Trip B-3

MIDDLE ORDOVICIAN CLASTICS, FRACTURES, FAULTS AND WATER FALL: GEOLOGY OF THE SALMON RIVER GORGE, ALMAR, NEW YORK

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INTRODUCTION TO THE REGIONAL GEOLOGY

The Tug Hill plateau is underlain by the Lorraine Group, that consists of a number of siliciclastic rock formations from oldest to youngest, the Utica, Whetstone Gulf, Pulaski and Oswego. The Utica shale and Oswego sandstone are end-members in a stratigraphic sequence that has increasing amount of siltstone and then sandstone beds upward progressively. This sequence of rocks represent the middle Ordovician trough that filled with clastic sediments in response to the Taconian orogeny, the Taconic Clastic Wedge. The high region of Tug Hill plateau is drained by rivers and streams that flow radially from the plateau in all directions, and most of these drainages have carved deep gulfs and gorges exposing the carbonates of the Trenton Group and the Lorraine Group clastics. The Salmon River flows from the plateau interior into the Redfield Reservoir. Downstream of the reservoir, the river flows over the top of the Oswego sandstone to the Salomon River falls (Figure 1). At the falls, the river plunges 33 meters into the top of the Pulaski Formation (interbedded sandstone, siltstone and shale), and forms the Salmon River gorge downstream. The river is bound by the gorge within the geographic limits of the Oswego formation. Exiting the Oswego formation, the Salmon River flows through a generally shallow banked cut in the Pulaski Formation, until it reaches Lake Ontario at the town of Port Ontario. This field trip is a visit to the Salomon River falls to examine the transition in strata near the top of the Taconic Clastic Wedge, structures in the strata, and how these features of the bedrock have contributed to the formation of the Salmon River falls and controlled the flow direction of the river. This trip includes two locations: 1. Top of the falls; 2. Below the falls (Figure 1).

Figure 1. *Oblique aerial view of the Salmon River falls, Oswego County, New York.*

THE TUG HILL PLATEAU

Situated between the Adirondack dome to the east and Lake Ontario to the west, the Tug Hill plateau rises about 500 meters from the lake shore to the highest point (Figure 2). The plateau covers an area approximately 3500 square kilometers and is underlain by the middle Ordovician strata that sit nonconformably on the Mesoproterozoic Adirondack basement. These strata are inclined approximately 2^o to 5^o toward the southwest as the result of faulting in the basement during the uplift of the Adirondacks (Roden-Tice, 2000; Roden-Tice et al., 2009) and Tug Hill plateau (Wallach and Reault, 2010). Approximately 500 meters of strata are exposed on the flanks of the plateau through river-beds, gulfs, road outcrops, and quarries, and the interior of the plateau is covered by thick ground moraine, drumlins and wetlands. There are long linear escarpments and valleys on the southern, northern, and eastern flanks of the plateau, that are the locations of unexposed faults (Wallach and Rheault, 2010). The southern flank of the plateau is bound by the Prospect Fault (Jacobi, 2002) and the northern flank of the plateau is coincident with the southwestern extension of the Carthage-Colton shear zone (Wallach and Rheault, 2010). Finally, the eastern flank of the plateau is the steepest slope, and the location of the proposed Black River fault (Wallach and Rheault, 2010). Superficially, it appears that the general geomorphology of the Tug Hill plateau was controlled by faults within the underlying basement that extend upward into the overlying sedimentary strata. The Salomon River forms the most pronounced cut into the southwestern margin of the plateau and the linearity suggests fault control (Figure 2).

