Depositional and Tectonic Models for Upper Devonian Sandstones in Western New York State

Saturday Field Trip A2

Sandstone Outcrops from Allegany, Cattaraugus and Wyoming counties.

Guidebook for the field trip held October 7th, 2006 in conjunction with the 35th Eastern Section AAPG Meeting and 78th NYSGA Field trips held in Buffalo, New York

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INTRODUCTION

Goals and Objectives

The intention of this field trip is to visit examples of the major clastic depositional environments prevalent in the Late Devonian Appalachian foreland basin. Additionally, we will examine how syndepositional faulting influenced, and in some cases controlled, the deposition of the major petroleum reservoirs. This field trip represents a continuing evolution in our understanding of the Upper Devonian depositional controls. Our earliest sandstone field trip (Jacobi et al., 1990) proposed turbiditic and storm depositional environments in a basin setting, consistent with the views of the time that the Appalachian Basin in New York State was essentially structurally featureless (except for rare folds in the south and the Clarendon-Linden Fault), and that the shorelines had been muddy. Our next field trip (Jacobi and Smith, 1999) showed that post-depositional faulting was likely, that sandy/silty shoreface environments were possible farther east, and that syndepositional faulting affected the Rushford Formation.

In this field trip, we will visit outcrops representing the major sandstone depositional systems (turbidites, shelf-ridges, beaches, and fluvial) which correlate with the main Upper Devonian oil and gas reservoir sandstones of the Elk, Bradford and Venango groups. At each stop we will point out sedimentary structures, trace fossils and bedding relationships that assist in determining the depositional environment. We will also discuss the significance of syndepositional deformation structures that occur ubiquitously within Allegany and Cattaraugus counties of New York State. These deformation structures, as well as other data sets (e.g., paleoflow indicators, structure contour maps, isopach maps, and ichnofacies), indicate that the depositional systems were influenced by an interplay among fault block rotation, eustatic sealevel and sediment supply.

OVERVIEW

The Devonian stratigraphic section is well represented in outcrop in the Appalachian Basin, with significant continuous sections occurring within New York State. Correlations of Lower and Middle Devonian stratigraphic units can be carried across long distances throughout the basin, but Upper Devonian stratigraphic correlations become difficult not only over long distances, but also over a township or across a river valley. The difficulty arises from a combination of deposition within an energetic system and recurring seismic activity, which modified the basin topography.

The reservoir sandstones of the Upper Devonian in New York and Pennsylvania are commonly conceptualized as "discontinuous bodies within marine shales" (Woodrow, et al., 1988). A multitude of names based upon the field location, rather than the stratigraphic unit, reflects the difficulty in correlation of Upper Devonian units on the basis of lithology. The problem is the lateral variability of sandstone and conglomerate units, referred to as lenses or lentils from 1902 onward (e.g., Clarke, 1902; Glenn, 1903; Tesmer 1955). The term "lens" provides an inadequate description of the unit, since sand-filled channels, sand ridges and remnants could all imply a lensing morphology (Figure 1). It is the tacit expectation that sedimentary units maintain a constant lateral thickness and lithology that in part drives the perception of lensing sandstones and the inability to correlate over long distances. Lateral variation is inherent in sandstone deposition; whether a tidal unit possesses internal mud-drapes or a tempestite contains basal coquina lags, the unit will not be laterally homogeneous in a shallow marine environment. Monolithic sands units of constant thickness will not form in typical clastic depositional environments; instead, a sand-packet comprised of several events will generate a thick sand unit. Accompanying this problem is the extrapolation of essentially point source data (well-logs) to reflect a broader area. A well-log will provide geophysical data for a narrow window surrounding the well-bore; two wells in the same sand-packet may yield different log responses, and therefore suggest no possible correlation between the wells, whereas outcrops would readily demonstrate that the two wells were sampling the same unit (Figure 2).

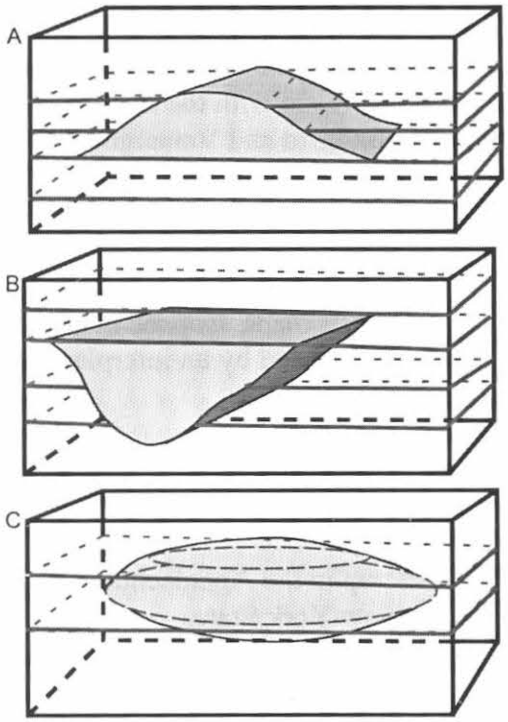


Figure 1. Variations in morphologies for lenses. A - ridge; B channel; C - erosional remnant.

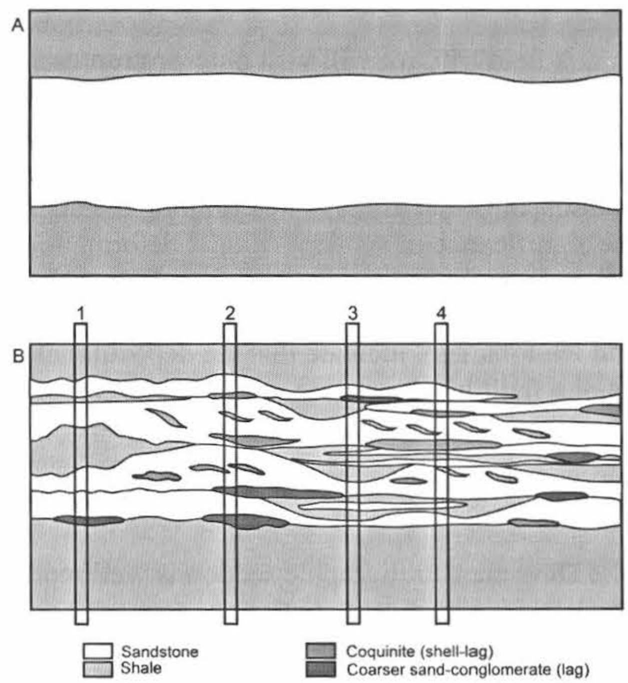


Figure 2. A - Cross-section of a homogeneous sand body that rarely occurs but are assumed to represent any correlateable sandstone. B - hypothetical example of a normal sandstone packet made up of several events with a distinct heterogeneous lithology. If a wells were drilled a locations 1, 2, 3, or 4 the logs would yield a "lensing" characteristic that is due more to lateral variation than as an isolated ridge or channel.

The focus area contains the Upper Devonian groups that comprise major hydrocarbon reservoir units in New York State. The sandstones in the upper part of the Canadaway and Conneaut groups are correlatives to the Bradford sands in Pennsylvania, whereas the sandstone and conglomerates in the Conewango Group are correlative to the Venango sands in Pennsylvania (Figure 3). Examination of the boundaries of the reservoirs shows a strong relationship between faults, folds and the oil fields (Figure 4 and 5). Syndepositional faulting along the Clarendon-Linden Fault System controlled the orientation of clastic deposits in Allegany County (Smith and Jacobi, 1996, 1998, 1999, 2001). Similar reactivation along other north-south trending faults in Cattaraugus

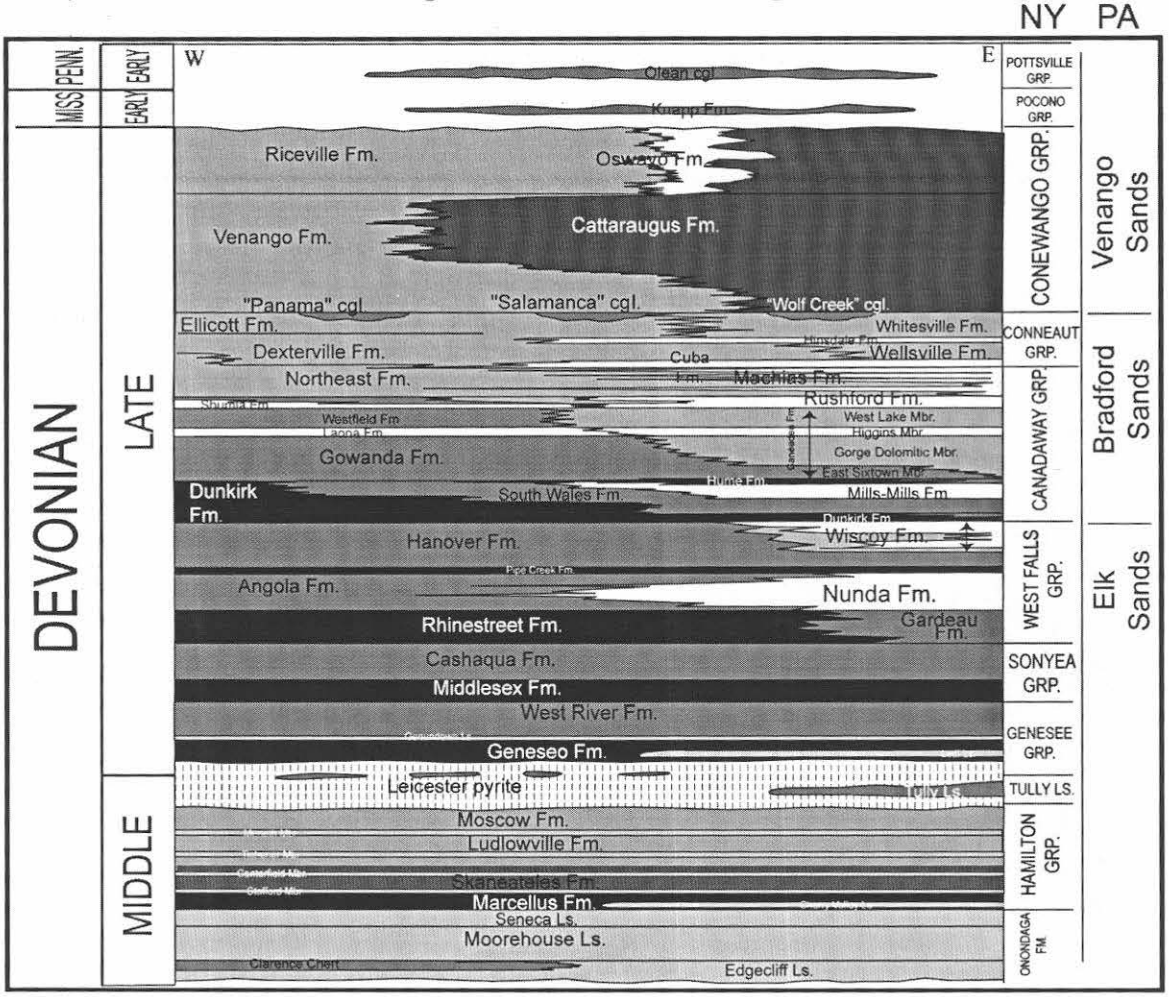


Figure 3. Devonian stratigraphic section for western New York State displaying oil and gas equivalent units. Based upon Rickard, 1975.

County also influenced the depositional trend of Upper Devonian reservoir and source rocks.

Other trends, such as the NE-trends, have a more complicated origin. Certainly Alleghanian folds form the structural closure that controlled many of the well-known fields such as the Sharon-Smithport anticline and pool. However, in addition, Iapetan opening faults that arc through Pennsylvanian and New York were reactivated and these fault-block reactivations controlled the depositional fabric of many of the sands, such as the Bradford field and the Elk sands (Jacobi et al., 2004, 2005, 2006)

The occurrence of northeast-trending sedimentary deposits such as shorelines and sand ridges were assumed to follow the paleoshoreline. Reconstruction of Devonian

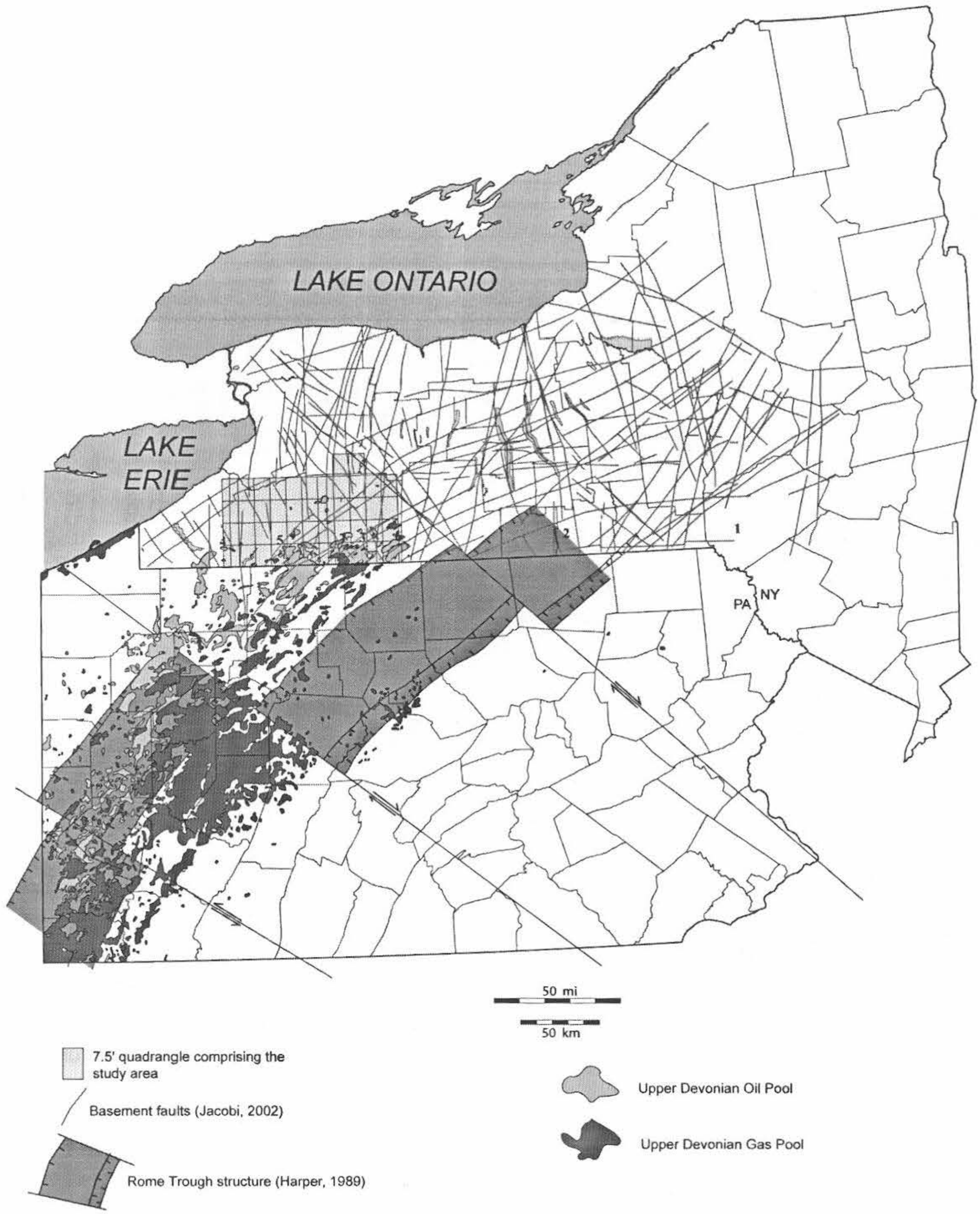


Figure 4. Upper Devonian oil and gas fields in relation to known and proposed basement structrures

paleoshorelines in West Virginia, Maryland and Pennsylvania by Boswell and Donaldson (1988), Dennison (1985) were derived from well-log data, based upon the sand

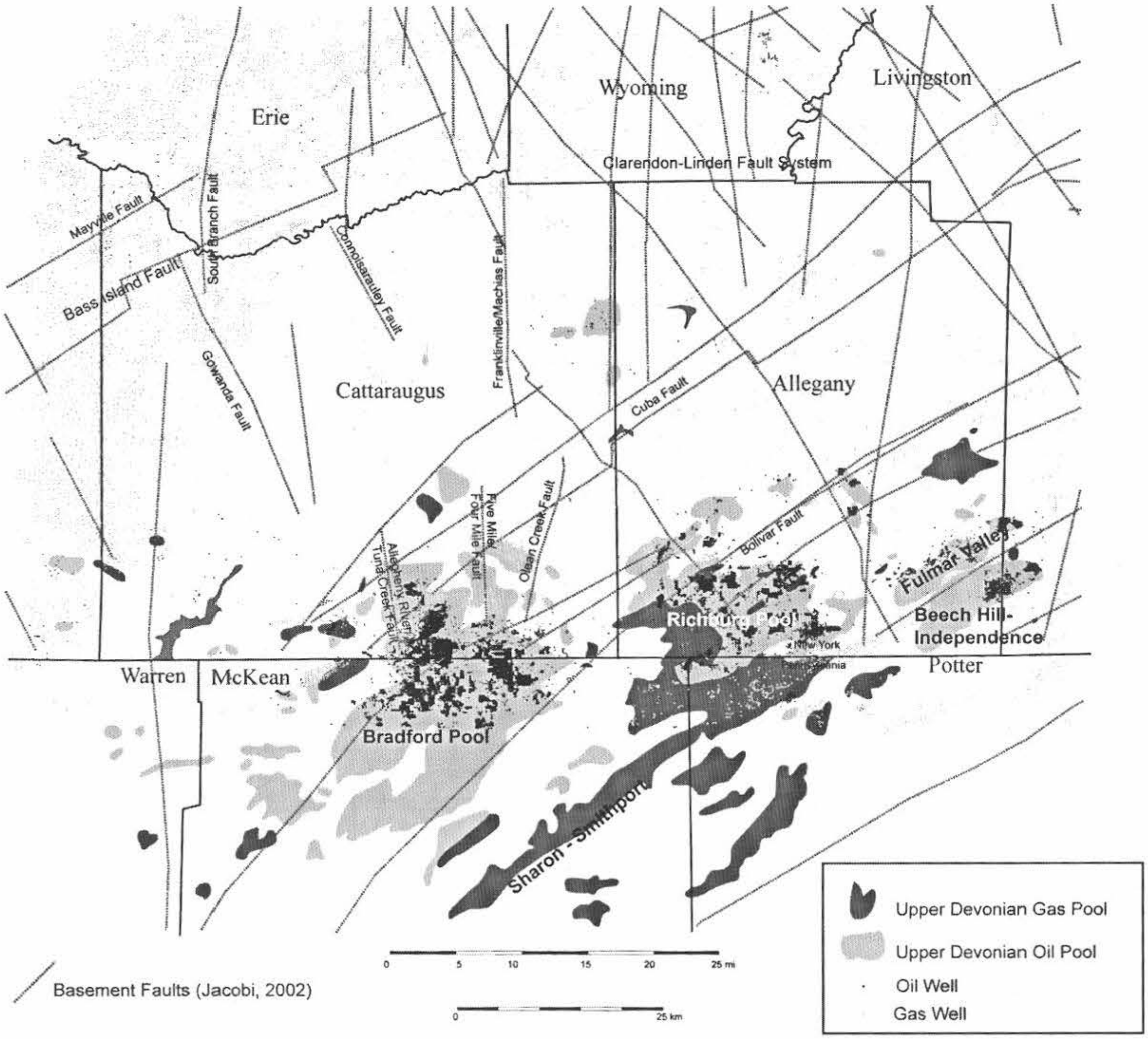


Figure 5. Apparent relationship between oil and gas fields and basement structures (after Jacobi et al., 2004)

percentage for a particular stratigraphic unit. Basinward limits and orientations for similar time periods seldom agree. For example paleoshorelines 4&5, 6&7 in Figure 6 both represent similar time periods in the Conneaut and Conewango groups, yet display differing trends in New York State. The coincidence between the basement structure and the location of the sedimentary deposits suggested that the paleoshoreline itself may have been controlled by reactivation of the Iapetan opening/Rome Trough fault system (Jacobi et al., 2004).

It is the intention of this study to correlate the "discontinuous bodies within marine shales", determine the architecture (size, shape and orientation) of the different sandstone packets and examine controls on the location and architecture of the sandstone packets. By understanding the architecture of the sandstone packets and what is controlling that architecture it is possible to better characterize known reservoirs and extrapolate the potential into unexplored locations.

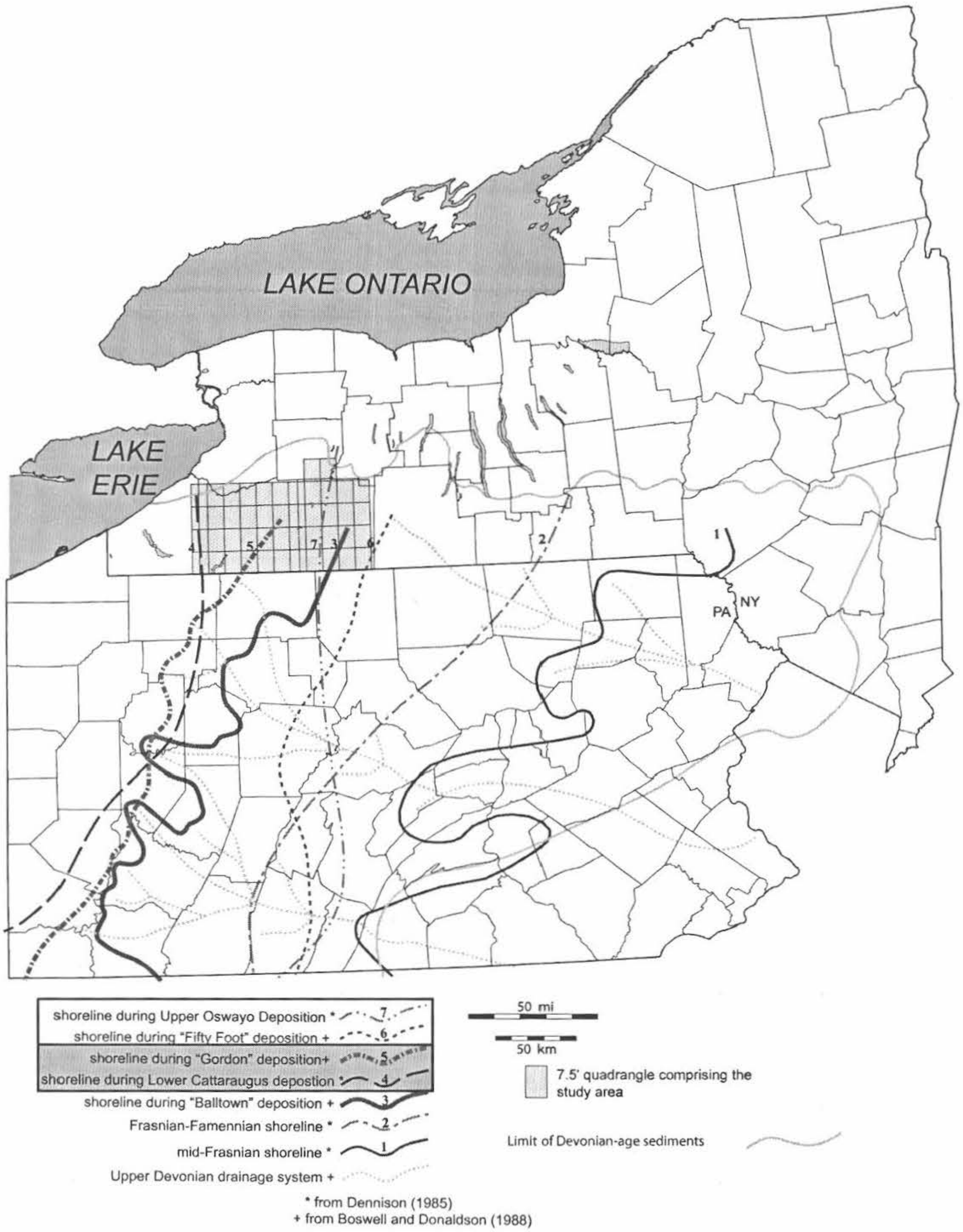


Figure 6. Paleoshorelines for different periods of the Upper Devonian. Note the "boxed" units (4&5, 6&7) represent very similar time frames in the Late Devonian.

Study Area Location

The study area is comprised of 46 7 ½' topographic quadrangles that cover the majority of Allegany and Cattaraugus counties (Figures 4, 5 and 6). The study area expands upon 15 years of fieldwork we have conducted in and around the Allegany – Cattaraugus county region. The outcrops within the area consist of Upper Devonian sandstones and shales of the West Falls, Canadaway, Conneaut and Conewango groups, and occur in streams exposures and road cuts. While a substantial number of oil and gas wells occur within the study area; the overwhelming majority of wells are located near the southern border of New York State, resulting in a sporadic covering of wells over approximately ¾ of the study area.

Methodology

The sedimentological and stratigraphical data were collected from 1991 through 2006 At each site, the location of the outcrop was obtained in recent years using a Garmin 76CSx GPS, and location coordinates were transferred to USGS 7 1/2' topographic maps. In earlier years, we used the topographic maps to locate the sites. The stratigraphic thickness of each distinct lithological unit was measured to the nearest millimeter; all sedimentary and bedding structures were also recorded for each bed.

Measurement of paleoflow orientations were taken with a Brunton compass corrected for the magnetic declination for the quadrangle studied at the time. Each outcrop was also carefully examined for trace fossils so that the ichnology and changes in ichnofauna could be used to supplement interpretations of the depositional environment. Annotated, scaled stratigraphic columns were made in Adobe Illustrator for each measured site.

Well log analyses were performed using scanned well-logs provided by the New York State Museum and the well-log viewer BlueView by Schlumberger. Only the gamma ray curves were examined, to enable consistent formation picks between wells. Of the 418 wells examined, 124 gamma ray curves were hand digitized in Adobe Illustrator to 1) allow better comparison between wells with different vertical scales, 2) enable the comparison between wells and outcrop stratigraphic columns, and 3) use both wells and outcrops in cross-sections. Only Devonian formations were examined for the purpose of this study. Well-log data were then entered into a GeoGraphix database, along with outcrop data for the Dunkirk Fm., Hume Fm., Lower Rushford Mbr., Machias 1st Sand, Cuba Fm. and Hinsdale Fm., to enable the generation of isopach and structure contour maps. Contouring in GeoGraphix was performed using a Kriging function at 30 iterations, without a geological bias to the data. The resulting contours were not subsequently modified to avoid imposing intentional or unintentional biases to the mapping.

