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

[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 $T_{A/B-C}$ 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.

<u>Caneadea Formation (Chadwick, 1933):</u>
Type Locality: Caneadea Creek, Caneadea Gorge, NY; *Members*: <u>East Sixtown Member</u> – 0.6 km. west of Rt. 19 and Cold Creek, <u>Gorge Dolomitic Member</u> – Caneadea Creek by bridge at Mill Rd., <u>Higgins Member</u> – at Higgins NY, <u>West Lake Member</u> – 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.

<u>Rushford Formation (Luther, 1902):</u>

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).

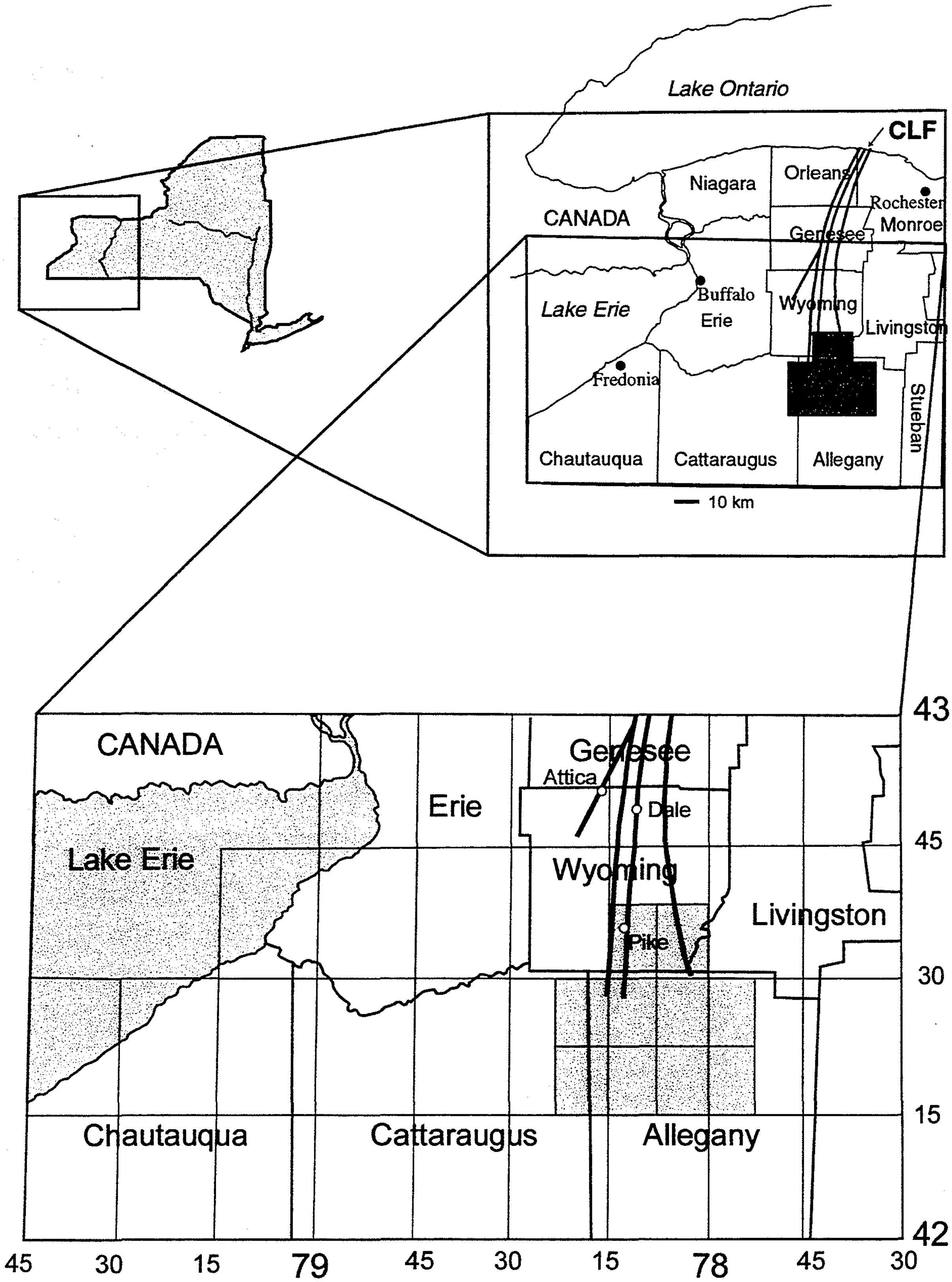
Figure 6: A) Legend for stratigraphic columns used in this paper.
B) Annotated stratigraphic columns for stops 2A and 2B, showing the similar sequence of lithologies at Stops 2A and 2B, including sandstones, sediment slides and deformed zones with pencil cleavage. Columns are "hung" at proper elevations (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
Buffalo
Erie
Lake Erie
Wyoming
Livingston
Fredonia
Stueban
Chautauqua
Cattaraugus
Allegany
10 km
CANADA
Genesee
Attica
Erie
Dale
Lake Erie
Wyoming
Livingston
Pike
Chautauqua
Cattaraugus
Allegany
43
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30
15
42
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15
79
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78
45
30

