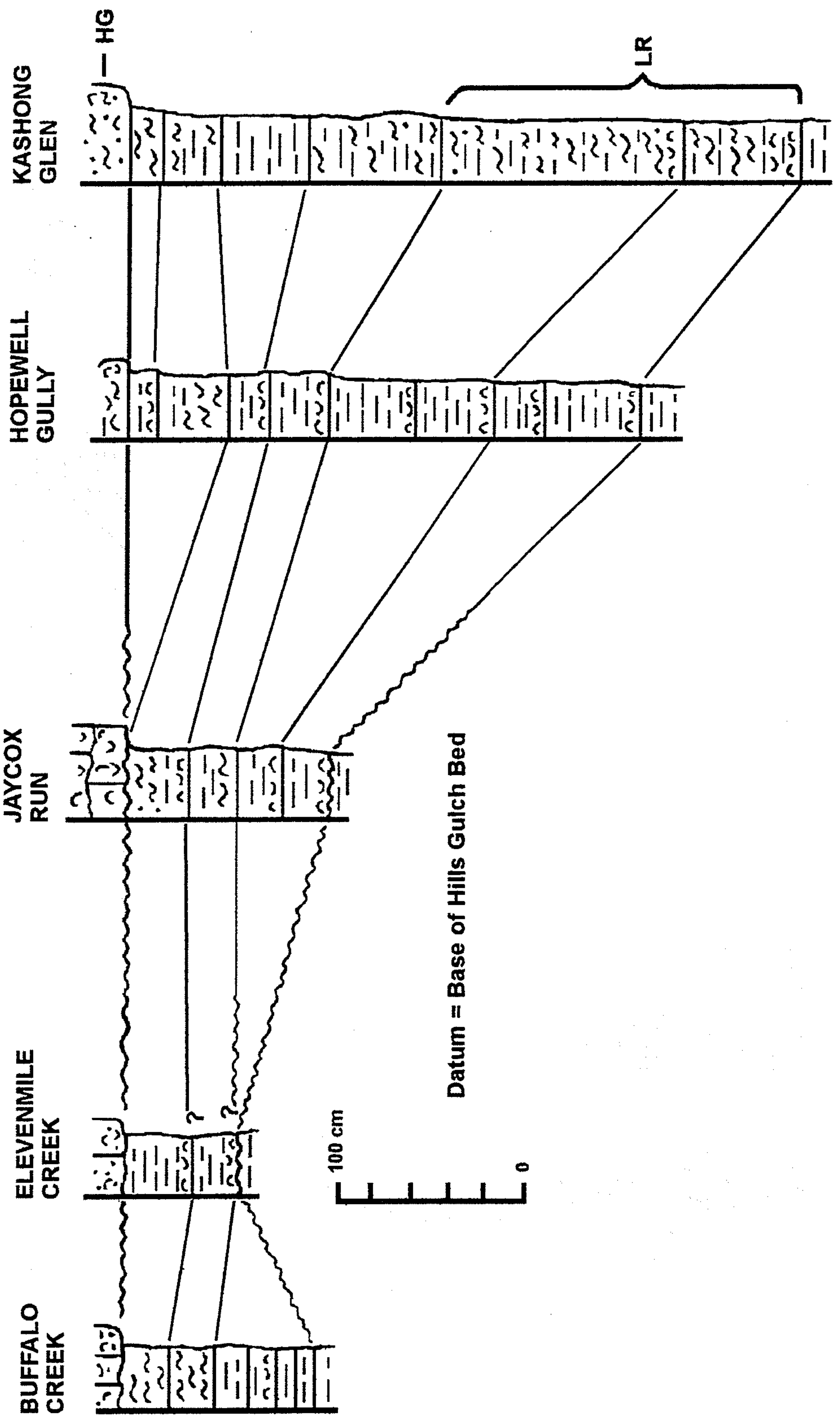


FIGURE 6. Correlation of measured sections through the Spafford Member from Buffalo Creek to Kashong Glen. Marker beds: LR Limerick Road Bed; HG Hills Gulch Bed.

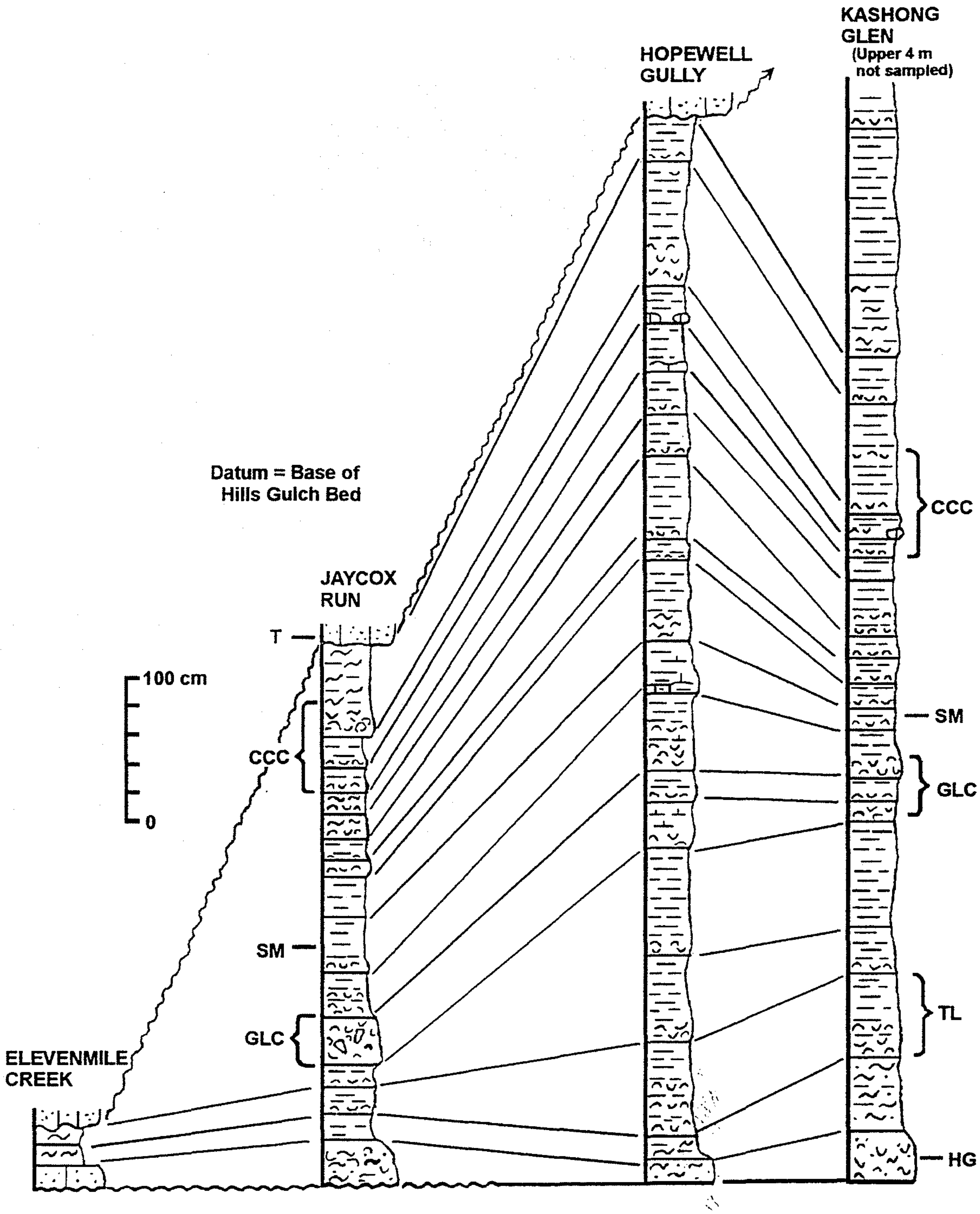
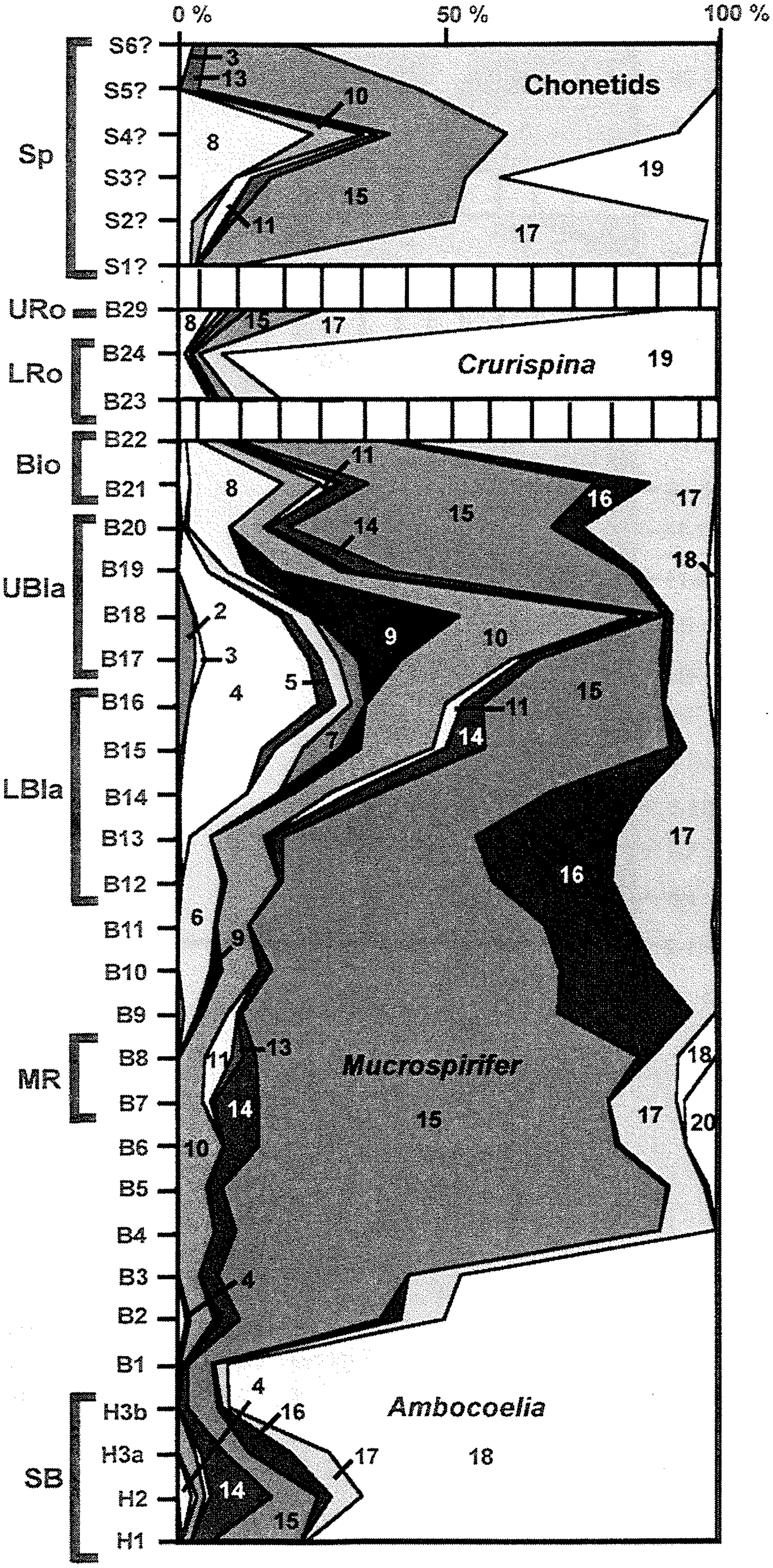


FIGURE 7. Correlation of measured sections through the Jaycox Member from Elevenmile Creek to Kashong Glen. Marker beds: HG Hills Gulch Bed; TL "*Tropidoleptus-Longispina* Bed"; GLC Greens Landing Coral Bed; SM "Sponge-*Megastrophia* Bed"; CCC Cottage City Coral Bed; T Tichenor Member.

