Trip A-3

FRACTURES AND FAULTS IN THE EASTERN LAKE ONTARIO BASIN, OSWEGO COUNTY, NEW YORK

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INTRODUCTION

The central Appalachian basin is host to a number of regional joint sets associated with the late Paleozoic Alleghanian orogeny (Engleder, 1979; Engelder and Geiser, 1980; Evans et al., 1989; Zhao and Jacobi, 1997; Younes and Engelder, 1999; Engelder et al., 2001). A number of researchers demonstrated the orthogonal relationship between fracture sets and the trend of broad-open folds in the Paleozoic strata, and concluded that a major set are cross fold joints (Engelder and Geiser, 1980; Engelder, 1985). Cross fold joints are fractures that develop perpendicular to fold axes, and occur as non-parallel sets (Zhao and Jacobi, 1997) in the Appalachian basin of Pennsylvania and New York due to the arcuate shape of the orogen. Generally, the cross fold joints radiate perpendicular to the acuate trend of the orogen. In central New York, the northern extent of the Appalachian basin, steeply dipping fractures that strike generally northwest are interpreted to be cross fold joints (Zhao and Jacobi, 1997). Development of these joints requires a component of orogen parallel tension. In a systematic study of regional joints, Engelder (1982) proposed a tie between specific joint sets and the contemporary stress within the lithosphere. This set of steeply dipping joints strikes generally east-northeast and were documented throughout the Appalachian basin from Ohio to central New York and it was proposed that they are related to the contemporary stress field (Engelder, 1982).

Along the southeastern shoreline of Lake Ontario (Figure 1) there are abundant outcrops of Ordovician Oswego Formation. As well, the eastern rivers within the basin are down-cut into the underlying Pulaski Formation forming excellent bedrock exposures in the Salmon River gorge (Figure 2). Both of these rock

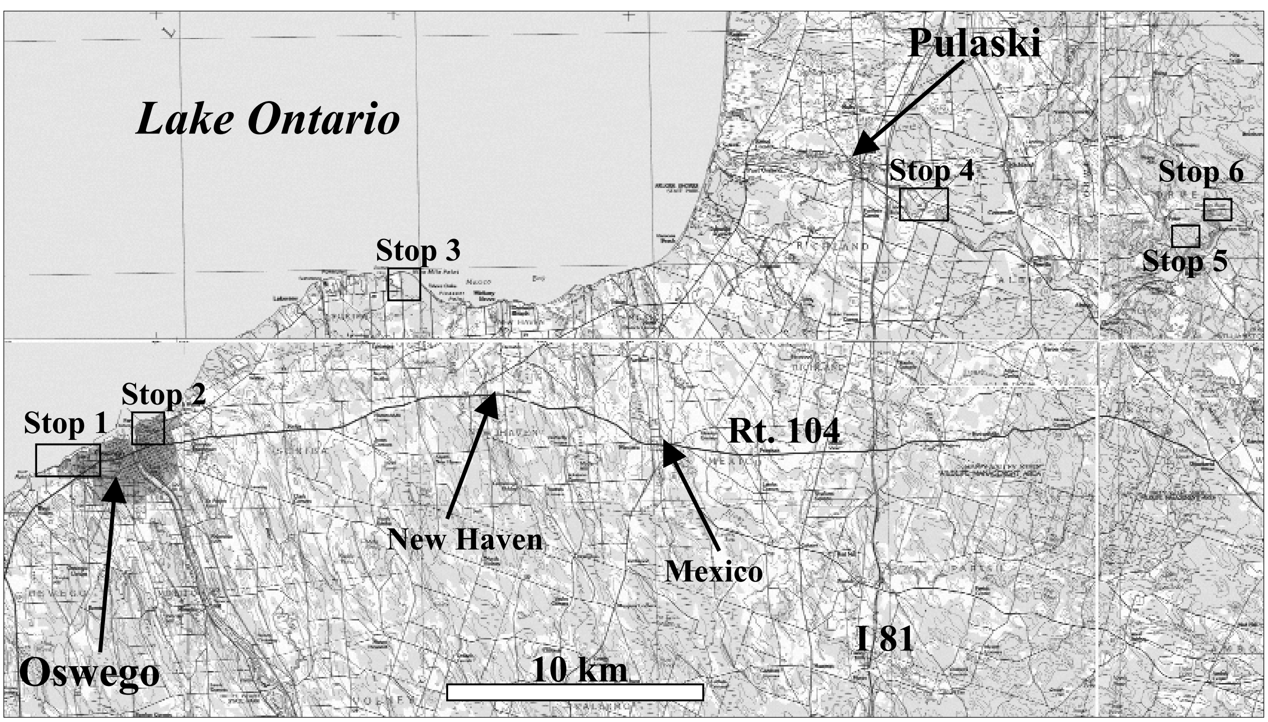


Figure 1 – Map of the eastern Lake Ontario region with stop locations shown.

formations are dominated by clastic sedimentary rocks, are generally flat lying and contain a number of systematic joint sets. A recent study of these joints documented sets with orientations similar to the cross fold joints described above. Additionally, a set of east-northeast striking joints have evidence for sinistral shear including displacement of earlier joints and parallel zones of en-echelon fractures. During this field trip six locations will be visited to show the regional and local fracture sets in the Ordovician Oswego and Pulaski Formations in the eastern Lake Ontario basin, with special emphasis on evidence for sinistral shear.

BEDROCK GEOLOGY OF THE EASTERN LAKE ONTARIO BASIN

The central region of Oswego County, New York is underlain by the Ordovician sedimentary rocks of the Pulaski and Oswego Formations. The Pulaski Formation consists of interlayered gray-red sandstone, siltstone and shale with the amount of shale decreasing upward in the section. The best outcrops occur in the Salmon River gorge in the eastern part of the county. The Pulaski Formation is overlain by the Oswego Formation, named for the excellent bedding-plane exposures in the Oswego River and along the shoreline of Lake Ontario in the city of Oswego, NY. The Oswego Formation is characterized by interlayered thin to thick beds of gray-green sandstone and siltstone containing large cross beds, abundant ripple marks, channel structures, and rare trace fossils (Patchen, 1978). The contact between the Pulaski and Oswego Formations is gradational with the Pulaski Formation containing substantial shale and the Oswego Formation containing only minor shale partings (Fisher and Laird, 1978). Taken together, these formations represent a regressive package of sediments associated with the transition from marine to terrestrial depositional environments and the onset of the Taconic orogeny (Patchen, 1978). The Pulaski and Oswego Formations are generally flat-lying with only minor eastward dip of a few degrees locally. No major faults are shown to break these formations in Oswego County, however, both formations contain extensive joints and minor faults.

Figure 2 – Photograph of the Pulaski and Oswego Formations at the Salmon River Falls, Altmar, New York. Most of the cliff face is the Pulaski Formation with the transition to the Oswego Formation in the uppermost section. The transition is marked by a decrease in shale and the absence of fossils (Patchen, 1978).

BEDROCK JOINT DATA

Joints were studied at outcrops of the Oswego Formation along the Lake Ontario shoreline, in the riverbed of the Oswego River, and in the Pulaski Formation in the Salmon River gorge. Outcrop maps were completed for all the exposures along the lake-shore and in the Oswego River. These maps include the attitude of every major joint (joints that transect the entire exposure) and a systematic sampling of typical discontinuous joints. As well, these maps document joint density for specific sets, the distribution of en-echelon fracture zones, and domains of high-density joints. The joint density was quantified at most outcrops by counting the number of joints that occur over the outcrop distance, measured perpendicular to the joint set, and the joint density was determined for each joint set separately. Where available, joint patterns were interpreted from high-resolution air photographs (Figures 3 & 4). The length and strike of individual joint traces were collected from the photographs. Finally, any kinematic information, such as slicken-sides, en echelon zones, or off-set markers were noted to assess potential displacements associated with shear fractures.