Stratigraphic Nomenclature

One of the persistent problems in Upper Devonian stratigraphy is the plethora of unit names that can refer to 1) the same unit (but with different names), 2) any oil-producing unit, 3) regional location of the well, 4) part of the same unit but with different tops or bases, and 5) a gross simplification of several units into one catch-all name.
For this report, we will follow the lithostratigraphic names that use outcrop-defined units that we have established in earlier studies (i.e., Smith and Jacobi, 2000 and 2001; Smith

Pennsylvanian		Pottsville Grp.	Olean Cgl.	
Mississippian		Pocono Grp.	Knapp Creek Fm.	
DEVONIAN	Famennian	Conewango Grp.	Oswayo Fm. ★	
			Cattaraugus Fm.	
			Salamanca Cgl. ★	
		Conneaut Grp.	Whitesville Fm. ★	
			Hinsdale Fm.	
			Wellsville Fm. ★	Wellsville 3rd
				Wellsville 2nd
				Wellsville 1st
			Cuba Fm.	
		Canadaway Grp.	Machias Fm. ★	Machais 4th
				Machias 3rd
				Machias 2nd
				Machias 1st
			Rushford Fm.	Upper Rushford Mbr. ★
				Intermediate Rushfrod Mbr.
				Lower Rushford Mbr.
			Caneadea Fm.	West Lake Mbr.
				Higgins Mbr. ★
				Gorge Dolomitic Mbr.
				East Sixtown Mbr.
			Hume Fm.	
			Mills-Mills Fm. ★	
			South Wales Fm.	
			Dunkirk Fm.	
	Frasnian	West Falls Grp.	Wiscoy Fm.	
			Hanover Fm.	
			Pipe Creek Fm.	
			Nunda Fm.	

★ - see text for additional comments

Table 1. Stratigraphic units for outcrop in Allegany and Cattaraugus counties. Units we will visit during this field trip indicated with a box around the name.

Some noted changes and observations in this stratigraphic section include:

Mills-Mills Fm. – We had commonly used the name Canaseraga Fm (Chadwick, 1923) as the formal name for this unit (i.e., Smith and Jacobi, 1998, 2000 and 2001), but upon further study, the Canaseraga Fm., as defined by Chadwick (1923) encompasses both the South Wales Fm., and sandstones we refer to as the Mills-Mills Fm. Since both the South Wales and Mills-Mills formations are distinct lithologically and both are mapable over a large areal extent, it seems reasonable to identify the Mills-Mills as a formation, and to be correlative to only part of the Canaseraga Fm.

Higgins Mbr. (Caneadea Fm.) – This unit is the probable eastern correlative of the Laona Fm., and contains the stratigraphically lowest seismite zone observed within the Canadaway Grp.

Upper Rushford Mbr. (Rushford Fm.) – This unit is comprised of several lensing sandstones that are relatively thin (1-2 meters) in Allegany County, but form a thicker (3-6 meter) sandstone packet in Cattaraugus County.

Machias Fm. – The original description by Chadwick (1923) described the Machias Fm. as primarily shale. Later studies by Woodruff (1942) and Manspeizer (1963) noted one or two thick sandstones and/or limestones. From outcrops examined during the past 15 years of fieldwork, as well as from well-log analyses, we have informally identified four traceable sandstone packets referred to as the Machias 1st through 4th.

Wellsville Fm. – This unit is similar to the Machias Fm.; we have informally identified three traceable sandstone packets: Wellsville 1st through 3rd.

Whitesville Fm. – although we observed several thick (1-3 meters) sandstone packets in outcrop, too few examples occurred to provide convincing correlations.

Salamanca Conglomerate – likely to be correlative to similar conglomerates at Wolf Creek and Panama, NY; each separate conglomerate possibly representing a separate incision valley formed during the same lowstand-transgressive sequence(s) marking the base of the Conewango Grp. Elevation variation between the separate localities may reflect different depth of valley incision, as well as later faulting.

Oswayo Fm. – depending on the classification system, the Oswayo Fm. is considered Mississippian-age in Pennsylvania, but in New York it is the uppermost Devonian unit.

Paleogeography

There are three main controls on any depositional environment: sealevel, structure and sediment supply. The interplay of all three controls will affect what can be deposited or eroded, as well as the size, shape and orientation of the final deposits.
The Acadian Orogeny began during the Early-Middle Devonian, forming the Acadian Mountains (the primary sediment source for the study area) and the Acadian Foreland Basin (the northern area referred to as the Catskill Sea) (e.g., Woodrow and Isley, 1983).

Paleomagnetics studies (Ziegler et al., 1979; Ziegler, 1988; Witzke and Heckel, 1988; Scotese and McKerrow, 1990 and Witzke, 1990) vary in exact placement of paleolatitudes for the study area, but generally concur that the area was located in the tropical region of the southern hemisphere, 15° and 30° S. The paleogeographic location of the study area (Figure 7) has two significant effects: 1) the Catskill Sea would have counterclockwise surface current rotation such that longshore currents would trend from the southwest to the northeast; 2) the region would likely be affected by a monsoonal climate, alternating wet-dry seasons, with intense, large storms.

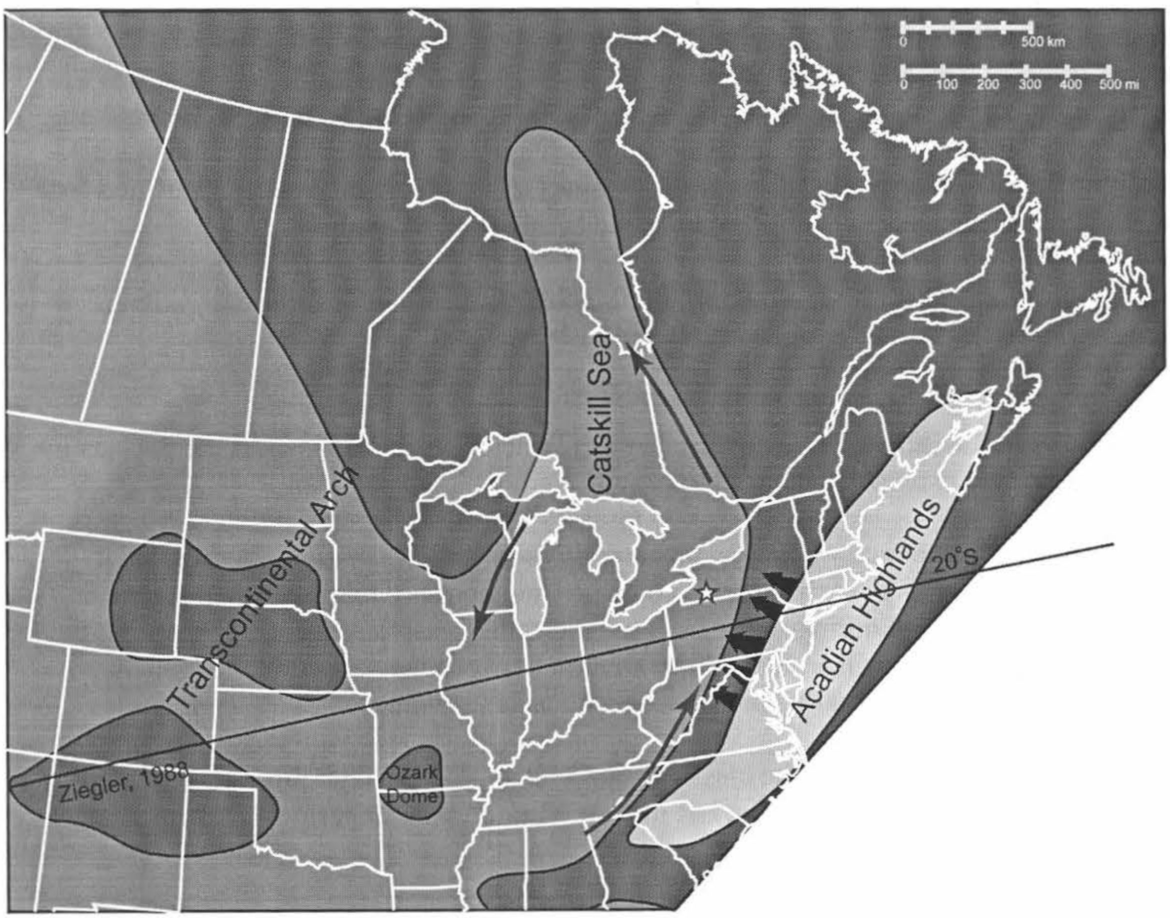


Figure 7. Catskill Sea paleogeography created by integrating models from Ettensohn (1985), Ziegler (1988), and Witzke and Heckel (1988). Paleolatitudes for the Late Devonain exhibit a wide variation in orientation, but all generally place the fieldtrip area (marked by the star) in the southern hemisphere from 5° to 32° south latitude.

Woodrow and Isley (1983) suggested that the Catskill Sea did not include the main bathymetric provinces of shore-shelf-slope-basin found in passive margin models; rather a gently sloping clinoform formed the margin. Such a province may be common for foreland basins (e.g., Pattison, 2005). The steady, shallow slope of the Catskill Sea would lead to a lateral gradation of clastic deposits that would shift dramatically with minor fluctuations in relative sealevel. Although the gently sloping clinoform of Woodrow and Isley (1983) describes the overall nature of the Catskill, it does not reflect smaller topographic variations within the basin caused by continual fault reactivations occurring during Late Devonian.

Tectonics and Regional Structure

Basement structures within the study area reflect the early geological history of eastern North America (see Figures 4 and 5). A reactivated intra-Grenvillian suture zone is locally expressed in the Paleozoic section as the north-south trending Clarendon-Linden Fault System (Jacobi and Fountain, 1993, 1996, and 2002).

Faults associated with Iapetan-opening/Rome Trough development are expressed as northeast-trending basement structures with complimentary northwest-trending cross-structures (Jacobi, 2002; Jacobi et al., 2004, 2005, and 2006). Syndepositional reactivation of these basement structures have been observed in seismic sections for the Ordovician Taconic Orogeny (Jacobi et al., 2004 and 2005) and for Devonian Acadian Orogeny (Jacobi, 2002; Jacobi and Fountain, 1996 and 2002). Syndeposition faulting is observable in the stratigraphic section; growth fault geometries are observed in the Upper Devonian Hume and Rushford formations (Smith and Jacobi, 2000, 2001 and 2002).

Further evidence for syndepositional fault activity are the numerous zones of seismites. Seismites are formed by the sudden dewatering of uncompacted sediments brought on by a sudden shock that is generally thought to be from a large magnitude earthquake (Figure 8). The ubiquitous occurrence of seismites at numerous stratigraphic horizons throughout the study area denotes seismic events of a magnitude greater or equal to magnitude 6. Earthquakes less than a magnitude 6 would only form seismites within 1 to 2 km of the epicenter whereas magnitudes of 6 or greater the distance from the epicenter expends to 20 to 110 km (e.g., Wheeler, 2002). At a magnitude of 5.5 earthquake, a maximum surficial displacement on the fault would be ~0.3m (Bonilla et al., 1984; dePolo and Slemmons, 1990; and Wells and Coppersmith, 1994). At greater magnitudes (M= 6-7), the surficial displacement can reach 1 to 2 meters along the fault. These small offsets may greatly impact deposition within the local area by reorienting currents, raising some areas into the fair-weather wave base, dropping other regions, and generally altering the accommodation space for the region. It is obvious that the interplay among fault block motion, eustatic sea level changes (Figure 9; Johnson et al., 1985), and sediment supply in this shallowly sloping basin can significantly alter the sediment architecture.

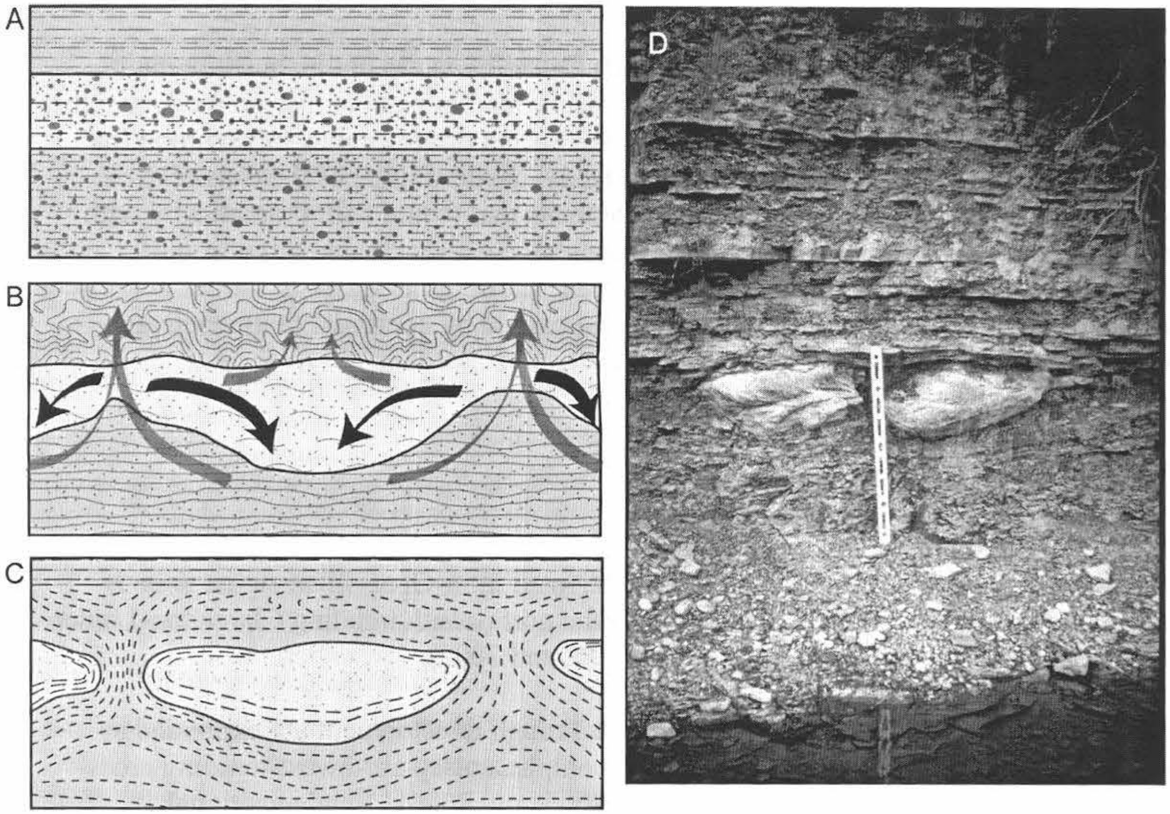


Figure 8. Stages of seismite formation.
A) In regions of high depositional rates, water saturated sediments are common.
B) A triggering mechanisn (generally assumed to be a seismic event greater than M=6) will cause rapid dewatering which will cause the water to escape toward the surface, bringing some of the clays up toward the surface and also cause the denser, heavier sands to sink into the underlying, unconsolidated clays.
C) The resulting structures will have sands which have turned or rolled-up edges, surrounded by a matrix of deformed shales.
D) A typical seismite occurring in outcrop in the Caneadea Formation. Ruler is 122 cm long.

DEPOSITIONAL ENVIRONMENTS

Assemblages of sedimentary structures, lithologies and ichnofauna enable the determination of water depth, current strength and salinity, which can be used to distinguish different depositional environments (Figure 10). From the collected field data we have determined the depositional environments that cover the stratigraphic section for Cattaraugus and Allegany counties (Figure 11).

Black shale deposits in the Late Devonian are thought to have formed from anoxia events (Ettensohn, 1994) rather than from great depths. High organic input combined with a stratified water column would produce a low-oxygen to anoxic system at shallower depths. Storm modified sandstones observed in outcrop within the Dunkirk and Hume formations suggest that these black shales formed within storm wave base. Above the anoxia boundary, the high organic content within the shales would oxidize, producing medium to light gray shales.

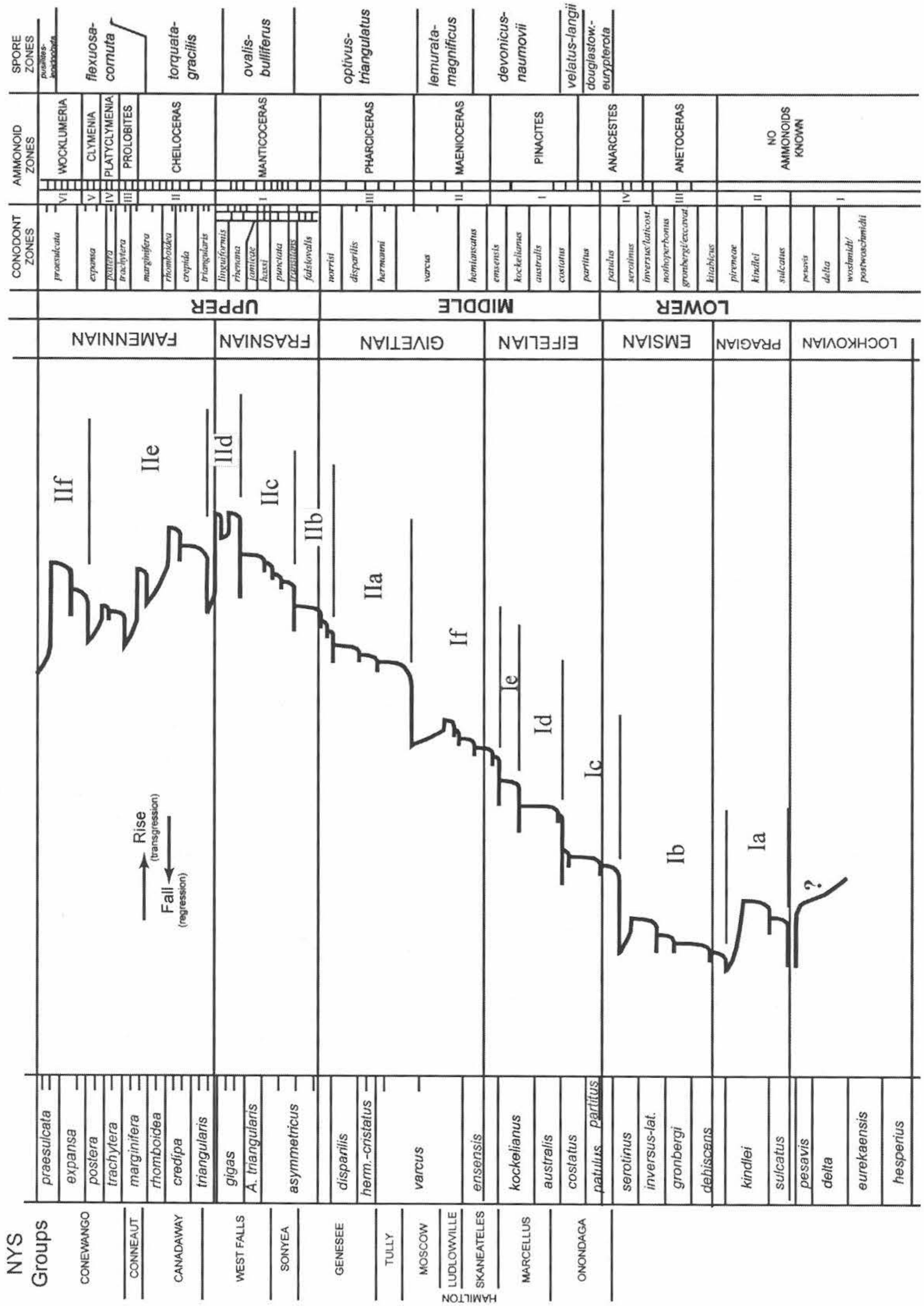


Figure 9. Eustatic sealevel curve from Johnson and others (1985) with biostratigraphic zones from Woodrow and others (1988) and House (2000).

Sand and coarser clastic materials were deposited in four major depositional environments: turbidites, shelf ridges, shoreface system, and fluvial. All four depositional environments are part of a larger deltaic system, but for describing depositional patterns and controls it is easier to examine the four parts separately.

Turbidites

Turbidites are formed from relatively dense, sediment-entrained currents flowing down-slope from a disturbance that introduces the sediment into systems (see for example, "Submarine Fans and Related Turbidite Systems", edited by Bouma, Normark, and Barnes, 1985; and "Fine-grained Turbidite Systems", edited by Bouma and Stone, 2000). Turbidites, in general, form sharp-based, fining-upwards deposits. Methods for initiating turbidites include up-slope slumps, storms or waves stirring up or eroding bottom sediments, suspended sediments introduced by rivers in flood stage and earthquakes. The resultant turbidity currents will construct submarine fans with a form controlled in part by the bathymetry of the basin and the sediment size carried by the turbidity flow. For steep slopes (such as the slope in a passive margin) and/or sand-rich environments (with a relatively close source of coarse sediment), the resultant submarine fan will be radial in shape (assuming relatively smooth pre-submarine bathymetry, Figure 12). For gentler slopes and/or mud-rich environments (with a distant sediment source), the resultant submarine fan may be relatively elongate in shape, since the finer sediment will be able to be carried farther into the basin (e.g., Stow, 1986; Bouma, 2000; Figure 12). For example, the turbidity current pathways on the west African margin can extend over 1000 km downslope to the abyssal plains (e.g., Jacobi and Hayes, 1982, 1992). The gentle slope of the Catskill Sea along with the fine-grained composition of the Nunda, South Wales and Mills-Mills formations would suggest that these units would form relatively elongate fan deposits orientated perpendicular to the paleoshoreline. However, characteristics (e.g., paleoflow data) of the South Wales Formation in western New York west of our present study area suggest a radial flow pattern, consistent with lobe fringe sands of Mutti (1977) (Jacobi et al., 1994). Shallower turbidite deposits, e.g., pro-delta fans of Pattison (2005) and wave-modified turbidites of Myrow and others (2002) form within storm-wave base. These shallower turbidites share similarities to turbidites with the exception of combined-flow ripples in the C part of the Bouma model (Brett, 1983; Myrow et al., 2002). The thick sandstones of the Nunda Formation and the Higgins Member of the Caneadea Formation, correlative to the Laona Fm. to west, possess many of the features attributed to wave-modified turbidite fans. West of the present study area, distal beds of the Nunda Formation were thought to represent sand lobes on a submarine fan, based on the massive nature, abrupt pinchouts, and lobate form of isopach maps of the thick sand beds (Jacobi et al., 1994).

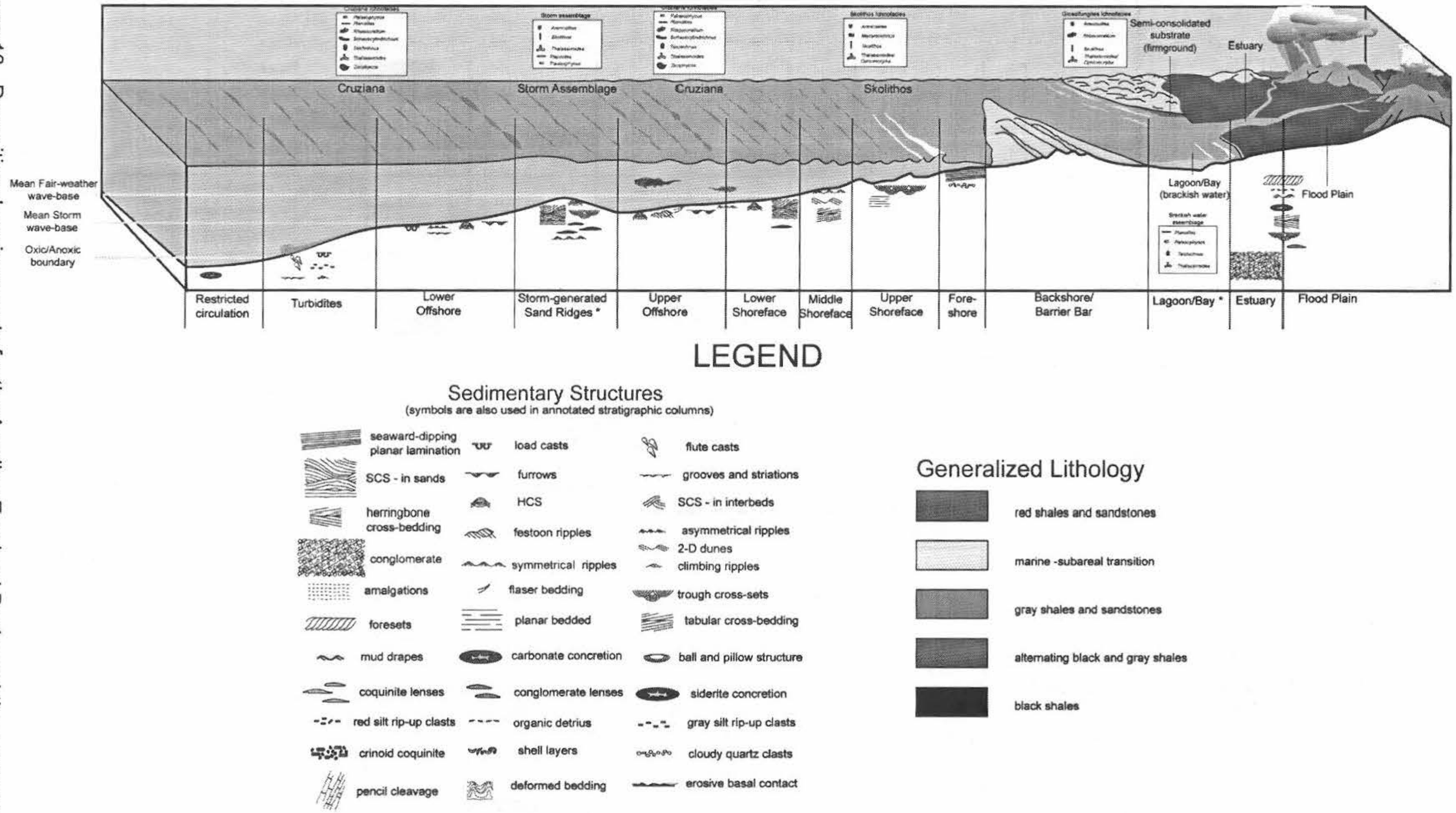


Figure 10. Depositional environments for the Acadian Foreland Basin and the common assemblages of sedimentary stuctures and ichnofacies.