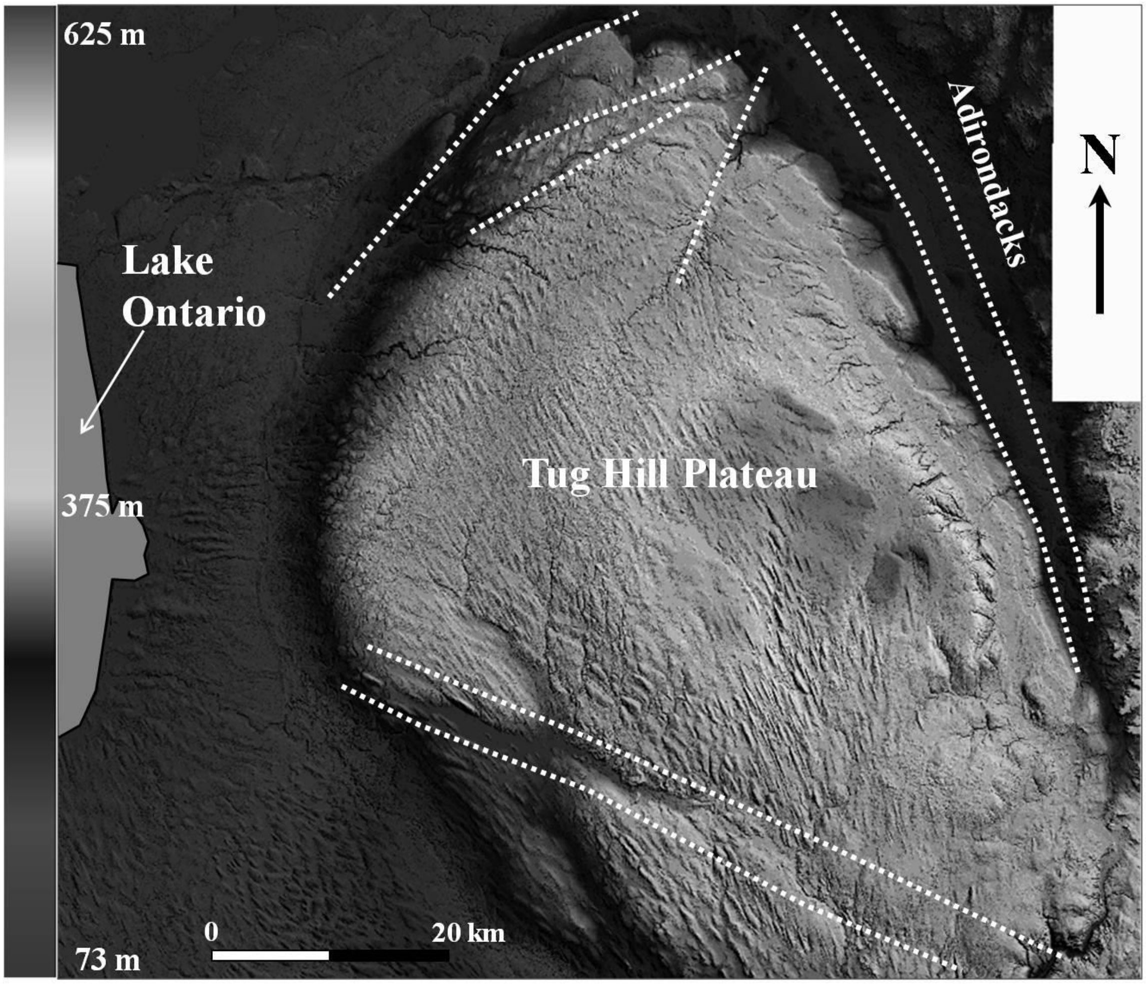

Figure 2. *Digital elevation model for the Tug Hill plateau. The dashed lines are proposed faults of Wallach and Reault (2010).*

TUG HILL PLATEAU GENERAL STRATIGRAPHY

The middle Ordovician strata of the Tug Hill plateau record the transition from marine to terrestrial deposition associated with carbonate sedimentation during the late stage of the Laurentian passive margin (Black River and Trenton groups), and siliciclastic deposition related to the onset of the Taconic orogeny (Lorraine Group) (Patchen, 1966; 1978) (Figure 3). The Tug Hill plateau sequence includes the Black River and Trenton Group carbonates that reside nonconformably on the crystalline basement, and the unconformity is exposed in the Black River valley. The thick limestone sequence that makes up the Trenton Group is directly overlain by the Utica black shale across an abrupt disconformity contact. With a progressive increase in the occurrence of siltstone beds, the Utica Formation transitions upward into the Whetstone Gulf Formation, and in turn the Whetstone Gulf Formation grades upward into the Pulaski Formation with the increase in the number of sandstone beds. Finally, with a marked decrease in the number of shale beds, the Pulaski Formation grades upward into the thin to thick bedded sandstone of the Oswego Formation. Although earlier geologic maps (Isachsen and Fisher, 1970) show a few isolated occurrences of Queenston shale, the cap-rock for the Tug Hill plateau is primarily the Oswego sandstone. The Oswego sandstone is interpreted to represent the transition from marine to fluvial deposition, with source region to the south-southeast based on paleocurrent indicators (Patchen, 1966; 1978).