Figure 1

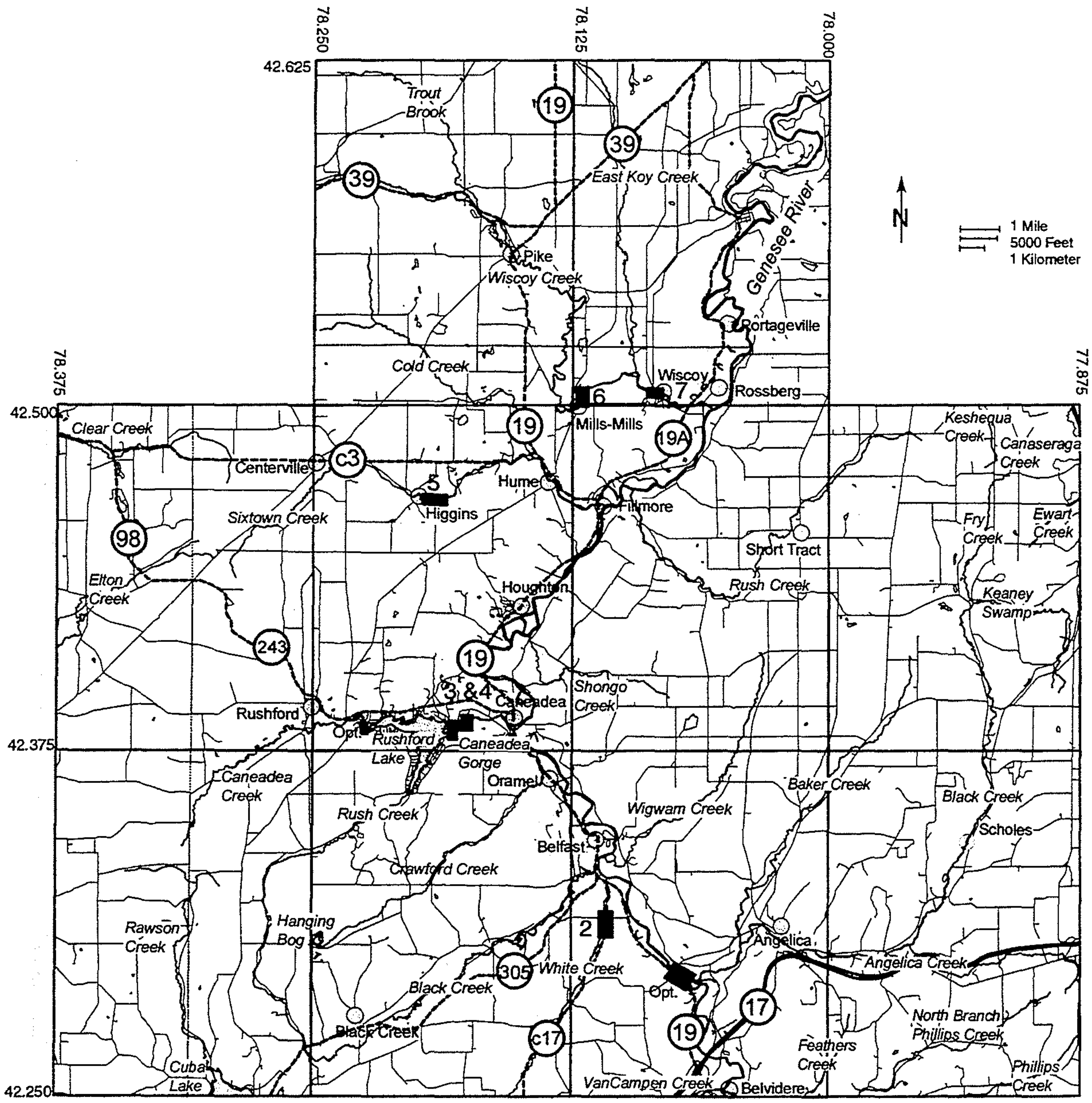
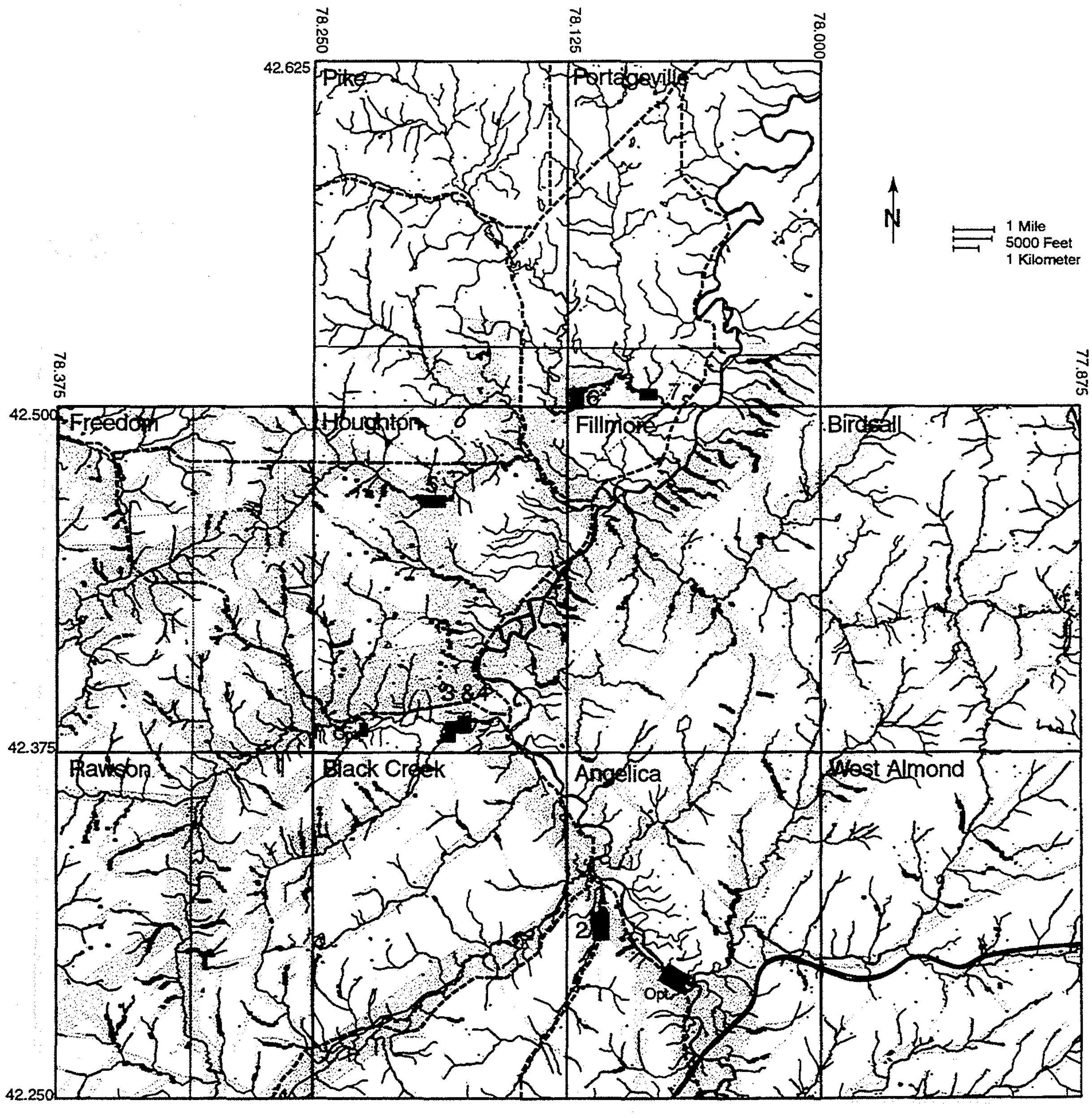