Regional Joints Patterns

In general, two joint dominant joint sets occur in the Oswego and Pulaski Formations in Oswego County. At any given outcrop, just one may be present, both present with either one as the dominant (higher density) set. Figure 5 shows the typical distribution and geometry of joint sets in the Oswego Formation at SUNY-Oswego. The Oswego Formation contains thick beds of sandstone with large cross beds common (Figure 5A), and the Pulaski Formation consists of interbedded shale, siltstone and shale (Figures 2 & 6). Generally, the two joint sets are subvertical and strike NW and ENE. The regularity of the spacing and planar morphology of two joint sets produced a “diamond” shaped pattern in the bedding planes (Figures 5B, 5C & 6C). Few plumose structures were observed on joint surface in the Oswego Formation, however, there are few favorable exposures to view joint surfaces, and many are severely weathered. On the contrary, the exposures of the Pulaski Formation exhibit excellent plumose structures (Figure 7). Some well exposed joint surfaces exhibit irregular jagged, or “stair-shaped” asperities (Figure 5D).

Systematic sampling of hundreds of joint orientations from the Lake Ontario shoreline reveals the consistency of joint attitude in the Oswego area. Rose diagrams were produced to portray the strike of the joints, and the obvious joint populations that are viewed at the outcrop dominate the plots (Figure 8), however, the attitude of the joints varies about 10^{o} to 20^{o} from the Oswego shoreline and in the Oswego River bed. A third population of joints with a generally N-S strike occurs in the rose diagrams, but are less apparent at most outcrops. The trend of joint traces interpreted from high-resolution air photographs (NYS GIS Clearinghouse) taken immediately offshore at SUNY-Oswego show nearly the same pattern that is observed at the outcrop, with the exception that the individual joints are much larger than the average shoreline exposures. These data was collected using a scale-calibrated image in a computer-mapping program (Canvas GIS), where interpreted joint traces were quantified for attitude and length. A map of the interpreted joint traces appears in Figure 4. The interpreted joint traces were sorted according to length and attitude, and the rose diagrams of Figure 9 show the systematic variation. Most very long joints are parallel to the east-northeast striking set.

EVIDENCE FOR SINISTRAL SHEAR

En-echelon Fracture Zones

En-echelon fracture zones have been found in the Oswego and Pulaski Formations. The individual fractures that make up the zones strike about 25^{o} to 30^{o} anticlockwise to the general east-northeast strike of the fracture zone (Figure 10). The boundaries of these en-echelon zones are roughly parallel to the joints that strike east-northeast. In some cases, the trace of an individual fractures terminates by curving into the leading en-echelon fracture in a zone. Figure 10B shows an example of en-echelon fractures where the individual fracture tips are curved and terminate on the adjacent fracture producing an

Figure 3 – High-resolution air photograph of the shoreline of Lake Ontario at the campus of SUNY Oswego. Air photograph data was obtained from the New York State GIS Clearinghouse internet database. The locations of bedrock exposures discussed in the text are shown. The image also shows major underwater fracture sets.

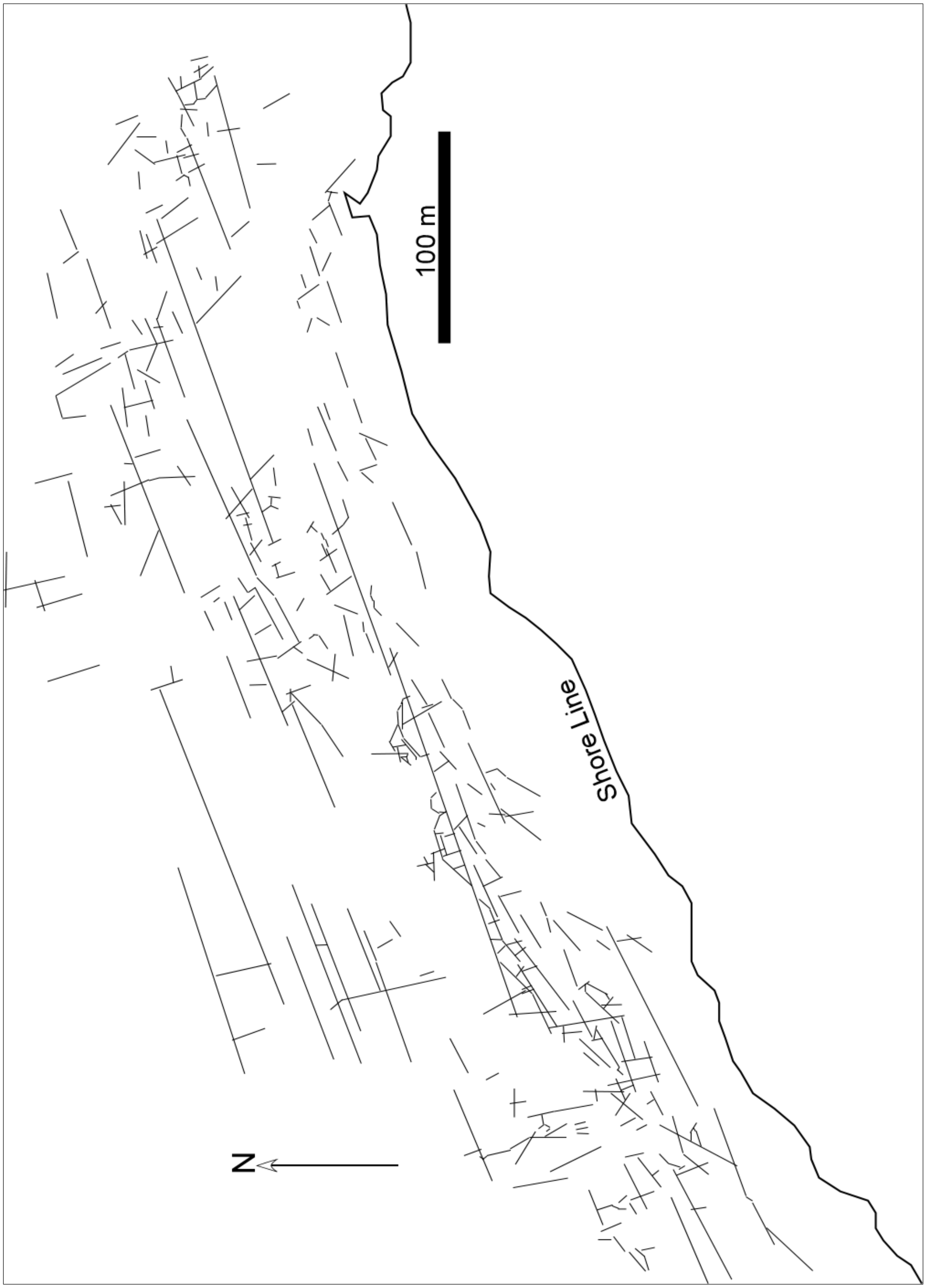


Figure 4 - Fracture trace map interpreted from the air photograph image of Figure 3. Note the continuous fractures that strike east-northeast. They range in length from 10 meters upward to more than 200 meters. These fractures are believed to be the same set that shows sinistral shear in the lake side bedrock exposures.

overall sigmoidal shape for each fracture. The orientation of these en-echelon domains, and the distribution of fractures relative to each other is consistent with a component of left-lateral shear. Often these en-echelon domains are confined to discrete beds in the Oswego Formation, and terminate where the they intersection with the bedding plane. Although the en-echelon fracture zones have been seen throughout the study region, they are best developed in the Oswego Formation along the shoreline of Lake Ontario.