FIGURE 9. Faunal frequency diagram for the Wanakah Shale and Spafford Member at Buffalo Creek. Additional bed prefix: S Spafford Member. Faunal categories and marker beds defined in Figure 8 caption, with additions: Ubla upper Blasdell Bed; Blo Bloomer Creek Bed; Lro lower Romulus Bed; Uro upper Romulus Bed; US upper Spafford Member. Lower gap represents maximum flooding surface at top of Bloomer Creek Bed; upper gap represents sub-Spafford unconformity.

BUFFALO CREEK SECTION - Wanakah and Spafford



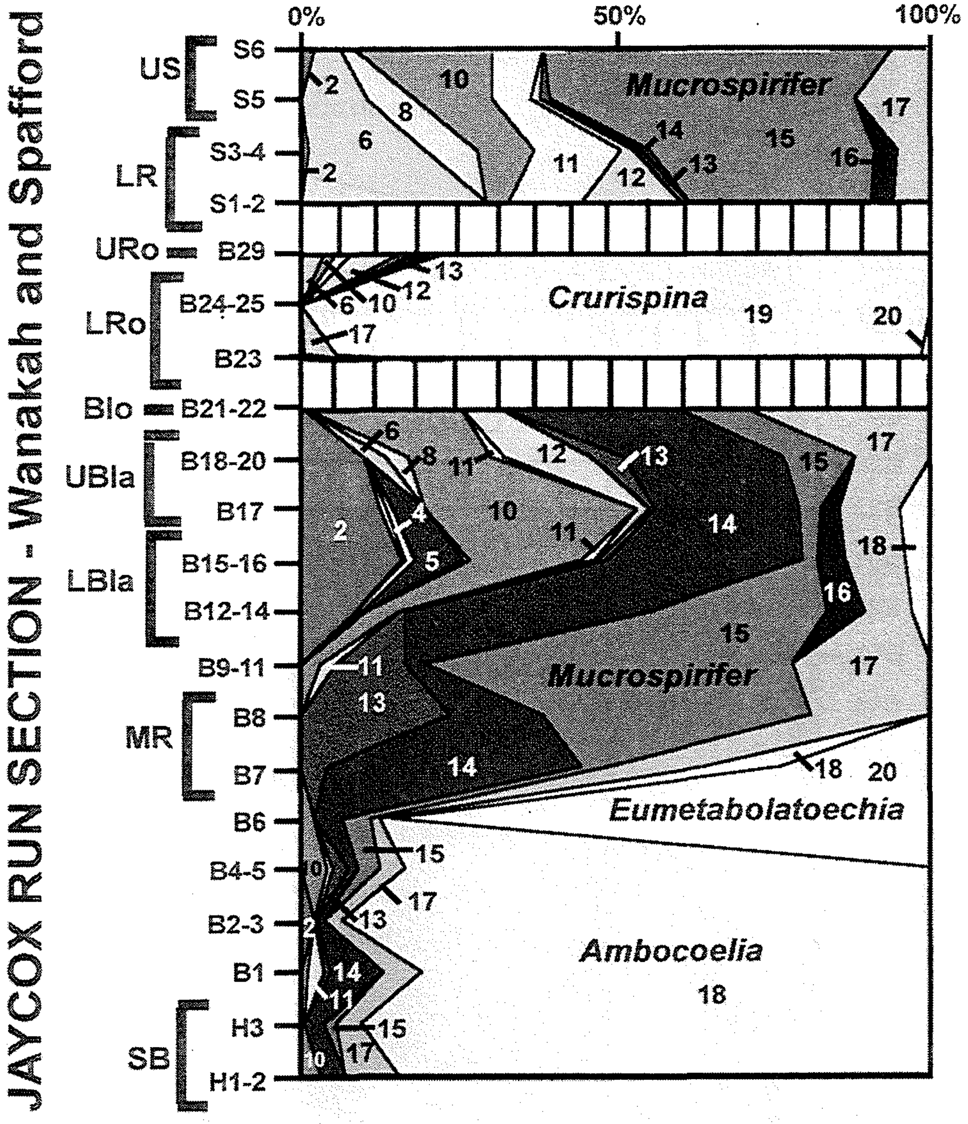


FIGURE 10. Faunal frequency diagram for the Wanakah Shale and Spafford Member at Jaycox Run. Faunal categories and marker beds defined in captions for Figures 8 and 9. Lower gap represents maximum flooding surface at top of Bloomer Creek Bed; upper gap represents sub-Spafford unconformity.

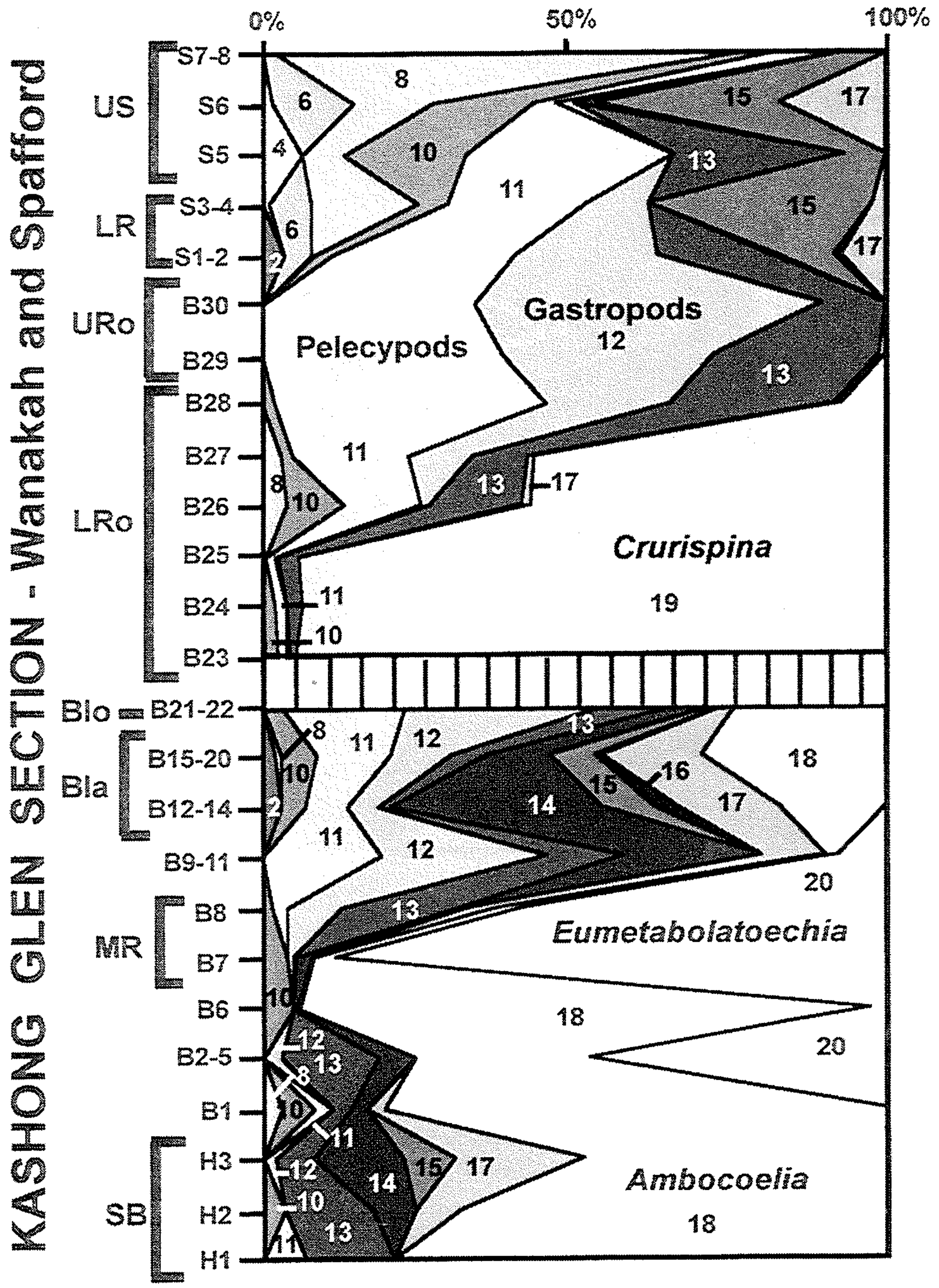


FIGURE 11. Faunal frequency diagram for the Wanakah Shale and Spafford Member at Kashong Glen. Faunal categories and marker beds defined in captions for Figures 8 and 9. Gap represents maximum flooding surface at top of Bloomer Creek Bed.

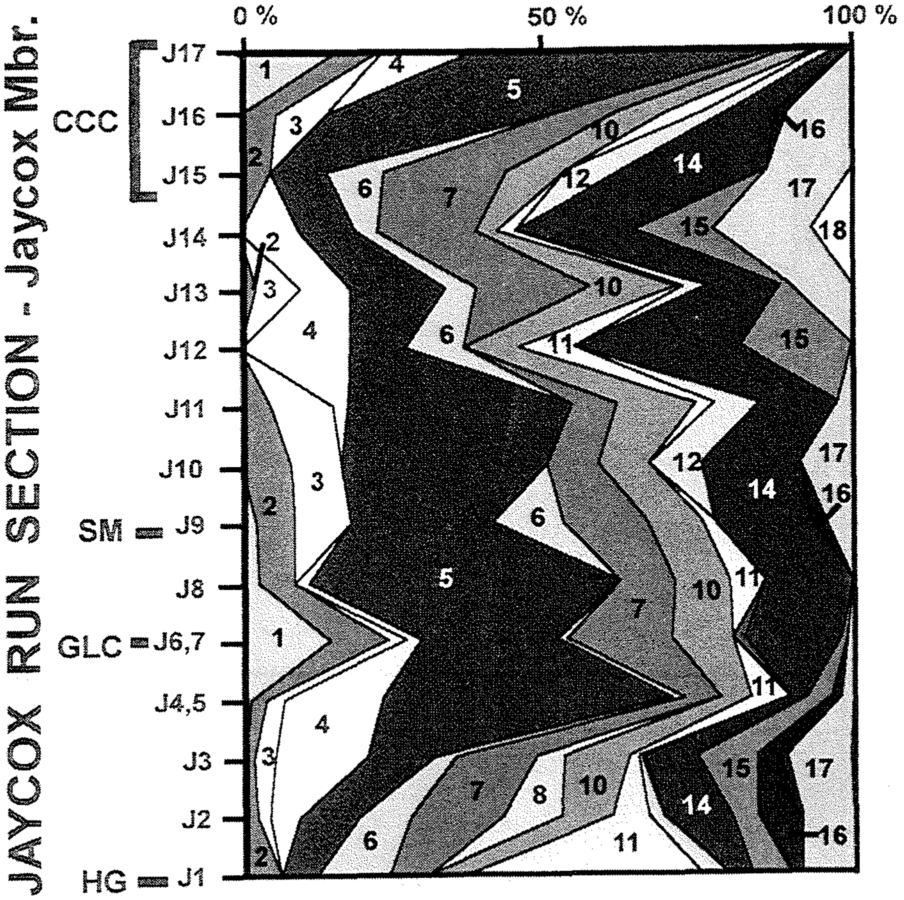


FIGURE 12. Faunal frequency diagram for the Jaycox Member at Jaycox Run. Faunal categories defined in Figure 8. Marker beds: HG Hills Gulch Bed; GLC Greens Landing Coral Bed; SM "Sponge-*Megastrophia* Bed"; CCC Cottage City Coral Bed.