78.250
78.125
78.000
78.375
77.875
42.625
42.500
42.375
42.250
Trout Brook
East Koy Creek
Genesee River
Pike
Wiscoy Creek
Portageville
Cold Creek
Wiscoy
Rossberg
6
7
Mills-Mills
Clear Creek
Centerville
Hume
Fillmore
5
Higgins
Sixtown Creek
Short Tract
Rush Creek
Elton Creek
Houghton
Keshequa Creek
Canaseraga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

Figure 2



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

Figure 3

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

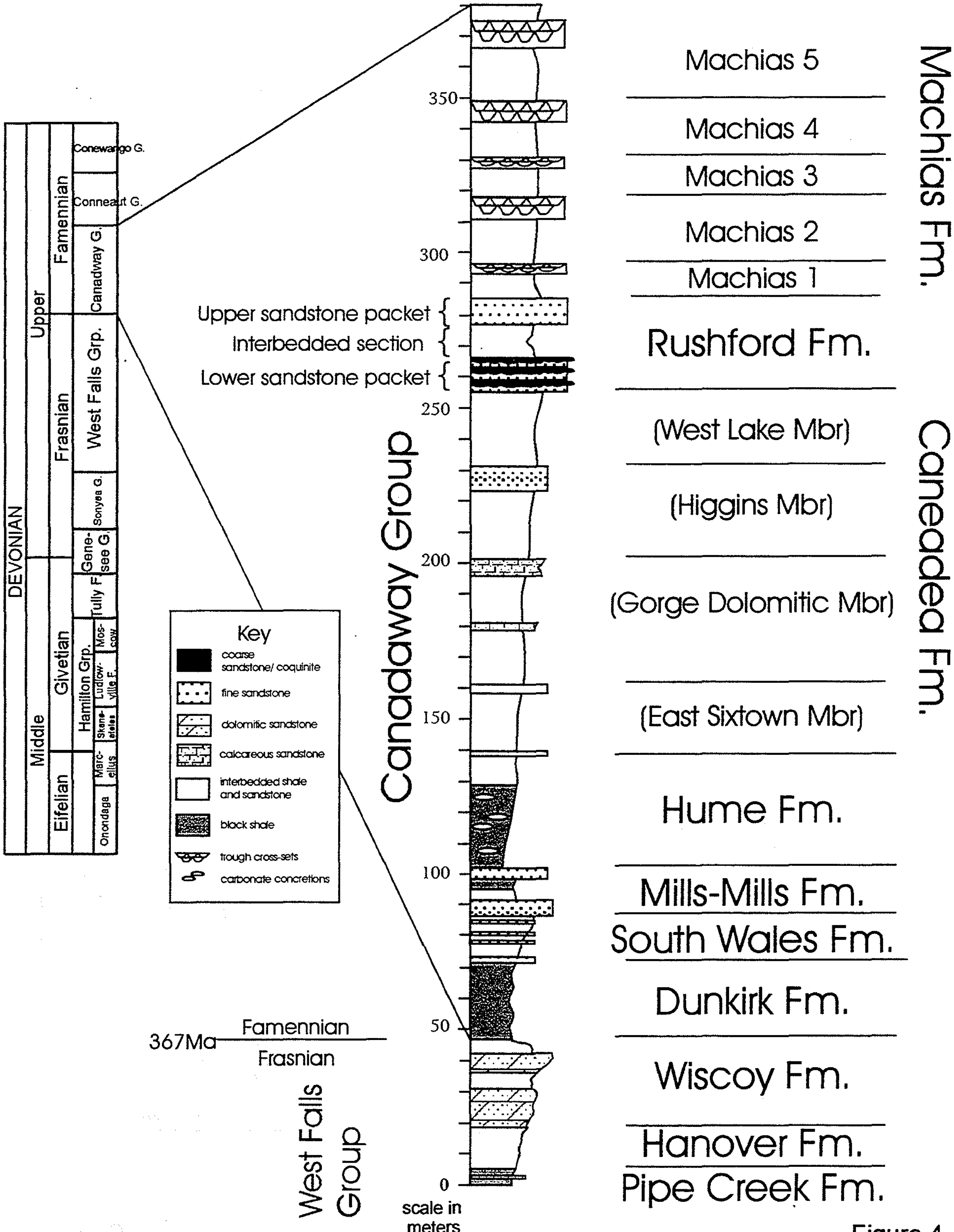