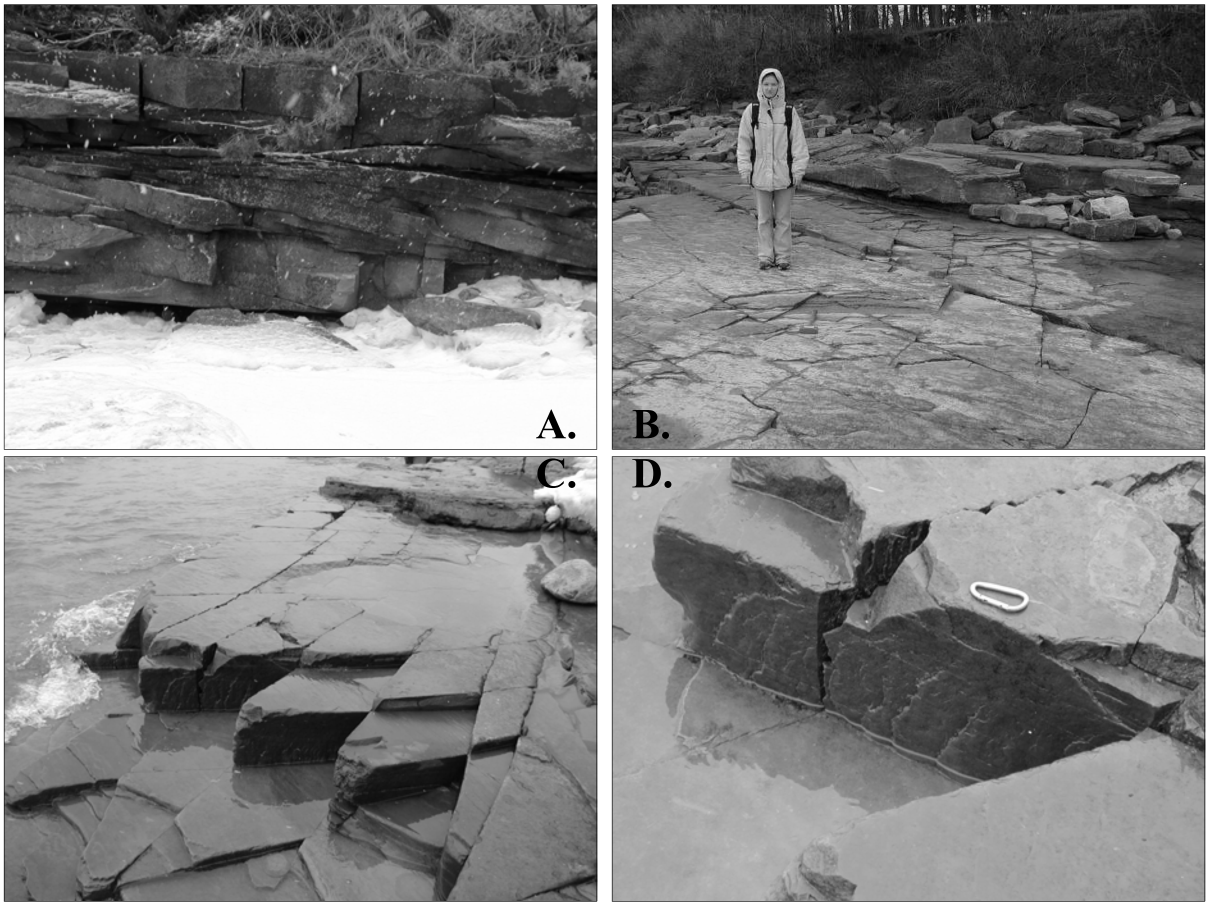


Figure 5 - Outcrop photographs of the Oswego Formation on Lake Ontario. A. Meter-scale crossbeds in sandstone. B. Bedding plane exposure with multiple joint sets. The view is looking southeast. C. Two intersecting joint sets. View is looking easterly. D. Close up view of the NW striking joint showing the irregular joint surface.

<u>Meso-scale Sinistral Faults</u>

Small faults have been documented in the Oswego Formation along the Lake Ontario shoreline. These faults strike about 070^{o} and are subvertical (Figure 11). They are approximately parallel to the dominant east-northeast striking joints and parallel the local en-echelon fracture zones. As well, they are parallel to the longest fractures that were interpreted from the high-resolution air photograph of Figure 4. Due to limited exposure, the length of these faults has not been accurately determined, however, the longest one observed was traced more than 70 meters parallel to strike. Sometimes these faults occur as discrete breaks in the bedrock, but more often they occur as fracture zones 10 to 20 centimeters wide. These faults appear to cross cut all other joints in the Oswego Formation and the northwest striking set have been used as offset markers (Figures 11B, C & D), that document a left lateral slip history. The most amount of displacement inferred for any one of these faults was about 1 meter, and the average displacement is about 20 centimeters. The dominant joints appear to be mutually intersecting at most outcrops with no apparent displacement, however, in the vicinity of these minor faults, both sets of fractures show evidence for left lateral displacement of the other joint set. Figure 12 shows two examples of northwest striking joints with apparent left lateral displacement of the east-northeast striking joints.