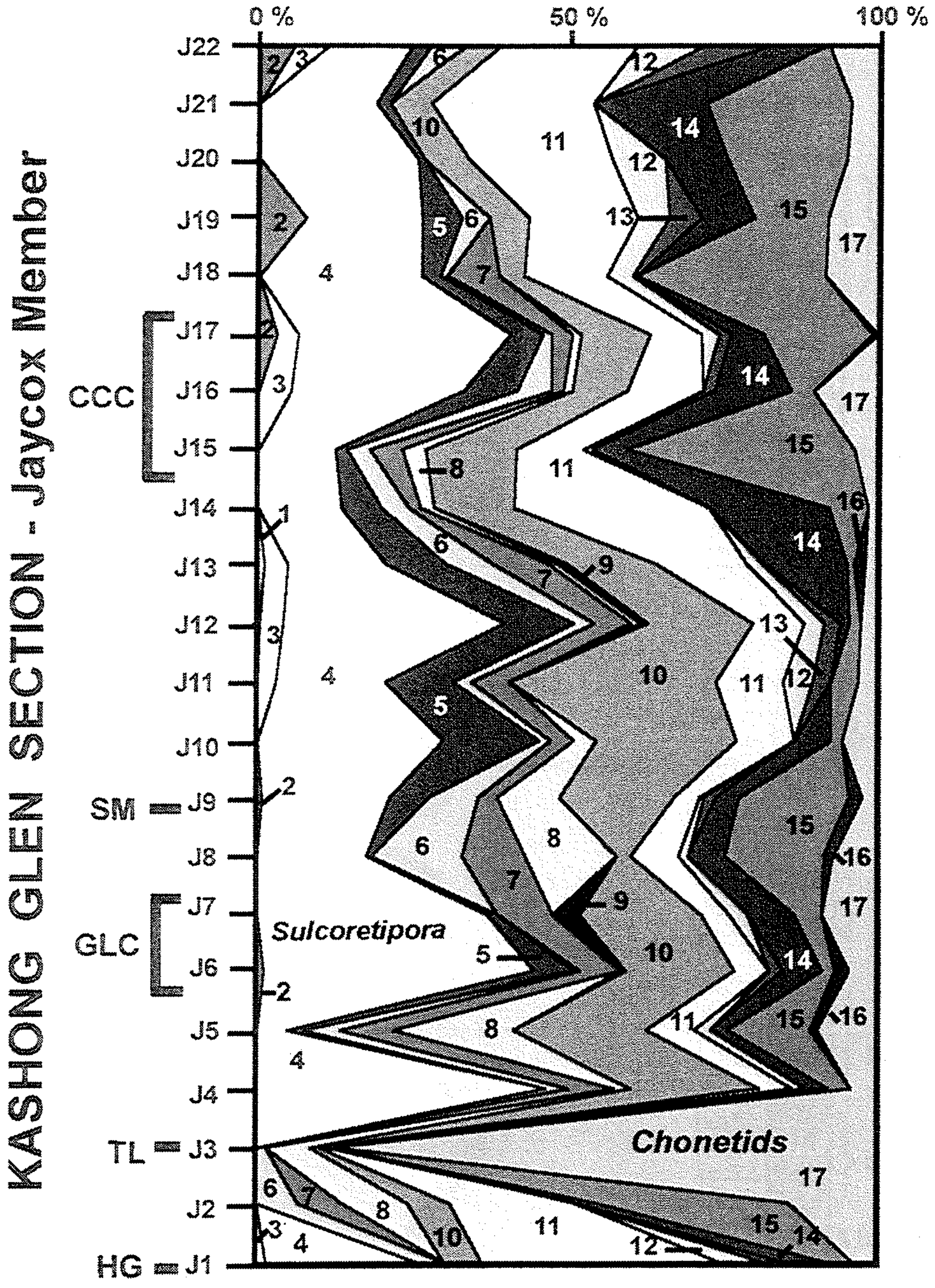


FIGURE 13. Faunal frequency diagram for the sampled portion of the Jaycox Member at Kashong Glen. Faunal categories defined in Figure 8. Marker beds defined in Figure 12 with addition: TL "*Tropidoleptus-Longispina* Bed".

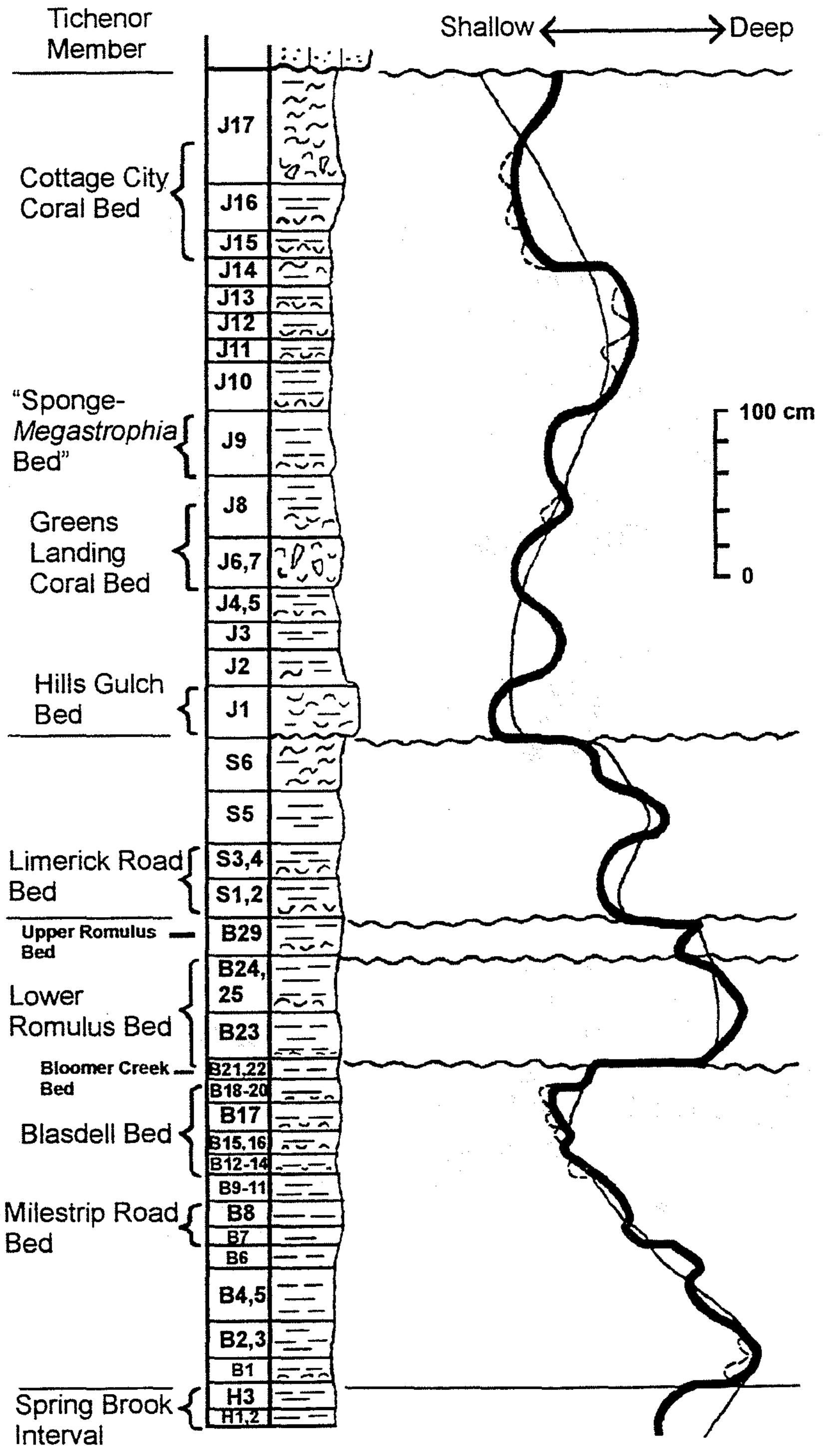


FIGURE 14. Study interval (Jaycox Run section) with interpreted sea level cyclicity shown at right. Three magnitudes of cycles are shown, superimposed on an overall shallowing trend.