Figure 4

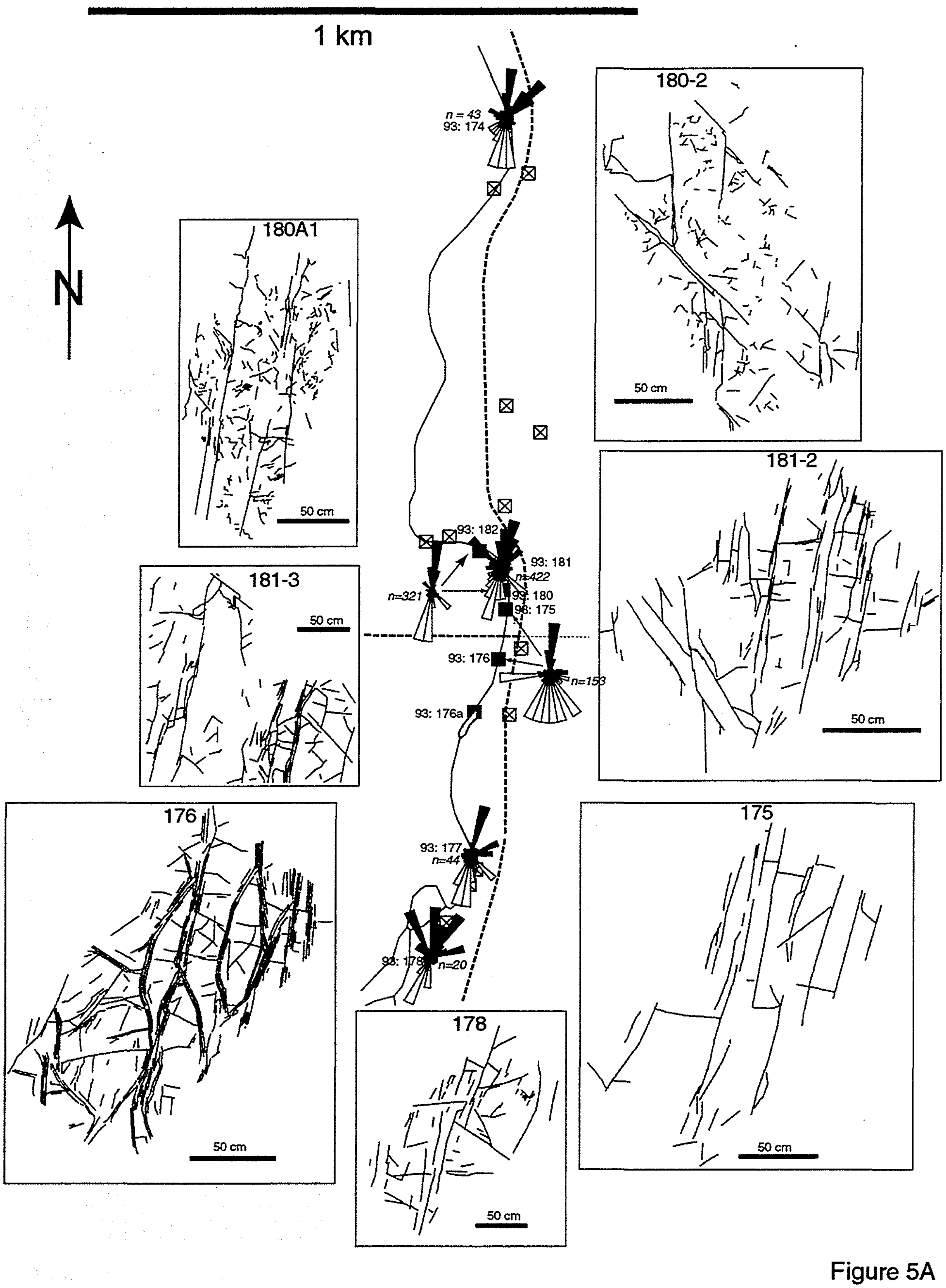
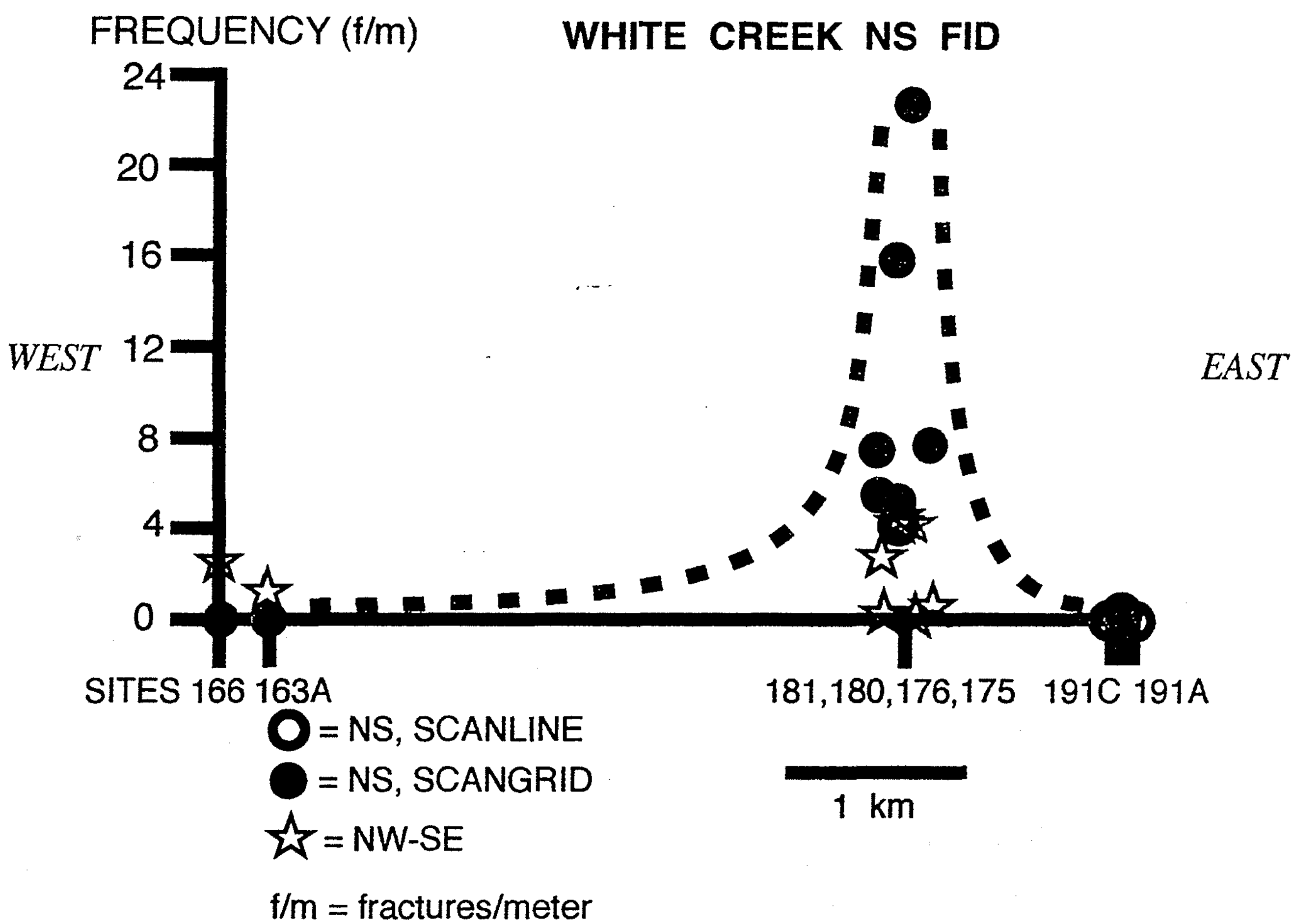

1 km
N
180-2
50 cm
180A1
50 cm
181-2
50 cm
181-3
50 cm
n = 43
93: 174
93: 182
93: 181
n=422
93: 180
93: 175
n=321
93: 176
n=153
93: 176a
93: 177
n=44
93: 178
n=20
176
50 cm
175
50 cm
178
50 cm

Figure 5A

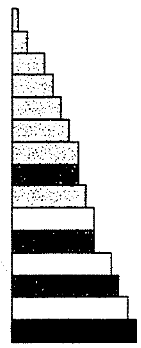


FREQUENCY (f/m)
WHITE CREEK NS FID
24
20
16
12
8
4
0
WEST
EAST
SITES 166 163A
181,180,176,175
191C 191A
= NS, SCANLINE
= NS, SCANGRID
= NW-SE
f/m = fractures/meter
1 km

Figure 5B .