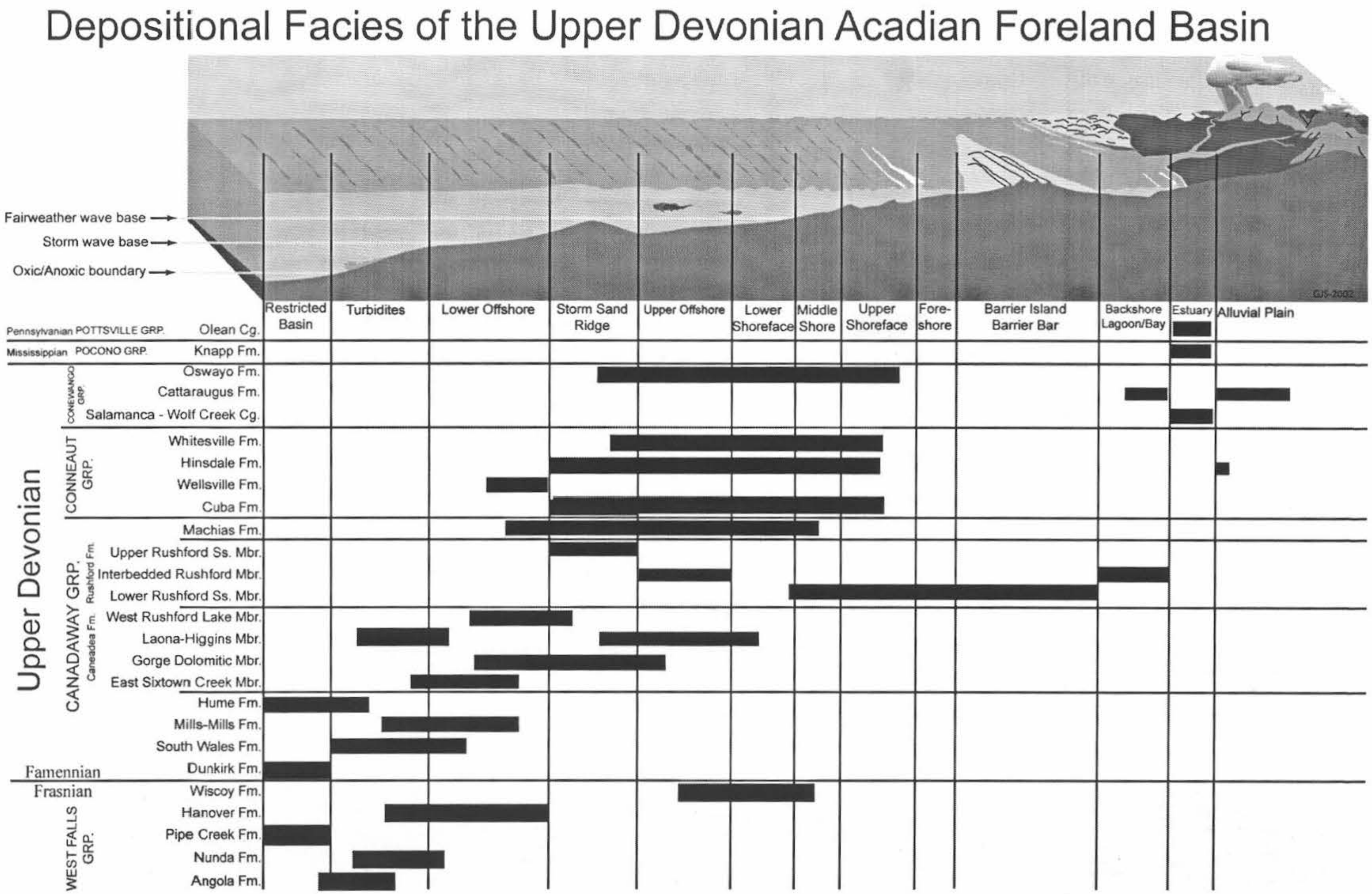


Figure 11. Depositional environments for the stratigraphic units within Allegany and Cattaraugus counties.

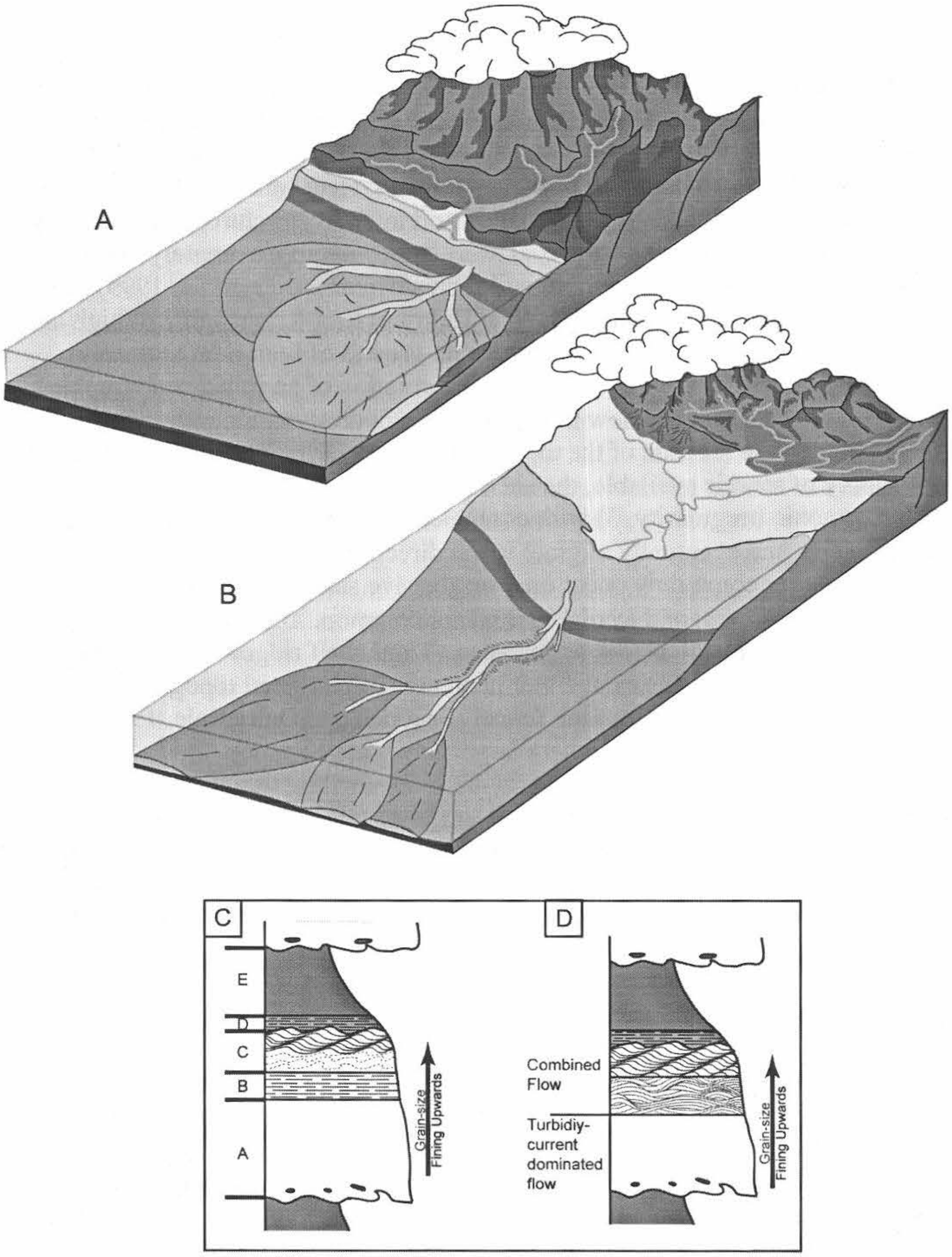


Figure 12. A) Where the sediment source is close to the shelf and typically comprised of sand and gravel and the slope is relatively steep and the pre-submarine fan bathymetry is relatively smooth, the resulting turibidite fan will be round and lobate. B) Where the sediment source is far from the shelf and typically comprised of shale, silts and fine sands the turbite fan will be farther from the shore, longer and narrower than the coarser endmemer in "A". The turbidites in the Late Devonian of western New York State may follow this model (modified from Bouma, 2000). C. Idealized turbidite model proposed by Bouma (1962), depicts the fining-upwards sequence and changes in bedding causes by decreasing flow velocity. Bouma (1962) model is proposed for a sand-rich system (depositional model A) but can still be applicable to finer-grained systems (depositional model B), although turbidite rarely exhibit a complete sequence ($T_{A\text{-}E}$). D) Generalized wave-dominated turbidite model from (Myrow et al., 2002) for comparison.

Shelf Ridges

Shelf ridges are generally thought to be relict sandstones reworked and reshaped by later currents (Snedden and Dalrymple, 1999). Shelf ridges have three main varieties: detached beach barrier bars, tidal shelf ridges, and storm shelf ridges. Whereas detached beach barrier bars can be considered part of the shoreface system (discussed below), both tidal and storm shelf ridges are similar in formation and internal structure, differing only in scale (Snedden and Dalrymple, 1999). Tidal shelf ridges are approximately 10-60 km in length, 5 to 40 m high and 0.7 km to 8 km wide (Snedden and Dalrymple, 1999). In contrast, storm shelf ridges are generally less than 15 km in length, average 7 m high and less than 8 km wide (Miall, 2000). The formation and growth of both tidal and storm shelf ridges can be described by the same model: 1) formation of an initial topographic irregularity oblique to the dominant flow that generates a hydrodynamic instability leading to deposition on the lee-side of the topographic irregularity (Huthnance, 1982), 2) if a sufficient supply of sand is available, the shelf ridge will grow, and the ridge now becomes the topographic irregularity, 3) with continued current activity, the ridge will grow to maximum size and eventually migrate in the direction of the current (Figure 13). Both types of shelf ridges commonly occur on transgressive surfaces where topographic irregularities (from ravinement) and available sand are common. In well-logs, shelf sand ridges will be sharp-based and blocky in appearance. Tidal shelf ridges form in areas of the shelf where strong tidal currents exist either in an area of restricted topography, such as the English Channel, or near an estuarine funnel (Snedden and Dalrymple, 1999). Storm shelf ridges can form in any area where large storms are common.

We suggest that many of the sandstone lenses (or lentils described in older papers) can be attributed to shelf sand ridges. The Upper Rushford Member, the sandstone packets in the Machias, Wellsville and Whitesville formations may all be shelf sand ridges, as would the basinward extent of shoreface sandstone in the Lower Rushford Member, Cuba and Hinsdale formation.

Beach and Shoreface

Beaches and shoreface systems in the Late Devonian Catskill Sea were thought to be non-existent, with only a transition from non-marine, muddy tidal systems to offshore muddy systems (Walker and Harms, 1971). Shoreface sequences are formed in wave-dominated systems and can be found as beaches attached to the land; as attached or detached barrier bar systems separated from the land by a shallow lagoon; or as cheniers where isolated beach ridges occur within the coastal mudflats (Elliott, 1986).

Our past work (Smith and Jacobi, 1998, 2000, and 2001) has shown that that the Lower Member of the Rushford Formation is comprised of three, stacked sandy shoreface sequences. Each shoreface sequence containing identifiable lower, middle, upper and foreshore zones (from lower shoreface ripples to trough cross sets to foreshore seaward-dipping planar laminae, Figures 10, 14). Organic-rich shales containing abundant examples of the brackish-water trace-fossil *Teichichnus* (Figure 14) within the Lower Rushford Member and overlying Intermediate Rushford Member indicate the presence of lagoonal or bay facies associated with the shoreface sequences, suggesting that in the northern part of the study area, the Lower Rushford Member shorefaces are part of a barrier bar system. In the Cuba and Hinsdale formations, lower to middle shoreface zones have been identified in outcrop. In well-logs the coarsening upward gamma ray curves are typical for normal (not subsequently modified) shorefaces. By default, beaches are parallel to the shoreline, although beach barrier bars can become more oblique as they become farther from land and transition to shelf sand ridges.

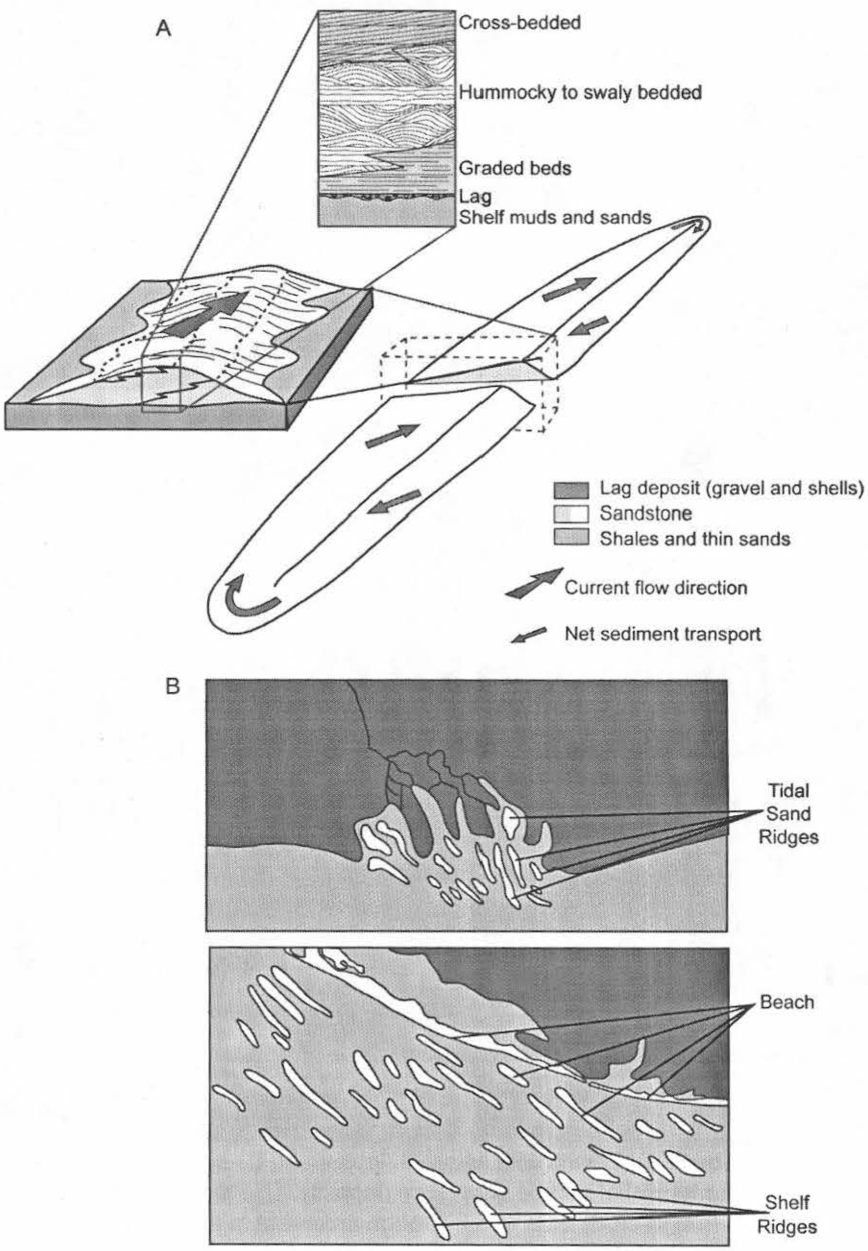


Figure 13. A) Anatomy of a shelf sand ridge incorporating models from Swift et al., 1986 and Dalrymple, 1992. B) Orientation of sand-ridges compared to shorelines, tidal sand ridges (top) are typically orientated perpendicular to shore. Beach barrier bars (bottom) trend parallel to shore, whereas shelf ridges (bottom) become more oblique offshore.

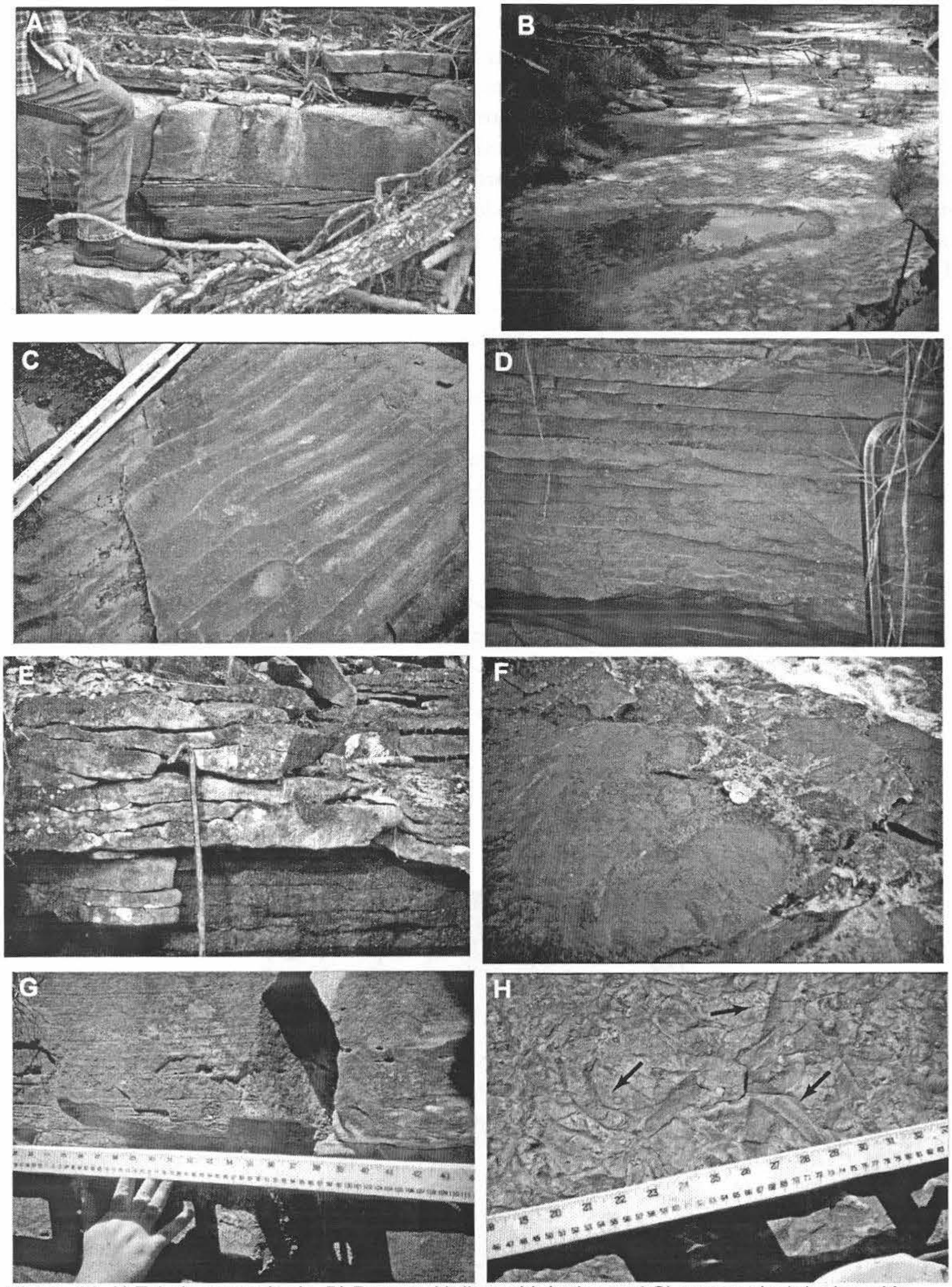


Figure 14. A) Tabular cross-beds, B) Dunes with linguoid ripples and C) symmetrical ripples with "tuning fork" and ladderbacks typical of middle shoreface deposits. D) Planer-bedded sandstones, E) Planer beds transitioning to trough cross-sets and F) trough cross-set in plan view typical of upper shoreface deposits. G) Planar lamiated sandstone with sporadic quartz pebbles indicative of foreshore deposits. Photos A-G taken from the Lower Rushord Member. H) Teichinchus (arrows) in thin sand-stones in the Intermediate Rushford Member.

Fluvial

Fluvial systems are found within the non-marine red-beds of the Cattaraugus Formation and more commonly in Pennsylvania closer to the source area. Common fluvial system sandstone beds within the study area are small tidal channel deposits that are light gray, steeply cross-bedded sandstone that is 1-2 meters in thickness and laterally limited to a few tens of meters. The tidal channel sandstones are generally heavily burrowed with *Skolithos*, *Arenicolites* and *Ophiomorpha* common to high-energy, shallow or tidal environments.

Less common, but more prominent, are the thick conglomerates that occur at the base of the Conewango Group. The Salamanca, Panama, Pope Hollow, Killbuck, Tunangwant and Wolf Creek conglomerates are thick orthoconglomerate deposits that range in thickness from 2 to 12 meters. These conglomerate deposits do not appear to be laterally continuous and have been previously interpreted to be non-contemporaneous (Tesmer, 1975). The problem with correlating the conglomerates is that outcrops are rare, although the large blocks of conglomerate can be easily found, but rarely in place. The sporadic occurrences across Chautauqua, Cattaraugus and Allegany counties produce exposures at varying elevations that would lead to the assumption that the conglomerates are different units. However, elevation differences between widely separated localities can also result from 1) different erosional depth for lowstand incision, and 2) post depositional faulting.

Tesmer (1975) interpreted the conglomerates with flat pebbles to represent a marine environment, whereas he suggested the spherical pebble conglomerates represent fluvial deposits. We interpret the conglomerates to represent incised-valley fill, where the fluvial system intensely erodes in response to a lowstand, and generates clastic sediment through erosion as well as transporting fluvial gravels farther basinward. During the ensuing transgression, the eroded, or incised, river valley is inundated by the rising sealevel forming an estuary. Tidal, fluvial and wave components rework and redeposit the lowstand sediments into to coarse-grained estuarine deposits. Components of an incised valley system include the "tripartite" systems: marine (barrier bar at the mouth of the estuary); mixed marine-fluvial and tidal (estuarine mud and tidal bars), and fluvial (bay-head delta, fluvial bars and overbank deposits) (Figure 15). In wave-dominated systems, the tripartite system is typically: sandy marine barrier, muddy estuarine lagoon, and sandy bay-head fluvial delta (Dalrymple, 1992). It is important to note the difference between estuarine tidal bars and tidal shelf ridges. Both can, and have been, referred to as tidal bars (e.g. Willis, 2005), but differ in size, orientation and formation. Shelf tidal ridges (as previously discussed) form in deeper water, oblique to the current and are limited in size by the strength of the current, supply of sediment, and depth of the water. Estuarine bars form parallel to the tidal current, and are limited in height by the depth of low tide (Willis, 2005). Estuarine sand bars are typically separated by ebb-tidal channels, which force the bar to parallel flow. Incised valley systems and tidal channels will generally by orientated perpendicular to shoreline.

To summarize, in the absence of additional controls (structural), sand packets will be orientated: perpendicular to the shoreline (turbidite fans, estuarine and fluvial deposits), parallel to the shoreline (beaches, beach barrier bars), or oblique to the shoreline (shelf sand-ridges) (Figure 16).

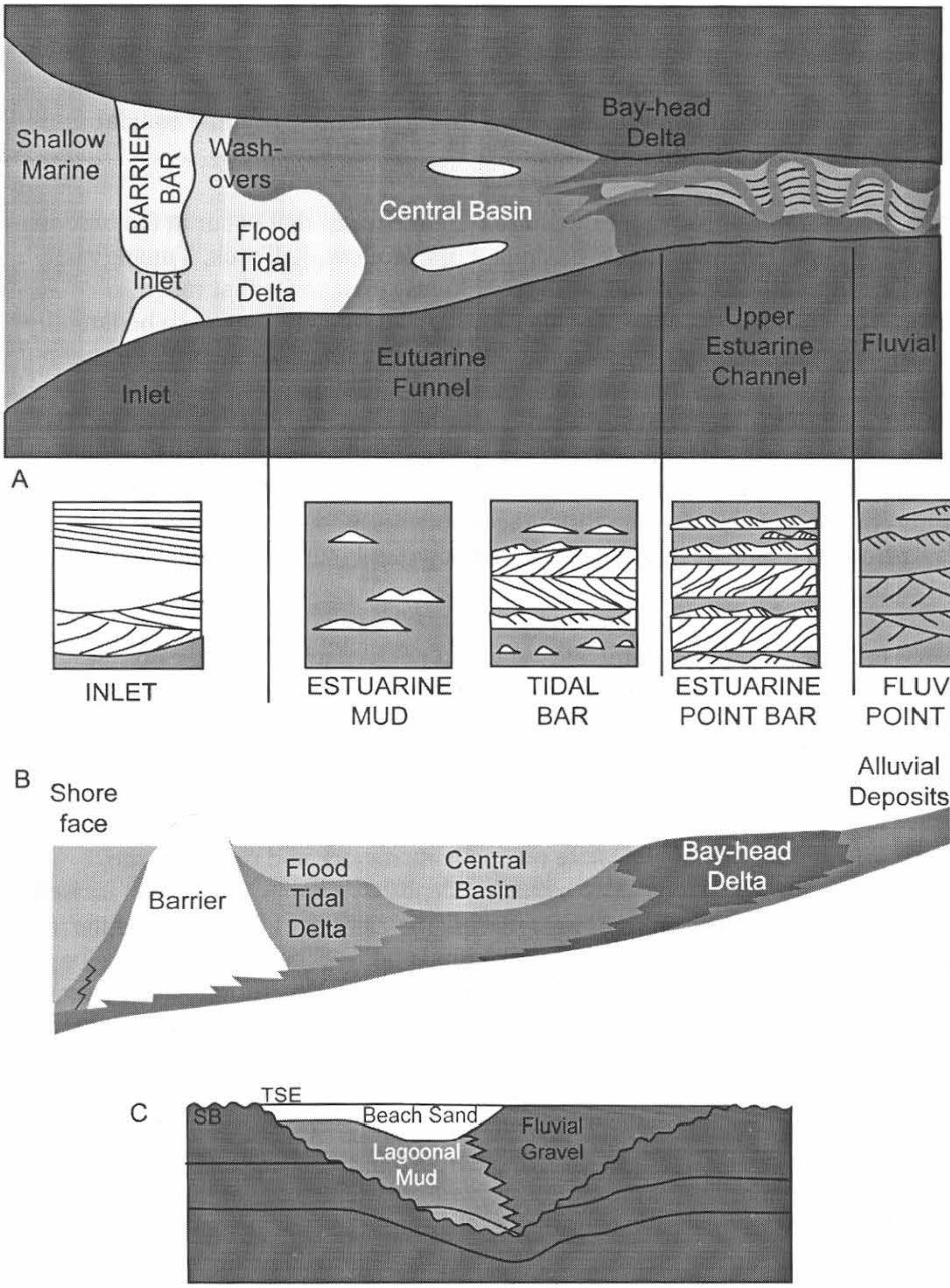


Figure 15. A) Estuarine deposition showing the "tripartite" components in a wave-dominated environment. B) Cross-sectional view of the estuarine system, parallel to the valley trend. C) Cross-sectional distribution of sediments, perpendicular to the valley trend. All modified from Dalrymple et. al., 1992 and Reinson, 1992.

