GEOLOGICAL INVESTIGATIONS OF THE CLARENDON-LINDEN FAULT SYSTEM: A SYNOPSIS

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by:

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1. GEOLOGY

1.1 Early Studies

The Clarendon-Linden Fault System (CLF) was first recognized by Chadwick (1920), who noticed that the Niagara and Onondaga escarpments have prominent doglegs in their outcrop map patterns near Batavia (Fig. 1). He ascribed the N-S offset in the escarpment to a roughly N-S
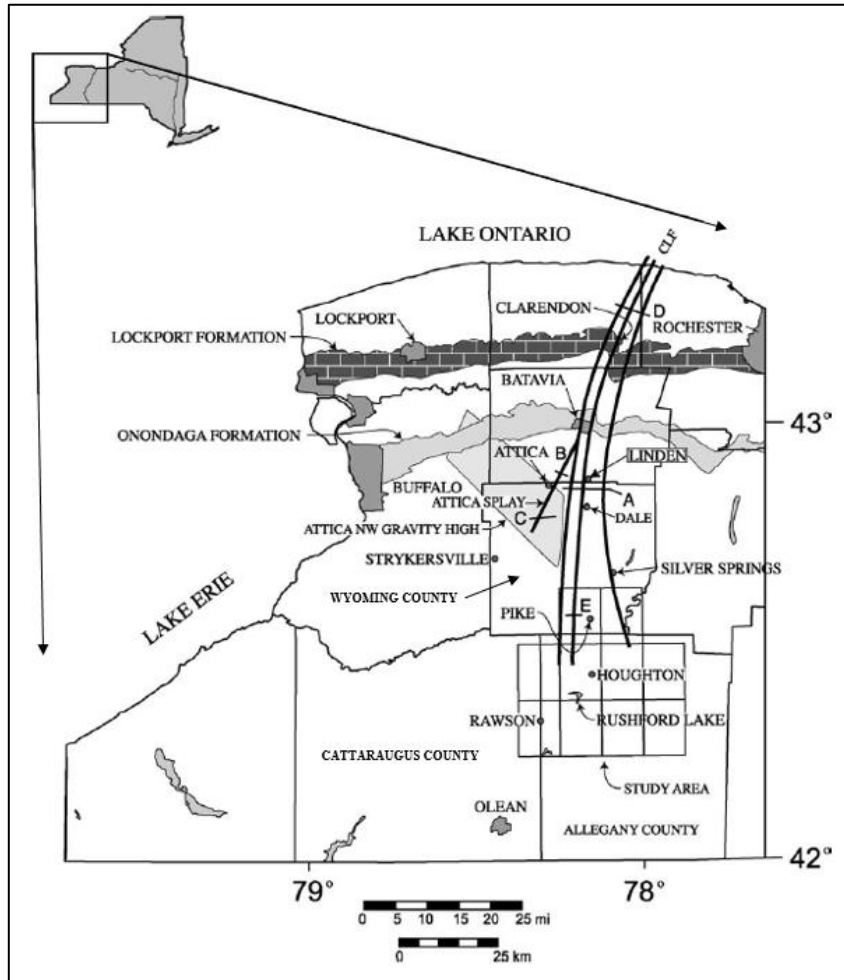
FIGURE 1. Location map displaying Van Tyne's (1975) main faults of the Clarendon-Linden Fault System (labelled CLF) in western New York State (NYS). The Niagara Escarpment is located along the northern boundary of the Lockport Formation outcrop and the Onondaga escarpment is located along the northern boundary of the Onondaga Formation outcrop. Labelled bars across the faults (A-E) indicate locations of NYS seismic lines shot by Fakundiny et al (1978b). The boxed area in Allegany and southern Wyoming counties indicates the 7.5' quadrangles studied in detail by the team led by Jacobi and Fountain (1993, 1996, 2002). From Jacobi and Fountain (1993)

striking fault between Clarendon and Linden, NY, that has about 30 m stratigraphic offset (down on the west). Chadwick (1920) believed the fault interpretation was supported by stratigraphic offsets of Upper Devonian units across a N-S trending valley and springs aligned in a N-S trend (see stratigraphic column, Figure 2, for stratigraphic units identified in text). Other publications following the original research suggested that perhaps the fault was actually a fold in units lying above the Silurian salt section, but was a fault in units lying below the Silurian salt (e.g., Chadwick, 1932). Although the Silurian salt section does not outcrop because it dissolves, the Silurian units lying above and below the salt section outcrop between the Onondaga and the Lockport escarpments (Fig. 1). Since the units all dip gently to the south, the units at the

surface in the region south of the Silurian salt "non-outcrop" were thought to be disposed in a fold in this scenario. However, the sharp offset in the Onondaga escarpment at Batavia is not consistent with a fold interpretation.
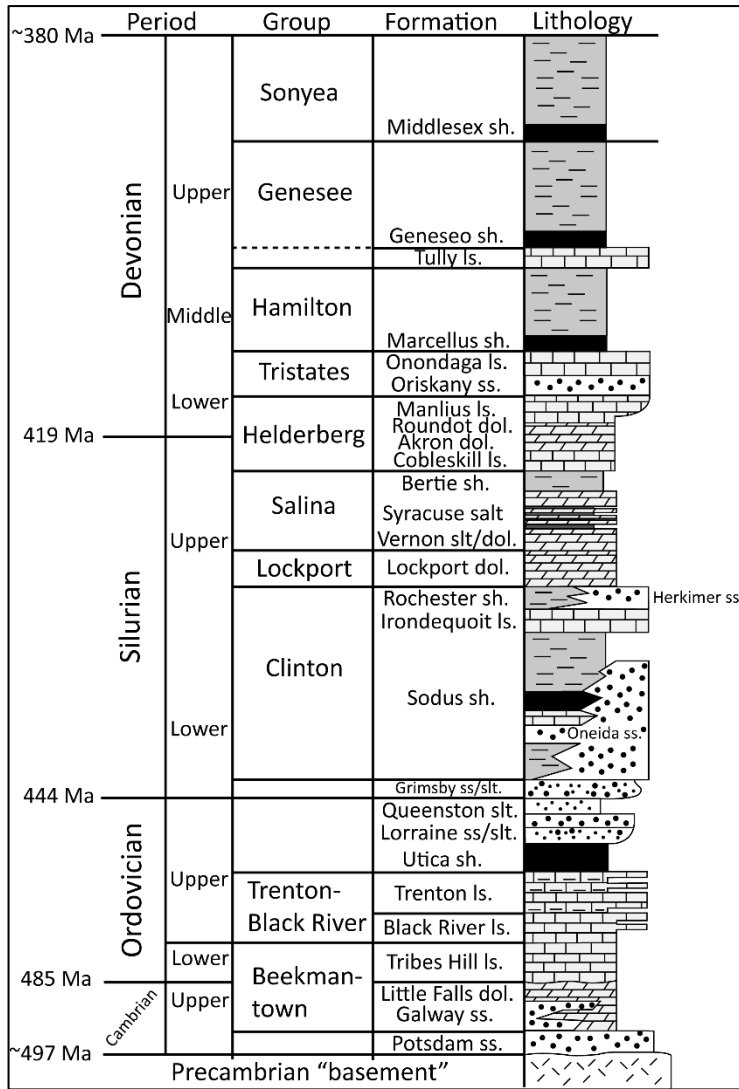
Period			Group	Formation	Lithology
~380 Ma					
Devonian	Upper		Sonyea		
				Middlesex sh.	
			Genesee		
				Geneseo sh.	
	Middle		Hamilton	Tully ls.	
				Marcellus sh.	
	Lower		Tristates	Onondaga ls.	
				Oriskany ss.	
419 Ma			Helderberg	Manlius ls.	
				Roundot dol.	
				Akron dol.	
				Cobleskill ls.	
Silurian	Upper		Salina	Bertie sh.	
				Syracuse salt	
				Vernon slt/dol.	
			Lockport	Lockport dol.	
	Lower		Clinton	Rochester sh.	Herkimer ss.
				Irondequoit ls.	
				Sodus sh.	
					Oneida ss.
444 Ma				Grimsby ss/slt.	
Ordovician	Upper			Queenston slt.	
				Lorraine ss/slt.	
				Utica sh.	
			Trenton-Black River	Trenton ls.	
				Black River ls.	
	Lower		Beekman-town	Tribes Hill ls.	
485 Ma		Cambrian Upper		Little Falls dol.	
				Galway ss.	
~497 Ma				Potsdam ss.	
			Precambrian "basement"		