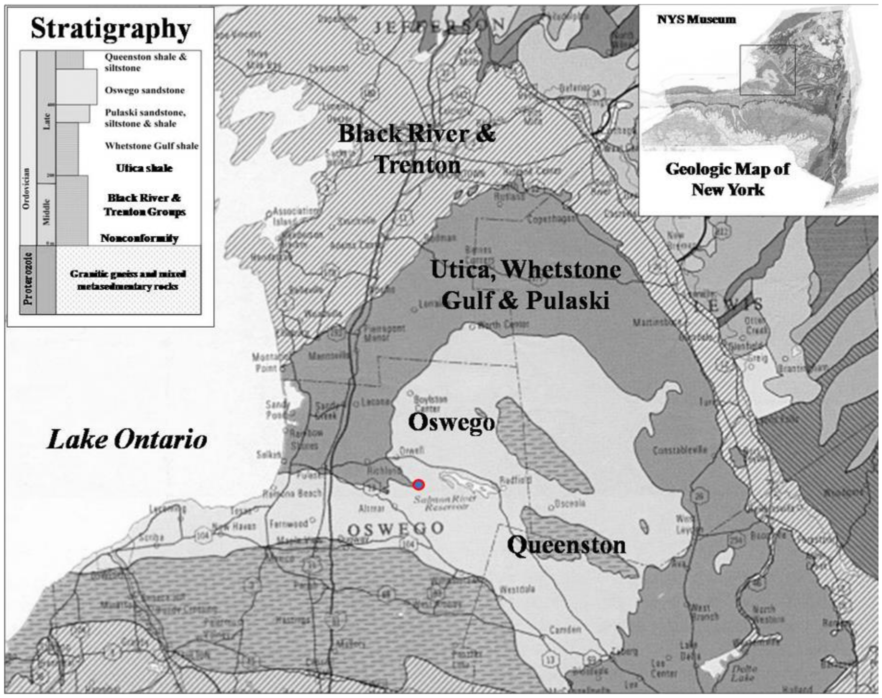

Figure 3. *Geologic map of the Tug Hill plateau (Isachsen and Fisher, 1970). The inset shows the general stratigraphy.*

Figure 4. *Photograph of the strata at the Salomon River falls. The gradational lithologic transition from the Pulaski formation (sandstone and shale) to lowermost Oswego formation (dominantly sandstone) is best exposed at this location. The stratigraphic column to the left represents the occurrences of sandstone (yellow) and non-sandstone (purple) strata (shale and siltstone beds).*

JOINTS, FRACTURE ZONES AND FAULTS

The orientation and density of various joint sets, fracture zones and faults in the strata of the Tug Hill – Eastern Lake Ontario region have been documented (Stilwell et al., 2005; Valentino et al., 2011). This field trip will focus on the variation in fracture systems within the Pulaski-Oswego formation transition that is fully exposed at the Salmon River falls, and this information was first presented in 2011 at NYSGA (Valentino et al., 2011).

Pulaski Shale-Siltstone-Sandstone.

Within the Pulaski Formation there are joints with strike variation on a bed-by-bed scale, where the shale, siltstone, and sandstone beds exhibit different fracture sets and densities (Figure 5A). Overall, there are northeast, east-northeast, southeast and south-southeast striking fractures that appear to be tied to specific lithologies. This is the only formation in the Tug Hill plateau that exhibits both joint sets that appear to be associated with the Appalachian basin (J1 & J2) (Engelder and Gross, 1993; Engelder and Lash, 2008) and with the crystalline basement (Valentino et al., 2016). In addition, the shale units in the Pulaski Formation have extensive tightly spaced fracture cleavage ranging from 2 to 5 fractures per centimeter (Figure 6A).