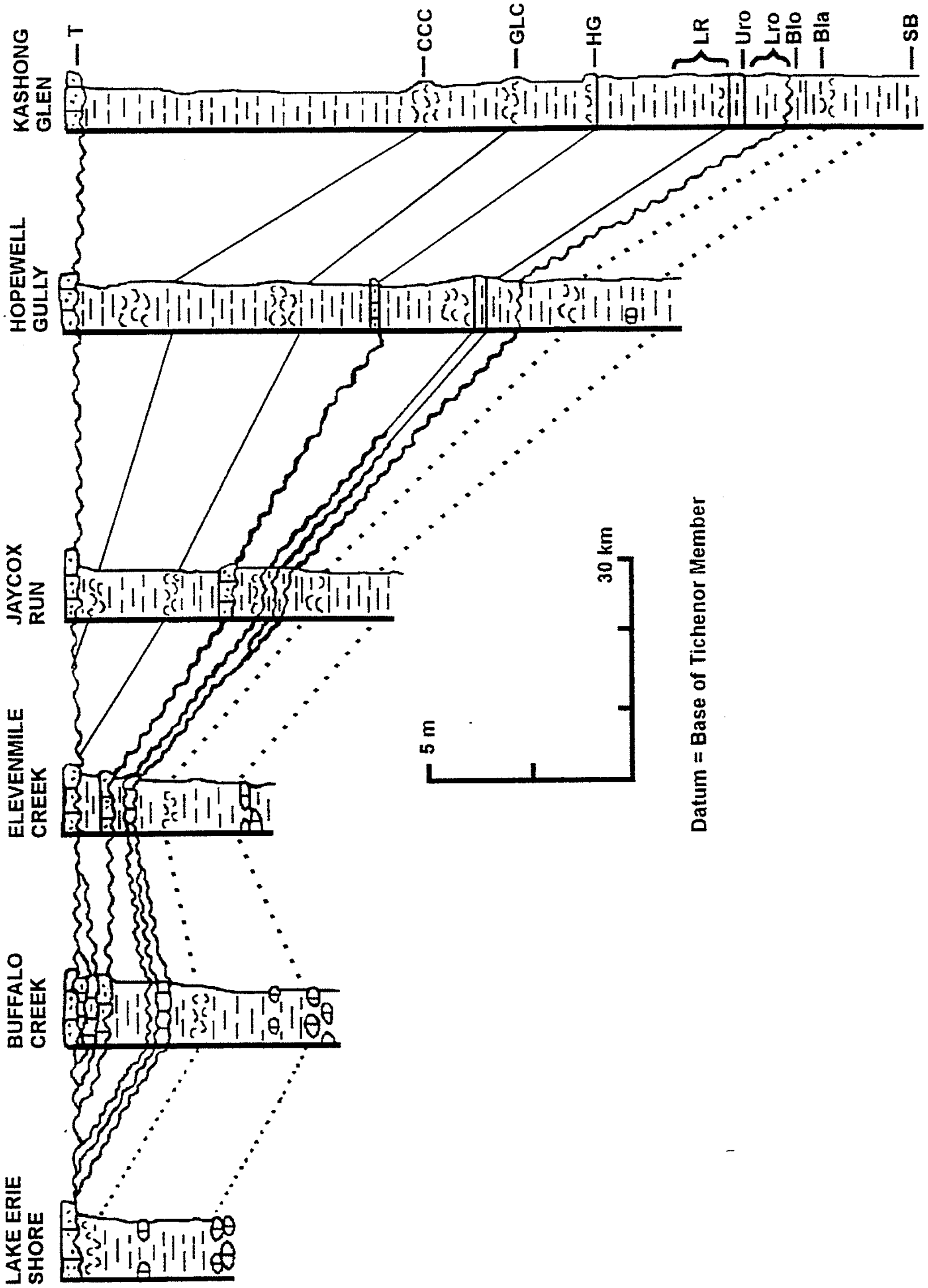


FIGURE 15. Correlation of study interval showing details of unconformities that merge westward to form a single sub-Tichenor unconformity at the Lake Erie shore. Marker beds: SB Spring Brook Interval; Bla Blasdell Bed; Blo Bloomer Creek Bed; Lro lower Romulus Bed; Uro upper Romulus Bed; LR Limerick Road Bed; HG Hills Gulch Bed; GLC Greens Landing Coral Bed; CCC Cottage City Coral Bed; T Tichenor Member.

Holocene Meander Incision Imposed Across a Buried Valley Wall

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TOPICS

This field trip provides an opportunity to visit two contrasting kinds of glacially buried valley fills. While looking at buried valley fills in northern Chautauqua County we have noticed that the fills are not internally deformed when not involved in modern landslides. The exception to this scenario occurs where the fills include near-surface outwash and lacustrine sediments among the Lake Escarpment and Lavery Moraines. These settings show ample evidence of deformation from the melt of underlying ice. Surface land morphology shows well-defined kettle holes and gently undulating surfaces with a few tens of feet of relief. Gravel pits show dips that range to between 50 and 90 degrees. Outcrops show folded and faulted sediments.

This trip will provide an opportunity to discuss recent meander incision across a buried valley wall. Our sketches and photography, in addition to published information, allow for a nearly complete reconstruction of meander movement during recent decades.

Although not part of our immediate objective, we will bring with us copies of the 1990 NYSGA Guidebook article by Gilman and Berkley. Their article included one of the stops that we will visit (our Stop 2). Their trek down Chautauqua Creek (and other parts of their article) paid particular attention to brittle structures in the bedrock. We will point these out while we hike to our Stop 2. We have been especially interested in the timing of the development of the pop-up folds. In scanning cliff walls of western and central New York streams, we note the absence of these folds. On the other hand, pop-ups occur routinely at quarter or half mile intervals in stream beds or Lake Erie cliffs. Also noteworthy is that one-meter amplitude folds are very commonly associated with basal tills. The non-glacial pop-ups are apparently related to erosional unloading.

FIGURES

Before flipping through the illustrations of this article, try beginning with Figure 1 and try drawing the buried valley outline that you might infer from Chautauqua Creek floodplain width. Then go to Figure 2. Yes, you are probably a little bit right as well as a little bit wrong. Figure 2 is based primarily on mapping of the elevations of exposed bedrock in tributaries (courtesy of the late Ken Fahnestock).

Figure 3 shows the historic positions of the meander loops at Stop 2 (the undeformed sediments at Stop 1 are exposed by a combination of natural gully growth and reservoir outlet erosion). From the dates it can be seen that the stream alternates periods of erosion between the two faces of the meander loop.

Figures 4 and 6 present sketches compiled from our approximately twice-yearly visits during the past 13 years. Figure 5 gives some food for thought. To what extent did Lake Escarpment glacial oscillations create this outcrop as opposed to a more complicated history that could include earlier glacial episodes? Lack of radiometric or other dates makes the answer difficult. Another idea for discussion ... are the gravels at the base of the outcrop from subglacial processes?

REFERENCE

Muller, Ernest H., 1963, Geology of Chautauqua County, NY, Part II, Pleistocene Geology: New York State Museum and Science Service Bulletin No. 392.

Figure 1. Topographic map of the region, showing stop locations. **Scale 1" = 2000'**

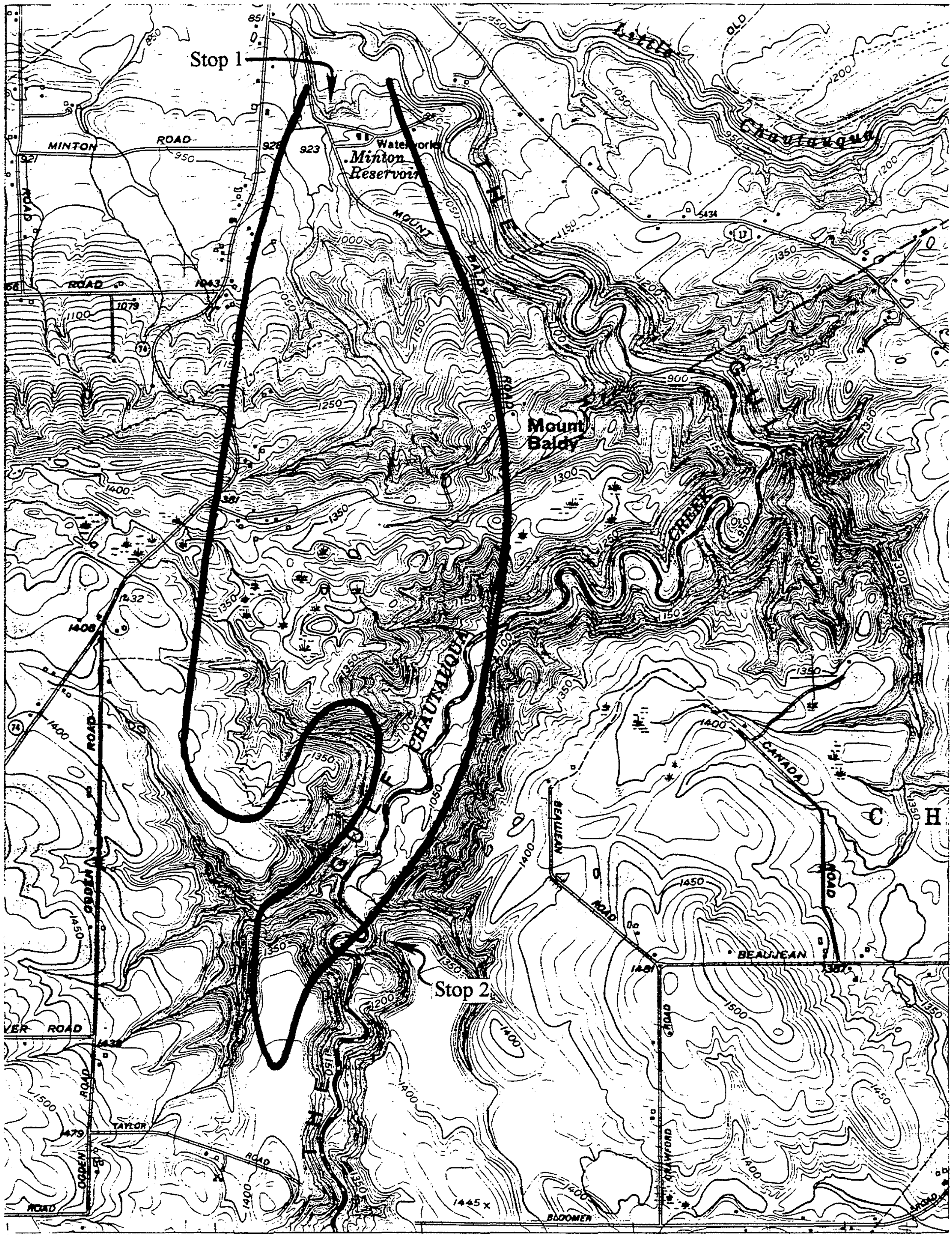


Figure 2. Approximate boundary of deeply buried bedrock, showing stop locations.