FIGURE 2. Stratigraphic column showing the units in the northern half of western New York State.

1.2 Studies in the 1970s

The potential siting of nuclear power plants along the Lake Ontario shore prompted the next wave of more detailed and comprehensive study of the CLF. Well log analyses by Van Tyne (1975) indicated that the CLF consisted of at least 3 main strands that extended from the Lake Ontario shore southward into southern Wyoming County (Fig. 1). Analyses of 2D seismic reflection profiles by Pomeroy et al. (1977) and Fakundiny et al. (1978a, b) (lines A-E in Figure 1 and four additional lines shot between the central and eastern faults) indicated that the CLF was a complex fault zone with multiple faults--more faults than could be recognized in the

relatively widely-spaced well log data of Van Tyne (1975). The cumulative amount of throw across all the individual faults was about 30 m to 50 m, down-on-the-west. The seismic data were crude by modern standards; the vertical resolution was about 30 m (Pomeroy et al., 1977), so faults with vertical offsets less than about 30 m could not be resolved.

Fakundiny et al. (1978b) did not find a clear relationship between the CLF and their regional compilations of fractures, pop-ups and faults. This observation was consistent with the belief from the crude seismic data (Fakundiny et al., 1978b) and the well log data (Van Tyne, 1975) that the fault system was merely a fold above the Silurian salt section. Later Van Tyne structure maps (e.g., Van Tyne and Foster, 1979) also implied that the faults developed into folds above the Silurian salt section.

More recent studies using better data from the rocks above the Silurian salt section have shown that in each of the data sets (seismic reflection profiles, well logs, and fracture analyses), faults are indeed required to honor the data. For example, using more well logs than Van Tyne (1975) had available to him, Murphy (1981) proposed that N-striking faults extend up through the Silurian salt section and displace the Middle Devonian Onondaga Formation. Gross and Engelder (1991) found anomalous NNE-striking fractures parallel to the CLF trend in a quarry adjacent to the main CLF faults at Clarendon, NY. And as detailed below, using advances in data acquisition and processing, detailed stratigraphic, structural, seismic, soil gas, and remote sensing analyses conducted by Jacobi and Fountain (1993, 1996, 2002) all showed that the faults extend to the surface in western NYS and extend south into the 10 quadrangle study area primarily in Allegany County (for location see Figure 1).

1.3 Studies in the late 1980s and early 1990s

The third phase of geological investigation of the CLF arose in the late 1980s in response to the possibility of radioactive waste storage in Allegany County. Jacobi and Fountain developed a detailed study in order to determine whether the CLF and other faults exist in Allegany County and if these fault systems could be seismically capable in Allegany County. Because the outcrop was not continuous, and because the fault issue was contentious at the time, the study integrated all the standard, traditional geological techniques as well as innovative techniques that Jacobi and Fountain pioneered and now are practiced routinely. The techniques included:

1) detailed stratigraphic measurements of units in outcrops measured and described at the cm scale at over 2,000 outcrops in Allegany County and regions to the west
2) digital collection of fracture and fault data using scangrids and scanlines at the same outcrops as in #1 above, with traditional structural analyses as well as fractal and other geostatistical analyses
3) soil gas analyses at 10 m spacings along transects

4) seismic reflection data acquisition and analyses
5) remote sensing analyses for lineament recognition, including
    a. topographic maps,
    b. air photos,
    c. SLAR, and
    d. Landsat
6) neotectonic studies in the Attica region and in Allegany County
7) analyses of potential field data, including
    a. gravity and
    b. aeromagnetics

These 11 tasks and subtasks were rigorously carried out under a QA/QC program developed by Jacobi and Fountain and approved by NYSERDA. Jacobi and Fountain performed weekly quality control checks on all active tasks and subtasks, and NYSERDA had a rigorous annual QC check involving personnel from NYSERDA at West Valley and Albany (Jacobi and Fountain, 1991, 1996). The QA/QC program meant that the findings were verifiable at very high level of detail (e.g., at the cm scale in the case of stratigraphy). The results of the study were compiled in a 2,106 page report to NYSERDA (Jacobi and Fountain, 1996), and the results were summarized in a series of over 50 abstracts and refereed papers (e.g., Jacobi and Fountain, 1993, 2002).

The integrated tasks showed that faults do exist in the 10 quadrangle study area, ranging from small faults observed in outcrop that have offset on the order of a few centimeters to faults inferred from well logs and offsets of units between outcrops that have offsets up to 45 m. An example of the larger-offset faults that extend to the surface are shown in the cross section in Figure 3a. These faults are located below prominent N-striking lineaments observed in topographic maps, air photos, SLAR imagery and Landsat. Further, soil gas anomalies are also coincident with these same lineaments. Stable isotopes and the ethane/methane ratios of the soil gas indicate it is not shallow "biogenic" (or "swamp") gas; rather, the natural gas has a subsurface source and apparently has leaked upward along fracture systems. The soil gas thus is an indicator of open fracture systems, in this case that trend NS parallel to the lineaments.