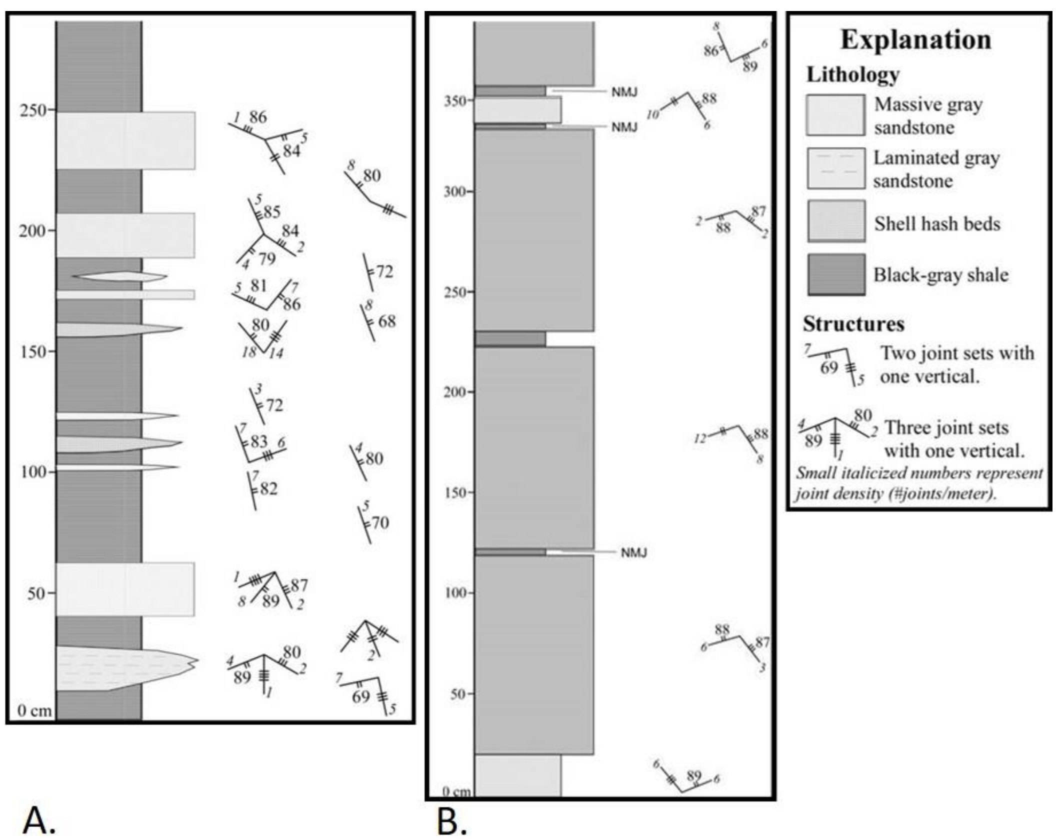

Figure 5. *Representative stratigraphic column for the Pulaski Formation (A) and Oswego Formation (B) at Salmon River Falls, Oswego County.*

<u>*Oswego Sandstone*</u>

Within the Oswego Formation, there are dominant east-northeast and southeast striking joint sets that persist from the region of Lake Ontario to the fringe of the Tug Hill plateau (Figures 5B). These joint sets are consistent throughout the sandstone and only vary in strike where beds are either very thick (> 40 cm) or very thin (<2 cm). There is evidence for minor left lateral shear (2 – 20 cm) on the east-northeast striking joint set, where the southeast striking joints have been displaced horizontally. Small en-echelon fracture zones with left lateral geometry have a consistent strike with the individual fractures (Stilwell et al., 2005; Valentino et al., 2011). At the Salomon River Falls, the large pavement outcrop reveals meter-scale right stepping fracture array associated with the east-northeast striking set (Figure 6).

REGIONAL FRACTURE SYSTEMS

Joint density (joints/meter) is the inverse of joint spacing. For example, a joint density of 5 joints per meter is equivalent to a rock with average joint spacing of 20 cm. Joint spacing was plotted using box-and-whisker (Mcgill et al., 1978) diagrams (Figure) for comparison within rock formations across the region, and for comparison between the different formations, including the Pulaski and Oswego Formations. Two integrated box-and-whisker diagrams were plotted to portray variation in the strike direction of the joint sets against the variation in the joint spacing. This type of plot allowed for visual and quantitative comparison within and across rock formations. Mean joint spacing of 10 cm is consistent throughout much of the Pulaski Formation,