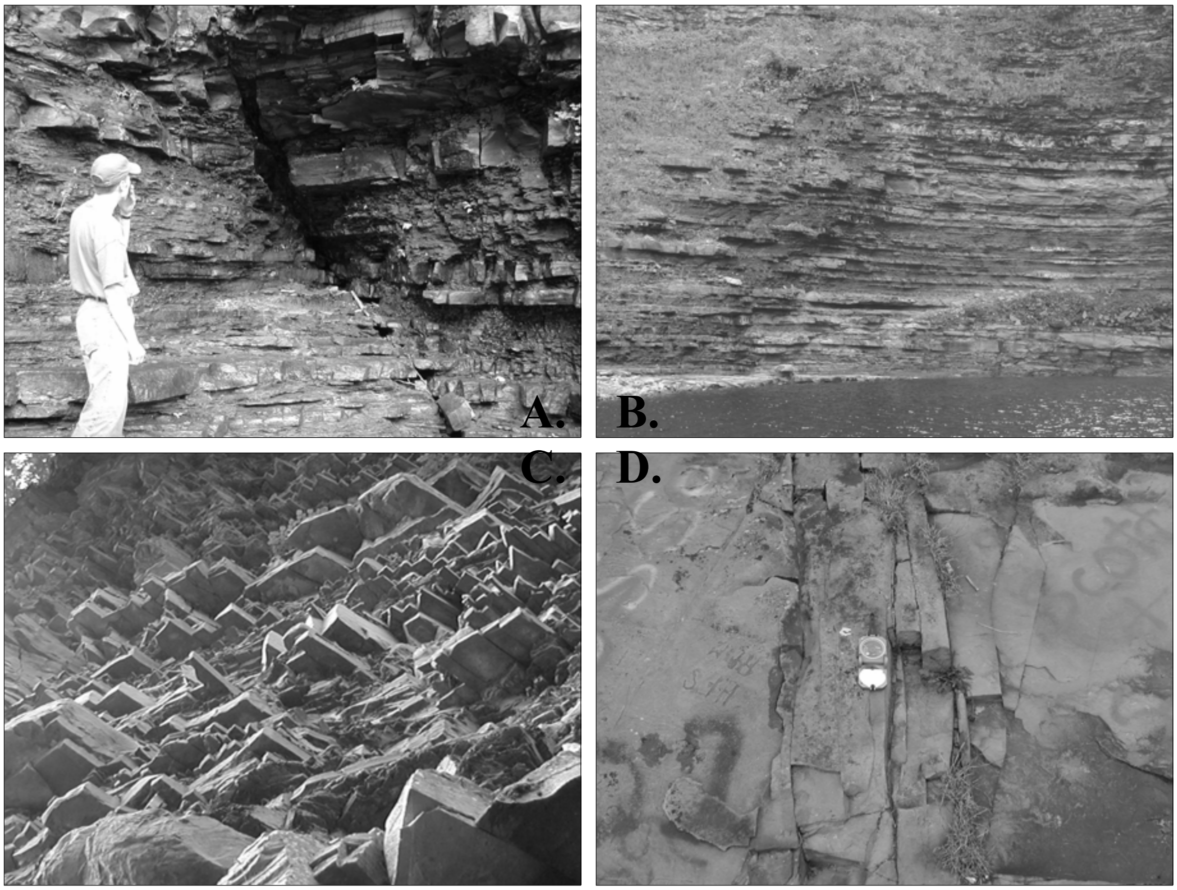


Figure 6 – Photographs of the Pulaski and Oswego Formations in the Salomon River gorge. A. and B. Outcrops of interlayered sandstone, siltstone and shale from the Salmon River falls with a minor normal fault in A. C. Irregular surface in the Pulaski Formation showing the two dominant joints. D. Pavement outcrop of the Oswego Formation from the top of the Salmon River falls with a fracture zone.

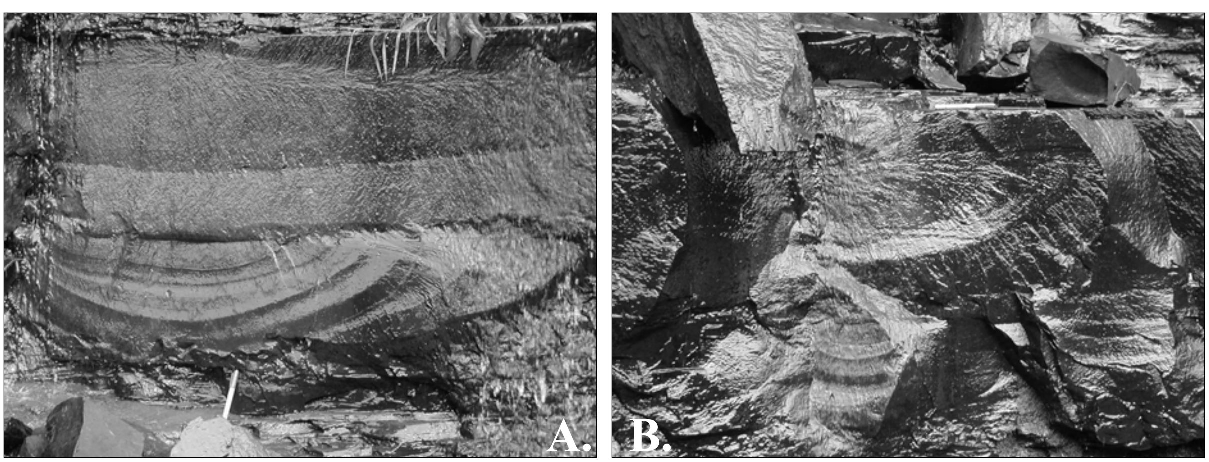


Figure 7 – Joint surfaces in sandstone layers from the Pulaski Formation with plumose structure. The plumose structures are almost always associated with the northwest striking, subvertical fractures. Pencil for scale in both photographs, and the view is looking northeast at subvertical joint surfaces.

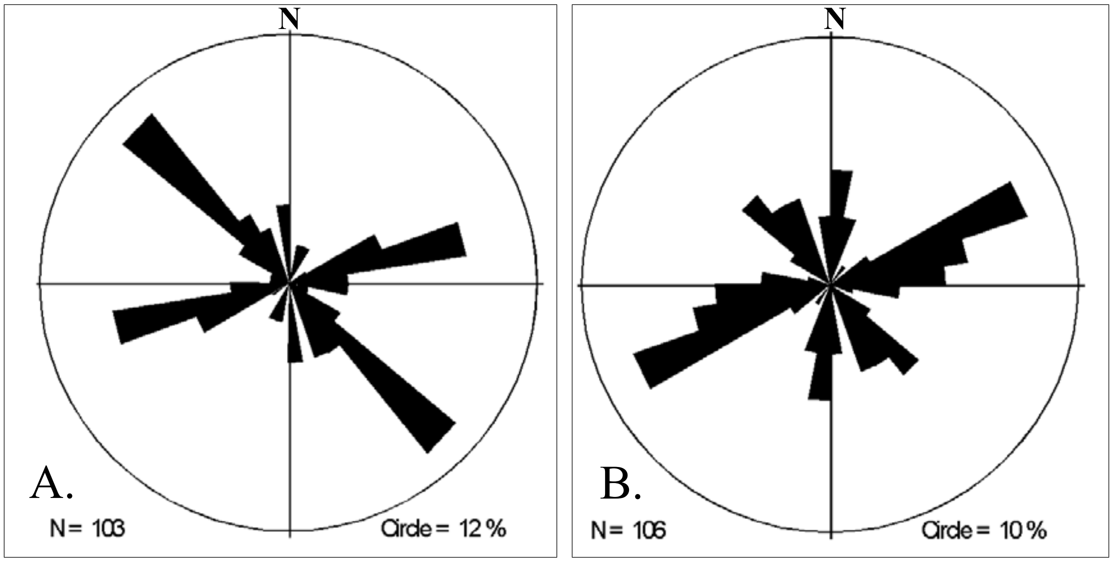


Figure 8 - Rose diagrams for joints that occur in the Oswego Formation in the area of Oswego, NY. A. A composit of shore line outcrops along Lake Ontario at SUNY-Oswego; B. Pavement outcrops that occur in the bed of the Oswego River south of the Utica Street Bridge (these exposures are only available during the lowest water times and will not be viewed during this trip).

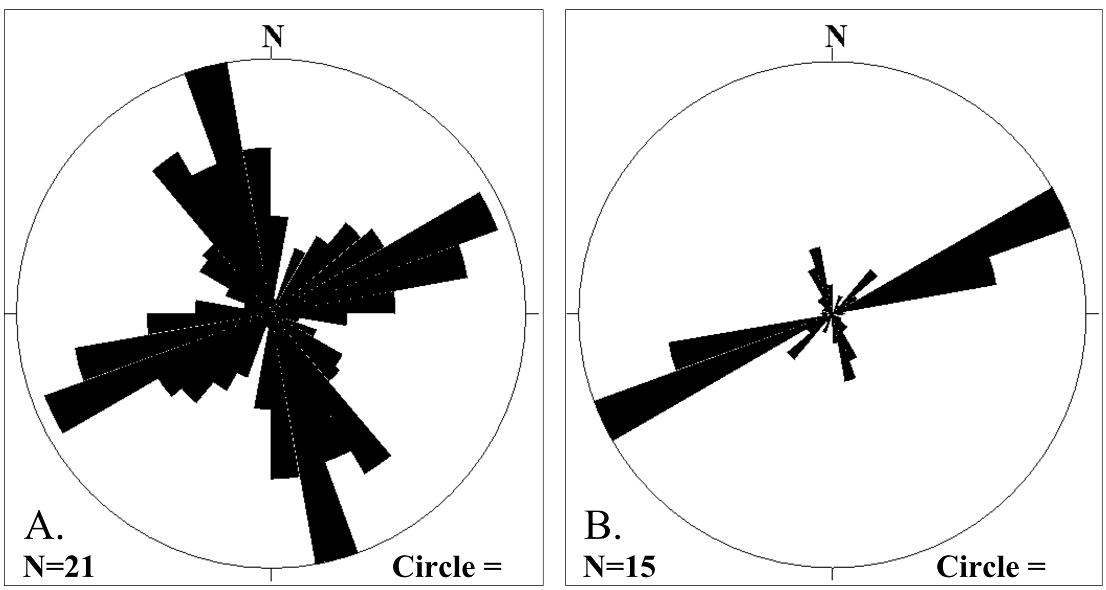


Figure 9 - Rose diagrams for joint traces interpreted from the high-resolution air photograph of Figure 3. The scale of the image was calibrated in a computer mapping program, and the length of joint traces were measured in addition to the attitude. A. Joint traces less than 10 meters in length; B. Joint traces greater than 10 meters in length.