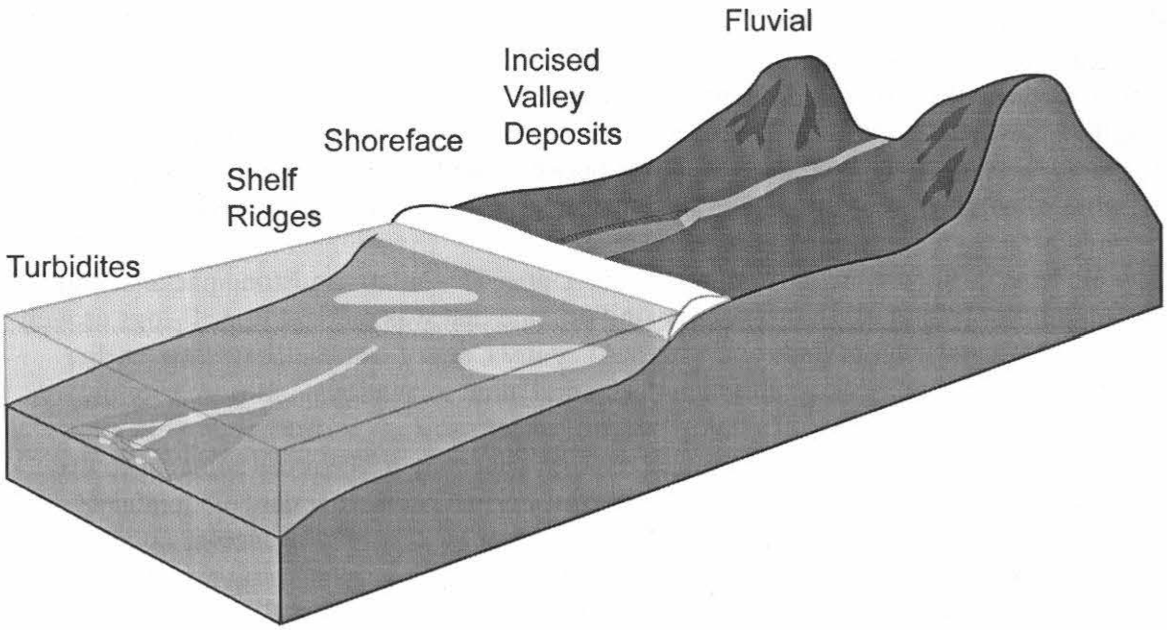


Figure 16. Summery of sandstone and coarser grained clastic depositional systems and the typical orientations to shoreline

Correlations

To correlate the Upper Devonian sandstone packets over the entire study area it was necessary to utilize well-logs to trace units observed in outcrop into the subsurface. Numerous well-logs were available for wells within the study; approximately 2,000 wells had logs on file or online with the New York State Museum. However, this number is far less than the 23,000+ wells the New York State Department of Environmental Conservation has listed in their well database. The discrepancy between the number of wells and the number of logs reflects the age of the oil and gas fields within the area; many of the wells predate electronic logging and more importantly predate state regulations requiring the submission of well logs.

Of the well-logs available, we focused on gamma-ray curves to provide stratigraphic correlations between wells, and between wells and outcrop. In many of the well-logs, only the zones of interest were logged, or logged up to casing which in turn removed much of the Upper Devonian section for most, if not all, of the Upper Devonian stratigraphic sections. Despite these limitations, we examined 418 well-logs that contained recognizable stratigraphic units and/or units that we might be able to correlate to adjacent wells or outcrop. For the purposes of this study we examined only the Devonian stratigraphic section, using the Onondaga Formation as our lower stratigraphic limit. Picked formations included in ascending stratigraphic order: Onondaga Formation, Cherry Valley Limestone, Marcellus Formation, Centerfield Limestone, Tichenor Limestone, Tully Limestone, Lodi Limestone, Geneseo Formation, Middlesex Formation, Rhinestreet, Nunda Formation, Pipe Creek Formation, Wiscoy Formation, Dunkirk Formation, South Wales Formation, Mills-Mills Formation, Hume Formation, Higgins

Member of the Caneadea Formation, Lower Rushford Member, Upper Rushford Member, Machias 1st Sandstone Packet, Machias 2nd Sandstone Packet, Machias 3rd Sandstone Packet, Machias 4th Sandstone Packet, Cuba Formation and the Hinsdale Formation. In effort to save time, formation tops for the Nunda Formation through the Higgins Member stratigraphic section were disregarded outside of areas adjacent to cross-sections as the subtle curve responses between the fine-grained sandstones, from the sandy shales and the silty black shales made formation picks ambiguous.

Crucial to our study are the correlations of the Upper Devonian sandstone packets, and most important was to identify a marker unit or zone that was evident in well-logs as well as outcrop. Correlation of outcrops within Allegany County was facilitated by marker units such as the black shales of the Dunkirk and Hume formations, but primarily the Upper Devonian sequence stratigraphy was of greater use for a wider geographic area, since exposures of the black shales were confined generally to the areas adjacent to the Genesee River Valley. The base of the Rushford Formation is a sequence boundary with lowstand shoreface deposits overlying offshore sediments (Smith and Jacobi, 2001 and 2003); the top of the Lower Rushford Member is marked by a transgressive surface of erosion, overlain by deeper-water deposits (Smith and Jacobi, 1996, 1998, 1999, 2001, 2002, 2003 and 2004). The three stacked, coarsening-upwards, shoreface sequences could be trace from outcrop to outcrop from the Fillmore quadrangle in Allegany County to the Ellicottville quadrangle in Cattaraugus County. By comparing these identified outcrops with adjacent well-logs in the northern section of the study area, we were able to identify a sequence with a coarsening-upward sequence at the base (typically with both a sharp base and top), overlain by a shale (which represents the Lower Rushford Member). A sequence representing the Lower Rushford – Upper Rushford – Machias 1st sequence was identified for wells in the major oil fields (Figure 17). Cross-section A-A' (Figure 18) is a north-south cross-section that incorporates both outcrop and well-logs. Outcrops of the Rushford Formation correlate with adjacent well-logs, and the resultant dips in the correlated Rushford match dips from the Onondaga and Tully. Two east-west cross-sections were made for this study to trace changes in stratigraphy as units were traced westward, deeper into the basin. The northern east-west cross-section B-B' (Figure 19) and the southern east-west cross-section C-C' (Figure 20) show an overall thinning of the stratigraphic section toward the west; the thinning appears more pronounced in the southern cross-section).

Significant lateral variations in shale thickness between outcrops and between well-logs indicate either syndepositional faulting along local fault basins (e.g., along the Clarendon-Linden Fault System, e.g., Jacobi and Fountain, 1996; Smith and Jacobi, 2002), or in some areas, tectonic thinning or thickening of the section. Such tectonic effects were expected from outcrops in Allegany and Cattaraugus counties that displayed pencil cleavage, bedding thrusts, disrupted bedding, and in one outcrop, a recumbent fold (Jacobi and Fountain, 1996; Peters, 1998; Zack 1998; Smith, 2002). These structural features are thought to represent post-depositional (Alleghanian Orogeny) crustal shorting (e.g., Engelder and Geiser, 1979) that could produce the apparent black shale thinning or especially thickening along duplexes within the interbedded sequences.

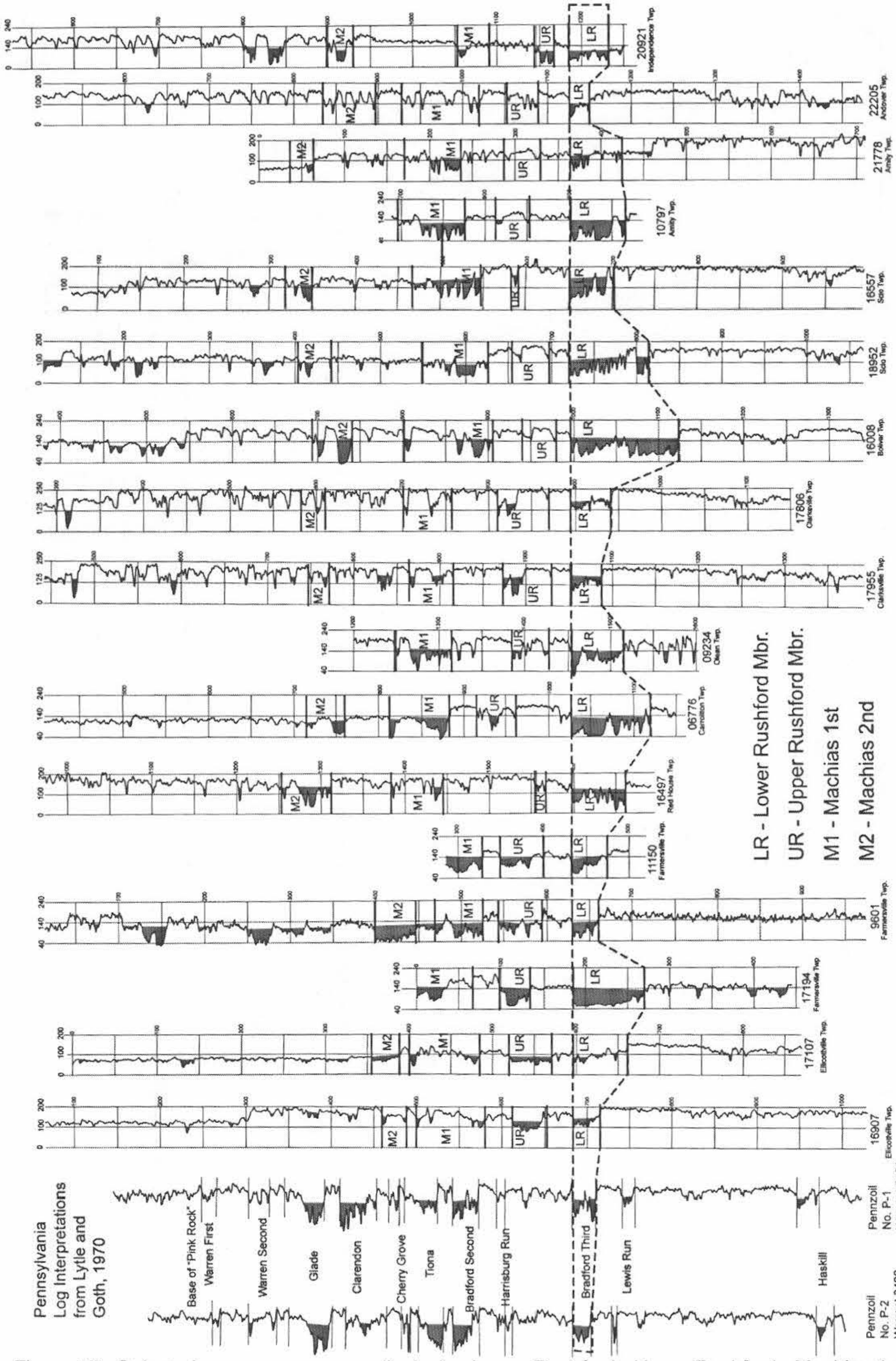


Figure 17. Selected gamma ray curves displaying Lower Rushford - Upper Rushford - Machias 1st sequence for selected wells ; Pennsylvania well-logs from eastern Warren County, are used for comparison of sands and common sandstone names.

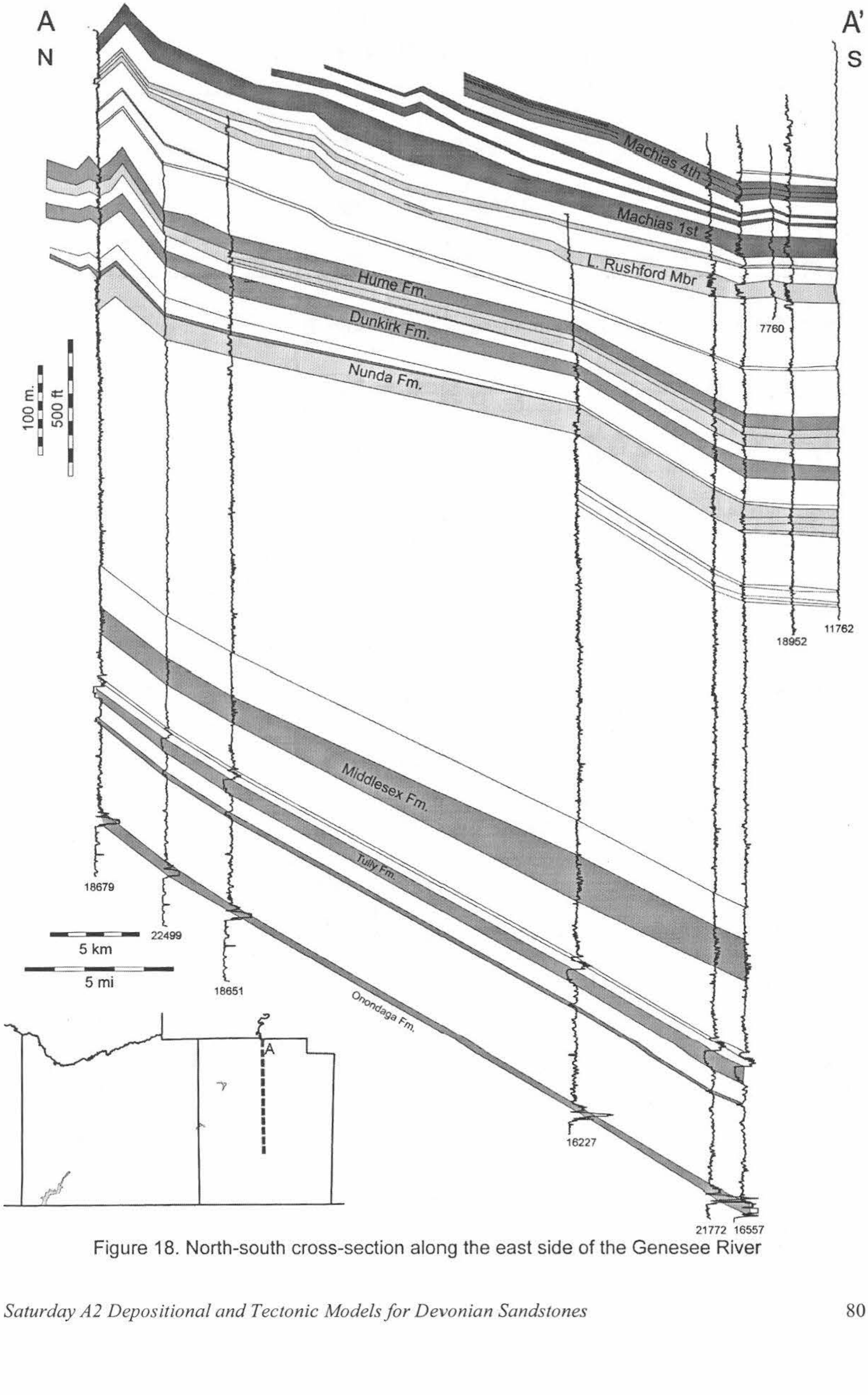


Figure 18. North-south cross-section along the east side of the Genesee River

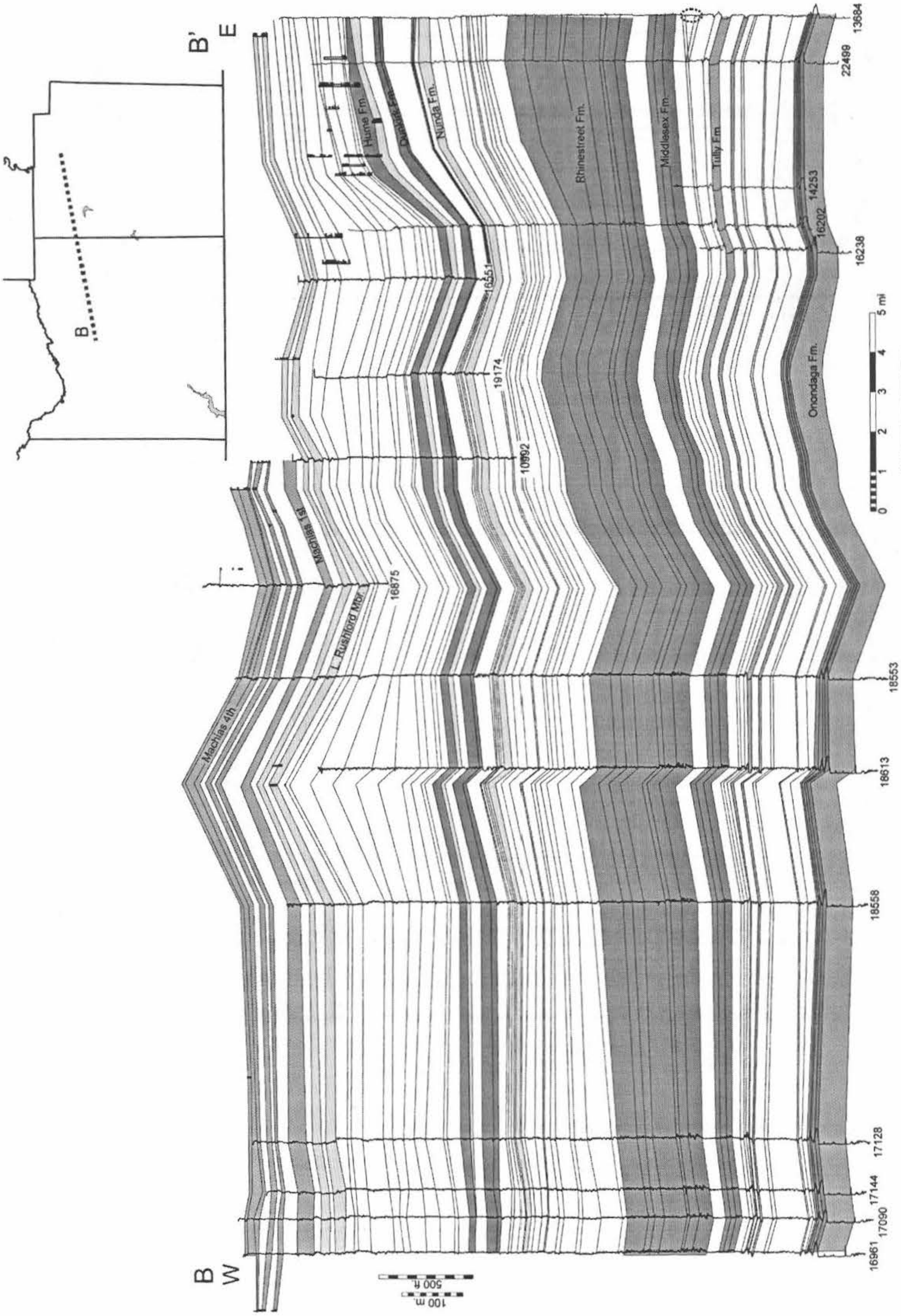


Figure 19. Northern east-west cross-section with ground elevation for datum. Repeated section circled in dashed circle.

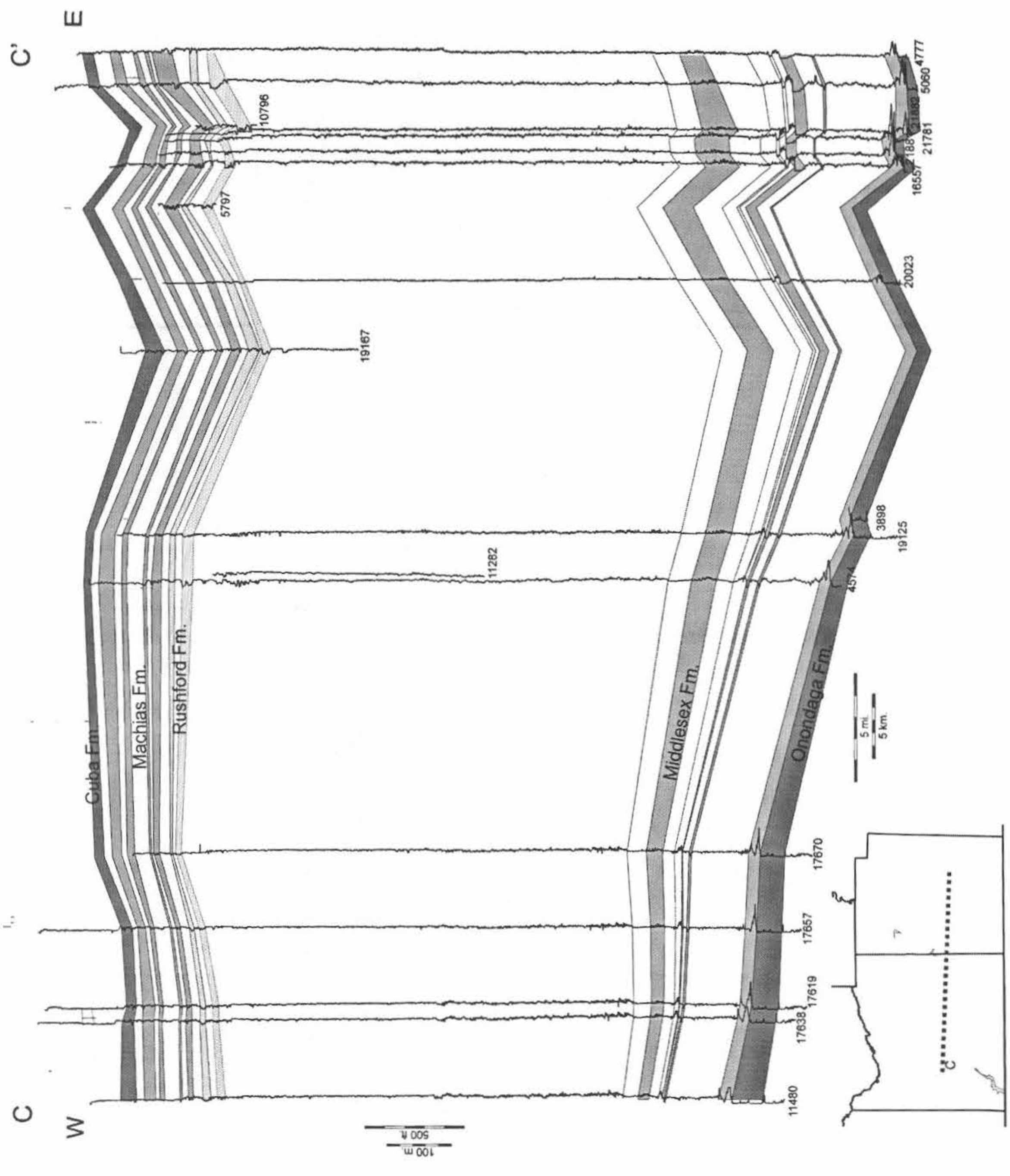


Figure 20. Southern east-west cross-section

OUTCROP EXAMPLES OBSERVED ON THE FIELDTRIP

Our fieldtrip will examine outcrop examples of the depositional environments that represent the major clastic reservoirs in the Upper Devonian that correlate with the Elk, Bradford and Venango reservoir sands to the south. Additionally, the fieldtrip shows examples of syndepositional faulting and the faulting influence/control on depositional environments. To cover as much ground as possible in the time allotted, we have chosen outcrops near roads, although these outcrops do not necessarily represent the best outcrop possible. Several stops are located on state property, or along roadcuts, and do not require obtaining landowners permission (although entry to Letchworth State Park will require an admission during certain periods of the year). Two stops are located on private property and will require obtaining permission from the landowner prior to visiting. Most landowners we have encountered are reasonable and offer no objection, unless they regularly discover trespassers or signs of trespasser. Please respect the wishes of the landowner.