Examples of the small-offset N-striking faults found in outcrops in the study area are shown in Figure 3b. These outcrops occur along the central fault in Figure 3a, and display the same sense of motion (down-on-the-west) as was inferred from the sense of offset determined from elevation changes of the Rushford Sandstone between the outcrops, in this case confirming the inferred offsets from both the subsurface well logs and the surface outcrops.
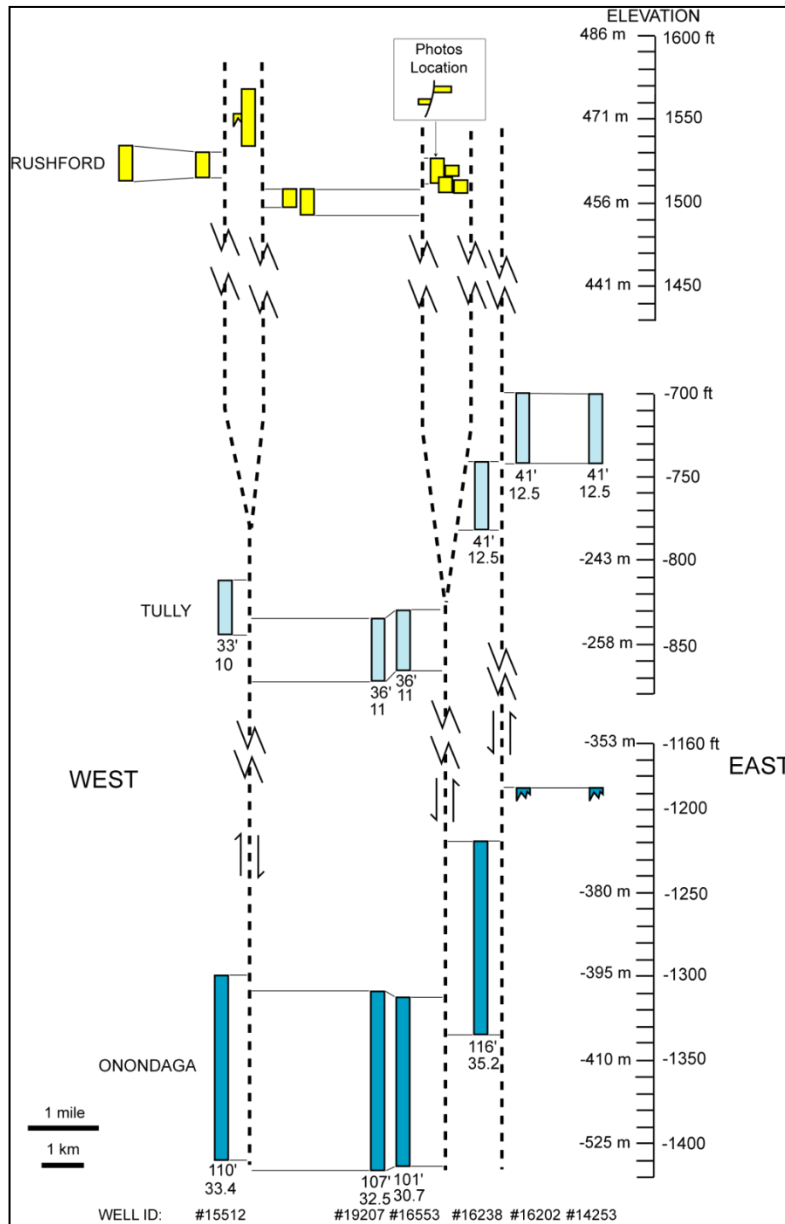
FIGURE 3a. East-west cross section roughly along the north shore of Rushford Lake (see Figures 1 and 4 for location of Rushford Lake). For the subsurface portion of the cross-section, which involves the Onondaga and Tully limestones, analyses of well logs were used to determine the sub-sea depth of the units. For surface outcrops of the Rushford Sandstone, topographic maps were used to establish the elevation of the outcrops. The Rushford Sandstone has offsets between outcrops that have the same sense of motion as those inferred from the well logs, confirming the general fault offsets inferred from the well logs. However, the surface outcrops indicate there are more faults at the surface than inferred from the well logs. This observation could indicate the faults splay upsection or that the well logs are not sufficiently closely-spaced to recognize the extra fault complications observed at the surface. From Jacobi and Fountain (1996, 2002)

The seismic reflection profiles acquired by Jacobi and Fountain (1996, 2002) all showed faults at depth, and two showed probable faults reaching to the surface. One of the seismic reflection profiles, CLF-3 is shown in Figure 4. The observed fault on this seismic line lies beneath