DISCUSSION AND CONCLUSIONS

From out observations of regional and local joint patterns along the southeastern Lake Ontario shoreline and in the Salmon River gorge, there are joints related to those described by earlier researchers in central New York. Specifically, the northwest striking set of subvertical joints is probably related to the late Paleozoic Alleghanian orogeny which produced regional cross fold joints in the Paleozoic strata

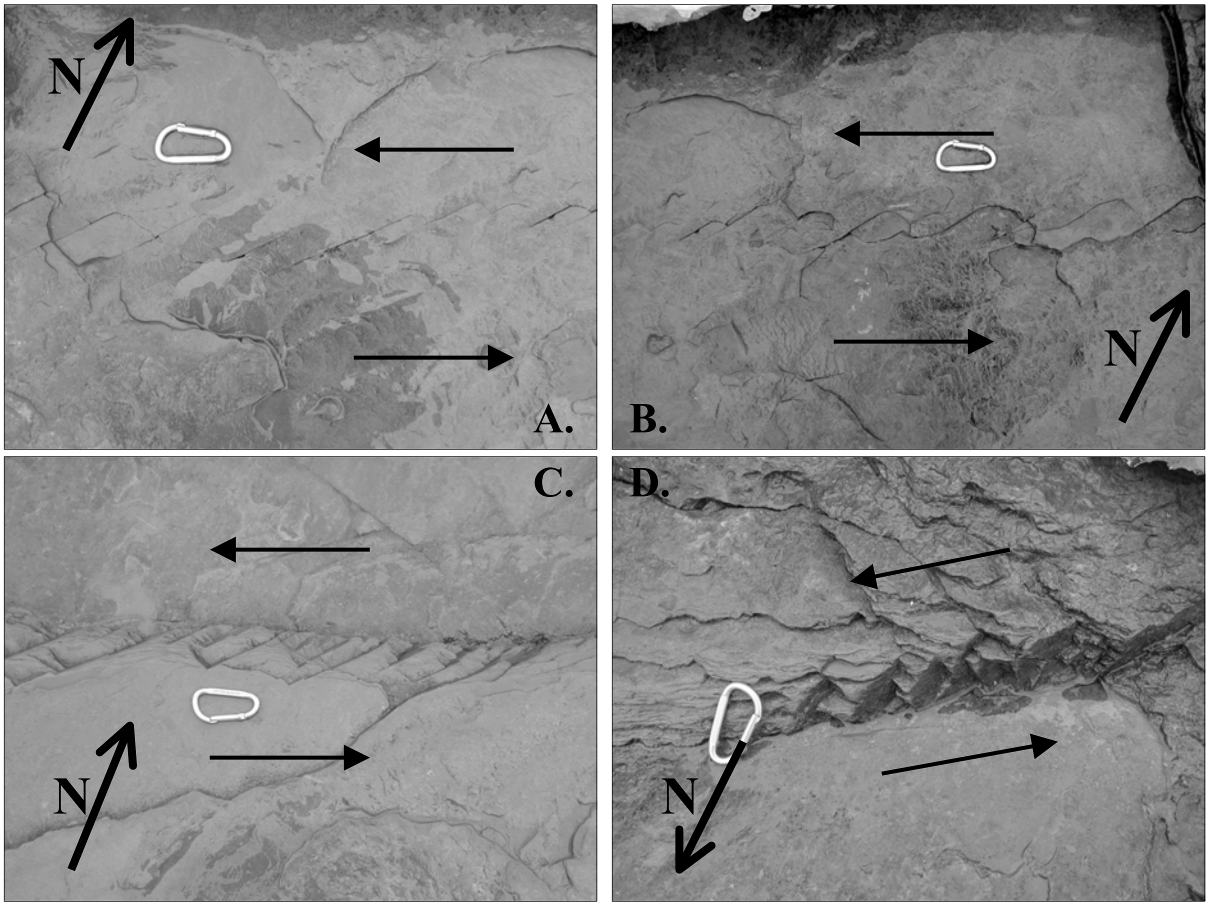


Figure 10 – Photographs from the Oswego Formation showing examples of en-echelon fracture zones. The view for each photograph is looking down at a pavement exposure and the direction of north is shown with the arrow. The metal ring shown in each photograph is approximately 10 centimeters long.

(Engelder, 1979; Engelder and Geiser, 1980; Zhao and Jacobi, 1997). The other dominant joint set, east-northeast striking, are parallel to joints described by Engelder (1982) and proposed to be associated with the modern stress field in the crust. At most outcrops of the Oswego and Pulaski Formations, it is difficult to determine the relative timing between these two joint sets because they appear to be mutually intersecting. However, the east-northeast striking left lateral en echelon fracture zones and minor left lateral faults appear to displace the apparent Alleghanian joints (NW striking set). Engelder et al. (2001) demonstrated minor displacement on joints in the Finder Lakes region, but attributed it to layer parallel deformation during the Alleghanian orogney. Only in the vicinity of these minor faults do the northwest striking fractures show evidence of shear. We interpret this local shear near the left lateral faults as sympathetic reactivation on older joints, possibly those with a locally favorable orientation relative to the stress field that produced the overall left lateral slip. Engelder (1982) proposed that the origin of the east-northeast striking joints could be the result of the contemporary stress field in the lithosphere. If these joints are directly associated with the en-echelon fracture zones and minor left lateral faults, then the local stress field should be consistent with this type of displacement. Overcoring data were collected for Ninemile Pont during the construction of the nuclear power stations (Dames and Moore, 1978). Engelder and Geiser (1984) compiled these data and show that the maximum horizontal compressive stress trends northeast-southwest. The orientation of te inferred stress would be consistent with left lateral slip on east-northeast striking failure surfaces.