Key for stratigraphic columns

Erosional Profile used in stratigraphic columns



COVERED
SHALE
SILTY SHALE
INTERBEDDED SILT & SHALE
SHALY SILTSTONE
INTERBEDDED SILT/SHALE & SANDSTONE
SILTSTONE
CALCAREOUS SILTSTONE
INTERBEDDED SILT & SANDSTONE
FINE SANDSTONE
LIMESTONE
MEDIUM SANDSTONE
DOLOMITIC SANDSTONE
COARSE SANDSTONE
CONGLOMERATE

Color Key for stratigraphic columns

- black shales and siltstones
- black & dark gray shales and siltstones
- gray shales and siltstones
- sandstones
- calcareous and dolomitic

- load casts
- HCS
- trough cross-sets
- symmetrical ripples
- furrows
- red silt rip-up clasts
- gray silt rip-up clasts
- cloudy quartz clasts
- shell layers
- organic detrius

- ball and pillow structure
- SCS
- 2-D dunes
- climbing ripples
- *Arenicolites*
- *Macaronichnus*
- *Rhizocorallium*
- *Thalassinoides/Ophimorda*
- *Skolithos*
- *Teichichnus*
- *Zoophycos*
- *Schaubcylindrichnus*

Figure 6A

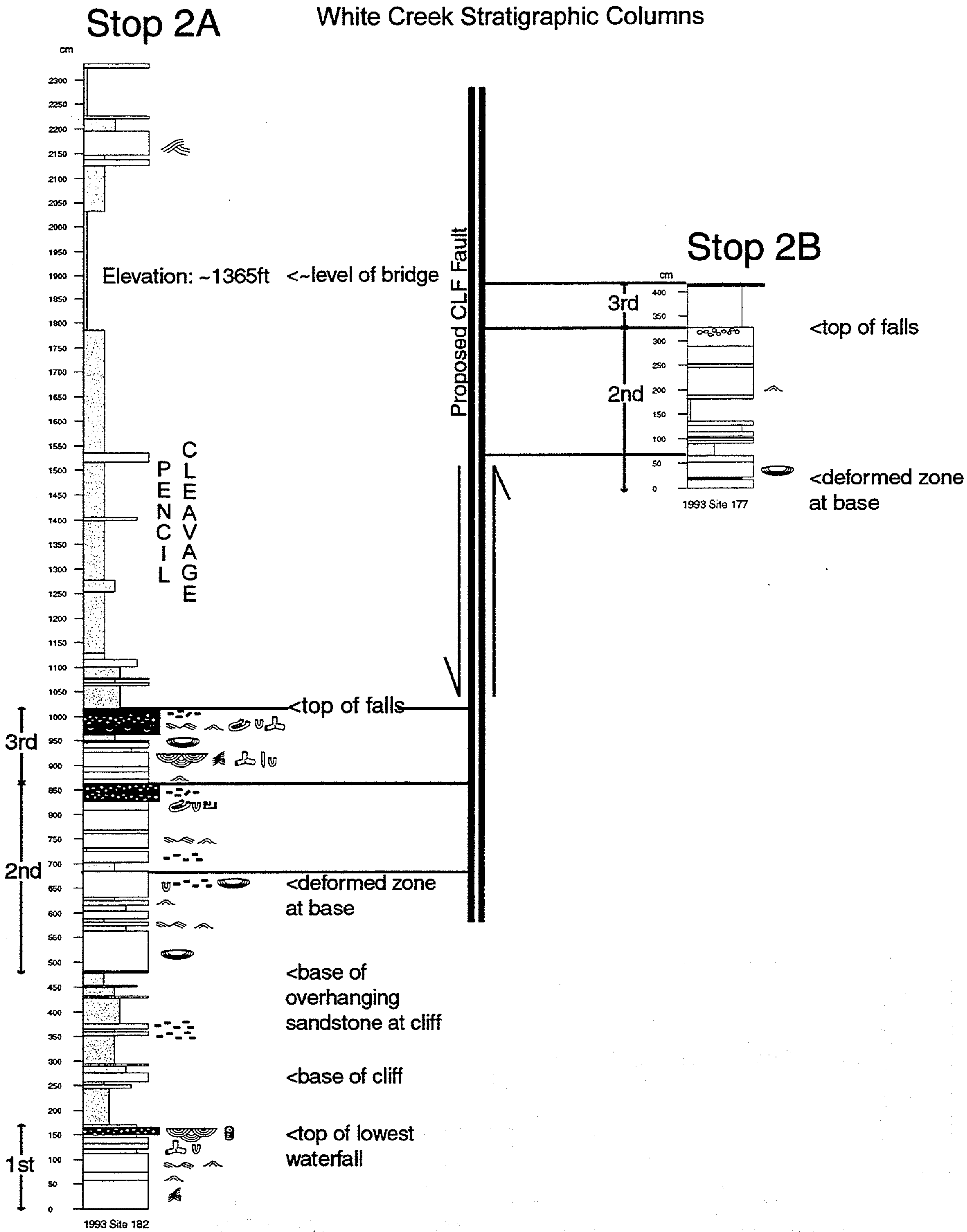

Stop 2A
White Creek Stratigraphic Columns
cm
Elevation: ~1365ft
<~level of bridge
Proposed CLF Fault
PENCIL
CLEAVAGE
<top of falls
3rd
2nd
<deformed zone
at base
<base of
overhanging
sandstone at cliff
<base of cliff
<top of lowest
waterfall
1st
1993 Site 182
Stop 2B
cm
3rd
2nd
<top of falls
<deformed zone
at base
1993 Site 177