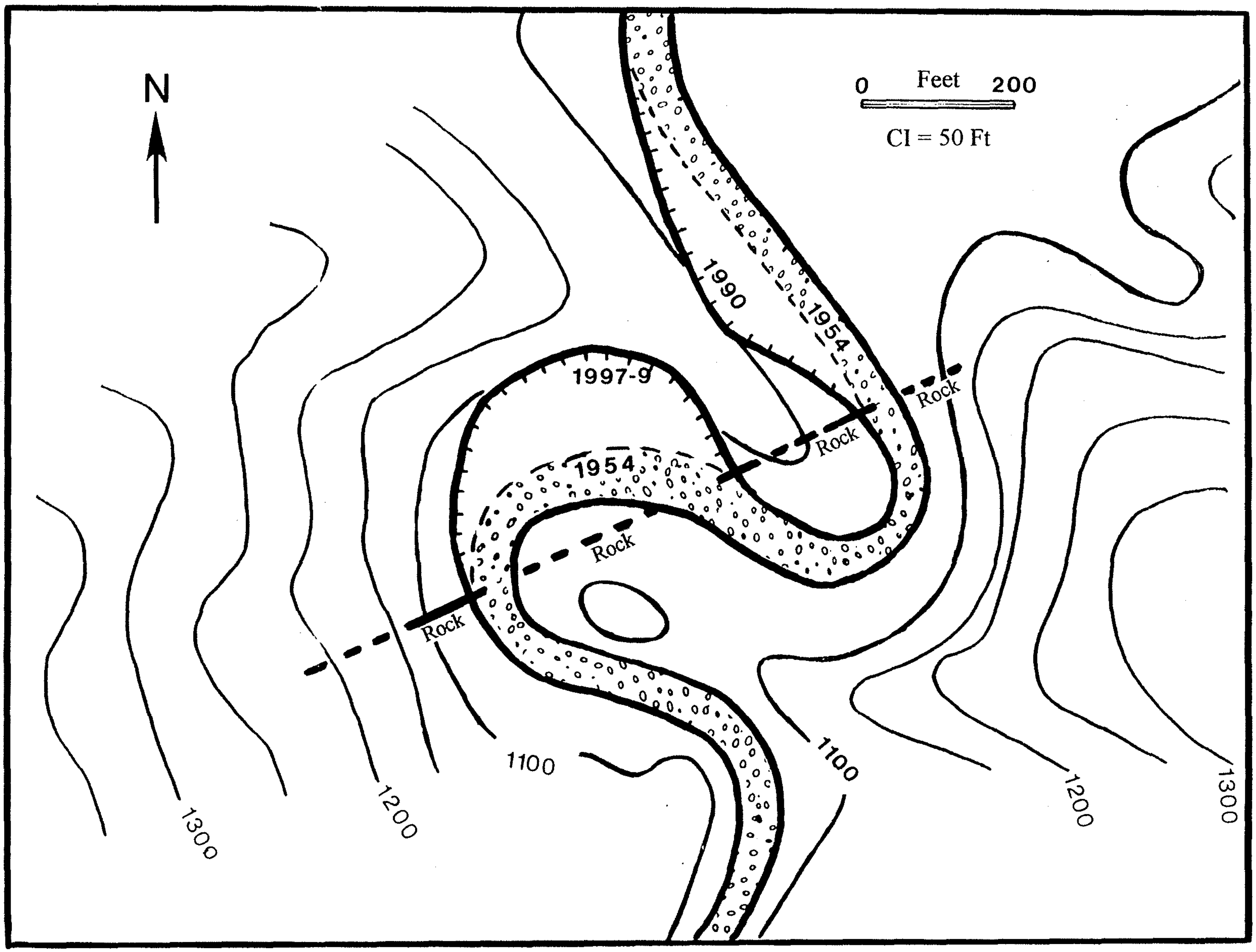


Figure 3. Map showing 1954 location of Chautauqua Creek with locations and dates of farthest lateral erosion since then.

Sun. D6

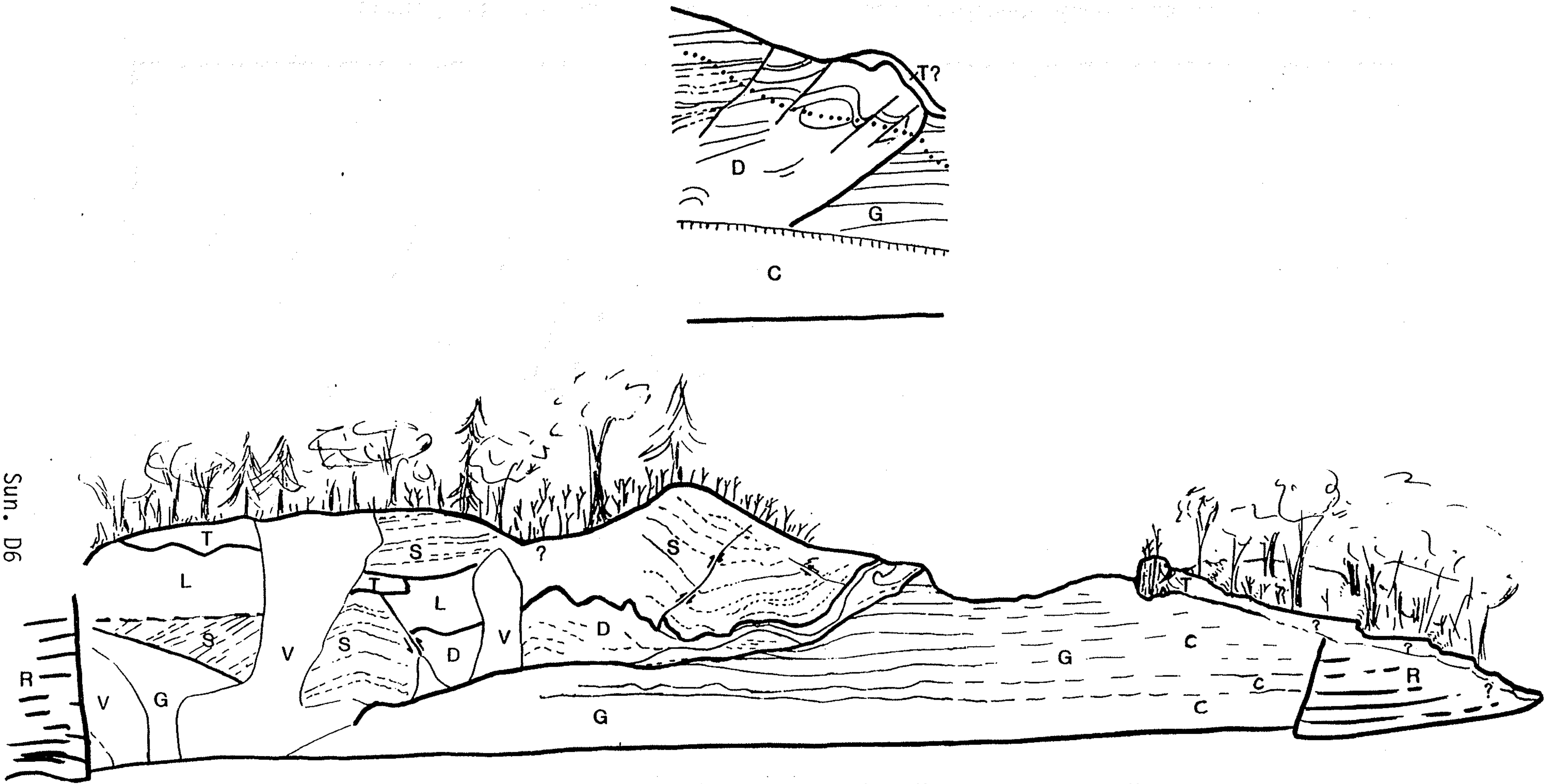


Figure 4. Composite section of south face, primarily representing sediments as exposed in 1997. Upper drawing is central section as exposed in 1988 (dotted line matches 1997 skyline). Symbols are: G = gravel; D = disturbed gravel; S = sand; L = lake sediments; T = till; R = rock; V = vegetation; C = covered.

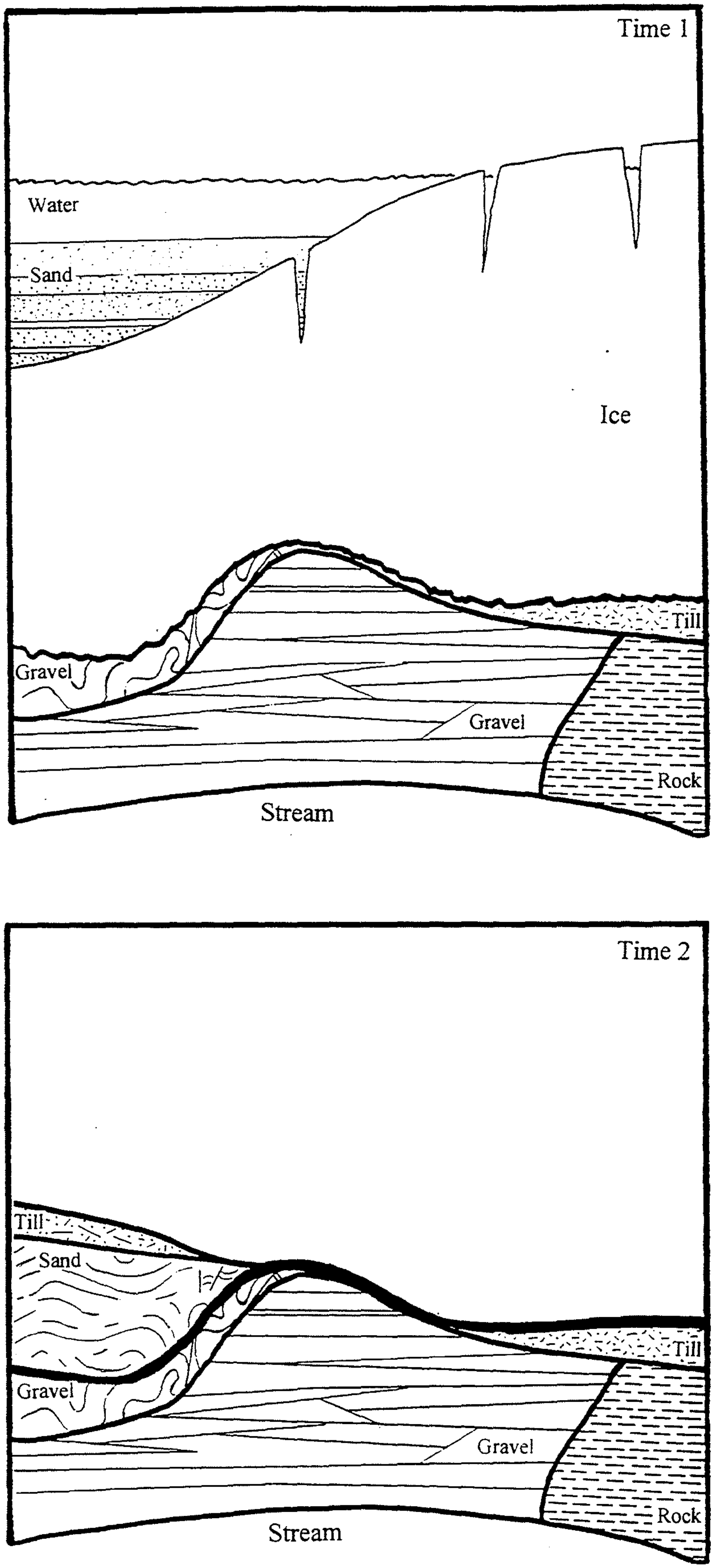


Figure 5. Schematic diagram of the central and eastern portions of the south face. Time 1 shows the glacier stagnant after deformation of the underlying gravel (left) and deposition of till (right). Time 2 shows subsequent let-down of sand layers as they are seen today. Till at the upper left post dates these events (and till at upper right may also).