Directions	Distance	Cumulative
START - LEAVE ADAMS MARK	0	0
Head west on Church St toward Bingham St.	0.1mi	0.1
Merge onto I-190S/NYS Thruway via the ramp on the LEFT towards RT-5 West/Skyway	5.1 mi	5.2
Merge onto I-90 W/NYS Thruway W via EXIT 54-61 toward ERIE	1.6 mi	6.8
Take the RT-400/ RT-16 exit - EXIT 54 - toward WEST SENECA/EAST AURORA	0.5 mi	7.3
Merge onto NY-400 S / AURORA EXPY	12.4 mi	19.7
Take the US-20A ramp toward EAST AURORA, turn LEFT (West) onto US 20A	0.2 mi	19.9
Turn RIGHT onto RT-78 S	2.1 mi	22
Strykersville - Turn LEFT onto PERRY RD/ CR-9	7.3 mi	29.3
North Java - Continue straight on WETHERSFIELD RD/ CR-32	6 mi	35.3
Wethersfield Spring - Continue straight on WETHERSFIELD RD	7.2 mi	42.5
Turn RIGHT on NY-19 South	3.4 mi	45.9
Turn LEFT onto NY-19A	2 mi	47.9
Turn SLIGHT LEFT to stay on NY-19A	2 mi	49.9
Turn LEFT onto DENTON CORNERS RD/ CR-38	0.2 mi	50.1
Bear RIGHT enter LETCHWORTH STATE PARK- Castile Entrance.	<0.1 mi	50.2
Past the Park Entrance, turn RIGHT and head toward the Middle Falls Parking Lot.	2.7 mi	52.9
STOP 1 - Letchworth Upper Falls Trail		

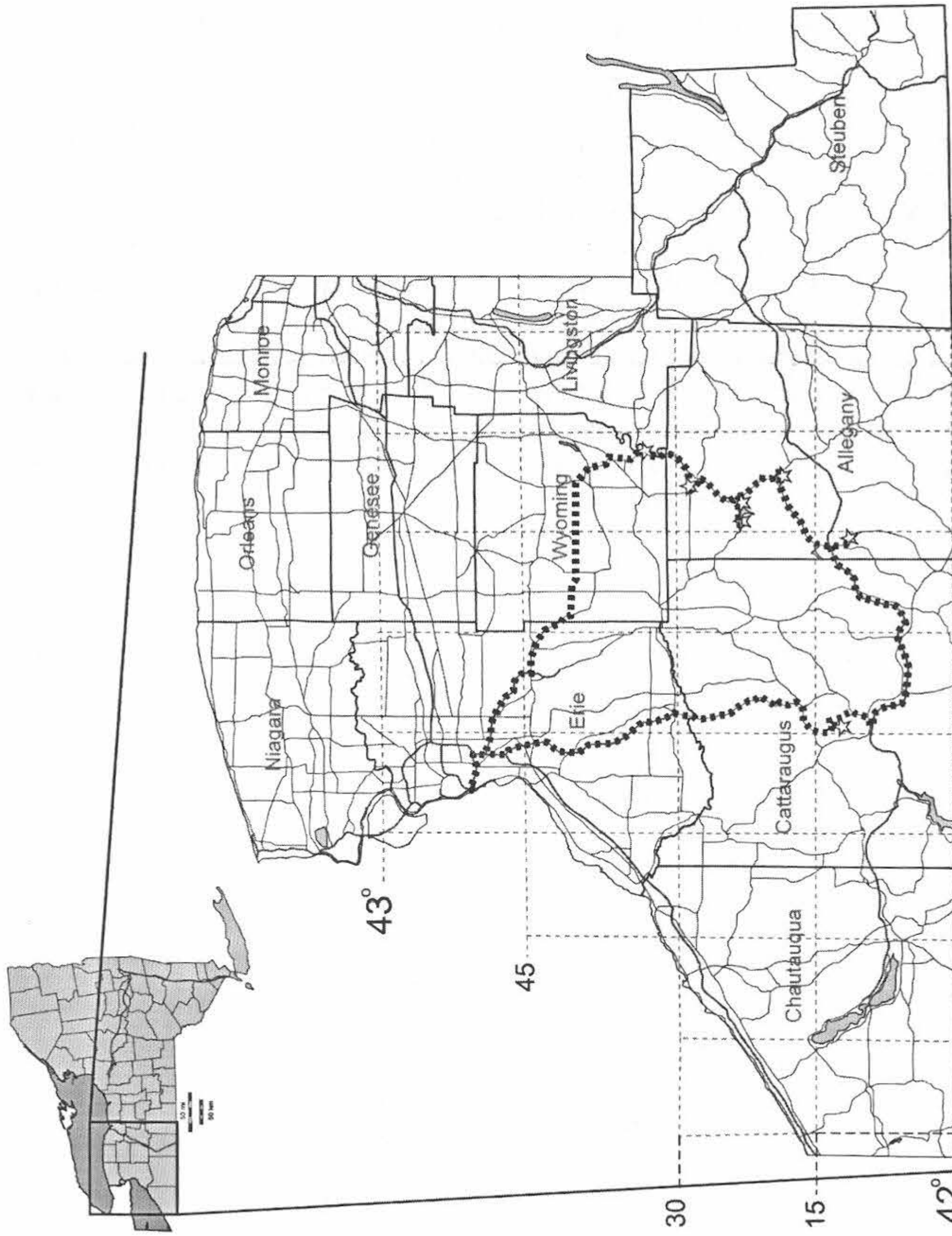


Figure 21. Overview of the route for the fieldtrip. Stops are indicated by stars (✩).

STOP 1 – Letchworth State Park – Upper Falls Trail (Figures 22, 23).
Location Coordinates (WGS 1984):
Lat – N42.57889°; Lng – W78.04927°
UTM Zone 17; N4718278, E0742154

Letchworth State Park contains a remarkable exposure of the Frasnian stratigraphic section along the 400 foot high cliffs and waterfalls carved by the Genesee River. Three major waterfalls are viewable in the park, the Lower, Middle and Upper Falls. Whereas much of the cliff sections are comprised of Gardeau Fm. shales and silty shales interbedded with thin turbidite/storm sandstones, the stratigraphic section above the

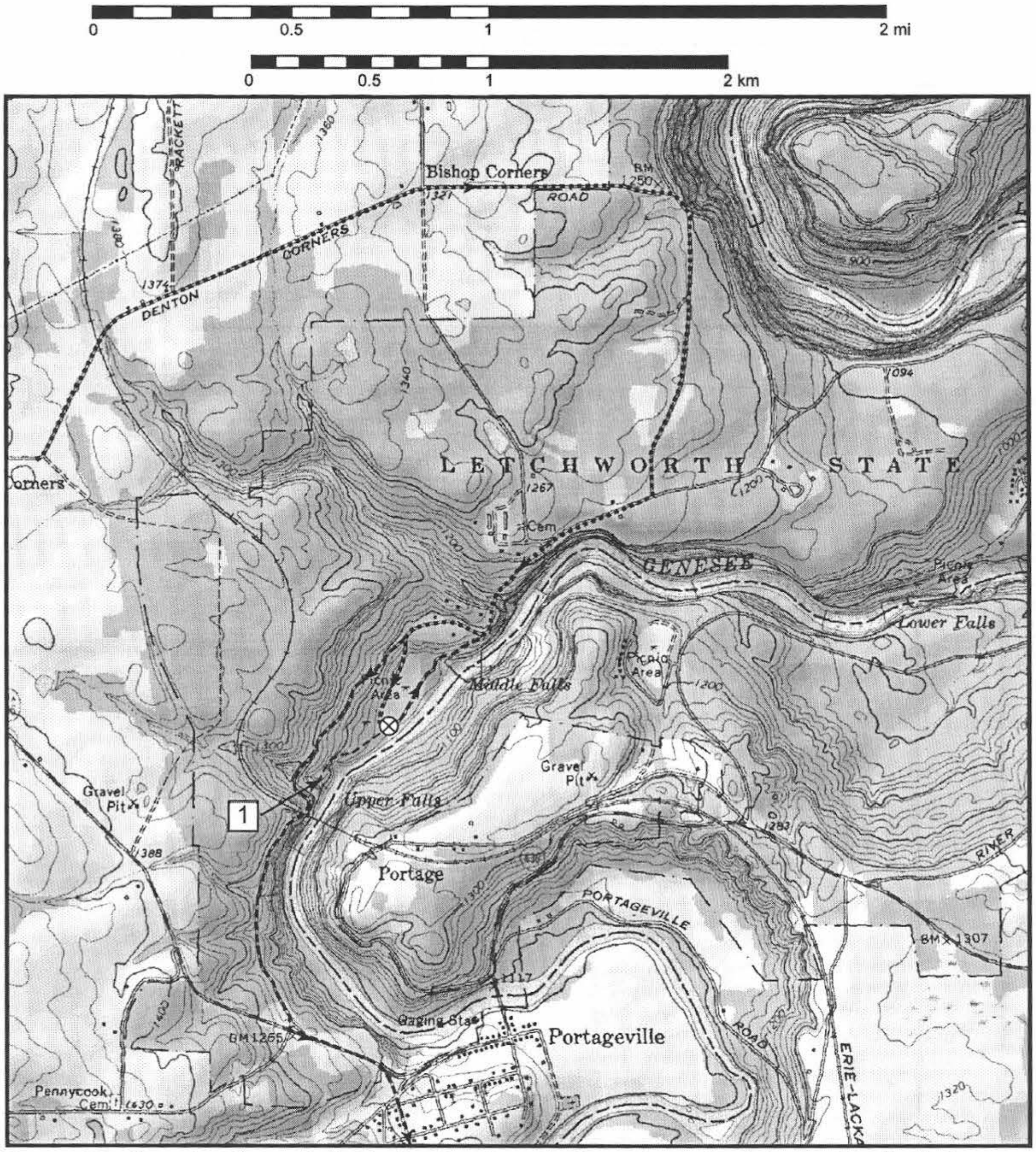
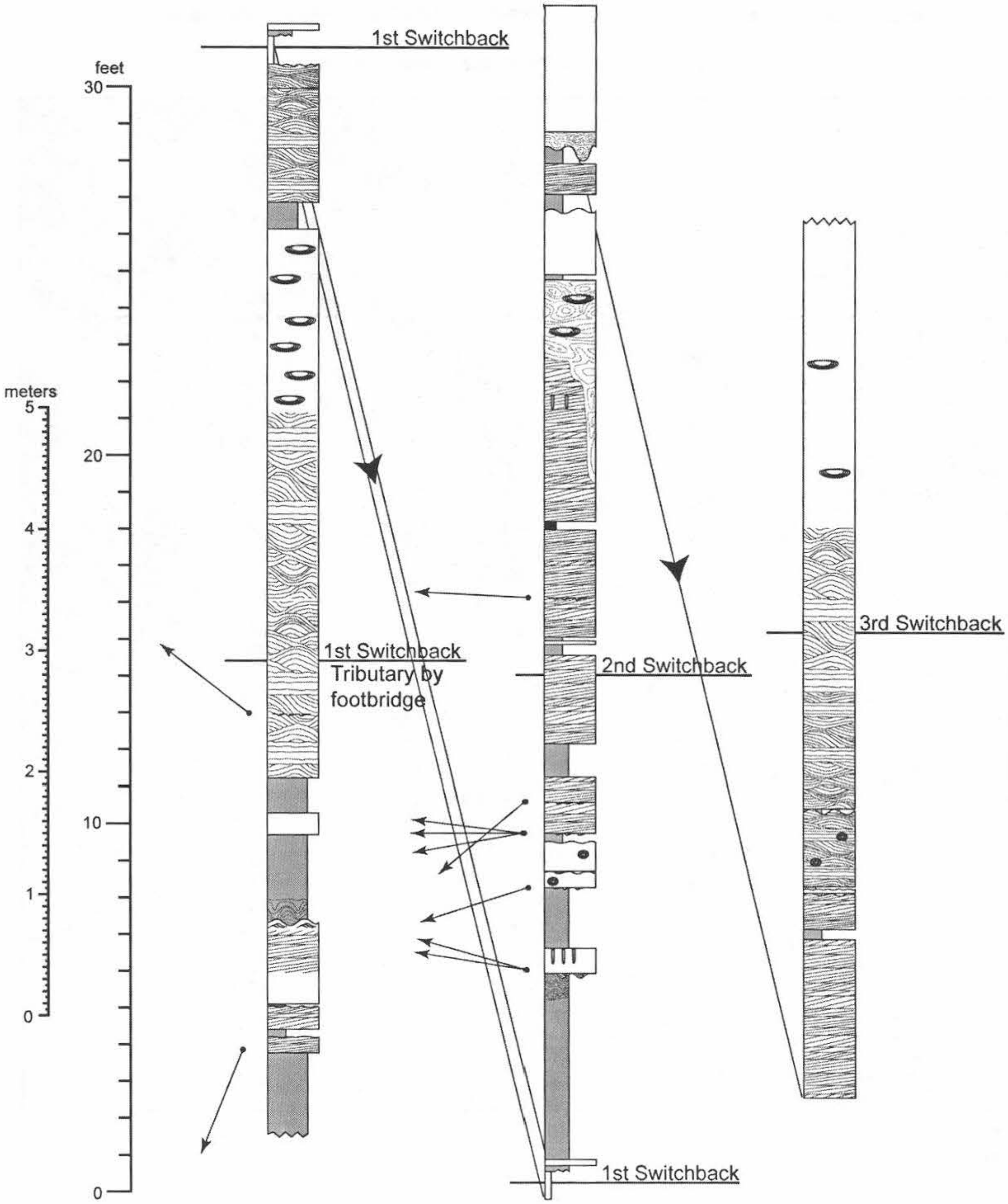


Figure 22. Stop 1 - Upper Falls Trail at Letchworth State Park. Park in the Middle Falls parking lot, and take the Upper Falls Trail south and west; accessible outcrop starts at the footbridge crossing the southeast flowing tributary to the Genesee River (1).

Upper Falls exposes outcrops of the Nunda Formation (Clarke, 1897; Figure 23). The Nunda Formation is correlative to Elk reservoir sands, and is a good example of a thick turbidite sandstone T_{AB}; however dewatering structures and wave-modification provide more variability than the original Bouma model (See figure 12).



STOP 1 - Letworth State Park Upper Falls Trail - Nunda Fm.

Figure 23. Measured annotated stratigraphic column for the Upper Falls Trail. Arrows represent measured paleoflow directions, key to the symbols may be found on Figure 10.

The outcrop we will examine is exposed along the trail toward the Upper Falls and the High Bridge. The path and stairs were cut through 24 m of stratigraphic section, mostly fine-grained sandstone. In addition to examples of primary bedforms and sedimentary structures typical of turbidites, soft-sediment deformation and liquefaction features including sandstone dikes, roll ups, load casts, and zones of liquefaction with sharp boundaries are quite common in both the sandstones and the interbedded shales. Small down-on-the-east stratigraphic offsets (~6 cm) along northwest-trending (317°) fractures typically coincide with observable deformation zones in the outcrop.

Bedding within some of the thicker sandstones appears similar to swaly-cross stratification, which suggests storm-wave modification/influence. Storm influence within the Nunda Formation is consistent with observations made higher in the stratigraphic section where "deep" water depositional environments (black shales and turbidites) show numerous bedforms (such as hummocky cross-stratification, 3-D ripples, linguoid ripples, e.g., Smith and Jacobi, 2002) that indicate depositional depth was within storm-wave base (Myrow et al., 2002; Pattison, 2005).

The specific depositional environment of the thick sandstones of the Nunda exposed at Letchworth is ambiguous. The thick nature of the sandstone beds, the striations on the base of the sandstone beds, the massive to planar (to possibly swaly bedding) all indicate proximal turbidites (T_{AB} to $T_{A\text{-}C}$). Such turbidites were typically are thought to represent submarine channel deposits. However, the lack of coarse basal sediments, and the constant thickness of the thick beds exposed along the High Cliffs at Inspiration Point suggest that either the channels were very wide, or that these represent a non-point source, more on the order of a storm-generated wash with a shoreface source. To the east we have found an erosional channel wall, indicating a channel (or slump scar) (Jacobi et al, 1994), and to the west, we suggested relatively thick Nunda sand beds represented sand lobe at the end of a channel (Jacobi et al, 1994), so it is possible that these sands at Letchworth do represent wide channels (or storm-generated wash that funneled into channels downslope).

Directions	Distance	Cumulative
STOP 1 - Letchworth Upper Falls Trail		
Exiting the Middle Falls Parking Lot, turn left heading south towards the Portageville Entrance. At the Portage Entrance Turn LEFT onto RT-486/RT-19A	0.8 mi	53.7
Keep RIGHT on RT-19A	0.7 mi	54.4
Rossberg - Turn RIGHT onto Wiscoy Rd/CR-27	5.2 mi	59.6
Wiscoy - Turn LEFT onto Wiscoy-MillsMills Rd	0.8 mi	60.4
Turn RIGHT at the stop sign at the western end of Wiscoy-MillsMills Rd park along right side of the road, outcrop is below the bridge crossing Wiscoy Creek.	1.9 mi	62.3
STOP 2 – Mills-Mills		

STOP 2 – Mills-Mills – Wiscoy Creek exposure (Figures 24, 25).
Location Coordinates (WGS 1984):
Lat – N42.50121°, Lng – W78.04927°
UTM Zone 17; N4718278, E0742154

Wiscoy Creek at Mill-Mills where Mills-Mills Rd. crosses Wiscoy Creek. This is the upstream end of a fairly continuous outcrop that extends down to the village of Wiscoy. Roadcuts on either side of the bridge contain weathered exposures of the Hume Fm. black shale (Pepper and deWitt, 1951). The basal contact of the Hume Fm. with the underlying Mills-Mills Fm. (Smith and Jacobi, 2000) occurs below the Mills-Mills dam. The sandstones near the contact have a distinct petroliferous odor.

The underlying Mills-Mills Fm. (Smith and Jacobi, 2000) is lowest, thick sandstone package in the Famennian stratigraphic section in Allegany County. The Mills-Mills Fm. can be separated into upper and lower sandstone packets. The lower sandstone packet is a thick (~3m), upward fining sequence of fine- to medium-grained sandstone interbedded with thin gray shales and siltstone. The lower sandstones have tabular cross-stratification and displays prominent climbing ripples. The lowermost sandstone is thick (20-40cm) and fine-grained sand; the sand bed has an erosional base and is channelized in cross-section. The upper sandstone packet ranges from 1 to 2 m thick and consists of thick beds (40 to 60 cm) of medium sandstones. Flute casts are observed on the soles of sand beds. Between the two sandstone packets is an interbedded section of thin gray sandstones, siltstones and shales that change upsection from gray to black. We have interpreted the Mills-Mills Fm. as offshore to restricted circulation deposits (Figure 12), with the sandstone packets deposited as T_{AB} to T_{AC} turbidites with T_C–starting turbidites in the upper packet. Many of the lower turbidites are consistent with proximal turbidites deposited in channels, whereas the T_C–starting turbidites appear more like lobe fringe sands.

The contact between the Mills-Mills Fm. and the underlying South Wales Fm. (Pepper and deWitt, 1951) is located downstream at the waterfall near the old RG&E powerhouse. The caprock of the waterfall is the basal thick fine-grained sandstone bed of the Mills-Mills Fm. The exposure of the Mills-Mills continues upstream with the sandstone beds forming small cascades up to the dam at Mills-Mills. The interbedded shales and siltstones grade from gray to black at the top of the formation.

Farther downstream, additional outcrops of the South Wales Fm. and Dunkirk Fm. (Clarke, 1903), are exposed along the southern bank, and in the north-flowing tributaries. Correlation of marker beds, such as the basal sandstones of the Mills-Mills and South Wales formations) indicate possible uplift along the fault east of STOP 2 (Figure 26).

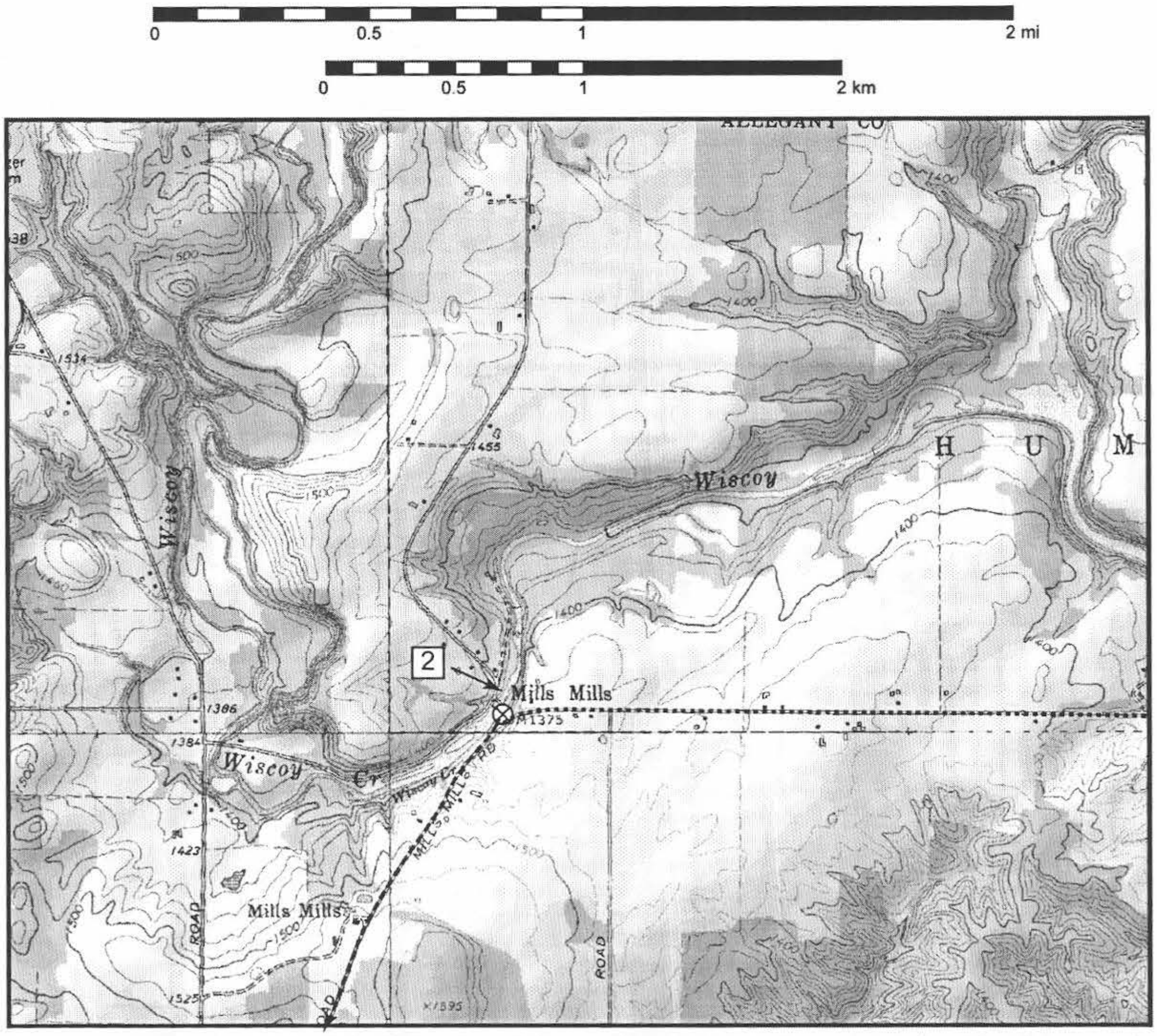
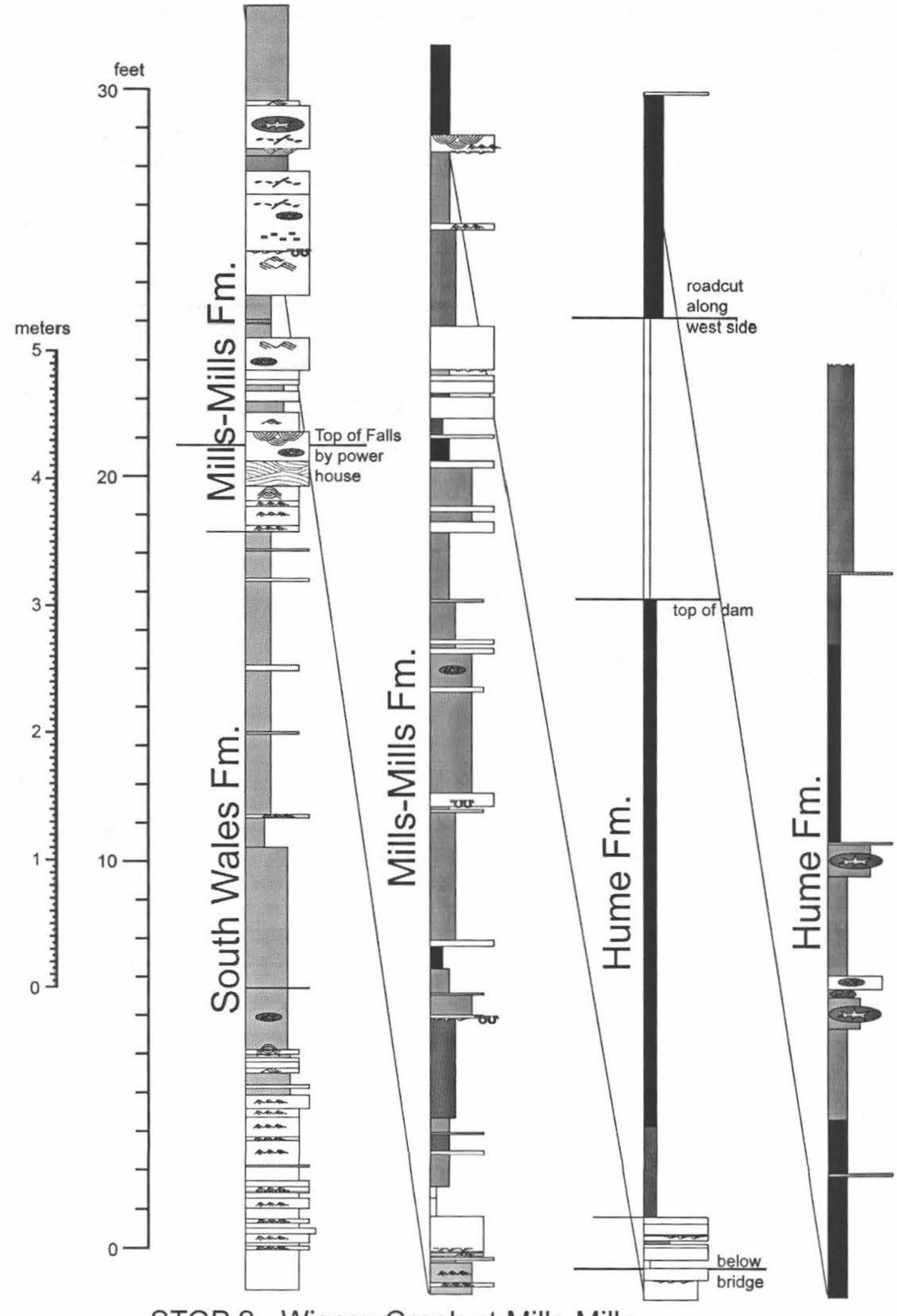


Figure 24. Stop 2 - Mills-Mills Falls along Wiscoy Creek. Park along the right side of the road, east of the bridge crossing Wiscoy Creek. The top of the Mills-Mills Fm. is below the bridge (2). Note: since this is private property, please contact the landowner prior to visiting and respect his wishes.



STOP 2 - Wiscoy Creek at Mills-Mills.
South Wales, Mills-Mills and Hume formations

Figure 25. Measured annotated stratigraphic column for the outcrop exposure along Wiscoy Creek at Mills-Mills. Key to annotations may be found on Figure 10.