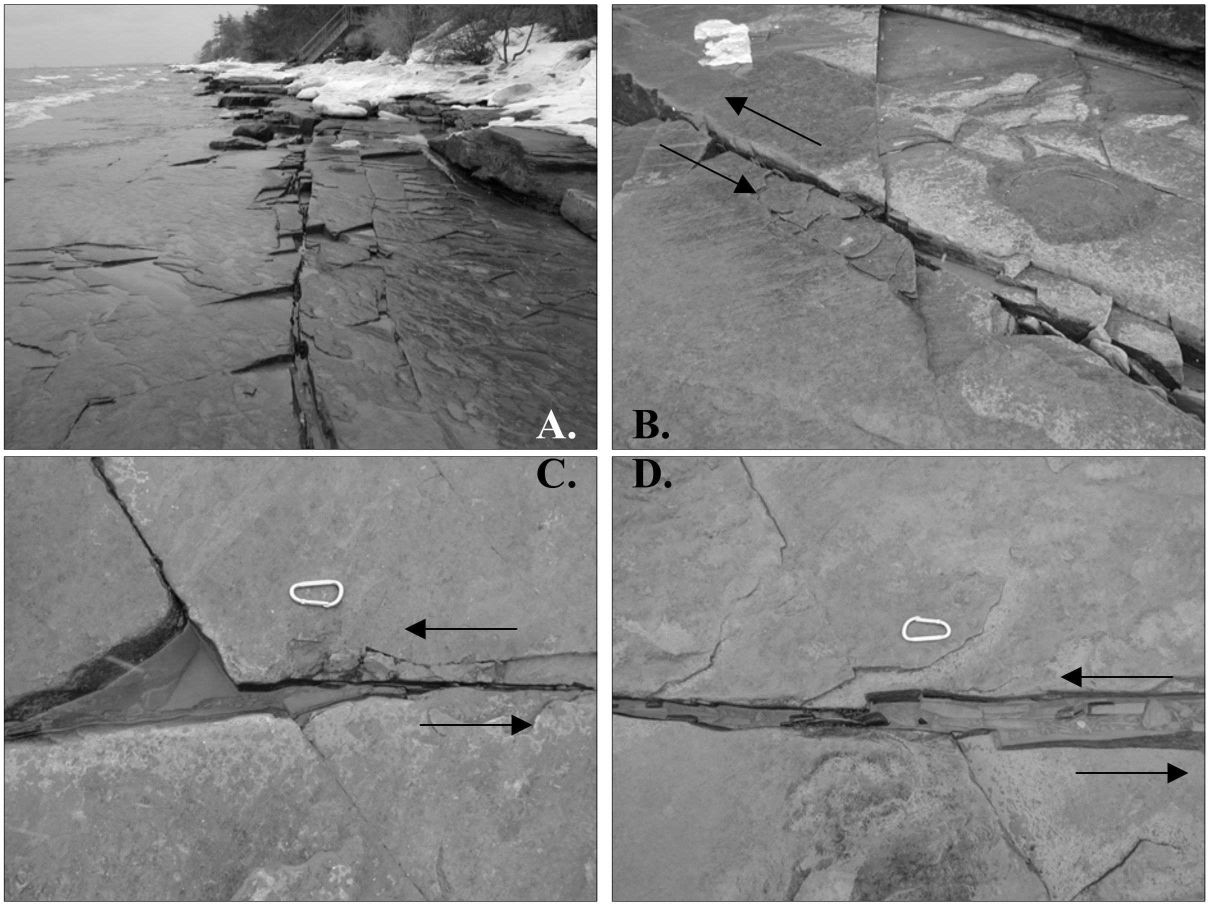


Figure 11 – Outcrops of the Oswego Formation showing a minor sinistral fault with parallel joints at the Lake Ontario shoreline on the campus of SUNY-Oswego. The offset on the fault was inferred from the apparent displacement of the northwest striking fracture set that occurs in the Oswego Formation. The view for A is east parallel to the shoreline. Photo B is a closer view of the central region of photo A. C & D show the apparent left lateral displacement of the northwest striking joints along the same fault.

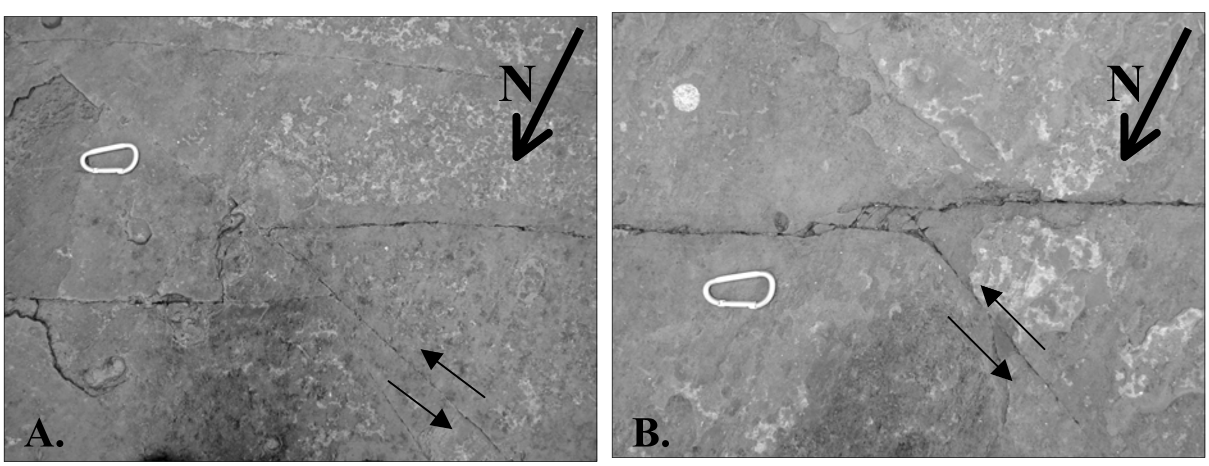


Figure 12 –A. The east-northeast striking joint is displaced about 15 centimeters toward the left along the northwest striking joint. B. The northwest striking joint merges with the east-northeast striking joint at a place where the through-going joint appears to be kinked by left lateral slip on the northwest striking joint.

FIELD TRIP DESCRIPTION AND ROAD LOG

Road Log:
Mileage:

0.0	The trip begins in the eastern parking lot of Piez Hall on the SUNY Oswego campus. Park vehicles at the lot and walk to the lake shore to view the outcrops for Stop 1.

STOP 1 – Pavement outcrops of Oswego Formation at the shoreline of Lake Ontario at SUNY-Oswego.

The shoreline of Lake Ontario at SUNY-Oswego has abundant outcrops of the Oswego Formation (see Figure 4 for the air photograph of this location). At this location, the Oswego Formation is a thick bedded green-gray sandstone (locally red) with minor siltstone and shale partings. Large cross beds and ripple marks are abundant. The fracture patterns described in the text can be seen at most outcrops, but this stop includes the pavement exposure located about 50 meters west of the westernmost metal staircase. This location contains abundant northwest and east-northeast striking joints, en echelon fracture zones, and one of the best exposed left lateral faults. See the text for details.

0.2	Return to the vehicles, turn left out of the parking lot onto Takamine Road and follow to the intersection with Washington Blvd.
0.3	Turn right onto Sheldon Ave. and proceed to the intersection with Washington Blvd.
0.6	Turn left onto Washington Blvd and follow to the intersection with Bridge Street.
2.1	Follow Bridge Street through the city of Oswego, cross the bridge over the Oswego River and continue to East 9th Street.
2.6	Turn left onto East 9th Street and follow to Crisafulli Drive. Turn left.
2.7	Turn right onto the drive that follows around Mcrobie Ball Field.
2.9	Turn right onto the short drive that leads to the parking area.
3.0	Parking area for the Fort Ontario Cemetery. Walk through the cemetery to the path that leads to the lake shore. Follow the railroad tracks west (toward the fort) until you reach the lake side outcrops.