Sun. D7

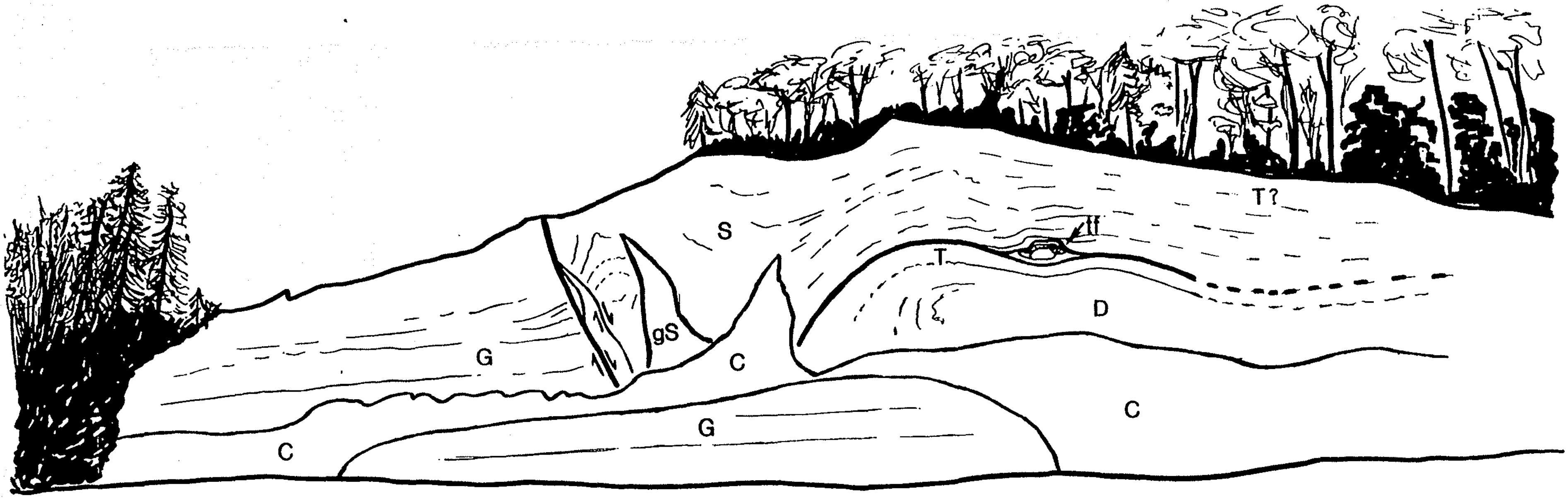


Figure 6. Composite section of north face. Symbols are: G = gravel; S = sand; gS = gray sand; D = disturbed gravel; T = till; tf = tunnel fill (?); C = covered.

Road Log

Imminent Breaching of Chautauqua Creek's Great Meander

Total Miles	Miles from Last Point	Route Description
0.0	0.0	Leave the SUNY Fredonia campus at the Temple Street exit. Turn Left (south) onto Temple Street
0.7	0.7	Turn Right (west) onto State Route 20. The Village of Fredonia lies mostly on Glacial Lake Warren shoreline and Canadaway Creek delta and terrace sand and gravel. We will drive for approximately 15 miles, mainly on top of the Warren shoreline. Often, about ½ to 1 mile to the south (left), the Glacial Lake Whittlesey shoreline (approx. 13,000 BP; Muller and Calkin, 1993) can be observed as a 20 to 40 ft. high terrace. Whittlesey shoreline deposits are typically narrower and more gravelly than Warren (Woodbury, 1992; Woodbury and Jenson, 1990). The Lake Escarpment Moraines (approx. 14,000 BP; Muller and Calkin, 1993) cap the top of the Portage Escarpment to the south. The ridge line is about 1000 ft above Lake Erie (1550 ft vs. 573 ft).
		Continue for about 15 miles, through the Village of Brocton, Town of Portland, and Village of Westfield.
16.0	15.3	Go over the long bridge over Chautauqua Creek on the immediate west side of the center of the Village of Westfield.
16.3	0.3	Turn Left (south) onto Chestnut Street.
17.5	1.2	Turn left (southeast) onto Mt. Baldy Road.
17.9	0.4	**STOP 1.** Outlet ravine of Minton Reservoir. Park on the roadside (don't drive all the way to the edge of the bulldozed area). This will be a brief stop to peer into the ravine and observe the nature of the buried valley fill and contrast these materials to those at Stop 2.
		Backtrack (northwest) down Mt. Baldy Road.
18.3	0.4	Turn Left (south) onto Chestnut Street.

20.5	2.2	Turn Left (south) onto Ogden Road.
22.0	1.5	Turn Left (east) onto Taylor Road.
22.6	0.6	**STOP 2.** Wet-foot trek into Chautauqua Gulf. Parking at end of Taylor Road (remains of gravel pits in kames).
44.5	21.9	Return: drive back down the hill to Westfield, then right (east) onto Rt. 20 to Fredonia; at the intersection of Temple Street and Rt. 20 (at Barker Common) in Fredonia, turn left ontoTemple Street, then right onto campus.

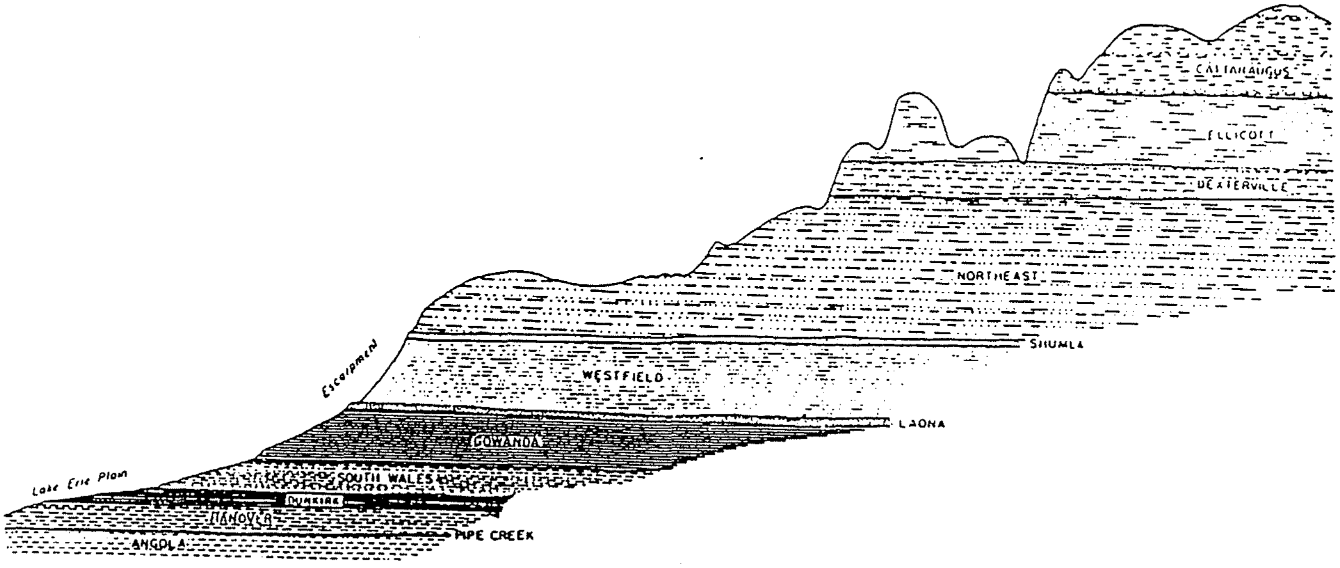
Total Trip Approximately 44.5 Miles.

EARTH SCIENCE FIELD TRIPS FOR HIGH SCHOOL STUDENTS
By
Brian Muirhead, Southwestern High School, Jamestown, NY

INTRODUCTION: A BRIEF GEOLOGICAL HISTORY OF CHAUTAUQUA COUNTY

Chautauqua County has an exposed geological record dating back about 370 million years to the Late Devonian Period (see geologic time scale, fig. 2). The majority of the bedrock exposed in the county (fig. 1) formed from sediment deposited during that time period, although some scattered outcrops of Early Mississippian bedrock occur southeast of Jamestown near the Pennsylvania state border.

Figure 1. Cross-section of a segment of the Portage Escarpment, showing the sedimentary layers of Chautauqua County. From Tesmer (1963).



The Late Devonian sediments were derived from erosion of the Acadian Mountains which rose to the east of New York State in New England. These mountains formed from the collision of a small continent, Avalon, with ancient North America during Early Devonian time. As the Acadian Mountains eroded, sediment shed from them accumulated in a shallow tropical sea called the Catskill Sea. This sediment deposit was named the Catskill Delta (fig. 3) and the bedrock layers of Chautauqua County formed a small part of the marine section of the delta.

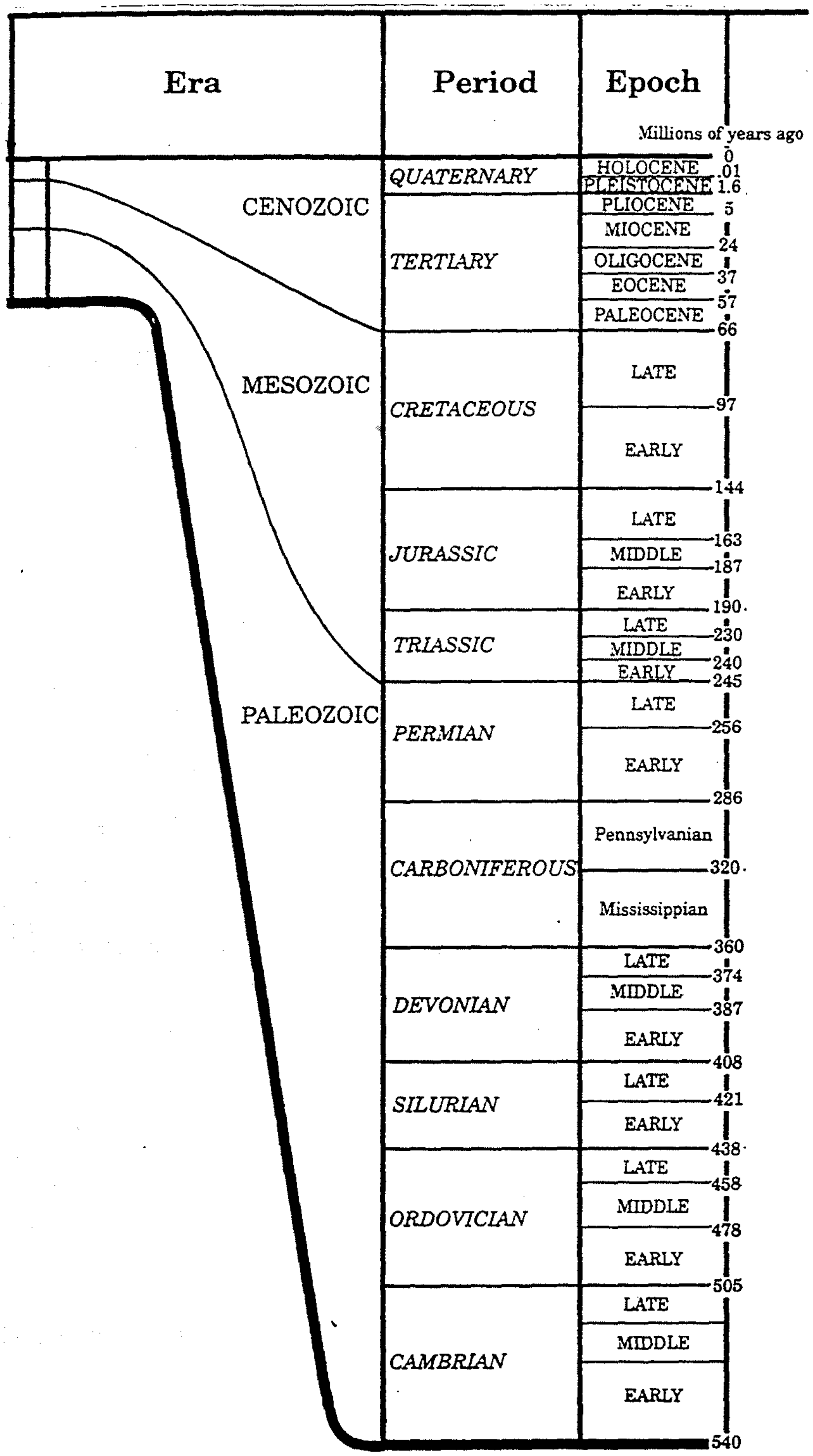


Figure 2. Geologic Time Scale. Adapted from the Earth Science Reference Tables.