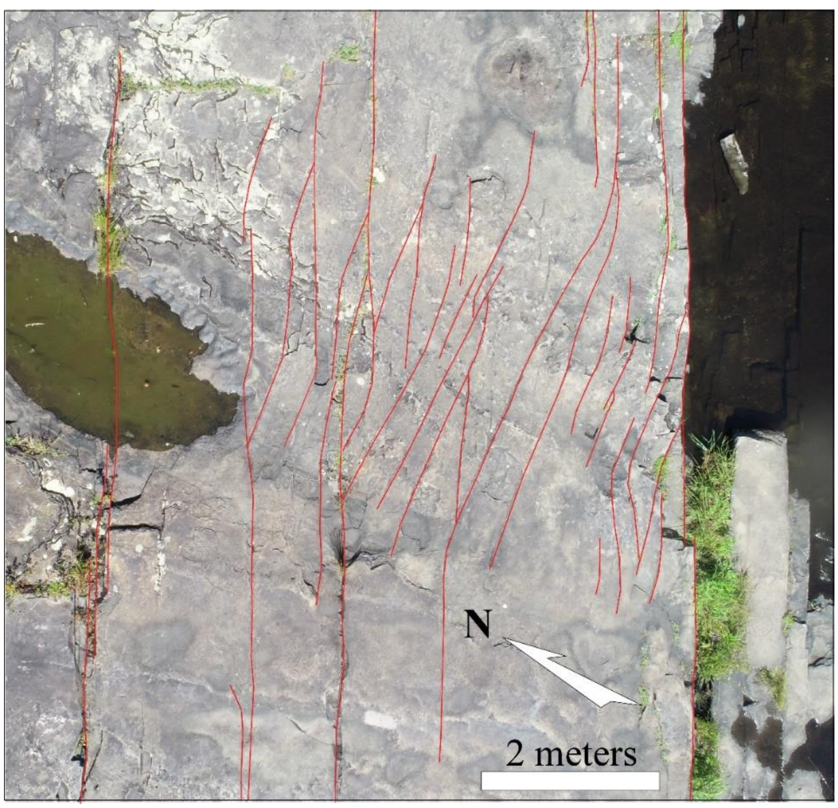

Figure 7 - Right stepping complex fracture array associated with the E-NE striking set. This is the same set of fractures that have sinistral en-echelon zones at the top of the Oswego sandstone.

where the southeast, east-northeast and northeast striking joint sets are dominant. Within the sandstone of the Oswego Formation, there are only southeast and east-northeast striking joint sets with mean spacing of 25 cm (Figure 7A). The Oswego Formation contains by far the most consistent joint-set occurrence in the entire plateau (Valentino et al., 2011), strike and spacing, probably reflecting the thick beds and relatively homogenous lithology of the formation.

From the field observations during this study, it is apparent that joint density and strike are variable at the outcrop scale. However, at the regional scale, it is also apparent that joint variability is related to the proximity to the crystalline basement both laterally and stratigraphically, and related to the variation in rock type with mechanical characteristic control on the fracture and fault formation (Figure 7). Starting at the base of the plateau, the limestone units have the most variability in joint strike with all sets that are present. The joint densities are relatively moderate with ~5 joints/meter in the rocks of the eastern flank of the plateau, and 2-3 joints/meter in the rocks of the western flank. In addition, the limestone units contain the highest number of southeast striking normal faults, and they are roughly parallel with the Black River fault (Figure 2) (Wallach and Rheault, 2010; Wallach, 2002). Within the shale-bearing rock formations, faults are not common, but the fracture density is high in all of the sets that are present, with density values that exceed 20 joints/meter. There are dominant northeast, east-northeast and southeast striking fracture sets with only a minor occurrence of the north-south striking Appalachian basin cross fold joints (Engelder and Lash, 2008). Finally, in the sandstone that caps the plateau, the fracture sets have a generally low density of <1-4 joints/meter (Figure 7A), and only the east-northeast and southeast striking fracture sets are present. The east-northeast striking joint set has evidence for left lateral shear (Stilwell et al., 2005; Valentino et al., 2011), which is evident in the offset of southeast striking fractures and primary en-echelon fracture zones.