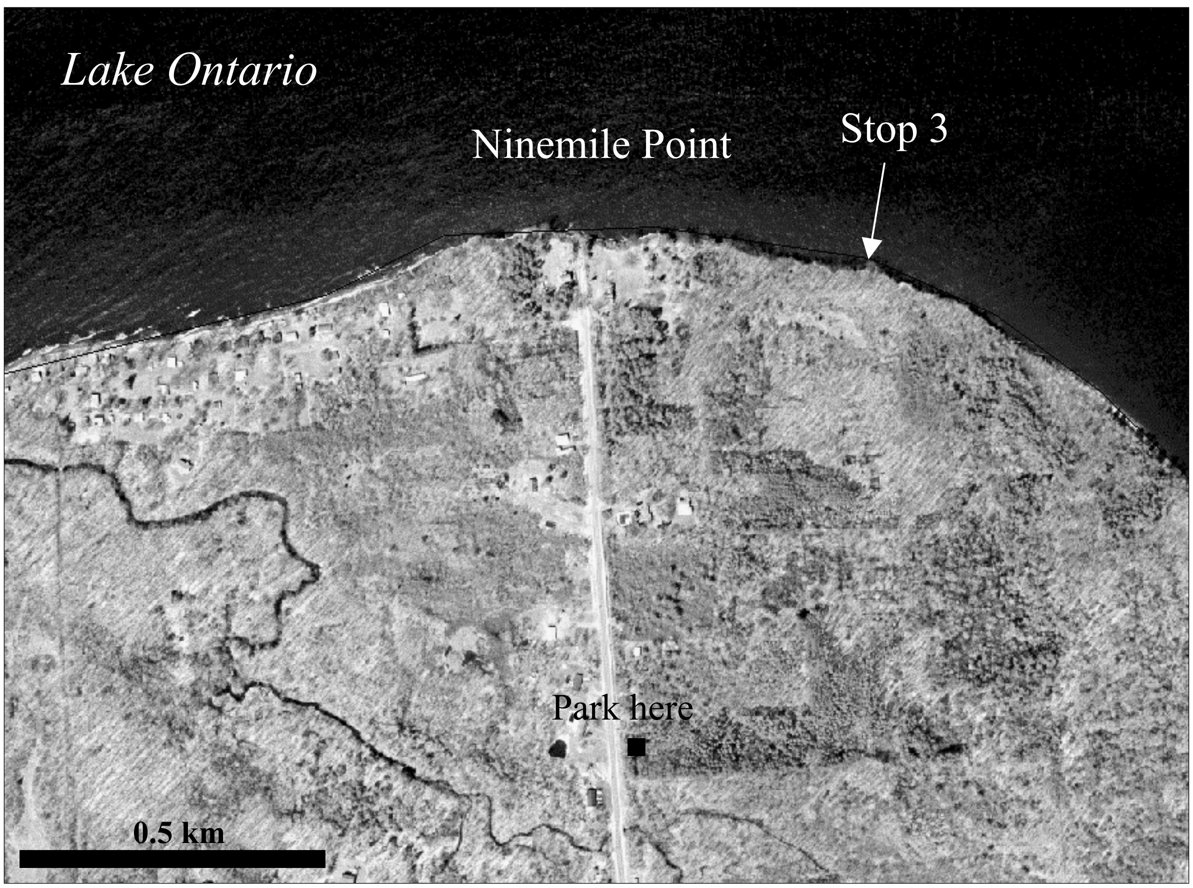
STOP 2 – Fort Ontario, Oswego Formation

A large exposure of the Oswego Formation is located at the lake level below Fort Ontario. If time permits, you are encouraged to visit the historical Fort Ontario, which dates back to the French & Indian War and the War of 1812. The air photo below shows the location of the parking area, the outcrop and Fort Ontario. At this location, the Oswego Formation is again a thick bedded sandstone with abundant joints.

4.9	Back track to the intersection of East 9th Street and Crisafulli Drive and proceed straight onto Mitchell Street to the intersection with East Seneca Street and proceed straight to the intersection with Rt. 1.
10.6	Follow Rt. 1 to the intersection with Ninemile Point Road and turn left.
12.5	Follow Ninemile Point Road to the parking area on the right.

STOP 3: Ninemile Point, Lake Ontario.

From the parking area, follow the foot trail through the forest to Lake Ontario. The walk is about 1.2 km from the parking area to the place where the lake can be easily accessed. At lake level, carefully walk west to the outcrops that form a small cliff. At this location, the bedrock is interlayered sandstone, siltstone and shale, and the relative quantity of shale is more than at Stops 1 and 2. This outcrop is the lower part of the Oswego Formation, and may even represent the transition between the Oswego Formation and the underlying Pulaski Formation.



The attitude of joints at this location varies from the attitude at the previous stops. The rose diagram of Figure 13 shows a composite of 118 joints measured at this location. Fracture density measurements are represented on the detailed stratigraphic column of Figure 13, and show more fractures in the silty and shale portions of the outcrop.

14.4	Back track to Rt. 1 and turn left.
19.1	Follow Rt. 1 to the intersection with St. Rt. 104B, and turn left.

22.1	Follow St. Rt. 104B to the intersection with Co. Rt. 3 and turn left.
26.2	Follow Co. Rt. 3 north to the intersection with St. Rt. 13 in Port Ontario, turn right.
31.3	Follow St. Rt. 13 through the town of Pulask (intersection with Rt. 11) and continue east. At the intersection with Co. Rt. 2A, turn left.
32.4	Follow Co. Rt. 2A to the first Railroad crossing. Park vehicles along the road near the crossing and follow the track west toward the Salmon River. Do not cross the bridge over the river. The outcrop is located in the hill-side along at river level to the right of the tracks. Proceed back to the vehicles.