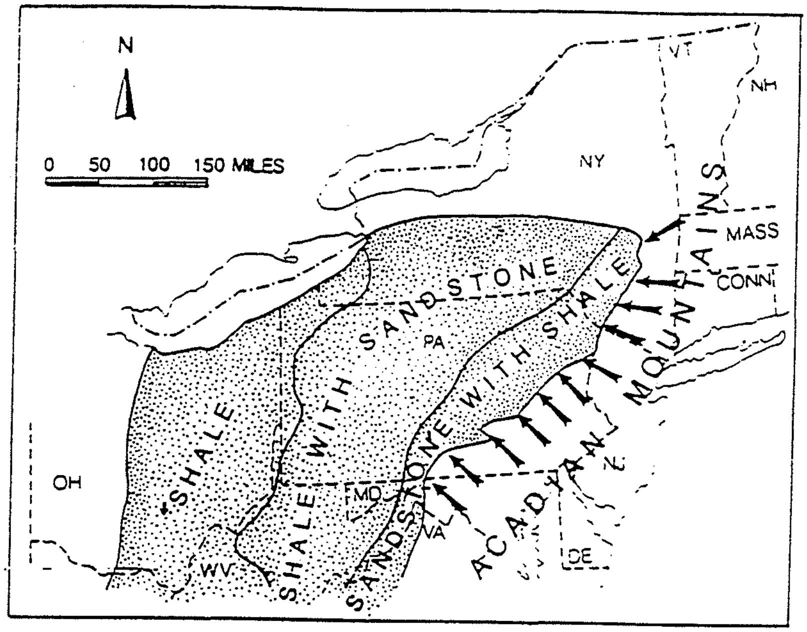


Figure 3. Erosion of the Acadian Mountains formed the Catskill Delta. From Isachsen et al., 1991.

As the Late Devonian progressed, the shoreline of the Catskill Sea in eastern New York gradually shifted westward across the state due to the sediment accumulation. The result was that coarser grained nearshore and terrestrial sediments were deposited on top of finer grained marine sediments. An example of this is represented by the sequence of layers from the Dunkirk Shale up through the Panama Conglomerate (bottom of the Cattaraugus Formation). This stratigraphic succession shows a coarsening upward trend in which sand and pebbles were deposited on top of muds and silts. It is assumed that sediment from the Mississippian Period was then deposited on top of the Devonian sediments over the entire region as the Catskill Sea slowly filled in.

The rock record from the Pennsylvanian Period (Late Paleozoic Era) through the Tertiary Period (Cenozoic Era) is not exposed in Chautauqua County. It is not known whether sediment from that time span was ever deposited in this area or if it accumulated and then was eroded. No bedrock from the Mesozoic Era exists anywhere in western New York.

Chautauqua County is located within two landscape regions: the Allegheny Plateau, which comprises most of the county, and the Erie-Ontario Lowlands, represented by a relatively flat strip of land approximately four miles wide oriented southwest to northeast along the Lake Erie shore. According to Isachsen et al. (1991), uplift of the Allegheny Plateau occurred during the middle of the Cenozoic Era. The Erie-Ontario Lowlands are believed to have formed by erosion prior to glaciation during the Pleistocene Epoch (Gilman and Berkley, 1990).

The Pleistocene Epoch, which began 1.6 million years ago, witnessed four major events of continental glaciation in North America. Only evidence from the last glacial advance, the Wisconsinan Phase, is found in Chautauqua County. As the Wisconsinan ice sheet melted and retreated north from the region it left a deposit of unsorted sediment on top of the Late Devonian bedrock. This deposit, known as glacial till, contains igneous, metamorphic, and sedimentary rocks transported from Canada, as well as pieces of ripped up Devonian bedrock of local origin. The boundary between the bedrock and till is a major unconformity representing a large gap in the rock record of Western New York.

As the ice sheet melted northward, flowing glacial meltwater deposited sediment called glacial outwash within pre-existing stream valleys. Deposits of glacial outwash can be found in several areas, such as Chautauqua Gorge. In addition, the meltwater produced two large glacial lakes that existed before Lake Erie. These lakes have been named Lakes Whittlesey and Warren, and clay and silt deposits from them can be observed on top of glacial till along the Lake Erie shoreline.

The Pleistocene Epoch ended ten thousand years ago with the final retreat of the ice sheet from New York State and thus began the Holocene Epoch. No major geological events have occurred in Chautauqua County since the beginning of the Holocene. Erosion is currently wearing down the Earth's surface with running water as the major agent. Deep gorges, such as Chautauqua Gorge, which cut into the landscape serve as evidence for such erosion.

A southerly bedrock dip (or inclination) of a few degrees and the forces of erosion have produced a distinct outcrop pattern in Chautauqua County (see Tesmer, 1963). The oldest layers are exposed in the northern section of the county while the youngest appear in the south. In the northern part of the county the layers from the Dunkirk Shale up through the Northeast Shale are exposed, or crop out, in a pattern that trends from southwest to northeast, paralleling the Lake Erie shoreline. The bedrock from the Dexterville Siltstone up through the Cattaraugus Formation is best exposed in the central and southern sections of the county.

POINT GRATIOT PARK

Point Gratiot is located in the northern part of the county, in Dunkirk.

At this location these features can be observed:

1. The Dunkirk Shale (see fig. 1)
2. Hydrocarbon odor from freshly broken pieces of black shale
3. Rust stains from oxidation and hydration of iron
4. Bedrock jointing
5. Fossil wood fragments
6. Glacial features:
    a. till
    b. erratics
    c. scratches (striations) on bedrock
7. Devonian/Pleistocene unconformity
8. Shoreline features:
    a. beach sediment
    b. clast imbrication
    c. longshore current
    d. headland-cove pattern
9. Soil development in glacial till

UNIQUE FEATURES

BEDROCK: The bedrock at this location is the Dunkirk Shale (see fig. 1), a unit of black shale that was formed from mud deposited on the floor of the Catskill Sea. Black shales form from sediment that is deposited underwater in low oxygen conditions.

HEADLAND-COVE PATTERN: Wave erosion along joints has produced an alternating headland-cove pattern on Point Gratiot where the bedrock is exposed. Because the joints are weakened zones where water can erode the bedrock faster, the heavily jointed sections have become the coves or inlets while the less jointed sections are small promontories protruding out into the water as headlands.

SOIL DEVELOPMENT: The relatively young age of the glacial till makes this site an excellent place to discuss soil development and maturity. Trees, shrubs, and weeds are growing in the soil, but the amount of biological activity and weathering has not been sufficient to produce a mature soil profile containing the A, B, and C horizons. The soil profile here is classified as immature because the B horizon is missing, and more time is needed before weathering produces a mature soil.

DIRECTIONS: If coming from the east, take Route 5 West through the city of Dunkirk. In the western part of the city you will pass the entrance to the Niagara-Mohawk power plant. Proceed for 0.3 mile past the entrance and then turn right on to Point Drive. Continue on Point Drive to the park entrance. Park at any one of the lots along the park road.

If coming from the west take Route 5 East to Dunkirk. As you enter the western part of the city you will pass the Moose Lodge on the left. The street on the left immediately after the Moose Lodge is Point Drive. Turn left on to Point Drive and proceed to the park entrance. Park your car at any one of the lots along the park road.

DJ'S CAMPGROUND

DJ'S Campground is located on the shoreline of Lake Erie, a few miles west of Brocton.

A rock hammer, chisel, and safety glasses will be helpful for collecting fossils at this location.

At this location these features can be observed:

1. The Gowanda Shale (see fig. 1)
2. Bedrock jointing
3. Hydrocarbon odor from freshly broken pieces of dark-gray shale
4. Rust stains from oxidation and hydration of iron
5. Glacial features:
    a. glacial till
    b. glacial erratics
    c. meltwater lake sediments
6. Devonian/Pleistocene unconformity
7. Shoreline features:
    a. beach sediment
    b. beach berm
    c. longshore current

    - d. clast imbrication
    - e. storm deposits

8. Septarian concretions
9. Pyrite nodules
10. Ripple marks
11. Fossils: pyritized cephalopods, wood fragments, and trace fossils
12. Erosion by gravity

UNIQUE FEATURES

BEDROCK: The bedrock at this location is the Gowanda Shale (see fig. 1), consisting of light-gray and dark-gray shale with some interbedded thinsiltstone.

SEPTARIAN CONCRETIONS: Within the bedrock are elliptical shaped rocks known as septarian concretions. The local people often refer to these as "turtle rocks" because of their resemblance to turtle shells. However, they are not fossilized turtles. Rather, these round concretions form from the precipitation of carbonate minerals in the sediment. When the concretions harden and shrink, cracks form and are filled in by the precipitation of the minerals calcite($CaCO_3$), siderite ($FeCO_3$), and, more rarely, barite ($BaSO_4$) (Gilman & Berkley, 1990, pg. G11). It is apparent that the concretions grew after the sedimentary layers were deposited because the layers are warped above and below them.

PYRITE NODULES: The existence of pyrite (FeS_2) nodules in the bedrock indicates a relatively high iron content. The pyrite nodules formed when iron in the sediment bonded with sulfur produced during the decay of organic material by bacteria in the sediment. Many of the nodules are rust-stained and are chemically weathering like the surrounding bedrock.

RIPPLE MARKS: Some of the thin siltstone layers exhibit ripple marks. Ripple marks form when waves or water currents move across loose sediment.

FOSSILS: This section of the Lake Erie shoreline is famous for its well preserved pyritized fossils. The most interesting fossils belong to the Phylum Mollusca, Class Cephalopoda. Cephalopods are marine organisms that swim by jet propulsion of seawater. Modern examples of these organisms include the nautilus and the octopus. The species of cephalopods at this location have long since been extinct and occur in two forms. One form, the orthoconic nautiloid, has a cone-shaped, segmented appearance. The other form, known as the goniatite, is coiled, much like a snail shell. The layer containing these fossils is near the water level and breaking waves may hinder collecting.