Figure 6B

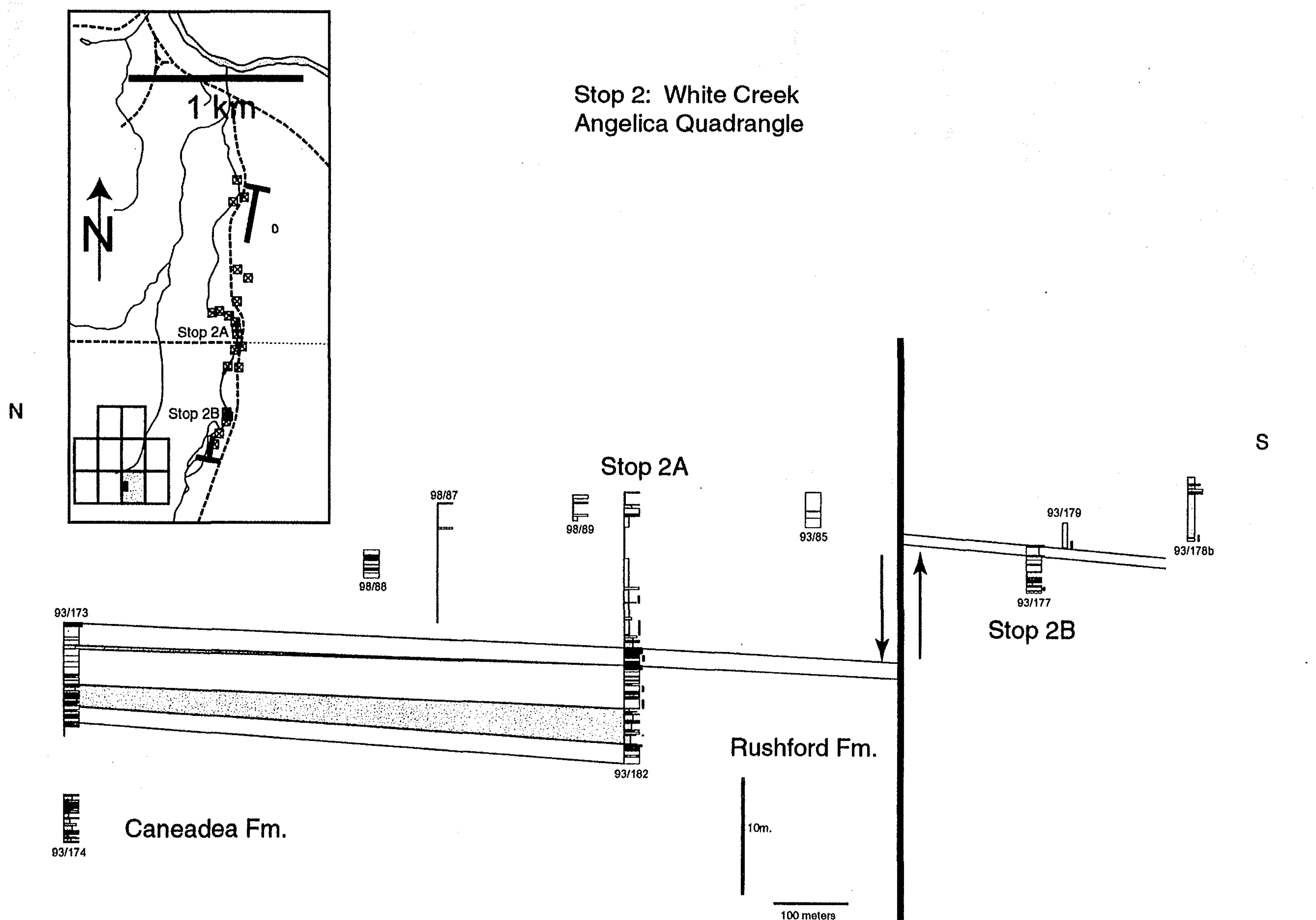

Stop 2: White Creek
Angelica Quadrangle
1 km
N
Stop 2A
Stop 2B
N
S
Stop 2A
98/87
98/89
93/85
93/179
93/178b
98/88
93/177
Stop 2B
93/173
93/182
Rushford Fm.
10m.
100 meters
93/174
Caneadea Fm.

Figure 6C

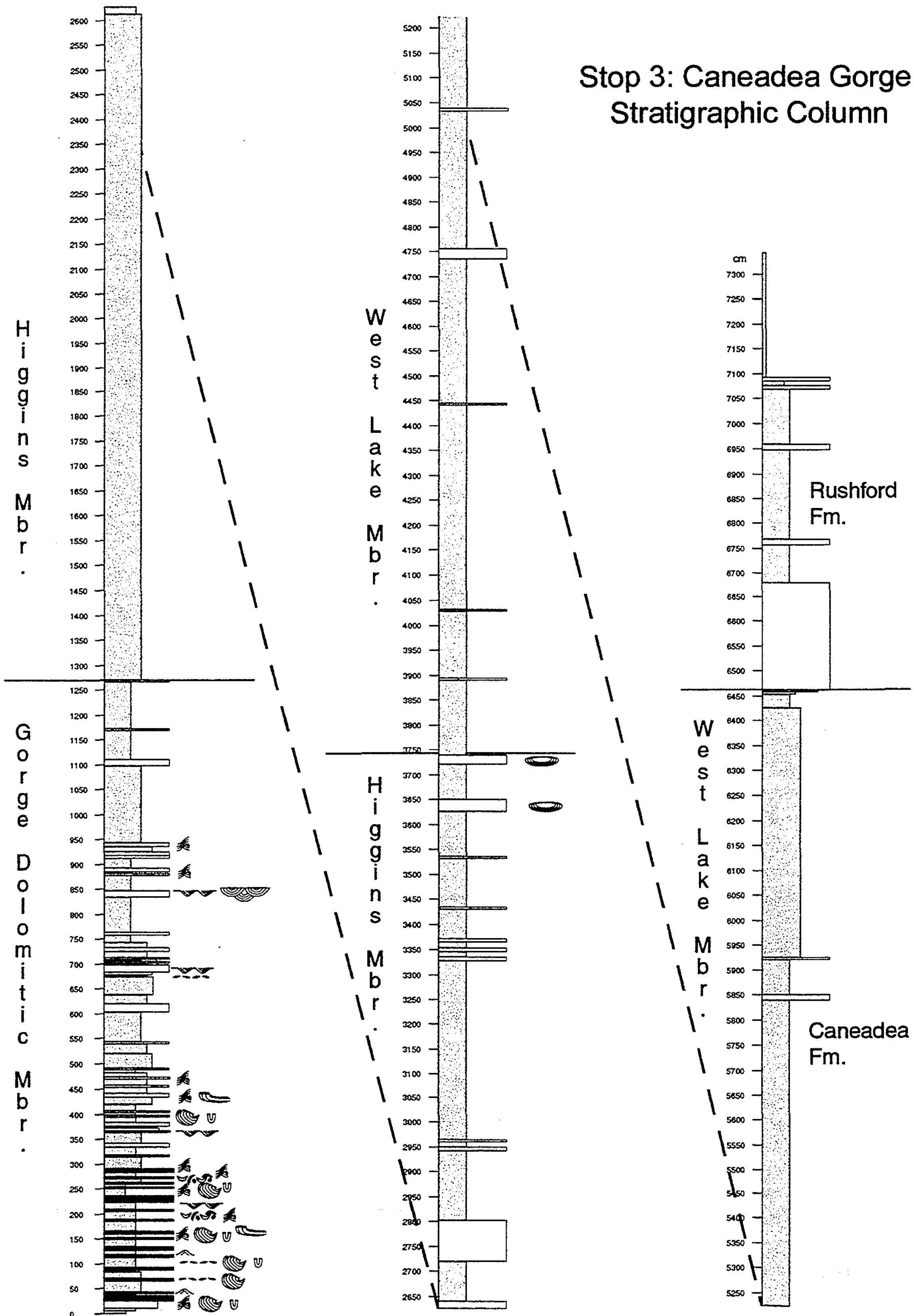

Stop 3: Caneadea Gorge
Stratigraphic Column
Higgins Mbr.
Gorge Dolomitic Mbr.
West Lake Mbr.
Higgins Mbr.
cm
Rushford Fm.
West Lake Mbr.
Caneadea Fm.