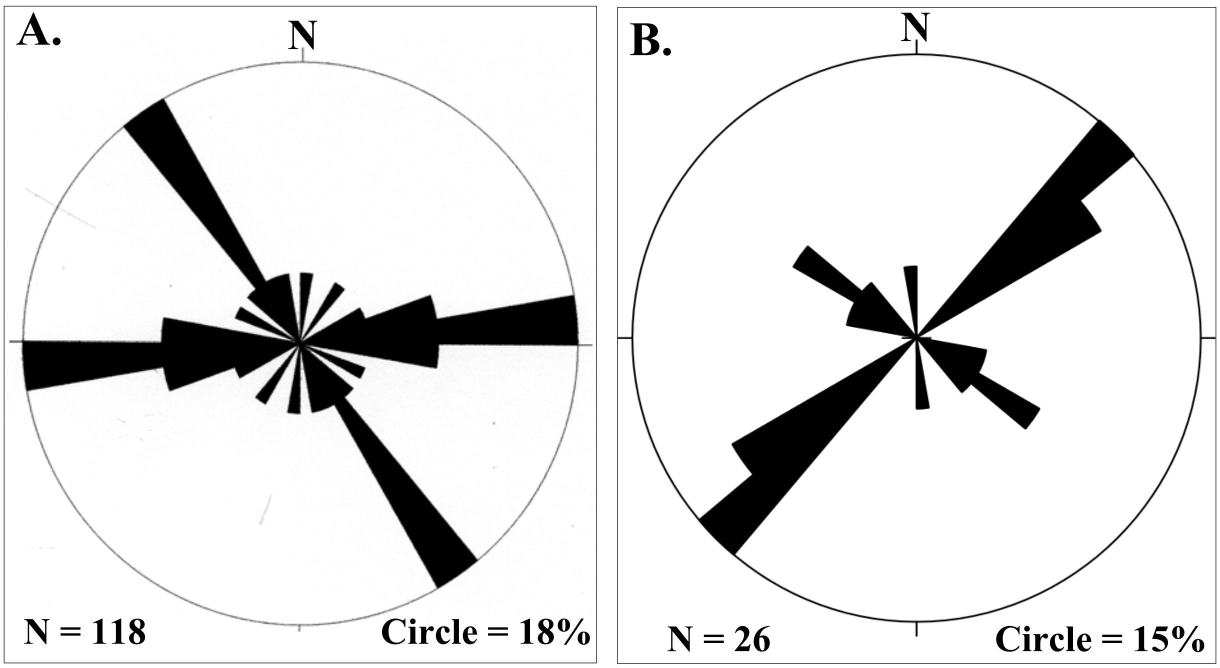
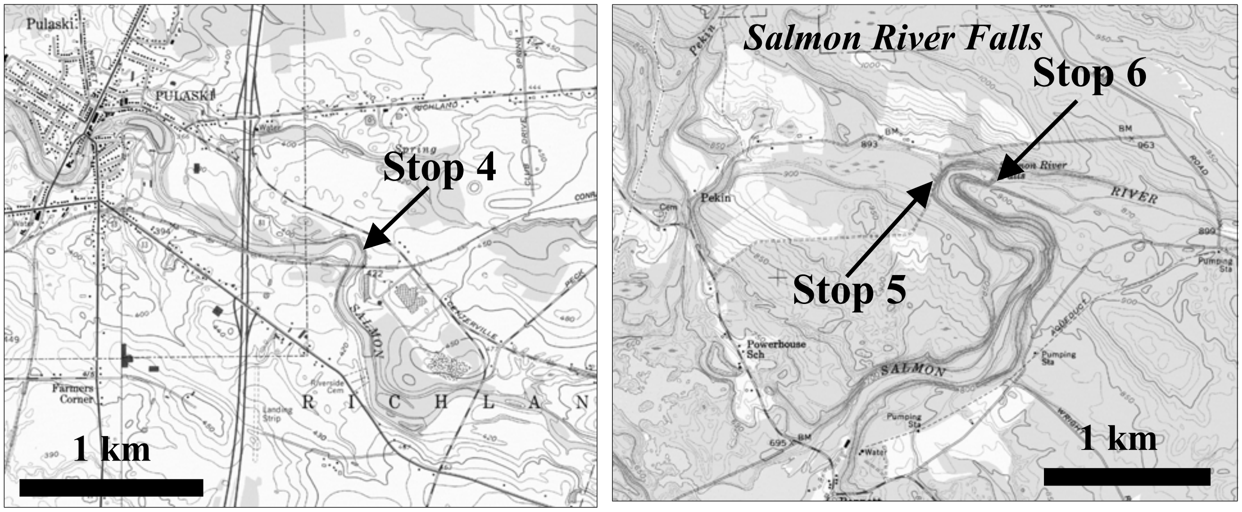


Figure 13 – Rose diagrams for the strike of joints in the lower Oswego (A.) and upper Pulaski (B.) Formations. A. Data collected at Ninemile Point on Lake Ontario, Scriba, NY. B. Data collected at Stop 4 on the Salmon River in Pulaski, NY. Although both dominant joint sets are present, the orientations vary considerably between each location.

STOP 4: Outcrop on the Salmon River under the railroad bridge east of Pulaski, New York.

Once the parking area is reached, where the railroad intersects County Route 2A, walk west along the railroad to the bridge over the Salmon River. Do not enter the railroad tracks, or cross the railroad bridge. At the eastern side of the railroad bridge, carefully traverse down the slope to the river level. There is a steep trail on the south side of the railroad tracks. The outcrop is located north of the railroad bridge on the eastern side of the river. Although this exposure is deeply weathered, there are few easily accessible outcrops of Pulaski Formation. Here the formation comprises interlayered sanstone, siltstone and shale. Sandstone beds range from 0.5 to 1 m thick and the shale contains cm-thick beds of siltstone. Occasional tool marks, ripple marks, and flute-casts are present in the sandstone beds, and the shale beds contain fossils. Joints are best observed in the sandstone beds, and are dominated by a northeast striking set (Figure 13B).



These topographic maps show the locations of Stops 4, 5 and 6 near Pulaski and Altmar, New York.

33.4	Back track on Co. Rt. 2A to St. Rt. 13 and turn left heading southeast.
39.0	Follow St. Rt. 13 to the town of Altmar and turn left onto Cemetery Street.
39.1	Follow Cemetery Street to the first intersection and continue straight. The road turns into Co. Rt. 22.
43.6	Follow Co. Rt. 22 past the NY State Fish Hatchery, past the lower Salmon River Reservoir, and turn right onto Falls Road.
44.9	Follow Falls Road up the hill to the parking area on the right.

STOPS 5 & 6: Below and above the Salomon River Falls.

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 joints are spaces about 1-2 meters and intersect discontinuous joints that strike northwest (Figure 14A). 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 joints. Additionally, there are en echelon fracture zones with apparent left lateral geometry that merge with the dominant joint set. Joint spacing varies from a few meters to well developed fracture zones with spacing less than 10 centimeters.

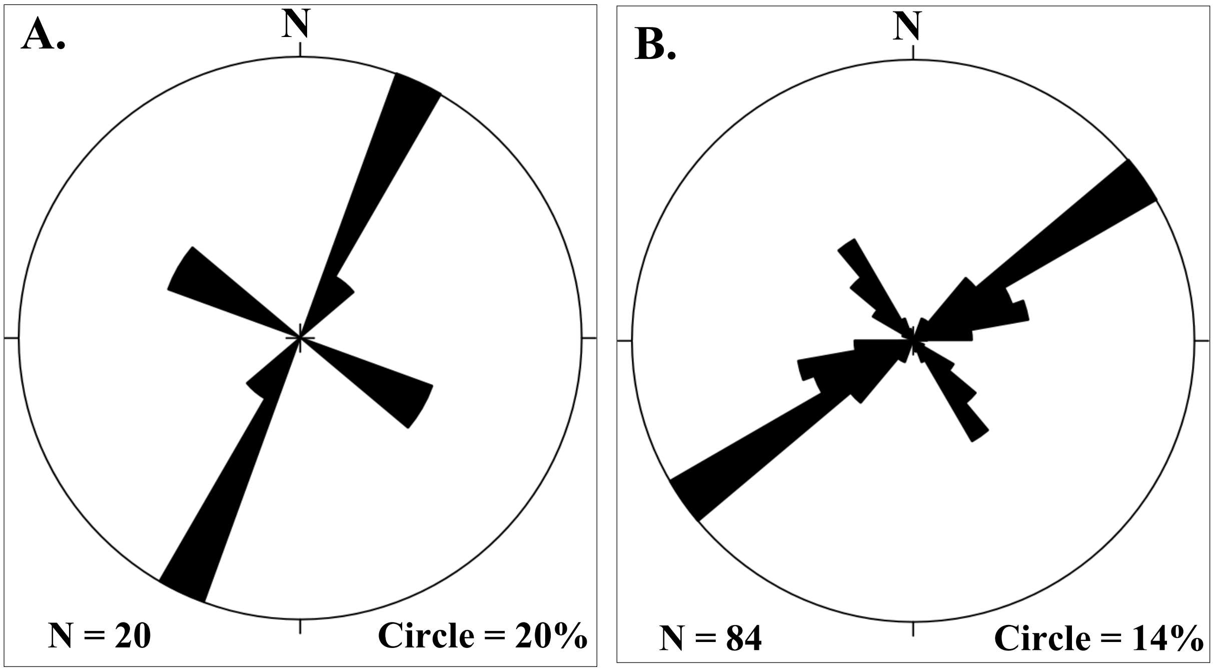


Figure 14. Rose diagrams for the strike of joints in the Pulaski (A.) and Oswego (B.) Formations at the Salmon River gorge near Altmar, New York. A. Data collected at river level down stream of the fall about 200m. B. Data collected at the pavement outcrops above the falls.

END OF TRIP.

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