1) a NS-trending valley (Rawson Valley) observed in topographic maps, air photos, and SLAR,
2) a N-S striking FID with N-S striking fractures in the valley
3) a zone of high soil gas anomalies
4) a structural zone of N-striking master fractures, FIDs and faults in outcrop that extends south from the location of the seismic line (Figure 5).
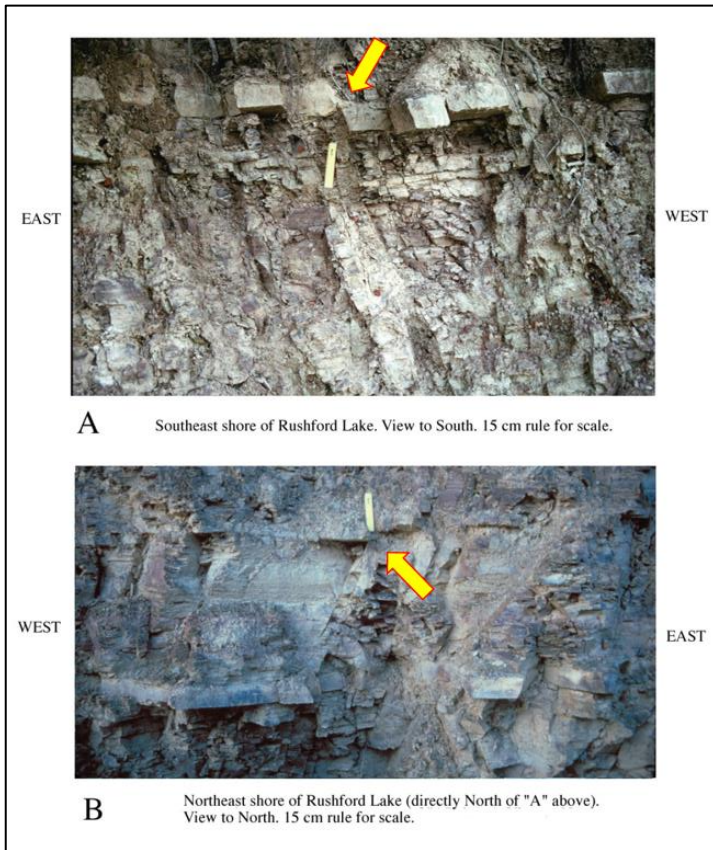
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FIGURE 3b. Photos of small-offset N-striking faults of the CLF along the shores of Rushford Lake. For a location of Rushford Lake, see Figures 1 and 4; location of the outcrops also shown diagrammatically in Figure 3a. Yellow arrows indicate where the sandstones are offset. The sense of offset on these small faults is consistent with the offset inferred from changes in elevation of the Rushford sandstone between outcrops. Note the elevated number of N-striking fractures here, forming a FID. The outcrops align with the middle main fault system of the Clarendon Linden fault System in this area. From Jacobi and Fountain (2002).
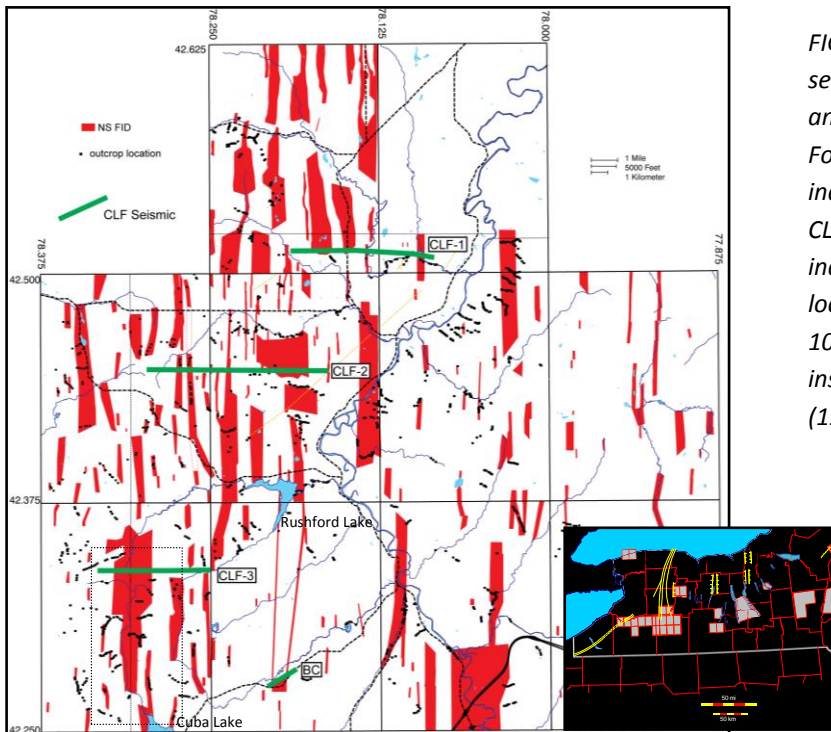
FIGURE 4a. Location map for seismic reflection lines acquired and analyzed by Jacobi and Fountain (1996, 2002). Red bands indicate N-striking faults of the CLF. Dotted box near Cuba Lake indicates the approximate location of Figure 5. Location of 10-quadrangle area shown in the inset. After Jacobi and Fountain (1996).
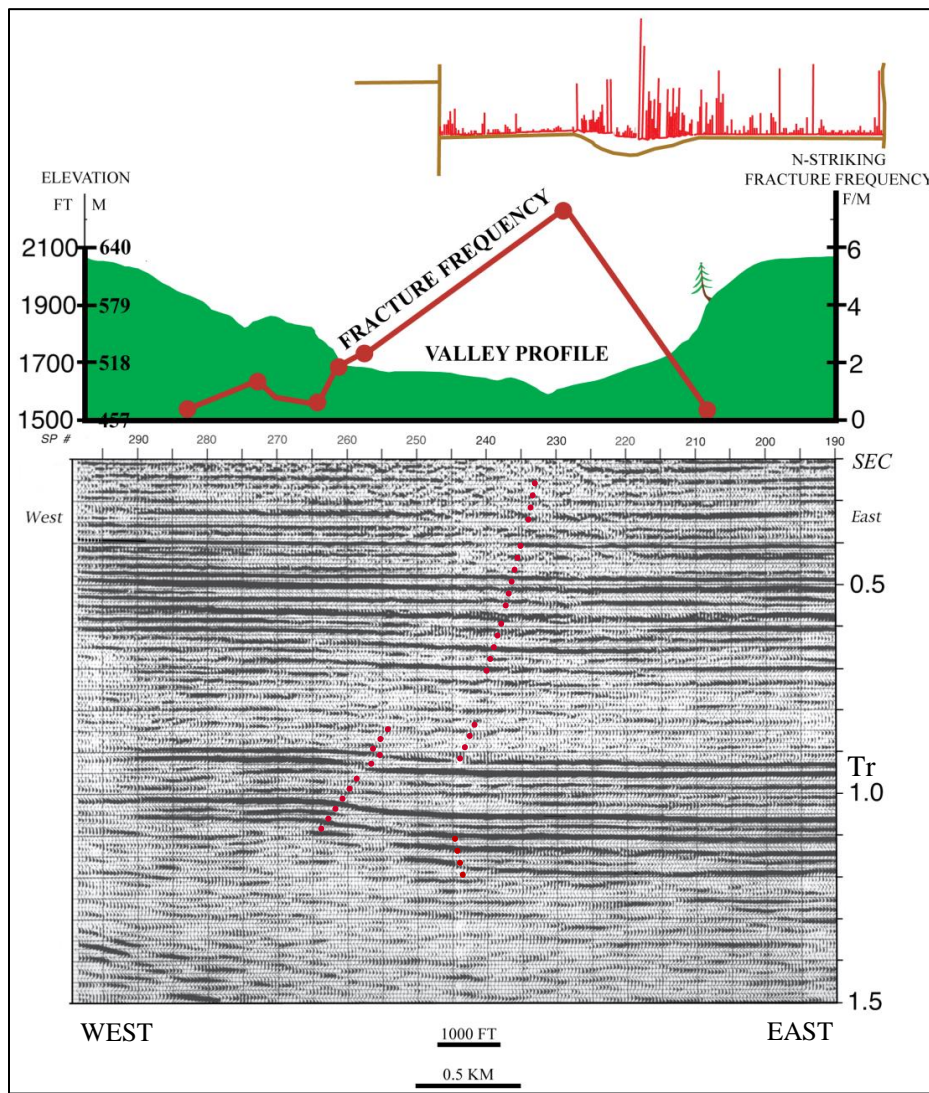
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*FIGURE 4b. Seismic line CLF-3 (bottom panel), N-striking fracture frequency and Rawson Valley topographic profile (middle panel), and soil gas anomaly transect on the same road along which the seismic was shot (upper panel). All three panels are aligned north-south. **Lower Panel**. Clear thrust fault at the Trenton ("Tr") and deeper reflectors. **Middle Panel.** Fracture frequency of N-striking fractures along a transect rises from a background frequency of 0 fractures/m at the valley walls and beyond to a high fracture frequency of about 8 fractures/m in the valley center; 8 fractures/m is indicative of an FID, which occurs in the region where the fault occurs. Dots indicate the location of outcrops, which were located proximal to the seismic line and soil gas transect (see Figure 5 for location). **Upper Panel**. Significantly elevated soil gas anomalies characterize the eastern valley wall, from about the site of the high fracture frequency eastward. Sporadic high soil gas anomalies also occur on the plateau east of the valley wall. Figure after Jacobi and Fountain (1996, 2002).*