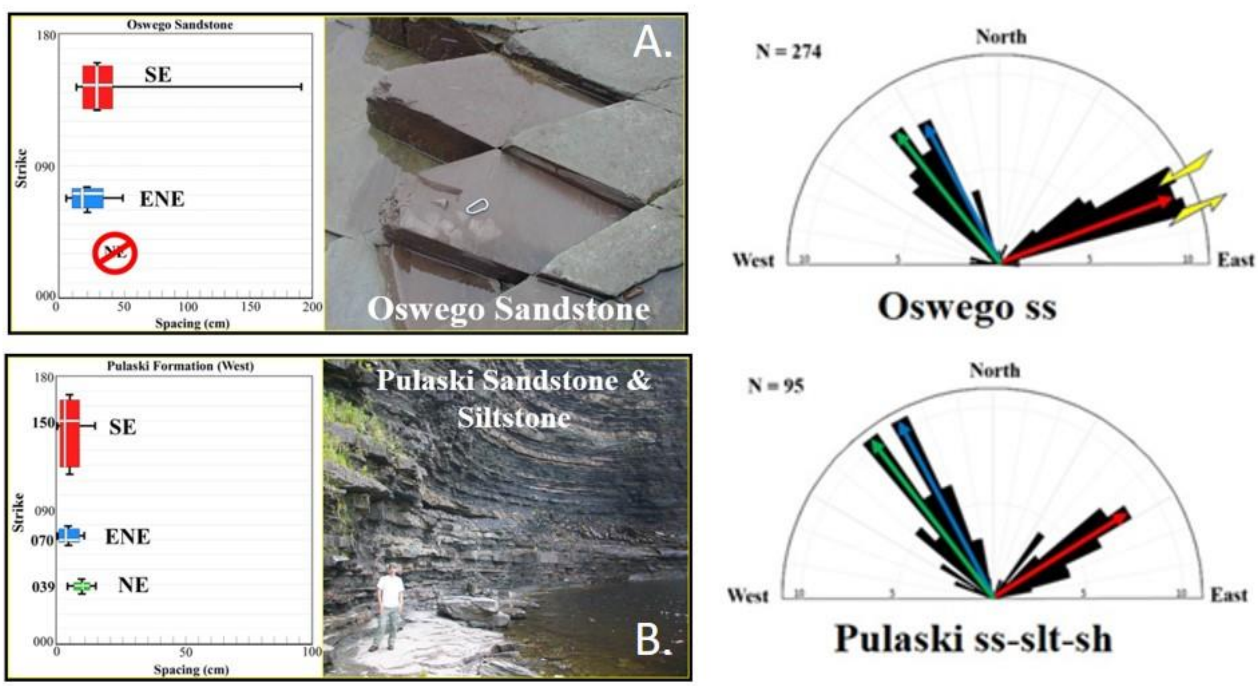

Figure 7. *Box and whisker plots and rose diagrams showing the orientations and spacing of fracture sets in the Oswego (A) and Pulaski (B) Formations at Salmon River falls.*