Figure 7

Stop 5: Sixtown Creek
Houghton Quadrangle

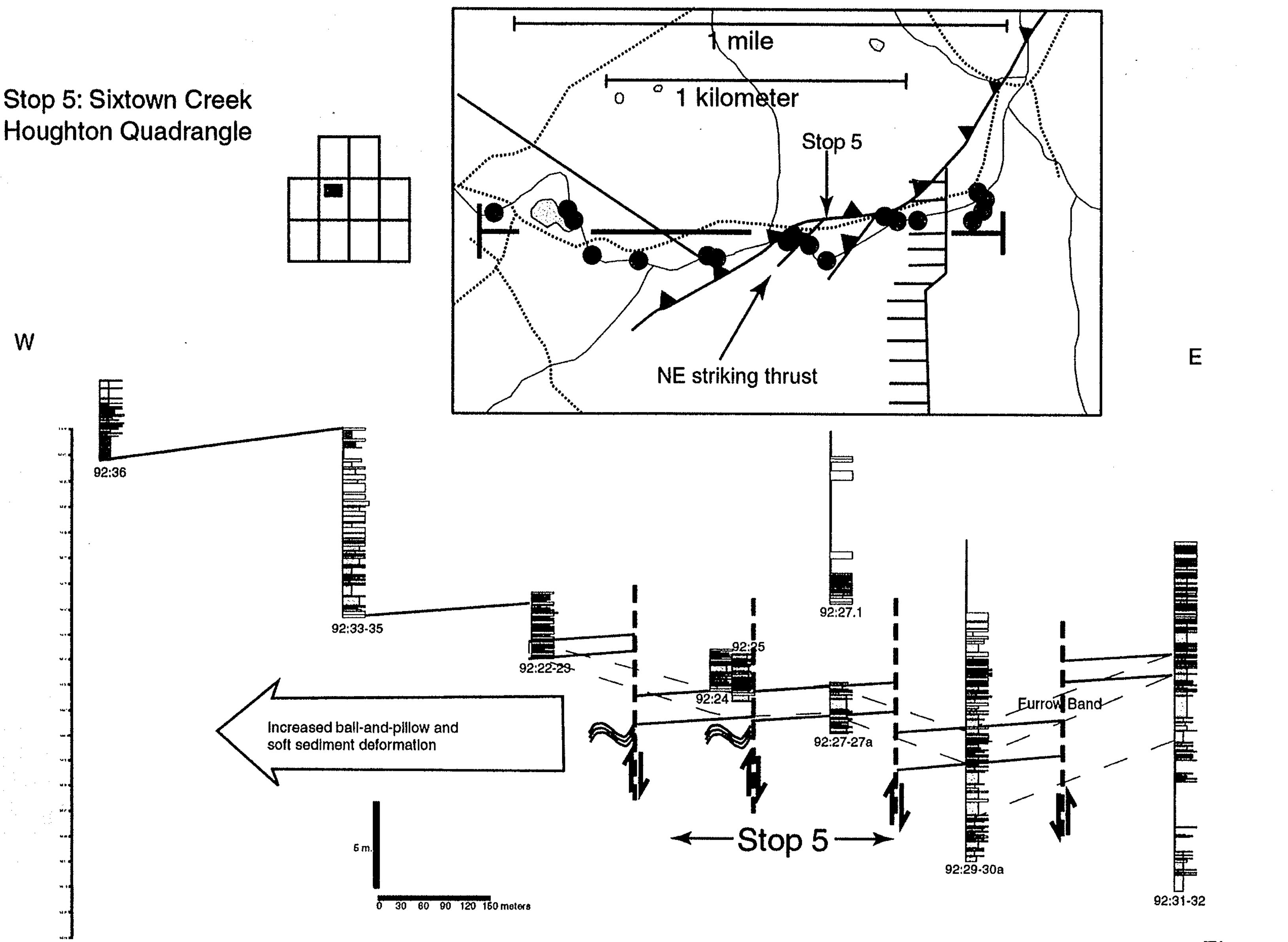


Figure 8

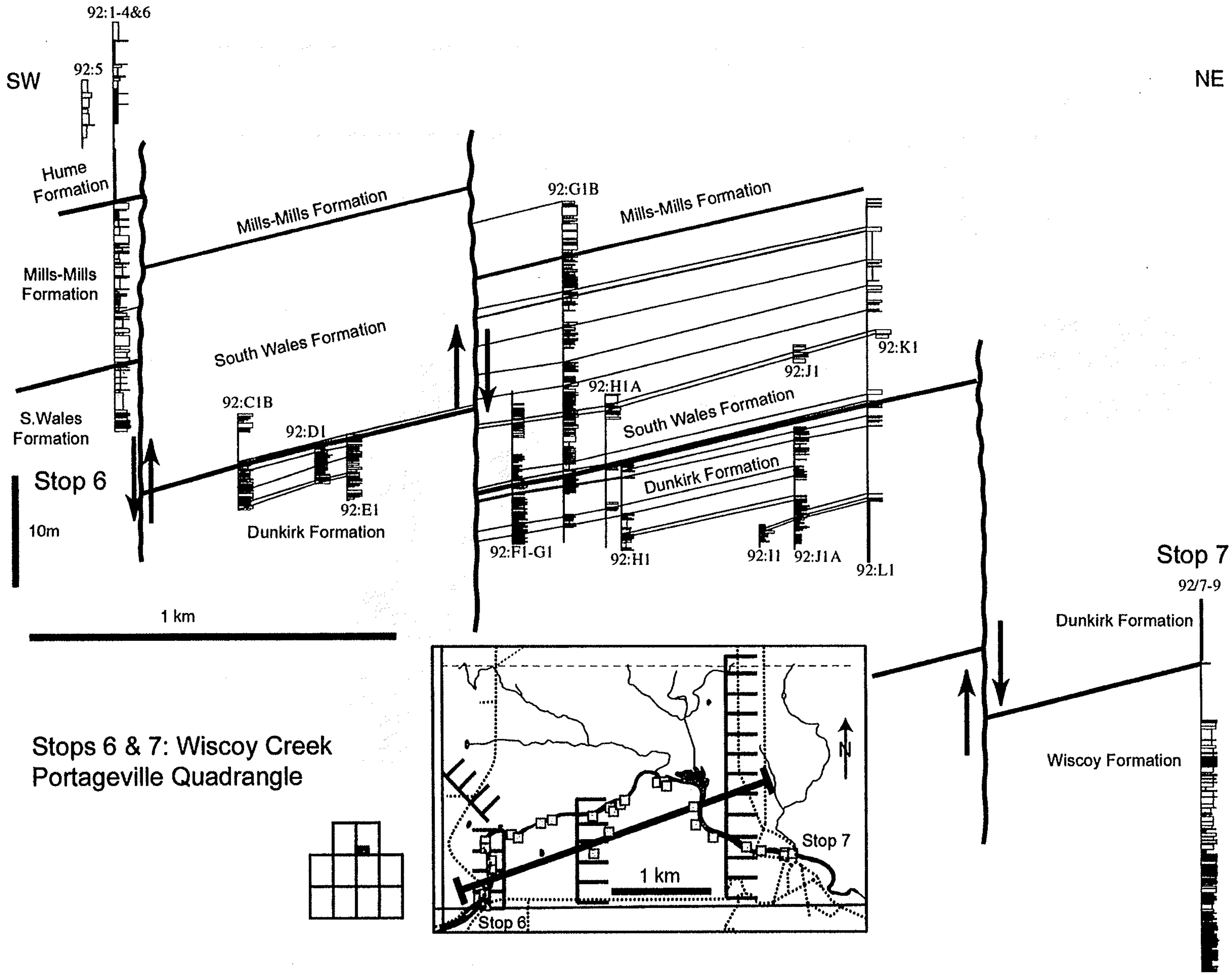

SW
NE
92:1-4&6
92:5
Hume Formation
Mills-Mills Formation
Mills-Mills Formation
South Wales Formation
S.Wales Formation
Stop 6
10m
92:C1B
92:D1
92:E1
Dunkirk Formation
1 km
92:G1B
Mills-Mills Formation
92:K1
92:J1
92:H1A
South Wales Formation
Dunkirk Formation
92:F1-G1
92:H1
92:I1
92:J1A
92:L1
Stop 7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