The coincident N-S valley, N-S band of anomalous N-striking master fractures, N-striking FIDs and N-striking, outcrop-scale faults indicates that the structural zone in Figure 5 is controlled by CLF faults observed in the seismic line in Figure 4, and suggests that the faults observed in the seismic line do extend up to the surface. Further, since the structural zone is aligned with the soil gas anomalies to the north, these fracture and fault system are presently open. Open fractures/faults and gas/fluid lubricated open surfaces are easier to reactivate than locked fractures/faults.
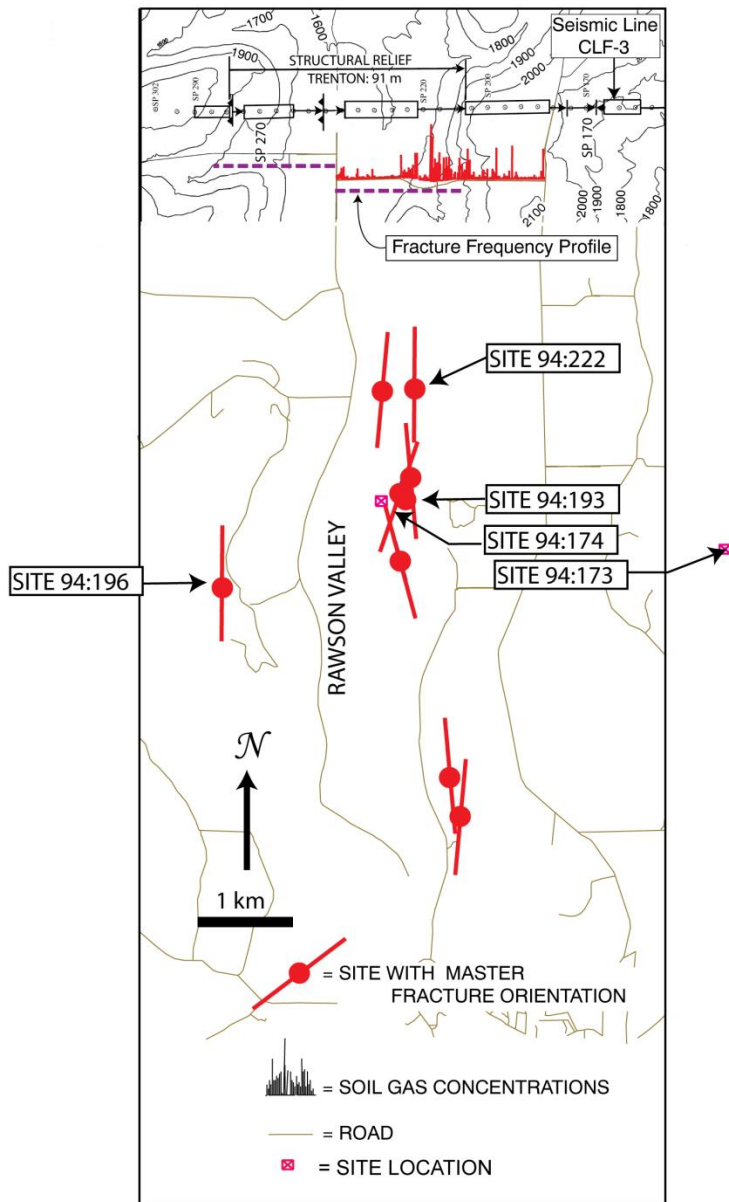
FIGURE 5. Map of the Rawson Valley region that shows the location of seismic line CLF-3 (shown in Fig. 4b), the soil gas transect shown in Figure 4b, and the fracture frequency transect shown in Figure 4. For location of Figure 5, see Figure 4a. Sites with master fractures that strike north are locally prevalent along a structural zone that trends south from the region of high soil gas anomalies (east wall of Rawson Valley and the plateau to the east). Some of these sites also display N-striking faults and N-striking FIDs (labelled localities). Figure after Jacobi and Fountain (1996, 2002).

This integration of data sets shown in Figures 4 and 5—data sets with coincident anomalous features that indicate a N-S trending fault system exists along the valley--demonstrates the usefulness of the different data sets in combination, but also the power of the data sets alone, if other data sets are lacking. For example, anomalous N-striking FIDs alone indicate that a N-striking fault is nearby, and long N-striking valleys with no other data sets probably indicate N-striking faults as well. Only with the intense detailed measurements of each data type could we determine what the background, regional signal was and what the locally anomalous signal

was. Previous researchers, as well as a few who worked later in western New York State did not have a sufficiently detailed and extensive data base to be able to recognize what was anomalous, and therefore was, in this case, indicative of faulting.