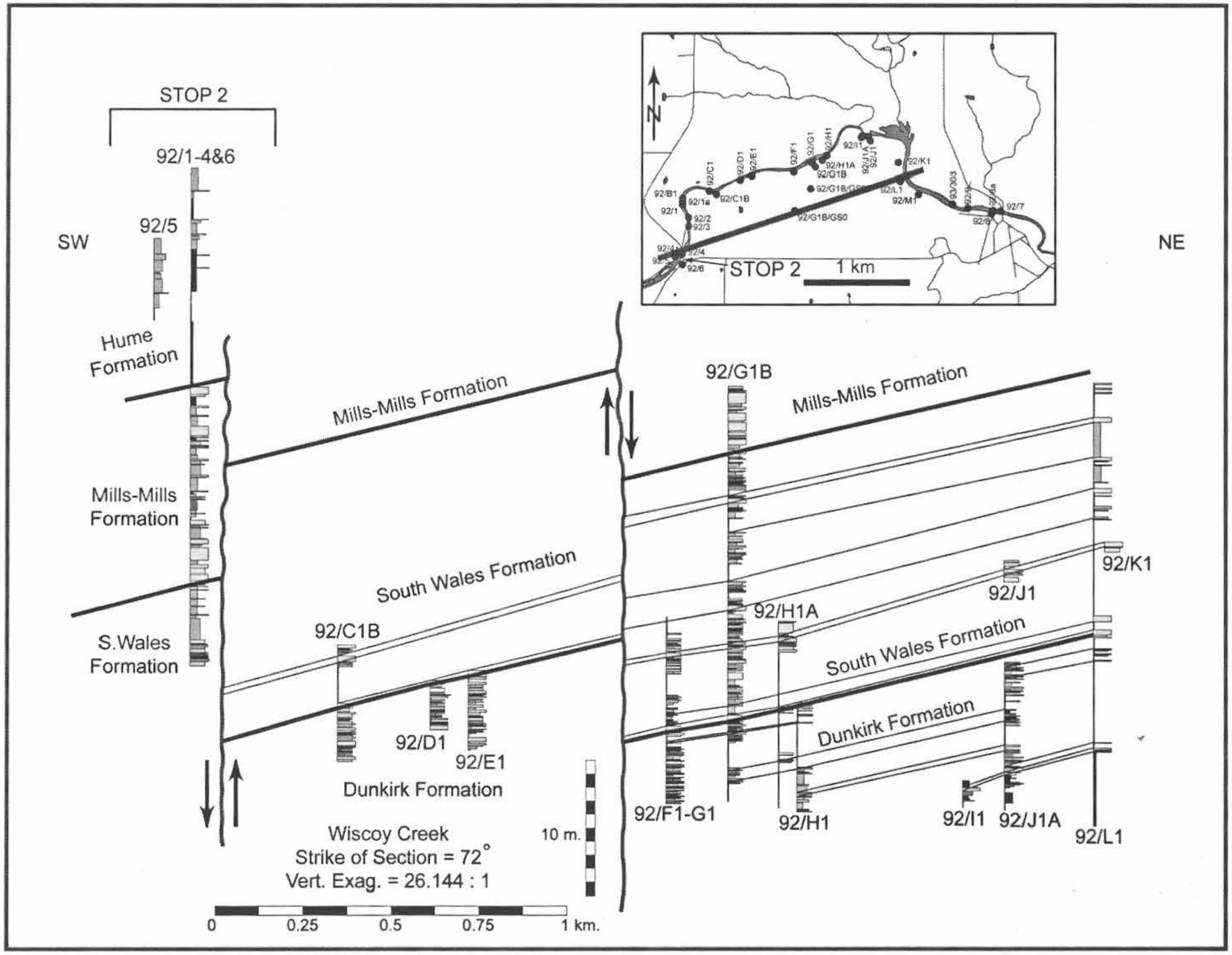


Figure 26. Cross-section of outcrops along Wiscoy Creek displaying down-dropped block based upon marker beds at the base of the South Wales Fm., and the distictive base of the Mills-Mills Fm.

Directions	Distance	Cumulative
STOP 2 – Mills-Mills		
From Stop 2, make a U-Turn and head west along Mills-Mills Rd. (Not Wiscoy-MillsMills Rd. taken before Stop 2).		
Continue STRAIGHT onto CR-23/Hume Rd.	1.9 mi	64.2
Turn LEFT onto SR-243	8.3 mi	72.5
Turn RIGHT onto CR-9/Hillcrest Rd.	0.2 mi	72.7
Outcrop for STOP 3 is on both the Left and Right sides of the road - park with care along the right since this is essentially a blind curve.	0.4 mi	73.1
STOP 3 - Hillcrest Rd.		

STOP 3 – Hillcrest Rd. Roadcut (Figures 27, 28)
Location Coordinates (WGS 1984):
Lat – N42.38221°, Lng – W78.22596°
UTM Zone 17; N4695944, E0728370

Thick laminated sandstone (> 3 meters thick) is exposed on either side of the road, where Hillcrest Rd. begins to climb the hill. The western side of the road exhibits the sharp contact between the Rushford Fm. (Luther, 1902) and the Caneadea Fm. (Chadwick, 1933), whereas the fracture controlled exposure on the eastern side gives an excellent view of the planar laminations and small, white, cloudy quartz pebbles incorporated into the fine-grained sandstone matrix.

The exposure of the Lower Rushford Mbr. here is interpreted as three stacked shorefaces. The upper shoreface (planar beds) and foreshore (planar laminations) facies of each shoreface is eroded by an overlying transgressive surface of erosion. The Lower Rushford Member is correlative to the Bradford 3rd reservoirs along the New York-Pennsylvania border (Fettke, 1939; Manspeizer 1963; Smith, 2006).

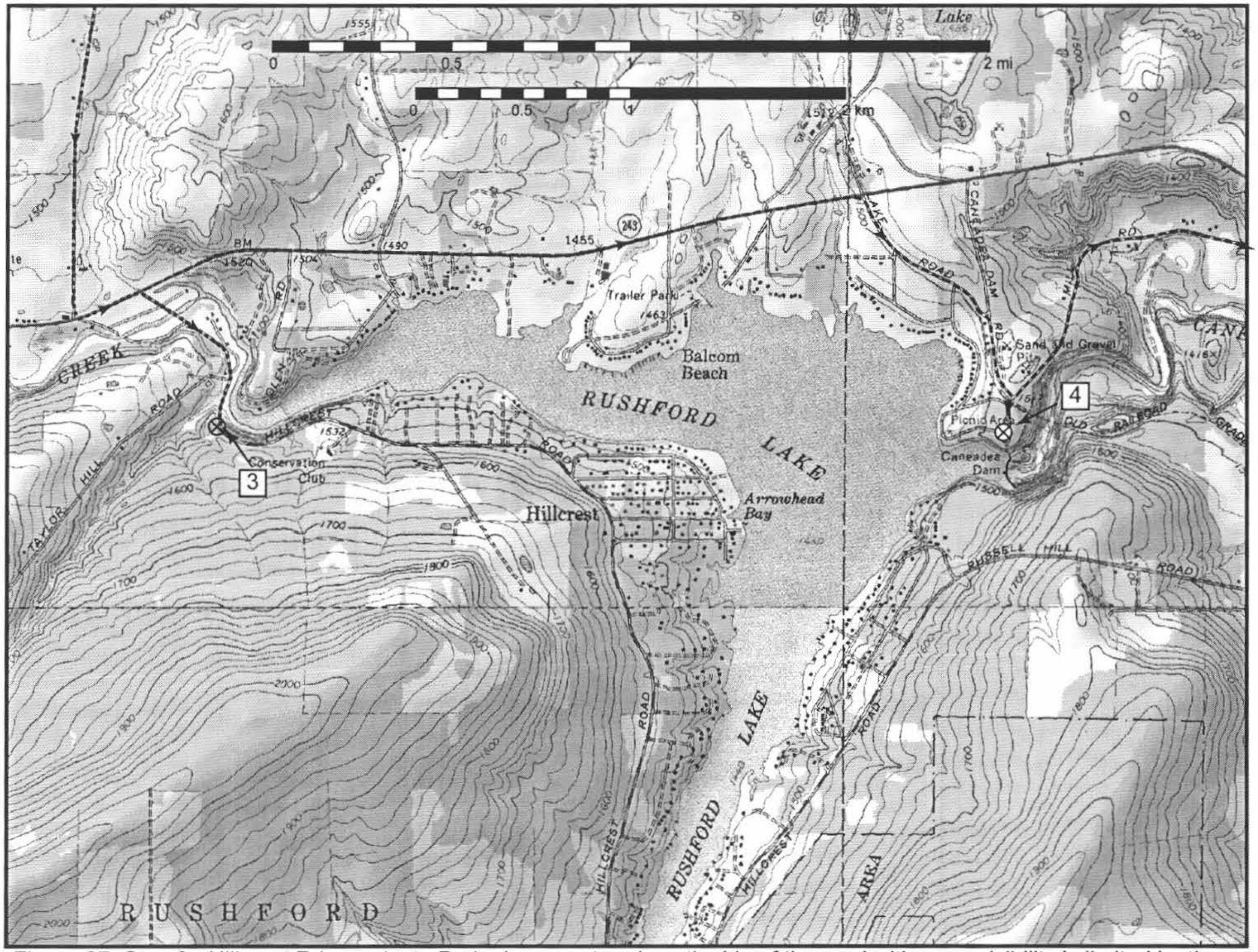
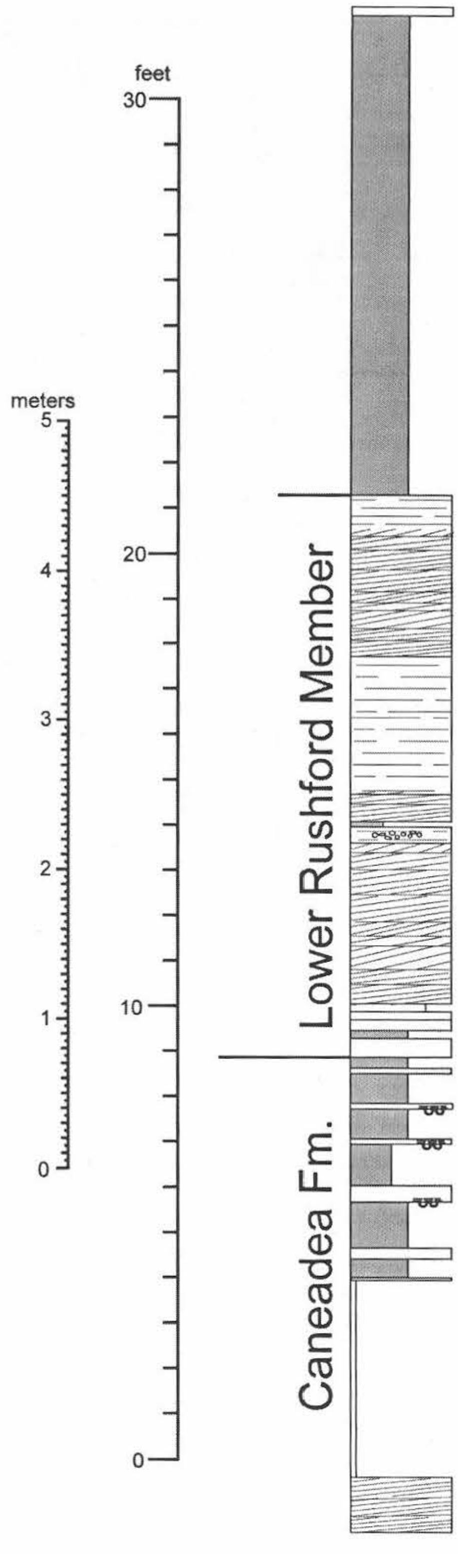


Figure 27. Stop 3 - Hillcrest Rd., roadcut. Park along west and south side of the road with care, visibility is limited by the curve of the road. Stop 4 - Lunch stop at Caneadea Dam Pinic Area.



STOP 3 - Hillcrest Rd. Rushford Fm.

Figure 28. Measured, annotated stratigraphic column for the Hillcrest Rd. outcrop. Key for the annotations may be found on Figure 10.

Directions	Distance	Cumulative
STOP 3 - Hillcrest Rd.		
Turn around and return to SR-243, Turn RIGHT onto SR-243	0.4 mi	73.5
Turn RIGHT onto Lake Rd.	2 mi	75.5
Turn RIGHT onto Caneadea Dam Rd.	0.5 mi	76
Continue STRAIGHT into Caneadea Dam Picnic Area	0.3 mi	76.3
STOP 4 - Lunch Stop		

STOP 4 – Caneadea Dam Picnic Area – Lunch
Location Coordinates (WGS 1984):
Lat – N42.38178°, Lng – W78.18311°
UTM Zone 17; N4696008, E0731902

Beyond the fence is Caneadea Dam and Rushford Lake. Old photographs of the construction of the Caneadea Dam in 1929 show the north wall of the gorge (the side we are on) devoid of trees, and show quarries of the Rushford sandstones. 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. When the lake level is lowered in the Fall, along the south gorge wall of the dam can be seen a series of north-striking, east-dipping, closely-spaced step faults; each with minor offsets (on the order of a few centimeters; Jacobi and Fountain, 2002). These small faults are consistent with well-logs that indicate a down-on-the-west fault of the Clarendon-Linden Fault System (Jacobi and Fountain, 2002) just west of this location. Other indicators of the fault include: 1) the north-striking valley (topographic lineament) where well-logs indicate a fault (Jacobi and Fountain, 1993), and 2) surface stratigraphy that suggests about 15.25 meters of offset across the fault (from Hillcrest Rd. outcrop (STOP 3) to the lake-level outcrops along the eastern edge of Rushford Lake.

Directions	Distance	Cumulative
STOP 4 - Lunch Stop		
From Caneadea Dam Picnic area, Turn RIGHT onto Mill St.		
Turn RIGHT onto SR-243	1.2 mi	77.5
Turn RIGHT onto SR-19	0.6 mi	78.1
Turn RIGHT onto CR-17/White Creek Rd.	5.7 mi	83.8
Off to the left is a roadcut of Lower Rushford Member, which is also exposed at Stop 4	0.2 mi	84
Turn RIGHT onto LittleJohn Rd.	0.45 mi	84.45
Park along the right side of the road, past the bridge over White Creek., outcrop for is north of the bridge.	0.05 mi	84.5
STOP 5 - White Creek		

STOP 5 – White Creek at the Little John Rd. crossing (Figures 29, 30)
Location Coordinates (WGS 1984):
Lat – N42.31537°, Lng – W78.10702°
UTM Zone 17; N468848, E0738417

White Creek contains some of the best exposures of Luther's (1902) Rushford Fm. Roadcuts north of Little John Rd. display the vertical section; creek exposures show the three, stacked shoreface sequences as well as exhibiting syn- and postdepositional deformation.

North of the bridge is a large exposure of the three-shoreface sequences that comprise the Lower Rushford Mbr. of the Rushford Formation. Basically similar to the Lower Rushford Mbr outcrops we examined near Rushford Lake, the outcrop here is much thicker (~8.5m). The variation of thickness of the Lower Rushford Mbr. coincides with faults of the Clarendon-Linden Fault System (Figure 31). The thicker regions possess preserved transgressive lags on offshore sequences, whereas the thinner regions possess eroded upper-shoreface and foreshore zones.

At the northernmost exposure of the outcrop, the 1st shoreface sequence forms the lowest step in the small falls of the outcrop. The top bed is a fossiliferous, medium to coarse sandstone that typifies the transgressive lags that occur on top of the shoreface sequences in the lower sandstone packet. Overlying the 1st shoreface is a thick interbedded section that is well exposure 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 also includes a sediment slide (debrite) with a large sandstone olistolith surrounded by a muddy debris flow with deformed sand clasts. The top of the 2nd shoreface sequence occurs near the main falls/cascade. The sandstone displays small dunes (amplitude - ~0.5m, wavelength ~2.0 m) that are a classic example of symmetrical ripples with tuning forks. The 3rd sandstone sequence forms the upper part of the cascade. The most noticeable feature is the transgressive lag that caps the sequence and 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.

We propose that the stress associated with the Acadian Orogeny caused a reactivation of basement faults, including those of the Clarendon-Linden Fault System and the Iapetan opening faults. Motion on these faults resulted in a number of small fault blocks that affected the basin topography. The motion and rate of slip and rotation among the faults was not identical, with the result that minor topographic highs and lows within the basin were created by small fault block motion that would create variable accommodation space over the faulted area (Figure 32).

We first proposed fault control of Upper Devonian sandstones to explain the occurrence and preservation of shoreface sandstones in the Lower Rushford Member (Smith and Jacobi, 1998, 2000, 2001, 2003 and 2005; Jacobi and Smith, 2004). Syndepositional fault activity would enable coarser sediments to accumulate along active fault blocks at and adjacent to the intersection of the north-south trending Clarendon-Linden Fault System, and the northeast trending shoreline would act as a groin (Figure 33).

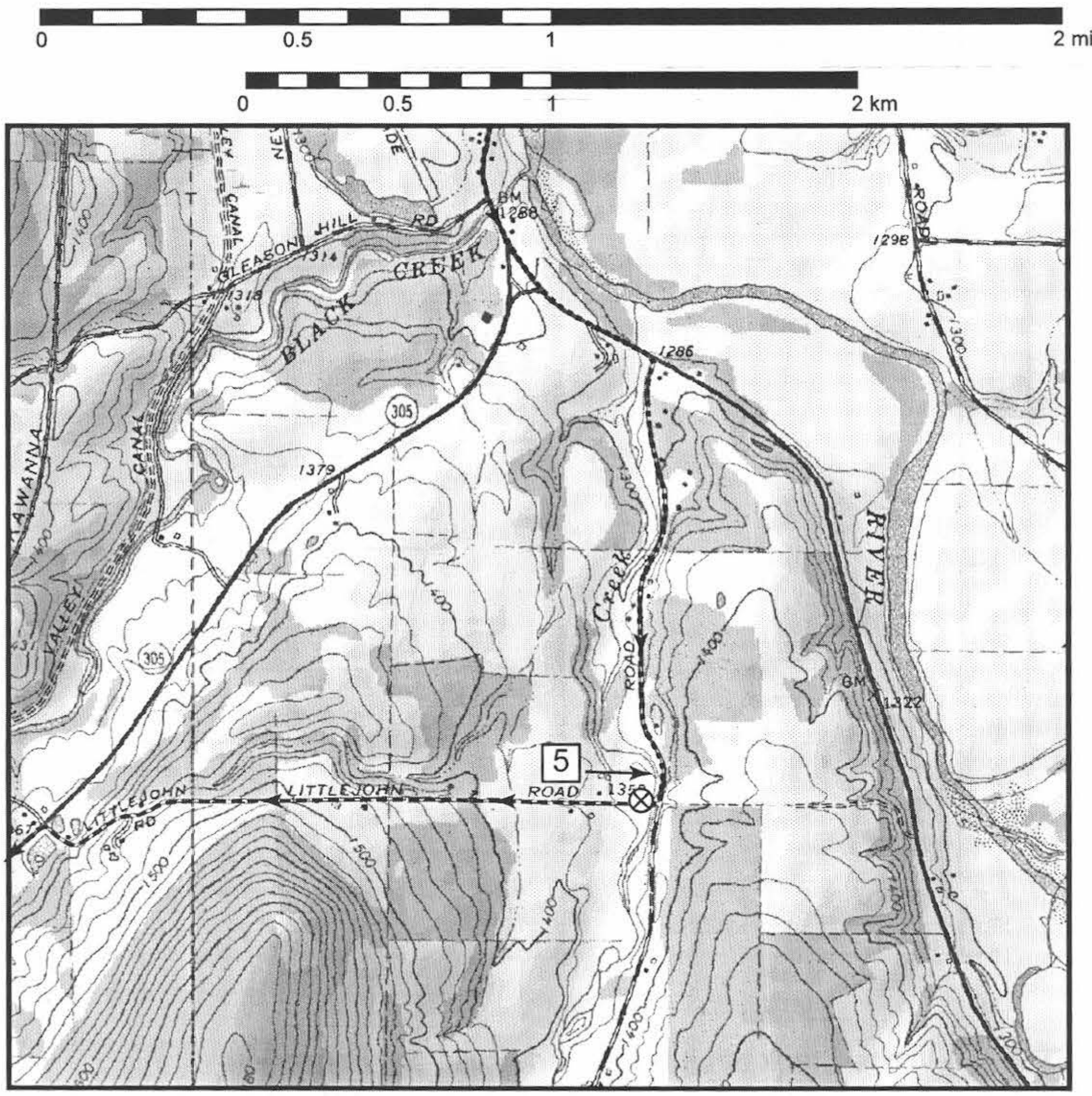
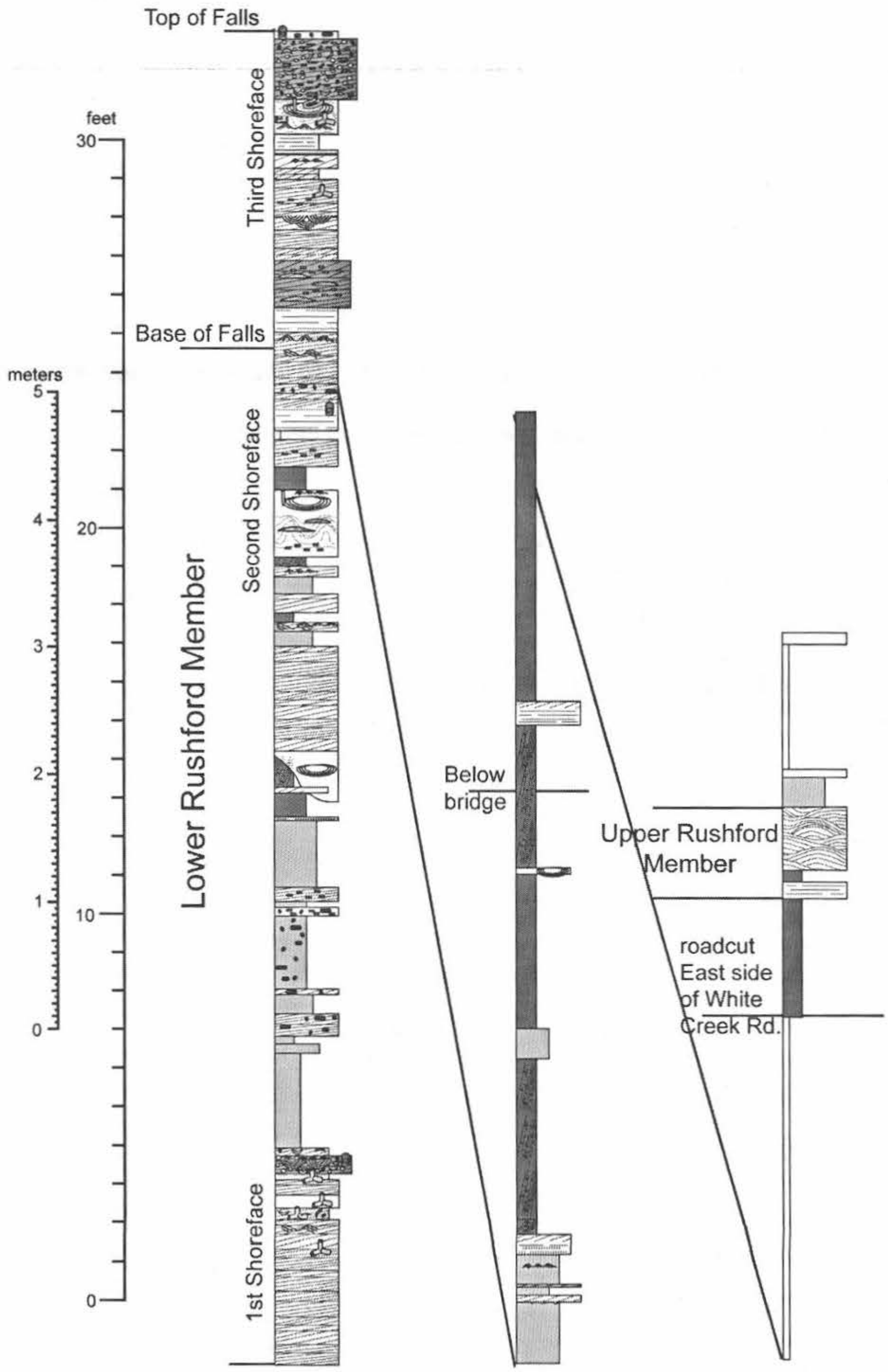


Figure 29. Stop 5 - White Creek at LittleJohn Rd. bridge. Park along north side of the road, west of the bridge crossing White Creek. Take path north along the creek to the cascade (5).



STOP 5 - White Creek at LittleJohn Rd. Rushford Formation

Figure 30. Measured, annotated stratigraphc column for outcrop along White Creek at LittleJohn Rd. Key to the symbols may be found on Figure 10.

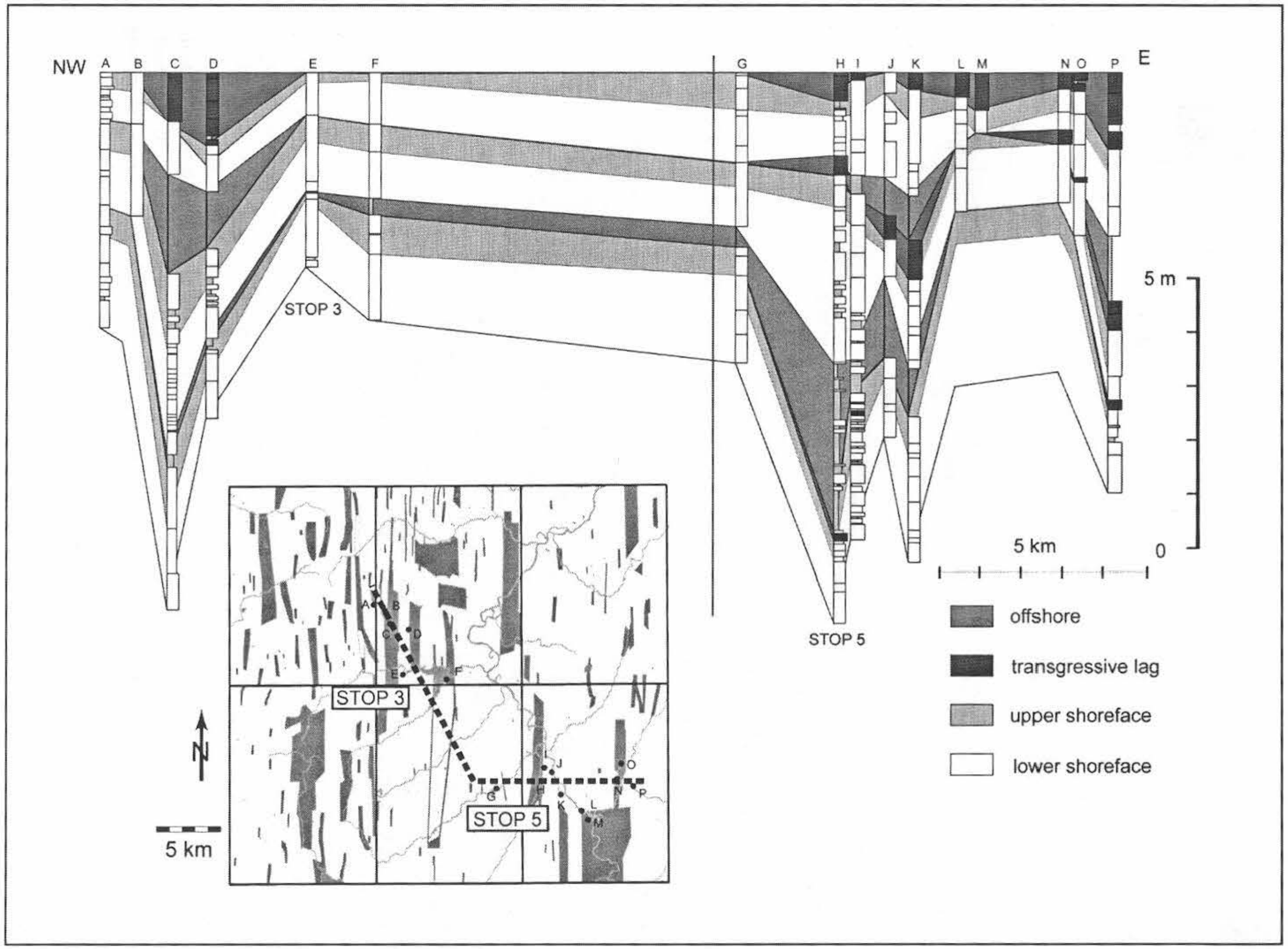


Figure 31. Cross-section of the Lower Rushford Member depicting the three stacked shoreface sequences, Note that the transgressive deposits (lags and offshore) generally coincide with the thicker outcrops, and that the upper shoreface deposits thin where the overall thickness of the Lower Rushford Member is thinner. Map at the bottom shows the relationship between the outcrops and north-south faults of the Clarendon-Linden Fault System (Jacobi and Fountain, 1996).