Figure 9

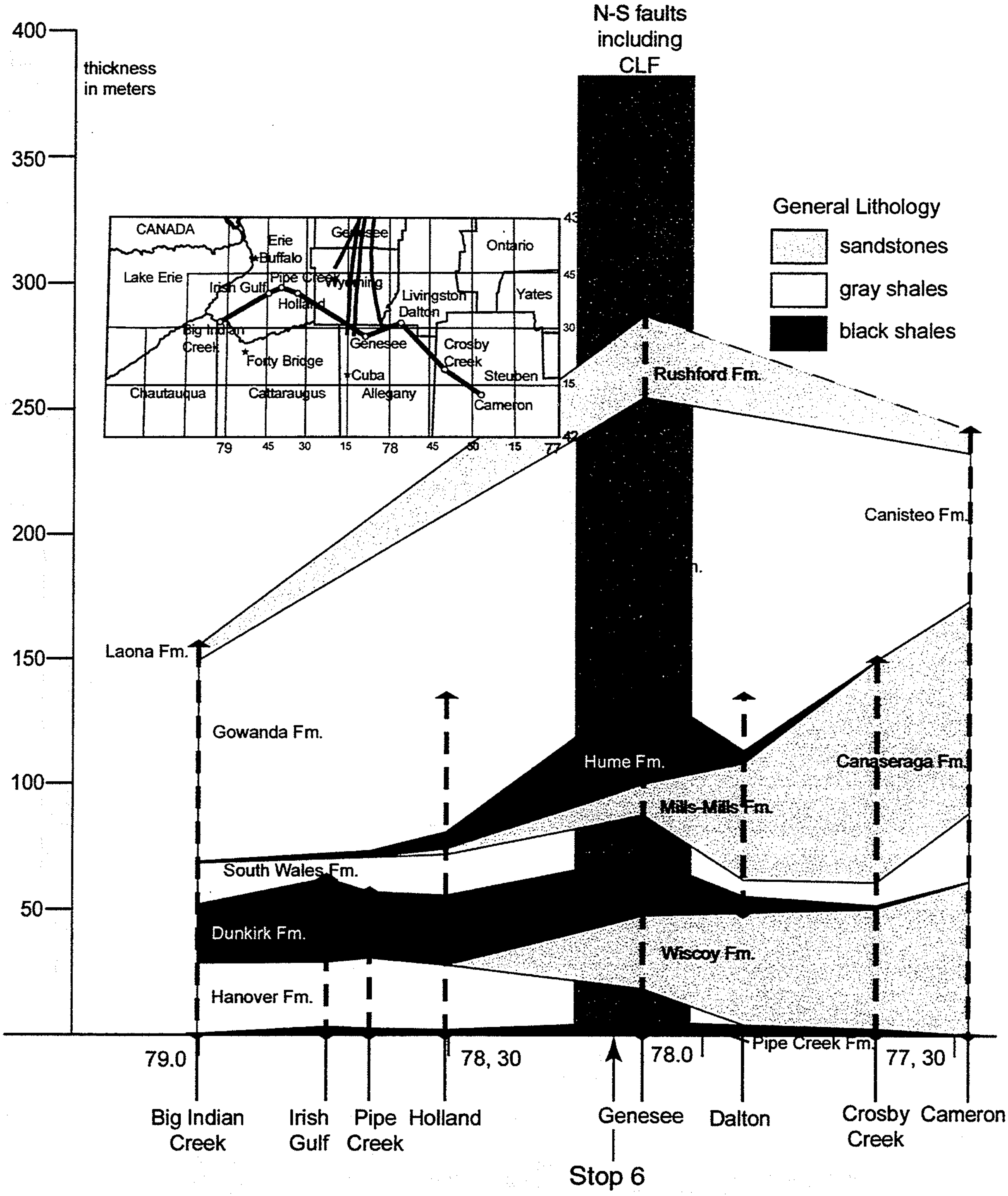

N-S faults including CLF
400
350
300
250
200
150
100
50
thickness in meters
General Lithology
sandstones
gray shales
black shales
CANADA
Lake Erie
Erie
Buffalo
Genesee
Ontario
Irish Gulf
Pipe Creek
Wyoming
Holland
Livingston
Dalton
Yates
Big Indian Creek
Forty Bridge
Genesee
Crosby Creek
Cuba
Steuben
Chautauqua
Cattaraugus
Allegany
Cameron
79
45
30
15
78
45
30
15
77
43
45
30
15
42
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