Integrating all the geological techniques allowed Jacobi and Fountain (1996, 2002) to construct the fault and FID map shown in Figure 6. Inspection of the map reveals that N-striking fault
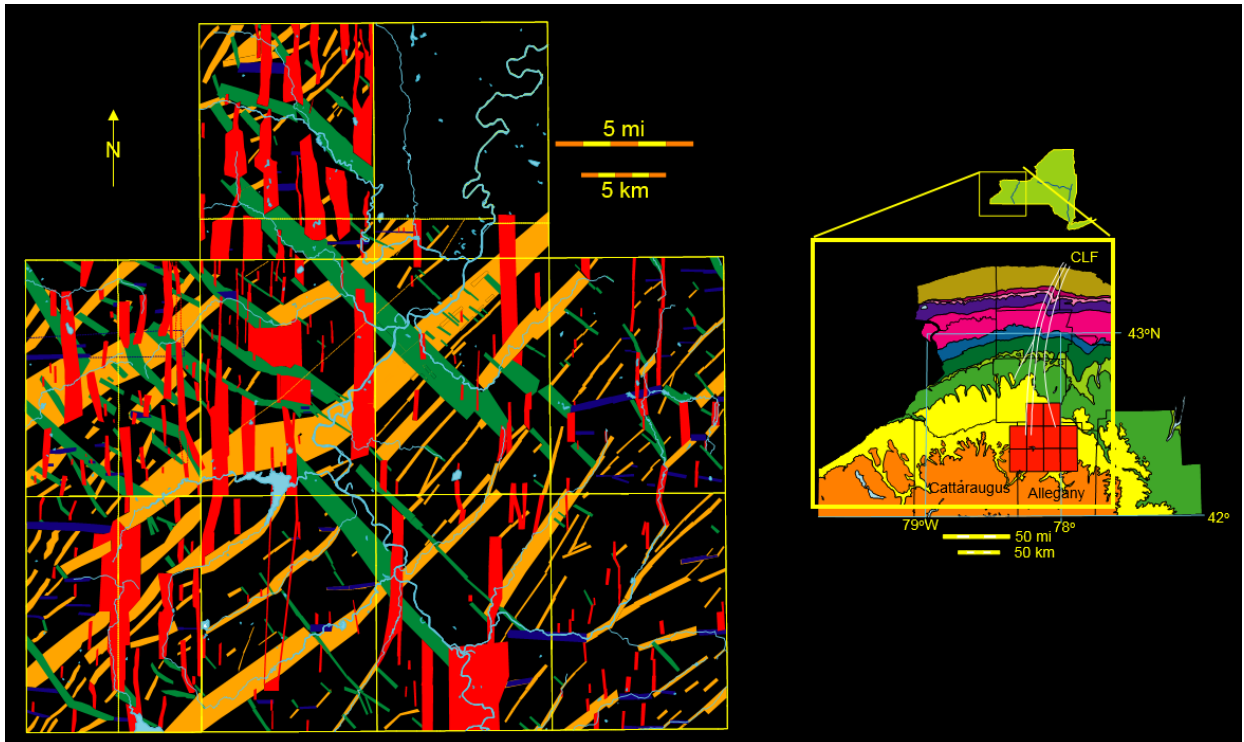

FIGURE 6. Map of faults and fracture intensification domains (FIDs) in the 10-quadrangle study area primarily in Allegany County. In this region FIDs commonly characterize faults, and occur adjacent to a fault, or above the tip of a fault. The colored bands and lines indicate orientations and width of fault systems/FIDs and the different colors denote variously-oriented systems of faults and FIDs. For location of the 10 quadrangle area, see the panel at the right and also Figure 1. Figure after Jacobi and Fountain (1996, 2002).

systems are not the only faults in the region. Rather, NE-striking faults, NW-striking faults, and relatively-rare E-striking faults also occur in the region. Because the present far-field horizontal stress is directed ENE-WSW (Zoback and Zoback, 1991), both the N-striking faults and the NW-striking fault systems are more susceptible to failure.

The Jacobi and Fountain (1996, 2002) studies (and all their ancillary studies) determined that N-striking faults of the CLF do occur in western NYS south of the trend proposed by Chadwick (1920). The faults extend into central NYS at the latitude of the proposed Alle-Catt Wind Energy (ACWE) project (Fig. 7). But what about seismicity? The following sections examine the seismicity of the CLF both to the north and in the Allegany County region.
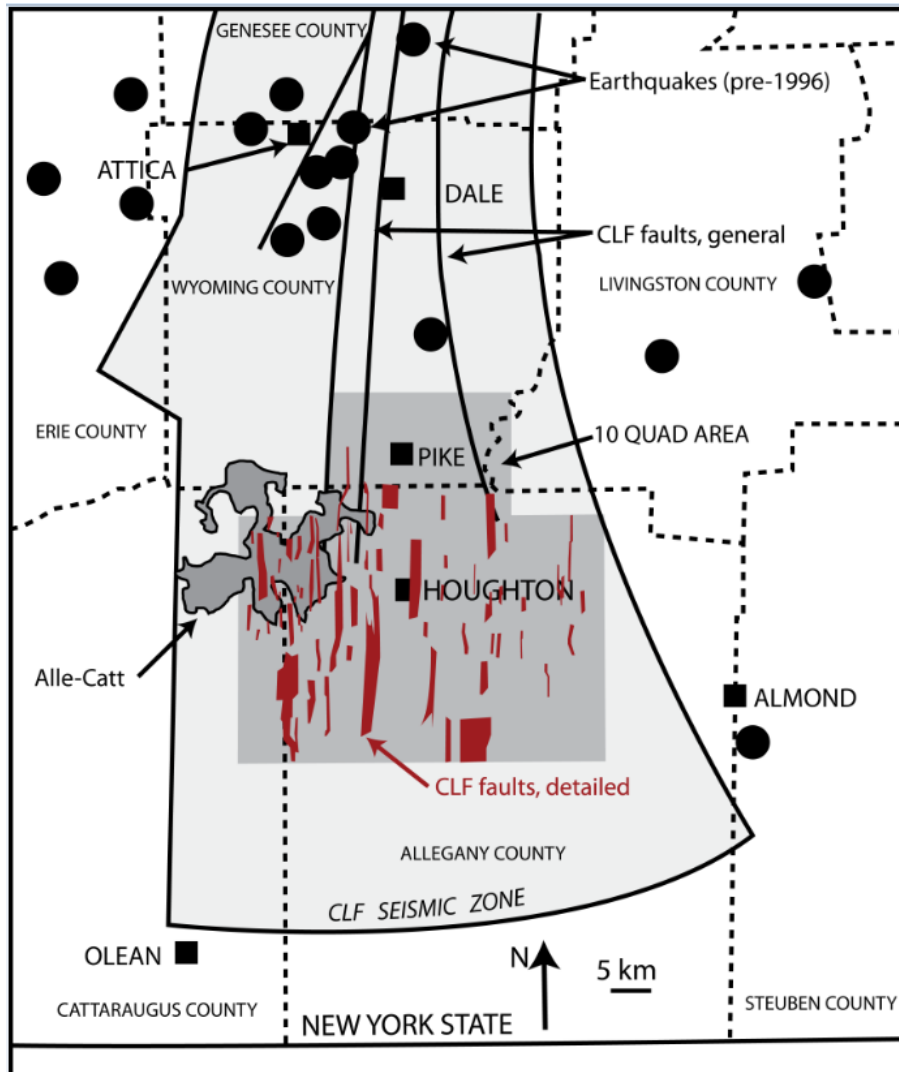
Figure 7. Alle-Catt Wind Energy project area in relation to the Clarendon-Linden fault system in western NYS. The 4 strands of the Clarendon-Linden fault system labeled "general" are from van Tyne (1975) and Fakundiny et al (1978a, b). The detailed Clarendon-Linden faults are from Jacobi and Fountain (1996, 2002) who mapped faults in detail in the 10-quad area by integrating eleven geological techniques. The CLF Seismic Zone was proposed by Jacobi and Fountain (2002) to include the more prominent segments of the CLF fault system. Earthquakes are from Jacobi and Fountain (1996), and thus do not include more recent events. Note that geological boundaries are approximate because of geological interpretations that are intrinsic to map making and because of errors introduced warping various maps in GIS to the same base.