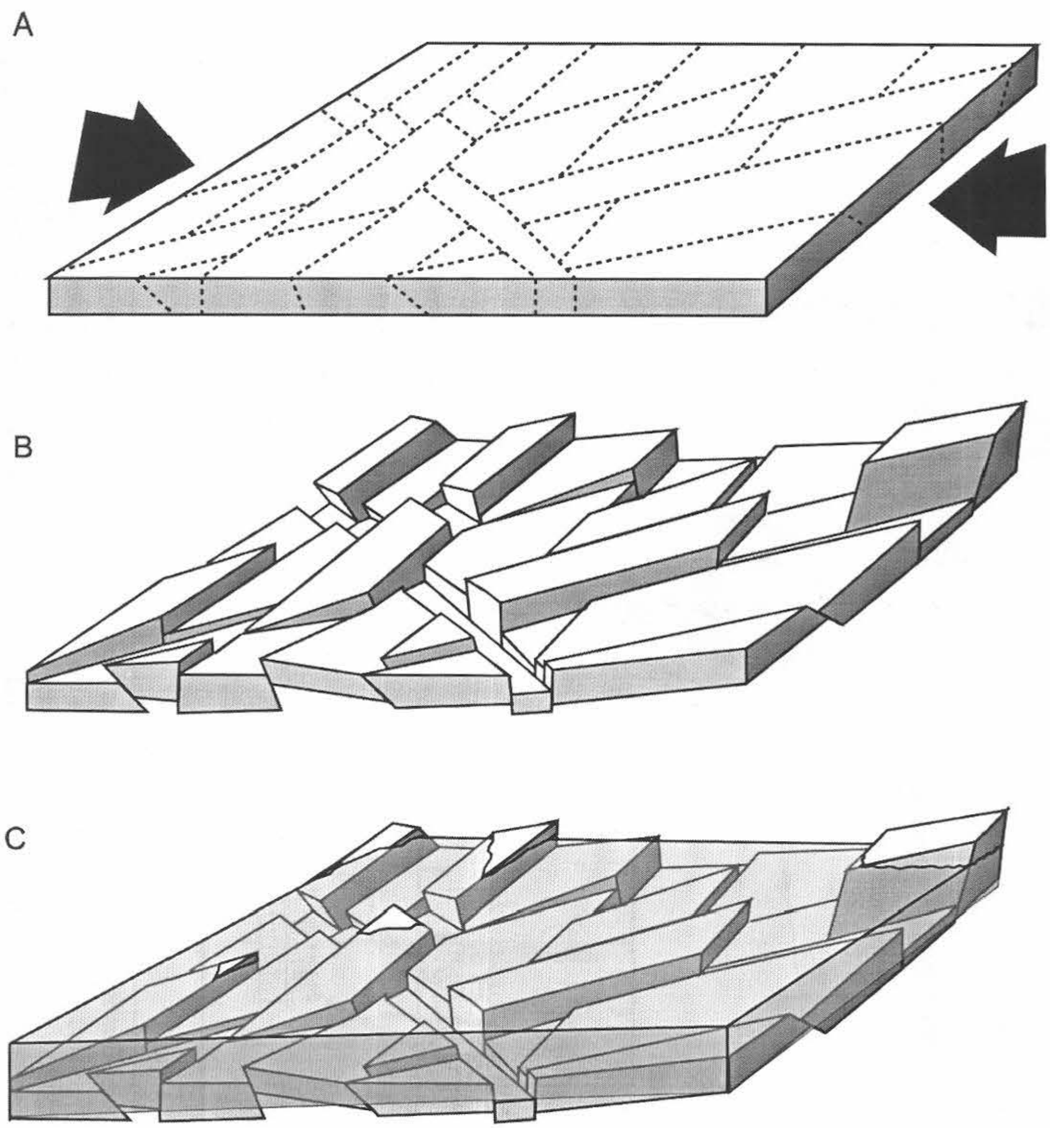


Figure 32. Hypothetical model of fault-block-derived accommodation variability. A) In an area with pre-existing faulting, reactivation is likely during periods of high stress such as compression during an orogenic phase (orange arrows). B) To relieve the stress, the faults may move, but at different rates creating highs and lows between faults blocks. Rotational motion will also create higher and lower regions. C) The overall effect on deposition will be to generate lows that accumulate sediment, and highs that will erode, deflect currents and create multiple trending sediment packets. If the fault activity occurs during deposition, then the changes may be observed within the sedimentary deposits. It is important to note that neither scale or orientation is implied by
this model - this model could represent the scale of basins or outcrop jointing.

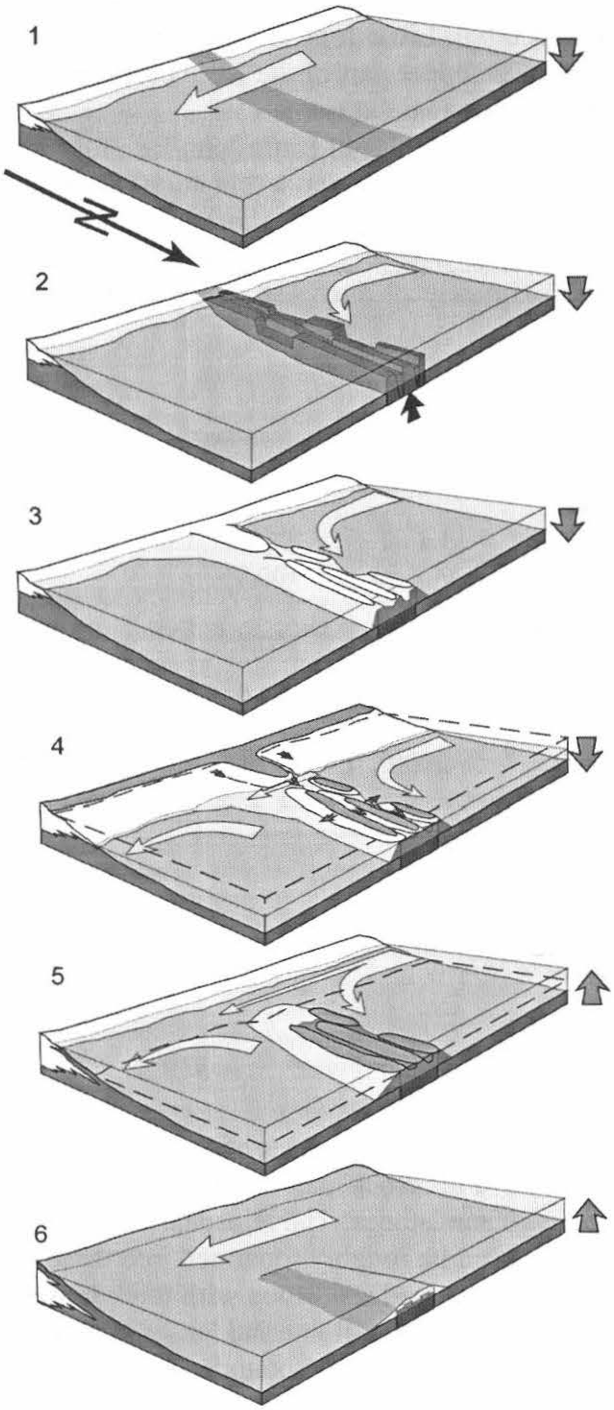


Figure 33. Model proposed for north-south depositional trend observed within the Lower Rushford Member in northern Allegany and Cattaraugus counties.
1) Preexisting fault zone (Clarendon-Linden Fault System) intersects the Late Devonian paleoshoreline at either an oblique or perpendicular angle. 2) Syndepositional fault activity causes variable uplift on the fault-blocks comprising the fault zone blocking the longshore current. 3) The fault zone behaving as a groin would redirect the sediment transport causing the shoreline to follow the trend of the fault zone. 4) During periods 1 through 4 relative sealevel has been falling, by time period 4 the shoreface is now subaerially exposed increasing erosion. Coarser materials (quartz clasts) are redeposited in immediately adjacent accommodation zones, while finer-grained material is transported away. The result is a generally cleaner and coarser sediment. 5) Sealevel rises during the ensuing transgression, reworking and redepositing the coarser material as a transgressive lag deposited at the top of the shoreface sequence. 6) With continued rise in sealevel during the transgression and later highstand tract, the fault-controlled shoreline becomes isolated offshore and is now buried under deep-water sediments. The resulting topographic anomaly may later serve as a depositional focus for shelf-ridge creation.
(Gray arrows represent the rise or fall of relative sealevel. The black arrow represents fault motion. The white arrows represent sediment transport. Small dark gray arrows represent erosion and redeposition of coarser sediments.

Upstream from the waterfalls located north of the bridge, deformation in the shales, silty shales and siltstones are readily observed; both deformed sandstones (ball and pillow) and pencil cleavages occur. At 0.25 mi (0.4 km) south of Little John Bridge, a repetition of the section appears to outcrop in White Creek. The upper part of the 2nd shoreface sequence and all of the 3rd shoreface sequence outcrops again at a small waterfall/cascade. Unlike the outcrop to the north of the bridge at Little John Rd., this outcrop does not have the thick transgressive lag deposits. However, 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. The offset between the outcrop by the bridge and the repeated (?) section is approximately 11.6 m (~38 ft), down on the west (or north).

Directions	Distance	Cumulative
STOP 5 - White Creek		
Continue west along LittleJohn Rd.		
Turn LEFT onto SR-305	1.1 mi	85.6
Turn LEFT onto Stout Rd.	14.7 mi	100.3
Drive straight through Cuba NY		
Turn RIGHT onto Farnsworth Rd.	0.1 mi	100.4
Park along the right side of the road, outcrop is exposed along the left side.	0.2 mi	100.6
Additional outcrop exposed farther along the road	300ft	
STOP 6 - Farnsworth Rd.		

STOP 6 – Farnsworth Road – road cut (Figures 34, 35).
Location Coordinates (WGS 1984):
Lat – N42.18096°, Lng – W78.25373°
UTM Zone 17; N4673512, E0726810

The roadcuts along the northern side of Farnsworth Road are exposures of the Hinsdale Fm. (Chadwick, 1933), (possibly a correlative to the "Pink Rock", an old drillers name), one of the stratigraphically higher Bradford reservoir sandstones. The Hinsdale Formation is comprised of thick sandstone beds that can be roughly separated into three packets. The thick sandstone lenses are typically fine-grained sandstone with thick lenses of coquinite that typically form basal lags, but also occur as small internal lenses (Figure 35). Thickness variability within the sandstones is high, further compounded by variable erosion of lower units by overlying sandstones.

Sedimentary structures are typically SCS with less frequent occurrences of TCS and tabular cross-beds. Small amplitude (and wavelength) symmetrical and interference ripples are commonly observed on the inner surface of large troughs and swales, implying complex, combined-flow during time of deposition (Figure 17). Thinner sandstones within the interbedded sections contain both asymmetric and 3-dimensional ripples and HCS; several thin sandstones also contain grooves and striations on the sole of the beds. Both the sandstones of the interbedded sections and the thick sandstone packets contain an abundant, but still low-diversity *Skolithos* ichnofacies. High frequency of *Arenicolites* and *Skolithos* occur in both the thinner sandstones as well as in the thick sandstone packets. A poorly developed *Cruziana* ichnofacies consisting of sporadic occurrences of Planolites and Teichichnus is found in the thicker interbedded sections.

We interpret the Hinsdale Formation as being deposited well above storm wave base, but still below fair weather wave base, most likely upper offshore to lower shoreface. The dominance of SCS and typical tempestite packets imply the Hinsdale Formation was deposited primarily by storms; the large amounts of fossils and the singular occurrence of red shales and sandstones suggest the shoreline was moving westward and terrestrial sediments were now being incorporated into the marine sedimentary deposits. The interpreted depositional environment is likely to be either nearshore storm-generated sand ridges or a storm-influenced barrier bars (Miall, 2000)

The roadcut displays the sharp-based sandstones that have lenses of coquinite throughout, but generally a thicker lag deposit at the base. Bedding in the sandstone is distinctly swaly, with large erosional surfaces cutting down into underlying units. At the lower roadcut, above the prominent, thick sandstone is a red to purplish red shale which aids the identification of the formation. The depositional environment for the Hinsdale and many of the similar thick sandstones between the Lower Rushford Member (STOPS 3, 4 and 5) and the Hinsdale Fm. are probably storm shelf ridges to storm-dominated barrier bars. The lateral variability observed at this location and many similar outcrops may explain the "lensing" nature of the Upper Devonian reservoir sands.

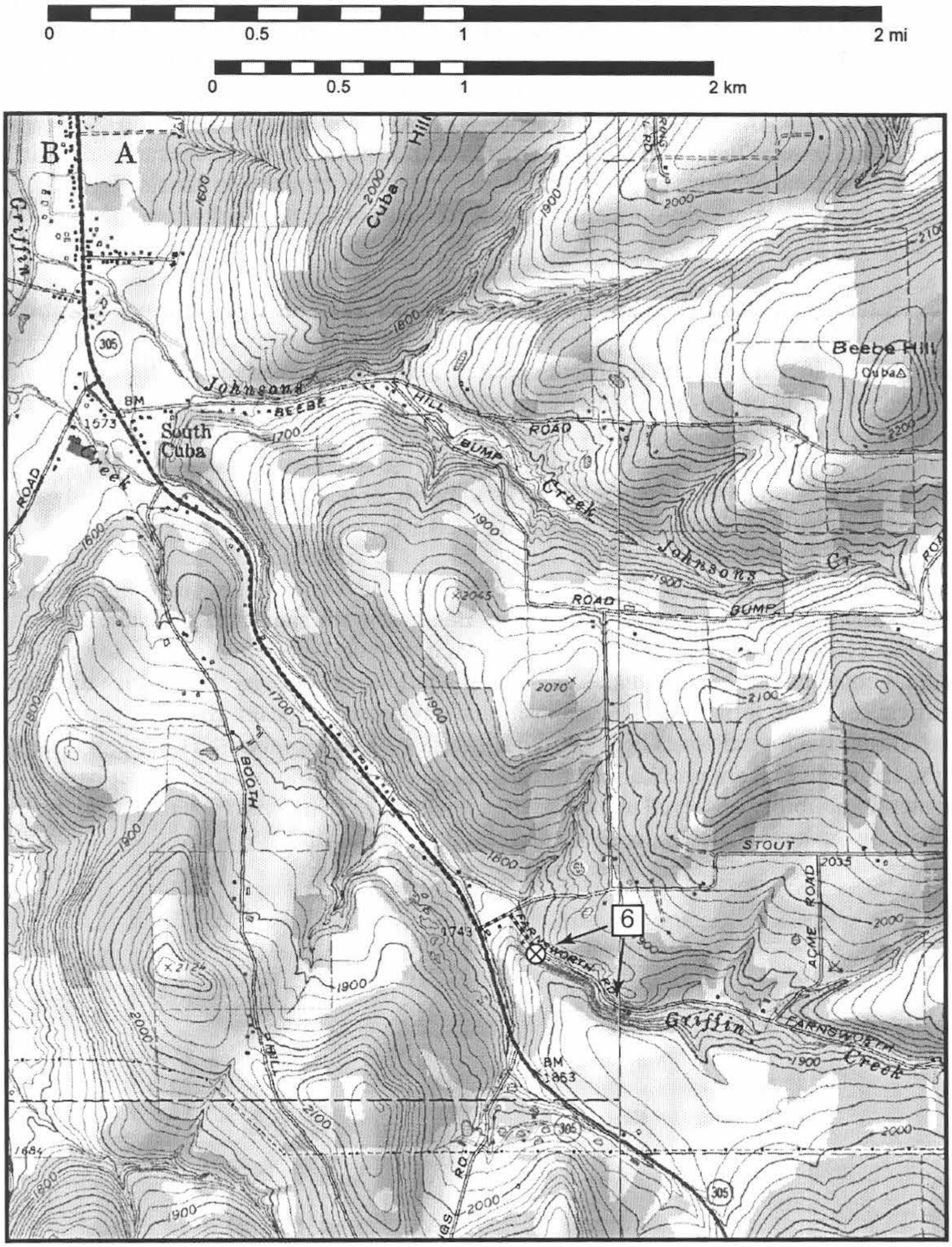
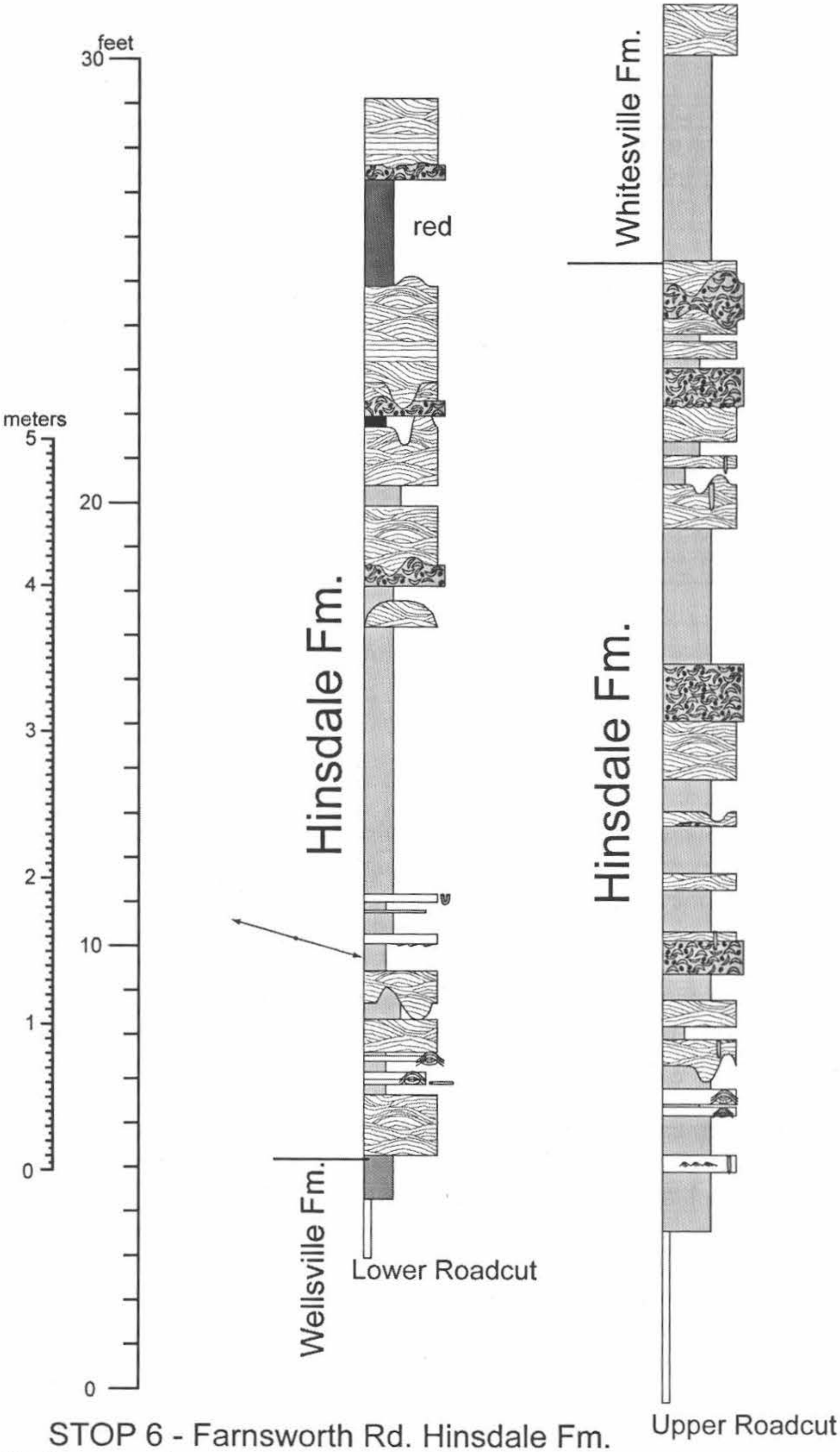


Figure 34. Stop 6 - Farnsworth Rd., roadcut. Park along south side of the road, past the house and garage, opposite is the lower roadcut. Outcrop is also present in Griffin Creek, but you will need permission from the landowner. Additional outcrop is accessible farther east along the road (marked by the second arrow).



STOP 6 - Farnsworth Rd. Hinsdale Fm.

Figure 35. Measured annotated stratigraphic columns for roadcuts along Farnsworth Rd. Arrow represents measured paleoflow direction. Key for symbols used may be found on Figure 10.

Directions	Distance	Cumulative
STOP 6 - Farnsworth Rd.		
Turn around and Turn LEFT onto Stout Rd.	0.2 mi	100.8
Turn RIGHT onto SR-305 heading N	0.1 mi	100.9
Turn LEFT onto ramp to US-86 W (old SR-17)	3.5 mi	104.4
Merge onto US-86	0.4 mi	104.8
Take EXIT 21 at Salamanca	30.4 mi	131.2
Turn RIGHT onto Parkway Dr.	0.1 mi	131.3
Keep RIGHT onto SR-417	0.1 mi	131.4
Turn LEFT onto US-219	0.5 mi	131.9
Turn LEFT onto Hungry Hollow Rd.	2.4 mi	134.3
Turn LEFT following Hungry Hollow Rd. (straight is McCarthy Hill Rd)	3.6 mi	139.9
Turn LEFT onto Little Rock City Rd	0.4 mi	140.3
Continue South to Parking Area	1.7 mi	142
STOP 7 - Little Rock City		

STOP 7 – Little Rock City (Figures 36, 37).
Location Coordinates (WGS 1984):
Lat – N42.20853°, Lng – W78.70802°
UTM Zone 17; N4675470, E0689203

Little Rock City is a State Forest under the supervision of the NYS Department of Environmental Conservation. The Salamanca Conglomerate (Carll, 1880) marks the basal contact of the Conewango Group with the underlying Conneaut Group. Sands and coarser units of the Conewango Group are correlative to the Venango reservoir sands in Pennsylvania. At this site exposures of thick orthoconglomerate (between 2 and 12 m thick) occur along the northern and eastern sides of the hill. House-size blocks separated along joints by periglacial expansion are abundant throughout the area; at least one was redeposited upside-down on top of another block by glacial activity.

Lithologically the Salamanca is an oligomictic quartz orthoconglomerate. The conglomerate consists of a medium to coarse sand matrix with clasts of cloudy white quartz. The clasts are oblate discoids that range from 0.5 centimeters up to 6+ centimeters in diameter. The oblate discoid shapes of the pebbles are typical of a wave-dominated shoreface. Large downlapping, graded cross-sets (1 to 4 meters high) and channels occur throughout the lower section of the outcrop. These bedforms may represent alluvial gravel bars. The form of the large cross sets is also similar to that found in estuarine tidal sand bars, but the thickness of the sets is high for the low (about 2 m) tidal fluctuations thought to characterize the Acadian Catskill Sea (e.g., Woodrow and Isley, 1983). However, the coarseness of the conglomerate indicates a high energy system, consistent with a tidal prism or bore in an estuary (and also consistent with the tidal gravels in the English Channel) that could have had a higher tidal range than the assumed 2m Catskill Sea tidal range. Thus, these large crossbeds could be fluvial bars or tidal. Tabular crosssets and crossbeds with a herringbone pattern are observed above the large cross sets (although some of the herringbone is a "pseudo-herringbone" that results from trough cross sets in opposite directions). Both herring bone patterns, however, are consistent with reversing currents of tidal flux, as in a tidal channel. Overall, the large scale crossbeds, trough cross-sets, and the herringbone pattern suggest an estuarine/estuarine mouth depositional environment (Dalrymple, 1992) with a strong tidal influence. Paleoflow indicators from sedimentary structures are few, ripples and troughs on the upper surface occur sporadically.

We recognized several distinct facies within the Salamanca Conglomerate: facies A is the caprock of the Salamanca Conglomerate with the largest quartz clasts (>5cm). The conglomerate is generally disorganized with clasts orientated obliquely and perpendicular to bedding, except for the top surface; large carbonized wood fragments also occur. Facies B is a less resistant, more friable unit that exhibits herringbone bedding marking current reversals. Facies C is comprised of two thick, graded foreset packets each ranging 1 to 4 meters thick with large clasts accumulating along bedding planes with some asymmetric ripples. Facies D is a less resistant, more friable unit that contains fewer clasts, but generally does not exhibit reversals in bedding (Figure 47).

We have observed similar arrangement of facies at conglomerate blocks loose in Allegany State Park and adjacent areas, and at the "Bear Caves" area outcrops at Mount Seneca in Allegany State Park. The outcrops and loose blocks examined south of Little Rock City were generally sandier than the Little Rock City conglomerates, with clasts occurring only along bedding planes, and the clasts typically are not as large (maximum clast ~ 2 cm) as the clasts measured at Little Rock City.