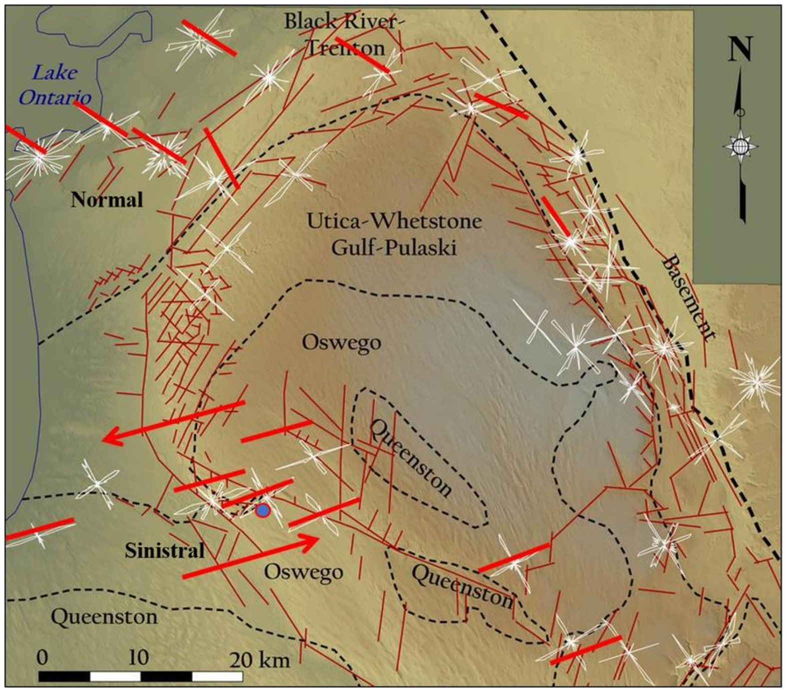

Figure 8. *Digital elevation model for the Tug Hill plateau with geologic formations, joint rose diagrams, and faults. The Black River fault is from Wallach and Rheault (2010). Minor faults are represented by short heavy lines represent observed faults. Those faults exhibit normal displacement in the northwest region and sinistral displacement in the Oswego Formation. The lighter weight red lines are interpreted topographic lineaments that are not related to glacial deposits.*

Four systematic joint sets were observed in the strata of the Tug Hill plateau. The east-northeast striking (J1 of Lash and Engelder, 2009) joints are well developed within all of the Ordovician rock units of the Tug Hill plateau, and there may also be some occurrences in the underlying basement. Note that these fractures are well developed in the underlying Trenton and Black River Group carbonates, suggesting that they are related to basement structure. Considering the persistence of these joints in all of the Ordovician strata, then perhaps they reflect the general east-west subhorizontal compression associated with the Alleghanian orogeny in the northern Appalachians, and the impact of that event on the underlying basement. On the contrary, the north-south striking cross-fold joints (J2 of Lash and Engelder, 2009) are only of minor occurrence, most likely due to the distal location relative to the Alleghanian thrust and fold belt.

The northeast and southeast striking fracture sets that dominate the crystalline basement (Figure 8) are also developed in the overlying Ordovician strata of the plateau, but the occurrence is variable. The northeast striking fractures have direct correlation with a suite of steeply dipping northeast striking normal faults in the southern Adirondacks (Roden-Tice, 2000; Valentino et al., 2011), however, no dip-slip deformation has been documented for the northeast striking joints in the Tug Hill plateau. Barosh (1990, 1992) proposed the northwest trace of oceanic fracture zones into eastern North America, showing several possible extensions into the Adirondack and Tug Hill regions. These proposed fracture zones are the likely cause of the southeast striking basement fracture set, in addition to the southeast striking faults that occur within the Trenton Group. In the statistical analysis of Adirondack faults, Deneshfar and Ben (2002) also concluded that the northwest striking faults to be candidates for seismic activity. Wallach and Reault (2010) demonstrated that southeast striking faults account for the southwestern regional tilt of the Ordovician strata and accommodated the vertical rise of the crystalline basement during formation of the Adirondack dome. The east-northeast striking sinistral faults in the Oswego Formation cross-cut the southeast striking fractures. This relative timing suggests that the sinistral deformation post-dates, or is synchronous with uplift of the Adirondack dome. This is most likely reactivation of the earlier developed J1 Appalachian joints (Lash and Engelder (2009) as the result of differential uplift of the Adirondacks. These faults were only observed in the Oswego Formation, suggesting that the underlying shale units accommodated strain through partial plastic deformation. Note the development of cleavage in the Pulaski Formation, as discussed above.

THE FALLS GEOMORPHOLOGY

Above the falls, the Salmon River flows generally toward the west-northwest (290^o). And continues on this path immediately downstream of the falls, until it enters two abrupt bends forming a "horseshoe shaped" gorge, then flows south-southeast parallel to the upper section (Figure 9). The river then takes another abrupt bend tow the southwest. Superficially, it appears that the river below the Salmon River falls is confined to a gorge that parallels the local fracture systems that occur in the Pulaski Formation. Despite this apparent correlation, the river flow across the Oswego Formation above the falls does not correlate with the fracture sets in the sandstone, but the face of the falls is clearly controlled by the northeast striking fractures (Figure 1). Although normal faults are not common in the Pulaski Formation, there is a minor fault that occurs in the strata on the southeast face of the falls and it traces upward into the Oswego sandstone where it can be observed at the lip of the falls. In the Pulaski Formation, this fault has minor normal offset (<1 m), but exhibits no displacement in the sandstone at the top of the falls. This fault is the location of the current face of the falls, and therefore, most likely contributed to the current orientation.