2. SEISMICITY

The CLF is undoubtedly seismically active, based on

1) the distribution of elevated seismic activity in the region of the CLF, as recorded by instruments and also documented by felt reports, and
2) nodal plane solutions of specific earthquakes located on the CLF that predate the deployment of seismographs.

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The earthquake epicenters have an uneven distribution across western New York State, with a concentration in the region of the CLF (Figs. 7 and 8). The lack of recorded seismicity in western New York State outside of the arbitrary CLF seismic zone is especially noticeable in Figure 8. The
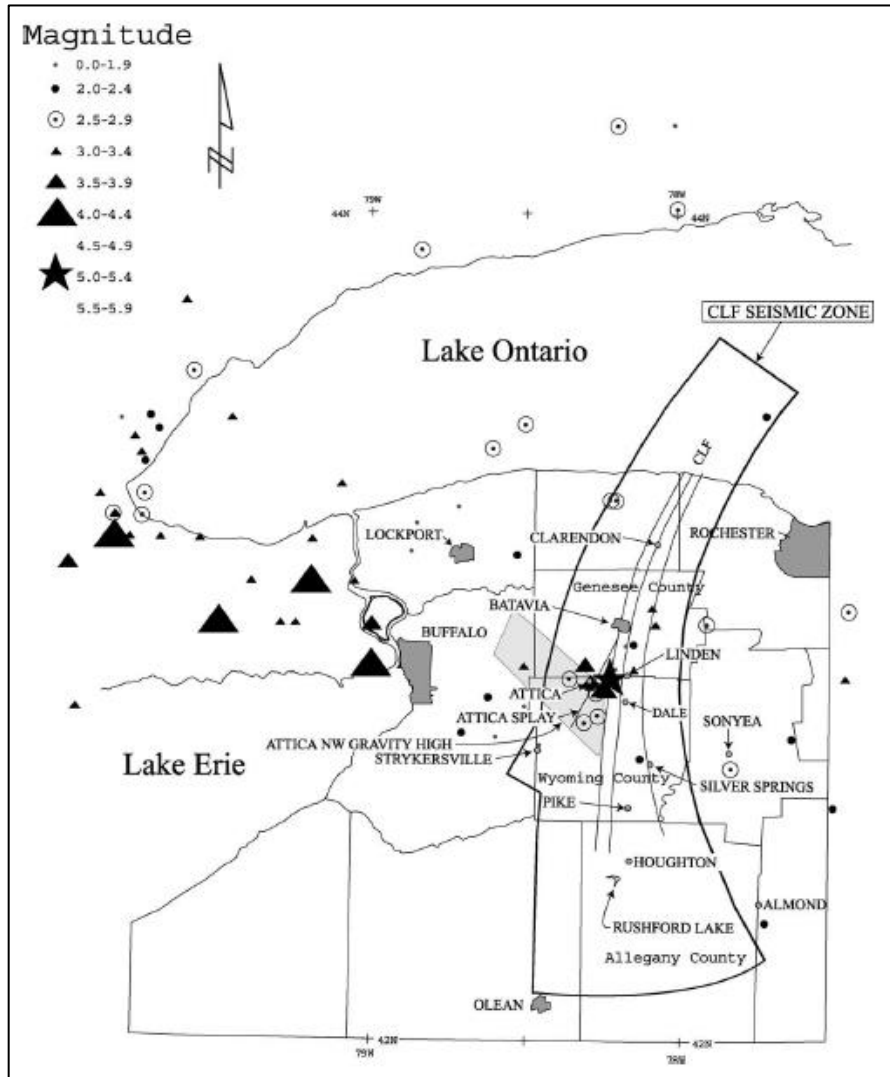

FIGURE 8. Epicentral locations of recorded earthquakes in western New York State before 1996. The boundaries of the CLF seismic zone were arbitrarily chosen to include all the known faults of the CLF. The relative sparsity of earthquakes in the southern tier of western New York State is probably partly a function of the lack of a seismograph network in western New York that could routinely record the smaller magnitude seismic events. Figure from Jacobi and Fountain (2002).

coincidence of elevated seismicity with the CLF convinced numerous researchers that the CLF is seismically active (e.g., Smith, 1966; Pomeroy and Fakundiny, 1976; Fletcher and Sykes, 1977; Sbar and Sykes, 1977; see reviews in Jacobi and Fountain, 1993, 1996, 2002). Furthermore, the second (or third) largest earthquake in New York State, a Modified Mercalli Intensity VII earthquake (estimated M = ~ 5.2) was felt near Attica in 1929 (the "1929 Attica earthquake"; Street and Turcotte, 1977). Based on aftershock locations determined from newspaper articles, Tuttle et al (1996, 2002) determined that the 1929 Attica seismic event occurred on the western main fault of the CLF (east of Attica). Numerous earthquakes with magnitudes ranging from 2.7 to 4.7 have epicenters along the CLF since the time of the 1929 Attica earthquake, including events in 1955, 1966, 1967, 1968, 1971 and 1973 (Fletcher and Sykes, 1977).

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Nodal plane solutions for seismic events in the Attica region in 1974 and 1975 (Fletcher and Sykes, 1977), and in 1966 and 1967 (Hermann, 1978) are consistent with a NNE-striking CLF fault. The sense-of-motion on these nodal planes (the fault surface) has both right-lateral and reverse components, which is consistent with the CLF fault orientation in the present far-field stress field (which has its SHmax directed ENE-WSW in this region; e.g., Zoback and Zoback, 1991).