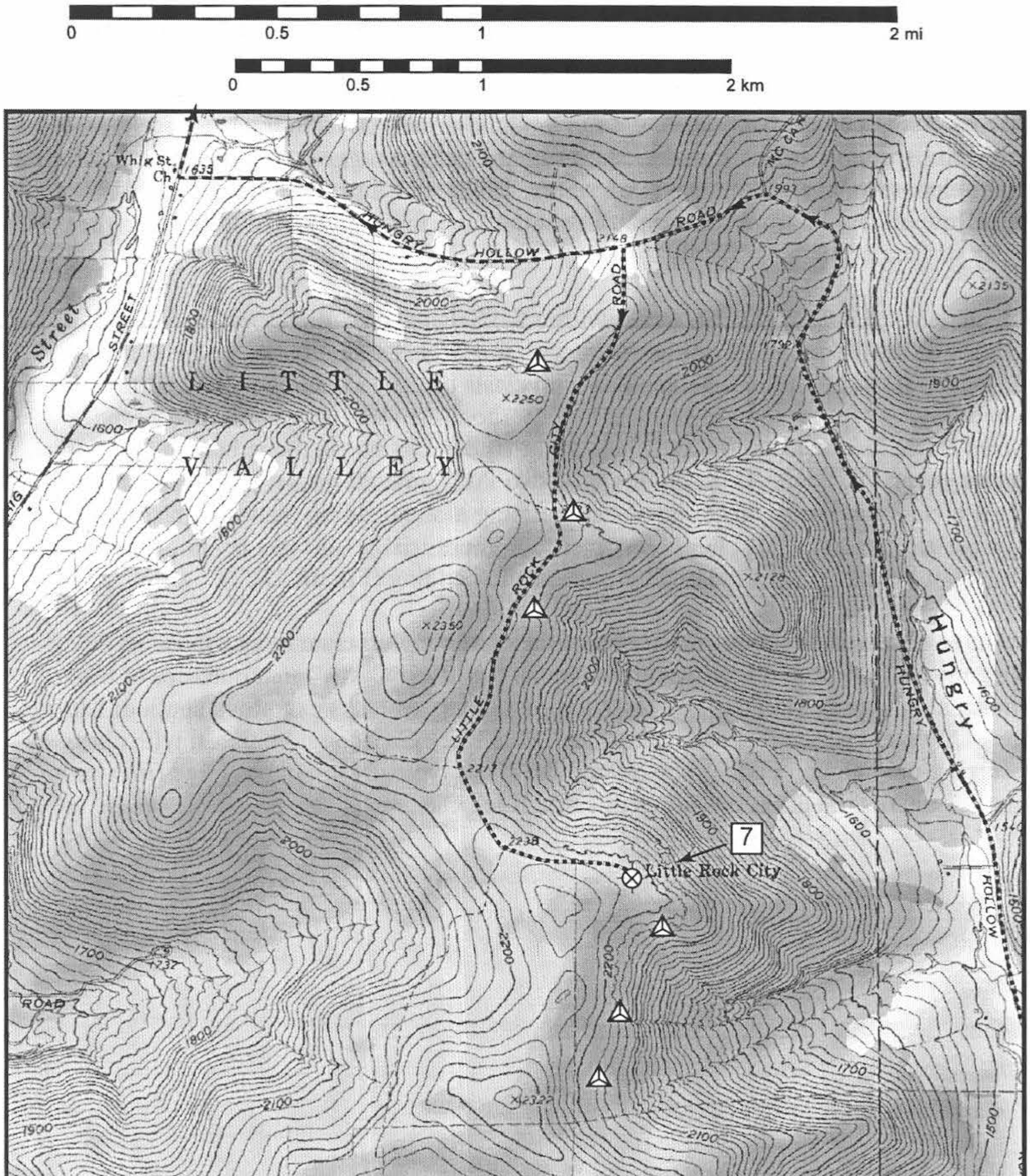
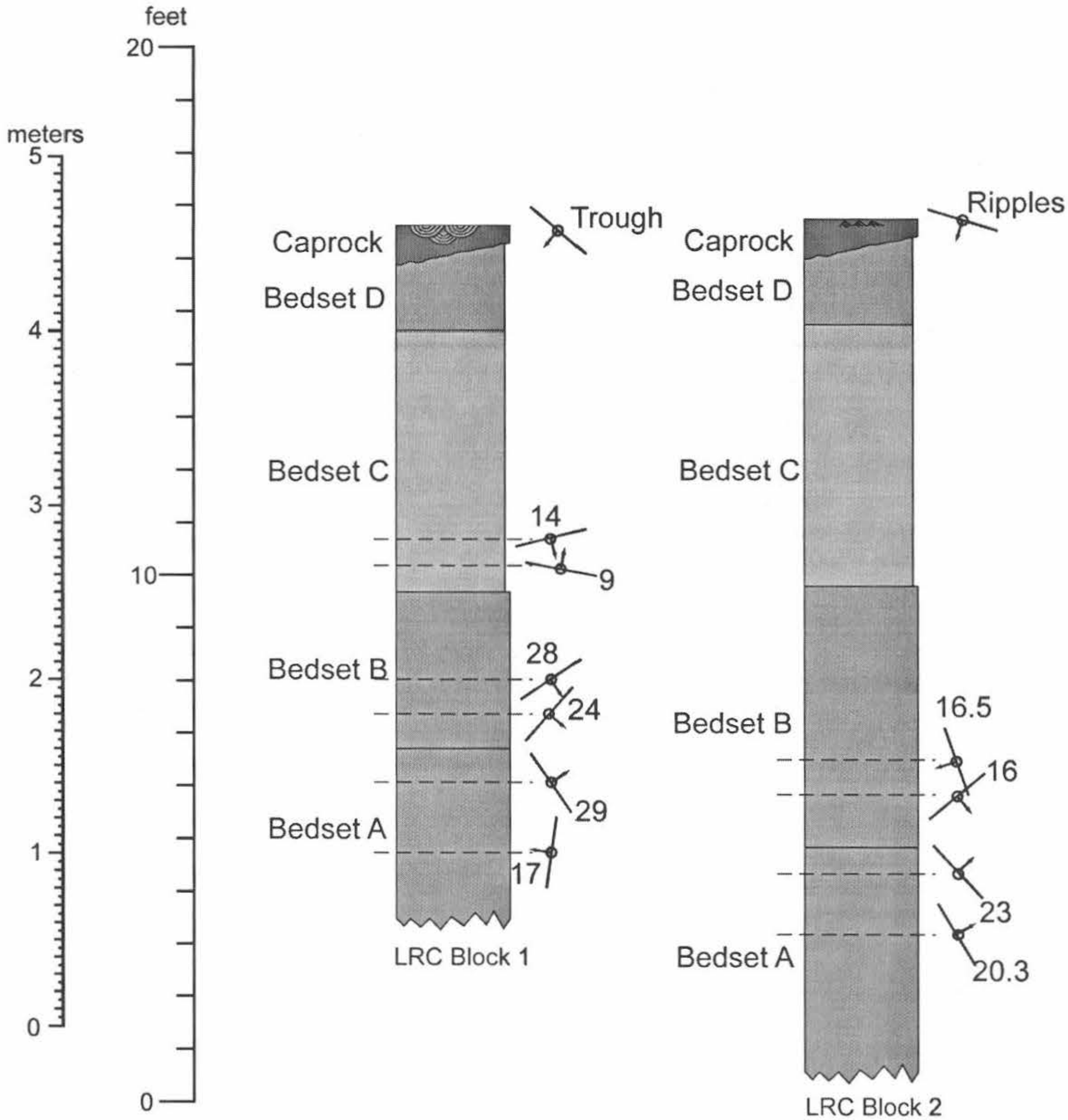


Figure 36. Stop 7 - Little Rock City. Park at the parking circle at the end of Little Rock City Rd. Outcrop is accessible immediately north of the parking area, but is easily found thoughout the area (marked by triangles).



STOP 7 - Little Rock City. Salamanca Conglomerate.

Figure 37. Measured, annotated stratigraphic columns for some of the outcrops at Little Rock City. Strike and dip symbols represent the calculated true strike and dip of measured crossbeds within the conglomerates. Block 1 is due north of the parking area; Block 2 is immediately east of Block 1.

Directions	Distance	Cumulative
STOP 7 - Little Rock City		
Travel north along Little Rock City Rd.		
Turn LEFT onto Hungry Hollow Rd.	1.7 mi	143.7
Turn RIGHT onto Whig St	1.1 mi	144.8
Turn RIGHT onto RT-242	2.2 mi	147
Turn LEFT onto US-219	3.8 mi	150.8
Turn LEFT following US 219 (also SR-39)	17.3 mi	168.1
Turn RIGHT onto ramp for US-219 (Southern Expy)	0.1 mi	168.2
Keep STRAIGHT onto Ramp towards I-90	23.6 mi	191.8
Keep LEFT to stay on ramp towards I-90/Thruway/ Ridge Road West/Buffalo/Lackawanna	0.4 mi	192.2
Take ramp (LEFT) onto I-90 toward I-90/Thruway/Buffalo	0.3 mi	192.5
At exit 53, take ramp (RIGHT) onto I-190 toward I-190/Downtown Buffalo/Niagara Falls	3 mi	195.5
At exit 7, turn RIGHT onto ramp toward Church St.	5.5 mi	201
Bear RIGHT (East) onto Broadcast Plaza (Church St)	0.2 mi	201.2
FINISH - RETURN TO ADAMS MARK		

REFERENCES

Bonilla, M.G., Mark, R.K., and Lienkaemper, J.J., 1984, Statistical relations among earthquake magnitude, surface rupture length, and surface fault displacement: Bulletin of the Seismological Society of America, v. 74, p. 2379-2411.

Boswell, R.M., and Donaldson, A.C., 1988, Depositional architecture of the Upper Devonian Catskill Delta Complex: Central Appalachian Basin, U.S.A.: *in* McMillan, N.J., Embry, A.F., and Glass, D.J., eds., Devonian of the World. Volume II: Calgary, Alberta, Canadian Society of Petroleum Geologists, p. 65-84.

Bouma, A.H., 1962, Sedimentology of some flysch deposits: a graphic approach to facies interpretation: Elsevier Scientific Publishing, Amsterdam, 168p.

Bouma, A.H., 2000, Fine-grained, mud-rich turbidite systems: Model and comparison with coarse-grained, sand-rich systems; *in*: Bouma, A.H., and Stone, C.G., eds., Fine-grained Turbidite Systems, AAPG Memoir 72/SEPM Special Publication 68, p. 9-20.

Bouma, A. H., Normark, W. R., and Barnes, N. E., (eds), 1985, Submarine Fans and Related Turbidite Systems: Springer-Verlag, New York, 351 pp.

Bouma, Arnold H., and Stone, Charles G., 2000, Fine-grained Turbidite Systems: American Association of Petroleum Geologists Memoir 72, 342 pp.

Brett, C.E., 1983, Sedimentology, facies and depositional environments of the Rochester Shale (Silurian; Wenlockian) in western New York and Ontario. Journal of Sedimentary Petrology, v. 53, p. 947-971.

Carll, J.F., 1880, The Geology of the Oil Regions of Warren, Venango, Clarion and Butler Counties: 2nd Pennsylvania Geological Survey, Report R, p. 2-397.

Chadwick, G.H., 1923, The Stratigraphy of the Chemung Group in Western New York: New York State Museum Bulletin, no. 251, p. 149-157.

Chadwick, G.H., 1933, Great Catskill Delta: and revision of late Devonic succession; Part 2, Areal refinements: Pan-American Geology, v. 60, p.189-204.

Clarke, J.M., 1897, The stratigraphic and faunal relations of the Oneonta sandstones and shales, the Ithaca and Portage Groups in central New York. New York State Museum Annual Report 49, v. 2, p. 27-81.

Clarke, J.M., 1902, Paleontologic results of the areal survey of the Olean Quadrangle: New York State Museum Bulletin. v. 52, p. 524-528.

Dalrymple, R.W., 1992, Tidal Depositional Systems, *in* Walker, R.G. and James, N.P., eds., Facies Models: Response to Sea Level Change. Geological Association of Canada, p. 195-218.

Dennison, J.M., 1985. Catskill Delta shallow marine strata: *in* Woodrow, D.L., and Sevon, W.D., eds. , The Catskill Delta: GSA Special Paper 201, p. 91-106.

dePolo, C.M., and Slemmons, D.B., 1990, Estimation of earthquake size for seismic hazards: *in* Krinitzsky, E.L., and Slemmons, D.B., Neotectonics in earthquake evaluation: Boulder, Colorado, Geological Society of America Reviews in Engineering Geology, v. 8, p. 1-28.

Elliott, T., 1986, Siliciclastic Shorelines, *in* Sedimentary Environments and Facies; ed. Reading, H.G., p. 155-188.

Engelder, T. and Geiser, P., 1979, The relationship between pencil cleavage and lateral shortening within the Devonian section of the Appalachian Plateau, New York. Geology, v. 7, p. 460-464.

Ettensohn, F.R., 1985, Controls on development of Catskill Delta complex basin-facies: *in* Woodrow, D.L., and Sevon, W.D., eds., The Catskill Delta: GSA Special Paper 201, p. 65-77.

Ettensohn, F. R., 1994, Tectonic Control on formation and cyclicity of major Appalachian unconformities and associated stratigraphic sequences: *in* Dennison, J.M., and Ettensohn, F.R., eds., Tectonic and Eustatic Controls on Sedimentary Cycles, SEPM Concepts in Sedimentology and Paleontology #4, p. 217-242.

Glenn, L.C., 1903, Devonic and Carbonic Formations of Southwestern New York: New York State Museum Bulletin, v. 69, p. 967-989.

Harper, J.A., 1989, Effects of recurrent tectonic patterns on the occurrence and development of oil and gas resources in western Pennsylvania; Northeastern Geology, v. 11, p. 225-245.

House, M.R., 2002, Strength, timing, setting and cause of mid-Palaeozoic extinctions; Palaeogrography, Palaeoclimatology, Palaeoecology, v. 181, p. 5-25.

Huthnance, J.M., 1982, On one mechanism forming linear sand banks; Estuarine and Marine Coastal Science, v. 14, p. 79-99.

Jacobi, R.D., 2002, Basement faults and seismicity in the Appalachian Basin of New York State: Tectonophysics, v. 353, p. 75-113.

Jacobi, R.D., and Fountain, J.C., 1993, The southern extension and reactivations of the Clarendon-Linden fault system: *in* Wallach J.L., and Heginbottom, J., eds., Neotectonics of the Great Lakes area, Geographie Physique et Quaternaire, 47, 285-302.

Jacobi, R.D., and Fountain, J.C., 1996, Determination of the seismic potential of the Clarendon-Linden Fault System in Allegany County, Final Report: NYSERDA (Albany), 2,106 p. & 31 oversized maps.

Jacobi, R.D., and Fountain, J.C., 2002, The character and reactivation history of the southern extension of the seismically active Clarendon-Linden Fault System, western New York State: Tectonophysics, v. 353, p. 215-262.

Jacobi, R. D. and Hayes, D. E., 1982, Bathymetry, microphysiography and reflectivity characteristics of the West African margin between Sierra Leone and Mauritania, in Geology of the Northwest African Continental Margin, U. von Rad, K. Hinz, M. Sarnthein and E. Seibold (eds.): Springer-Verlag, Berlin, pp. 182-212.

Jacobi, R. and Hayes, D., 1992, Northwest African continental rise: Effects of near-bottom processes inferred from high-resolution seismic data, IN C. Wylie Poag and Pierre C. de Graciansky, eds., Evolution of Continental Rises: Van Nostrand Reinhold, New York, p. 293-326 + pocket folded figure.

Jacobi, R.D. and Smith, G.J., 2004, Geologic Mapping in the Appalachian Basin of western New York State; Geological Society of America, Abstracts with Program, v. 36, n.2 p.18.

Jacobi, R.D., Gutmann, M., Piechocki, A., Singer, J., O'Connell, S., and Mitchell, C.E., Frank, S., Scheuing, D., and Hasiotis, S., 1990, Upper Devonian turbidites in western New York:

Characteristics and implications for submarine fan deposition models: New York State Geological Association 62nd Annual Meeting Field Trip Guidebook, SUNY at Fredonia, p. Sat E1- Sat E25.

Jacobi, R., Gutmann, M., Piechocki, A., Singer, J., O'Connell, S., and Mitchell, C., 1994, Lobe & lobe fringe sands in the Upper Devonian of western New York, in Studies in Paleontology & Stratigraphy in Honor of Donald W. Fisher, E. Landing, (ed.,): New York Geol. Surv. Bull. 481, p. 101-115.

Jacobi, R.D., Loewenstein, S., Martin, J., and Smith, G., 2000, Magnetic, Gravity, and Landsat Lineaments in the Appalachian Basin, New York State: Groundtruth, Faults, and Traps: American Association of Petroleum Geologists Bulletin, v. 84, no.7, p. 1387.

Jacobi R.D., Loewenstein S., and Smith, G.J., 2005, Seismic Data Bearing on Iapetan Opening/Rome Trough-Related Faults, Their Reactivation History and Effect on Deposition in the Appalachian Basin of New York State. 2005 AAPG Annual Meeting Official Program, Calgary, v. 14

Jacobi R.D., Loewenstein S., and Smith, G.J., 2006, The Corner Zone of the Pennsylvania Salient in the Northern Appalachian Basin of NYS and PA: Separating the Spiderweb of Faults Into Grenvillian to Present Strands That can Stretch From the Surface to 250 km Depth. American Geophysical Union, Joint Assembly Conference, Baltimore. Abstracts with Program.

Jacobi, R.D., Loewenstein, S., Smith, G., Fountain, J., Lugert, C., and Martin, J., 2004, Iapetan Opening/Rome Trough-Related Faults and Their Reactivation History in New York State, 2004 Eastern Section AAPG Meeting, Columbus, Ohio.

Jacobi, R.D., and Smith, G.J., 1999, Structure and Upper Devonian stratigraphy in the Appalachian Plateau of Allegany County, New York State, including the Clarendon-Linden Fault System, NYSGA71st Annual Meeting Field Trip Guidebook, SUNY at Fredonia, p. Sat C1- Sat C44.

Johnson, J.G., Klapper, G., and Sandberg, C.A., 1985, Devonian eustatic fluctuations in Euramerica: Geological Society of America Bulletin, v. 96, p. 567-587.

Lytle, W.S., and Goth, J.H., 1970, Oil and gas geology of the Kinzua quadrangle, Warren and McKean Counties, Pennsylvania, Pennsylvania Geological Survey, 99p

Manspeizer, W., 1963, A Study of the Stratigraphy, Paleontology, Petrology and Geologic History of the Canadaway and Conneaut Groups in Allegany County, New York. Unpublished Ph.D. thesis, Rutgers University.

Miall, A.D., 2000, Principles of Sedimentary Basin Analysis, 3rd Edition: New York, Springer-Verlag, 616p.

Myrow, P.M., Fischer, W., and Goodge, J.W., 2002, Wave-Modified Turbidites: Combined-flow shoreline and shelf deposits, Cambrian, Antarctica; Journal of Sedimentary Research, v. 72, p. 641-656.

Pattison, S.A.J., 2005, Storm-influenced prodelta turbidite complex in the lower Kenilworth Member at Hatch Mesa, Book Cliffs, Utah, U.S.A.: implications for shallow marine facies models; Journal of Sedimentary Research, v. 75, p. 420-439.

Pepper, J.F., and deWitt, W., 1951, Stratigraphy of the Late Devonian Perrysburg Formation in Western and west-central New York: U.S. Geological Survey; Oil and gas investigations Chart OC 45.

Peters, T.W., 1998, Geologic Mapping of the Rawson 7.5' Quadrangle in New York State: Characterization of Multiple Fault Systems; Unpubl. M.A. thesis, SUNY at Buffalo, Buffalo, NY, 161p.

Reinson, G.E., 1992, Transgressive Barrier Island and Estuarine Systems, *in* Walker, R.G. and James, N.P., eds., Facies Models: Response to Sea Level Change. Geological Association of Canada, p. 179-194.

Rickard, L.V., 1975, Correlation of the Devonian rocks in New York: New York Museum and Science Service Map and Chart Series 24.

Scotese, C.R., and McKerrow, W.S., 1990, Revised world maps and introduction; *in* McKerrow, W.S., and Scotese, C.R., eds., Palaeozoic Palaeogeography and Biogeography: Geological Society of London Memoir 12, p. 1-12.

Smith, G.J., 2002, Sequence Stratigraphic Analysis of the Conneaut and Conewango Groups in Western New York State; Final Report to New York State Energy Research and Development Authority, Albany, 66p.

Smith, G.J., and Jacobi, R.D., 1996, Transgressive surfaces of erosion in the Upper Devonian Catskill Delta Complex: Evidence for support of the incised shoreface model: Geological Society of America Abstracts with Programs, v. 28, n. 3, p. 100.

Smith, G.J., and Jacobi, R.D., 1998, Fault-influenced transgressive incised shoreface model for the Canadaway Group, Catskill Delta Complex: Journal of Sedimentary Research B, v.68, p. 668-683.

Smith, G.J., and Jacobi, R.D., 1999, Syndepositional fault-controlled reservoir formation: Lowstand shoreface deposits in southwestern New York State: 1999 AAPG Annual Meeting Official Program, v. 8, p. A131.

Smith, G.J., and Jacobi, R.D., 2000, Re-evaluating the Canadaway Group: A revised stratigraphic correlation chart for the Upper Devonian of southwestern New York State; Northeastern Geology and Environmental Sciences, v.22, p. 173-201.

Smith, G.J., and Jacobi, R.D., 2001, Tectonic and Eustatic Signals in the Sequence Stratigraphy of the Upper Devonian Canadaway Group, New York State; American Association of Petroleum Geologists Bulletin, v. 85, no. 2, p. 325-357.

Smith, G.J., and Jacobi, R.D., 2002, Anomalous paleoflow orientations: A potential methodology for determining recurrence rates and magnitudes in paleoseismic studies of syndepositional faults: *in:* Ettensohn, F.R., Rast, N., and Brett, C.E., (eds.,) Ancient Seismites; GSA Special Paper 359, p. 145-164.

Smith, G.J., and Jacobi, R.D., 2003, Clastic Depositional Environments and Sequence Stratigraphy in the Acadian Foreland Basin in Western New York State; 2003 AAPG Annual Meeting Official Program, Salt Lake City, v.12, p. A159.

Smith, G.J. and Jacobi, R.D., 2004, Upper Devonian Sands in New York State: Examples of Storm-Generated Offshore Sand-Ridges; 2004 AAPG Annual Meeting Official Program, Dallas, v. 13, p. A130.

Smith, G.J., and Jacobi, R.D., 2005, The Influence of Basement Structures on Upper Devonian Deposition in western New York State; 2005 AAPG Annual Meeting Official Program, Calgary, v. 14, p. A.

Snedden, J.W., and Dalrymple, R.W., 1999, Modern shelf sand ridges: From historical perspective to a unified hydrodynamic and evolutionary model; *in:* Bergman, K.M., and Snedden, J.W., eds., Isolated Shallow Marine Sand Bodies: Sequence Stratigraphic Analysis and Sedimentologic Interpretation, Society of Economic Paleontologists and Mineralogists, Special Publication No. 64,, p. 13- 28.

Stow, D.A.V., 1986, Deep Clastic Seas, *in* ed. Reading, H.G, Sedimentary Environments and Facies;. p. 399-444.

Swift, D.J.P., Thorne, J.A., and Oertel, G.F., 1986, Fluid processes and sea-floor response on a modern storm-dominated shelf: middle Atlantic shelf of North America. Part II: response of the shelf floor; *in* Knight, R.J., and McLean, J.R., eds., Shelf Sands and Sandstones: Canadian Society of Petroleum Geology Memoir 11, p. 191-211.

Tesmer, I. H., 1955, Restudy of the Upper Devonian (Chautauquan) Stratigraphy and Paleontology in Southwestern New York State: New York State Museum and Science Service, v. 42, 22 p

Tesmer, I.H., 1975, Geology of Cattaraugus County, New York; Buffalo Society of Natural Sciences Bulletin, v. 27, 105p.

Walker, R.G. and Harms, J.C., 1971, The "Catskill Delta": A prograding muddy shoreline in Central Pennsylvania; Journal of Geology, v. 79, p. 381-399.

Wheeler, R.L., 2002, Distinguishing seismic from nonseismic soft-sediment structures: Criteria from seismic-hazard analysis; *in:* Ettensohn, F.R., Rast, N., and Brett, C.E., (eds.,) Ancient Seismites; GSA Special Paper 359, p. 1-11.

Willis, B.J., 2005, Deposits of tide-influences deltas; *in*: Giosan, L., and Bhattacharya, J.P., eds., River Deltas – Concepts, Models, and Examples, SEPM Special Publication 83, p. 87-129.

Witzke, B.J., 1990, Palaeoclimate constraints for Palaeozoic palaeolatitudes of Laurentia and Euramerica *in* McKerrow, W.S., and Scotese, C.R., eds., Palaeozoic Palaeogeography and Biogeography: Geological Society of London Memoir 12, p. 57-73.

Witzke, B.J. and Heckel, P.H., 1988, Paleoclimatic indicators and inferred Devonian paleolatitudes of Euramerica: *in* McMillan, N.J., Embry, A.F., and Glass, D.J., eds., Devonian of the World. Volume I: Calgary, Alberta, Canadian Society of Petroleum Geologists, p 49-63.

Woodrow, D.L., Dennison, J.M., Ettensohn, F.R., Sevon, W.T, and Kirchgasser, W.T., 1988: Middle and Upper Devonian stratigraphy and paleontology of the central and southern Appalachians and eastern Midcontinent, U.S.A. *in* McMillan, N.J., Embry, A.F., and Glass, D.J., eds., Devonian of the World. Volume I: Calgary, Alberta, Canadian Society of Petroleum Geologists, p. 277-301

Woodrow, D.L., and Isley, A.M., 1983, Facies, topography, and sedimentary processes in the Catskill Sea (Devonian), New York and Pennsylvania: Geological Society of America Bulletin, v. 94, p. 459-470.

Woodruff, J.G., 1942, Geology of the Wellsville Quadrangle, New York: New York State Museum Bulletin, no. 326, 135p.

Zack, D.L., 1998, Geologic mapping of the Freedom 7 ½' topographical quadrangle in southwestern New York State: Evidence for multiple fault systems in the Appalachian Basin; Unpubl. M.A. thesis, SUNY at Buffalo, Buffalo, NY, 163p.

Ziegler, P.A., 1988, Laurussia - The Old Red Continent. *in* McMillan, N.J., Embry, A.F., and Glass, D.J., eds., Devonian of the World. Volume I: Calgary, Alberta, Canadian Society of Petroleum Geologists, p. 15-48.

Ziegler, P.A., Scotese, C.R., McKerrow, W.S., Johnson, M.E. and Bambach, R.K., 1979, Paleozoic paleogeography; Annual Reviews of Earth Science, v. 7, p. 473-502.