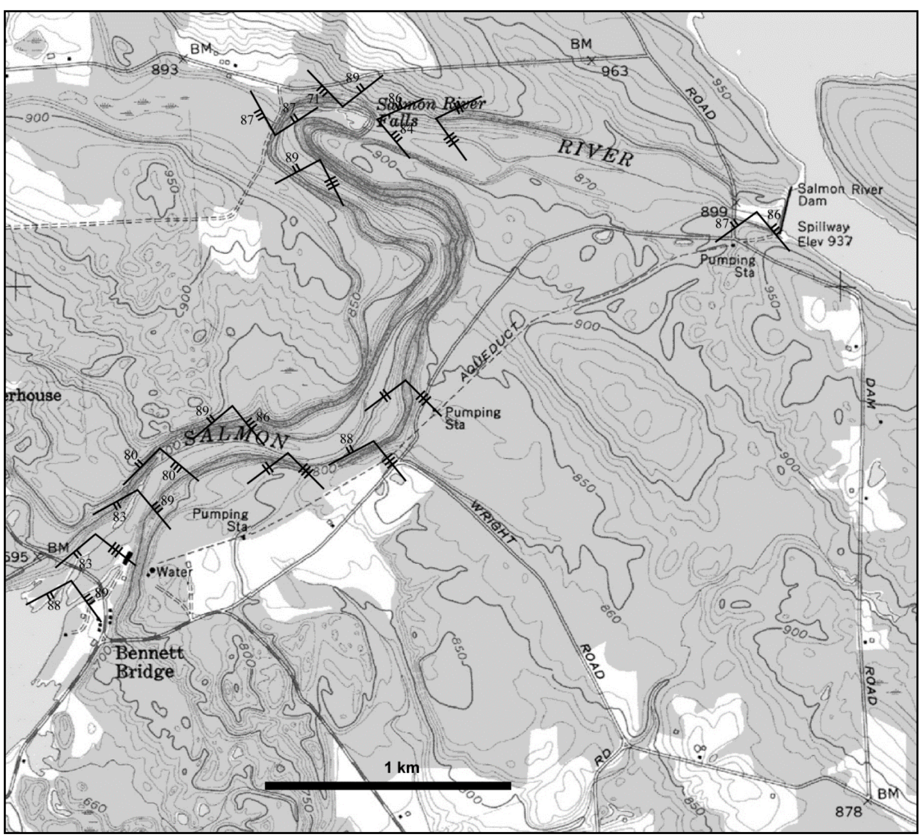

Figure 9. *Joint map for the Salmon River gorge, Oswego County, New York.*

ROAD LOG AND OUTCROP DESCRIPTIONS

Drive to the following coordinates: 43°32'56.47"N; 75°56'37.41"W

Park vehicle in the designated place. Follow the path northeast to the top of the Salmon River Falls.

This stop description was first prepared for the 2005 NYSGA conference and appears in Stilwell et al. (2005). Follow the steep path (with stone stairs) into the Salmon River gorge. The path splits in two directions at the river level. Follow the river bank to the right (southwest) about 200 m to the waterfall. Stop 5 is the series of outcrops that start at the waterfall and end at the sharp bend in the river downstream. At the river level, thick beds of sandstone comprise the lower part of the Pulaski Formation. Long joints (up to 30 m long), strike about 025 and are steeply dipping. These fractures are spaced about 1-2 meters and intersect discontinuous joints that strike northwest (Figure 9). The thick sandstone beds are overlain by interbedded sandstone, siltstone and shale that is progressively more dominated by fine grained sedimentary rocks upward. This sequence of rocks is best viewed in the cliff face that occurs in the sharp bend in the Salmon River. Walk back to the path and climb up the gorge. Follow the path eastward to the top of the Salmon River Falls. At this location, please obey all safety signs and stay in the designated areas. Stop 6 is the pavement outcrop at the top of the falls of Oswego Formation. Here the rocks are green-gray sandstone with abundant ripples and large cross-beds. Joints transect the entire outcrop for many meters and occur in complex zones. The dominant joint set strikes about 060, but is associated with some complex joint patterns. In places the individual joints with an average strike of 035 curve and are continuous with the 055 striking fractures. Additionally, there are en echelon fracture zones with apparent left lateral geometry that merge with the dominant fracture set, and large right-stepping fracture zone (Figure 7)

End of trip.

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