Minor fossils at this location include bits and pieces of carbonized and partially pyritized wood, and trace fossils. The fossilized wood is dark-gray to black from carbon and often contains small pyrite crystals. The trace fossils are burrows produced when sea bottom dwelling organisms roamed through the mud looking for food. They appear in the light gray shale as narrow, curved features slightly darker or lighter in color than the surrounding bedrock.

EROSION BY GRAVITY: The weak glacial lake deposits above the glacial till are very susceptible to erosion by gravity. Evidence of mass movement is the landslide debris on the bluff slope and at the base of the bluff.

DIRECTIONS: From the intersection of Route 380 (Lake Ave.) and Route 5 northwest of the village of Brocton, take Route 5 West for 3.4 miles to DJ's Campground, which is on the right.

If coming from the west the campground is 6.5 miles northeast of the intersection of Route 394 and Route 5 East at Barcelona. Turn left into the campground.

Go to the campground office, the small trailer near the entrance, to ask permission to park down at the shoreline. The owner is very accommodating and has been letting people on his land for years, so this should not be a problem. After parking walk about 300 feet southwest along the shore until you come to exposed bedrock.

CHAUTAUQUA CREEK AT BARCELONA

Barcelona is located on the shore of Lake Erie, one mile northwest of Westfield.

At this location these features can be observed:

1. The Westfield Shale (see fig. 1)
2. Root action
3. Rust stains from oxidation and hydration of iron
4. Differential weathering of siltstone and shale
5. Stream erosion and deposition:
    a. sediment shape and size
    b. gravel bars
    c. clast imbrication
    d. relationship of particle size to the water velocity of transport

6. A reverse fault
7. A monocline

UNIQUE FEATURES

BEDROCK: The bedrock at this location is the Westfield Shale (see fig. 1), composed of gray shale with some interbedded siltstone.

REVERSE FAULT: Facing upstream, on the right bank is a reverse fault, a fault in which the hanging wall appears to have moved upward relative to the footwall. Some rock and dirt debris may obscure the fault plane, so a shovel would be handy to expose the fault better. Facing the fault, the hanging wall is on the left side of the fault plane and the footwall is on the right. Especially obvious is that the siltstone layers on the hanging wall are not horizontally continuous across the fault plane to the footwall. By comparing the positions of siltstone layers on each side of the fault it appears that the vertical displacement is approximately 4 feet. In addition, the distorted nature of the rock along the fault plane is observable with closer inspection.

MONOCLINE: Another interesting structural feature is the monocline 50 feet upstream from the reverse fault. This fold has layers dipping (tilting) upstream. A monocline is a one-limbed fold, as opposed to anticlines and synclines which have two limbs.

The monocline and the fault resulted from probable local compressional stress in the bedrock, although the origin of the stress is unclear.

DIRECTIONS: From the intersection of Routes 394 and 5 at Barcelona, go 0.2 mile west on Route 5. Turn left (or right if coming from the west) on to North Gale Road and drive to its end at the closed bridge. Park your car there. Walk down to Chautauqua Creek and proceed upstream for approximately 150 feet. The water level may be high and it is suggested that you wear old shoes or sneakers.

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Project SunSHINE
Students Help Investigate Nature in Eastchester

Julie Ann Hugick
Eastchester Middle School
Eastchester, New York

Overview:

The eighth graders of Eastchester Middle School are presently embarking on the second year of conducting an interdisciplinary solar research investigation in partnership with Project SUN, NASA's Mission To Earth program, and the International Science Network using resources of The Use of Astronomy In Research Based Science Education program sponsored by the National Optical Astronomy Observatories. Throughout the 1998-2000 school years, over 350 eighth graders have participated in some aspect of Project SunSHINE. In various classes, the students are divided into teams for the purpose of gathering data, making hypotheses, interpreting data, and reporting the findings.

Objectives:

This multi-year research project is attempting to answer these specific scientific questions:

1. How do visible and ultraviolet light levels in this location vary throughout the school year?
2. How do visible and ultraviolet light levels correlate to daily weather conditions, if at all?
3. How do visible and ultraviolet light levels correlate to sunspot activity, if at all?

Along with the above stated questions SunSHINE is striving to change /enhance students perceptions regarding the following affective skills:

1. Students will become aware of how long-term scientific research is conducted using a multi-level team approach.
2. Students will realize it is in their best interest to be aware of the interrelationship of ultraviolet energy and how it effects them on a local scale
3. Students will have a new understanding of how information can be shared through a wide variety of mediums.

Ultraviolet & Visible Light:

Student teams in the computer technology classes measure and record the levels of ultraviolet (UV) and visible light daily. Two sensors, mounted on roofing, are interfaced to a Macintosh computer. The visible light and UV sensors make independent measurements throughout a predetermined length of time. These readings are displayed and graphed on the computer monitor. The Sensor Activation Team "turns on" the sensors from the computer at precisely 8:15 AM. After six hours, both datasets are stored as text files for later analysis and transmission to the Jet Propulsion Laboratory. The hardware system being used to collect the local solar data consists of a solar radiation sensor and a UV sensor made by Davis Instruments connected to a Macintosh computer using a Vernier Serial Box Interface.

Weather Reporting:

At 8:15 AM and 1:15 PM each day, a Weather Team records measurements in the log book. A weather station located on the roof of the school measures the temperature and barometric air pressure. For current measurements of humidity, wind speed and direction, students access local weather readings from the Yahoo! Weather website. The internet is used to provide measurements not available from the school weather station.

Counting Sunspots:

Sunspots are visible areas of relative darkness on the sun's surface, the photosphere, caused by very strong magnetic fields. Small spots, measuring about 220 km, may exist for less than one hour while spots 75,000 km across can remain for six months. The quantity of sunspots varies over a predictable, eleven-year cycle, as does other solar activities such as the level of ultraviolet emission. One measure of the changing sunspot cycle is the "sunspot number," calculated to be ten times the number of sunspot groups added to the number of individual sunspots observed.

As of 1998, the sun entered a period of increased sunspot activity. Project SunSHINE will determine if the local levels of ultraviolet are affected by maximum solar activity. Our student researchers are using the sunspot number as one indicator of changes in the solar cycle. Although sunspots can be observed with small, solar observing telescopes, an accurate count of the day's sunspot number could not be made with these instruments. Therefore, the Sunspot Number Team relies upon the web for this information. The daily sunspot number is published on the website entitled Sunspots and the Solar Cycle (http://www.sunspotcycle.com/).

Calculating Sunspot Areas:

Although the sunspot number is an indicator of solar activity, it does not take into account the various sizes of sunspots. Their diameters range from hundreds to tens of thousands of miles, greater than that of Earth. Therefore, the total area of all observable sunspots is calculated every day as a second measure of solar activity.

The Sunspot Area Team must download a solar image from the internet daily, and then use specialized software to calculate the area of the observable sunspots.The Kitt Peak Vacuum Telescope (National Solar Observatory) publishes the latest solar images on the web at http://www.nso.noao.edu/ synoptic/synoptic.html. The students use the "intensity" image to determine sunspot areas.

Reporting The Findings:

The scientific findings of Project SunSHINE are being e-mailed weekly to NASA's Jet Propulsion Laboratory and are published on their website (http://sunshine.jpl.nasa.gov/). Project SUN, NASA's Mission To Earth program, is determining how local visible light and ultraviolet levels vary geographically. The solar data being studied is submitted by participating schools worldwide.

Dr. Gil Yanow, at the Jet Propulsion Laboratory (JPL), is compiling and analyzing similar reports received from Europe, Asia and the Americas over three years. For in-school use the data is organized into an excel dataset that the school's network system. Teachers and students can access this information at anytime.

The computer technology classes are writing a solar handbook to provide background information about the sun and solar radiation. This guide will be published on the school's website this Fall.

The datasets and their statistical analyses are being used by the science classes to hypothesize if weather variations, changing seasons, and sunspot activity have any measurable effect on average levels of solar radiation. Throughout the school year, students are attempting to interpret the data and statistics, modifying their hypotheses as necessary. Their findings are published on the Project SunSHINE website: http://www.westnet.com/~rickd/.

Exciting Findings:

Based upon the first year of data, students have developed some working conclusions. These preliminary conclusions were written in abstract form and shared with Dr. Yanow of JPL. He was very excited to see data that supported an inverse relationship between relative humidity and ultraviolet levels. Less surprising was the inverse relationship of visible light and relative humidity. Many of the other variables, such as ultraviolet level vise sunspots or cloud types, will need a larger dataset to determine if there is any type of relationship.

SunSHINE Future:

In May 1999, The Journal News Golden Apple Awards named Project SunSHINE the 1999 New York Wired Applied Technology Award winner. The award consisted of a $20,000 grant for the acquisition of additional equipment to enhance the existing research program. SunSHINE is purchasing an AirWatch Weather Station, a state-of-the-art digital instrument for the collection of local weather data. The station will make continuous measurements of temperature, air pressure, humidity, wind speed and direction, while displaying these values in real time on a dedicated website. The team is also buying a Celestron Celestra 8 inch Schmidt-Cassegrain telescope with a full-aperture glass solar filter so students can make live sunspot observations. This will enable SunSHINE to move to the next level of research.

Conclusion:

The first complete year of Project SunSHINE has been a truly rewarding experience. The students have gained a new respect for the Sun's energy and teamwork in long-term scientific research. From a teacher point-of-view, it has been a splendid endeavor that is allowing our students to conduct true reteach that is unheard of at the Middle School level. The truly interdisciplinary nature of SunSHINE requires a tremendous amount of work but it has been well worth the effort.

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Useful internet sites:

Project SUNSHINE	http://members.aol.com/mrdonahue2/sunshine/sunshine0.html
Eastchester Middle School	http://www.westnet.com/~rickd/
Sunspots- NASA	http://www.sunspotcycle.com/
Project SUN	http://sunshine.jpl.nasa.gov/
The Use of Astronomy Science Education	http://www.noao.edu/noao.html
AirWatch Weather System	http://www.aws.com/
Kitt Peak Vacuum Telescope latest solar images	http://www.nso.noao.edu/ synoptic/synoptic.html

Introduction to Automated Weather Source (AWS)

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Using the Automated Weather Source (AWS), students have access to real-time meteorological data from thousands of schools across the United States. Using this information, students will be able to chart weather patterns, determine trends, make weather forecasts and conduct local and national climate studies. The AWS allows for year-round exploration of the weather, seasons and climate. Teachers, and students, are not bound to a curriculum time frame with the AWS; the information is always available. Using the Internet and/or modem teachers and students can access single or multiple stations in the AWS network. Many of the schools in the AWS network also make their information available to the community on the World Wide Web.

With the influence of the New York State Learning Standards and current curriculum changes, students are being required to demonstrate higher levels of thinking and reasoning. By effectively incorporating the AWS into lessons, students will exhibit critical thinking and problem-solving skills in relation to meteorological studies. Once mastered, these skills will transfer to different areas of the curriculum.

This workshop is intended to provide educators with an introductory experience with the Automated Weather Source (AWS) network and AirWatch v4.5 software. Attendants will be guided through the basics of the AWS program, which will include accessing, graphing and charting weather data from cooperating stations. Sample lessons utilizing the AWS will be distributed and modeled during the workshop.