All the maps that complied earthquakes for differing historical time spans show that most of the seismic events occurred in the Attica region; for example Figure 8 shows the location of epicenters that predate 1996; Figure 9 shows the locations of epicenters that occurred between 1973 and 2012, and Figure 10 shows all the events up to 2014.
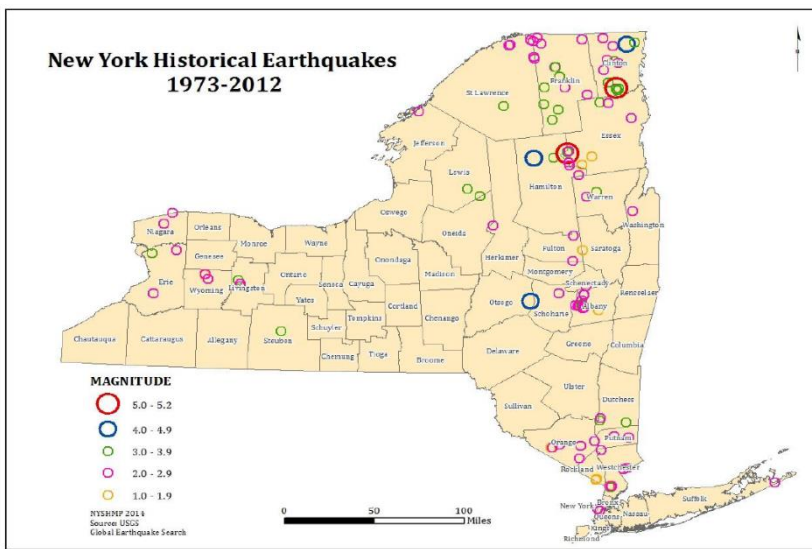

FIGURE 9. Historical earthquakes in New York State between 1973 and 2012. From the 2014 New York State Hazard Mitigation Plan, available at http://www.dhses.ny.gov/recovery/mitigation/documents/2014-shmp/Section-1-Introduction.pdf).
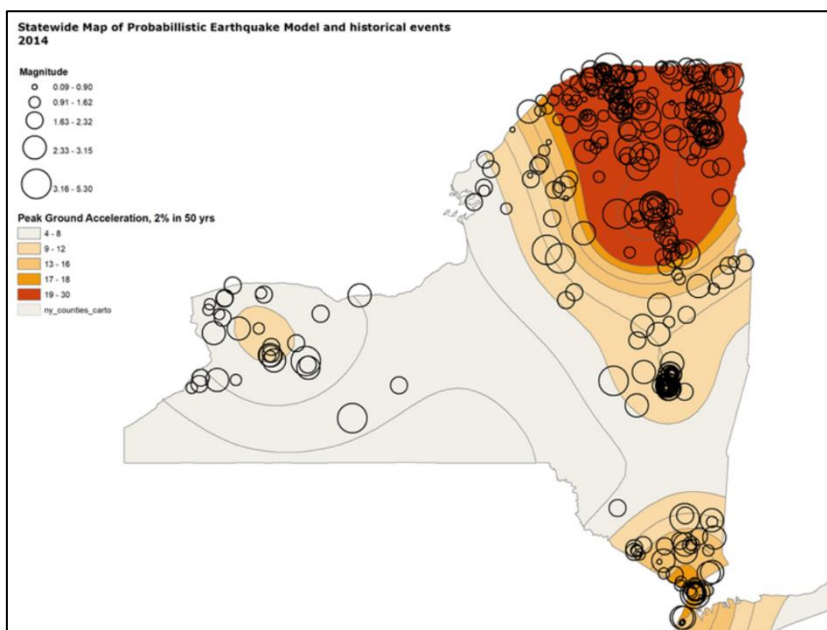

Figure 10. Map of historical earthquakes and a probabilistic earthquake model. The base map shows the 2% probability of a peak ground acceleration (PGA) exceedance in 50 years). Historical seismicity is superimposed. From the earthquake section of the 2019 New York State Hazard Mitigation Plan, available at https://mitigateny.availabs.org/hazards/earthquake

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The concentration of seismicity in the Attica area may be related to weakened crust caused by the intersection of the N-striking CLF faults with proposed NW-trending faults that are associated with a NW-trending gravity high (Jacobi and Fountain, 1996, 2002; see Figure 8 for location of the gravity high). The question becomes: is the CLF to south of the Attica area also seismically capable (i.e. capable of generating seismic events) and what magnitude might be expected if the faults are capable?

2.1 CLF faults seismically capable along their entire length

Based on several considerations, Jacobi and Fountain (1996, 2002) suggested that the CLF faults are seismically capable as far south as the areas studied in Allegany County. These considerations include the following elements.
1) The CLF clearly extends from Attica south into Allegany County.
2) Faults of the CLF are leaking gas, which indicates they are open and gas-charged, making them lubricated and thus easier to reactivate.
3) The present far-field stress field has SHmax oriented about ENE-WSW, making the CLF susceptible to thrust motion combined with strike-slip motion (oblique slip).
4) The intersection of the NW-striking fault system with the CLF at Attica has similar counterparts in the Allegany County region, so the crust is probably weakened in that region as well.
5) Earthquakes have occurred south of the Attica area, including recorded events near Almond, NY; Silver Springs, NY; Strykersville, NY; and the 1855 historical seismic event near Olean that was estimated to be about a M = 3 (Fig. 8 and Seeber and Armbruster, 1993).
6) The energetic gas seeps at Pike, NY, that initiated after the November 25, 1988, Mb = 6.5 Saguenay earthquake in Quebec indicates that some fractures/faults of the CLF were reactivated in the Pike area (Jacobi and Fountain, 1993, 1996, 2002).
7) A study of faults and earthquakes in the Lake Ontario area sponsored by the AECB (Atomic Energy Control Board, Canada), using a probabilistic approach, included the CLF in a group of faults that are seismically active, but have low recurrence rates (Geomatrix, 1997; Jacobi, et al., 1997).

2.2 Earthquake recurrence rates and maximum credible earthquake on the CLF

Having established that the CLF is most likely seismically capable along its length south into Allegany County, the question becomes what is the magnitude and recurrence rates of earthquakes that might be expected on the southern parts of the CLF, and what is the

maximum credible earthquake that could occur on the CLF? Because of the elements discussed below, definitive answers to these questions are difficult to determine.

In regions with many earthquakes, such as along the Pacific coast, the high recurrence rates of many different magnitudes of seismic events allow researchers to determine a curve that relates the magnitude of the events to the recurrence rate for selected regions. However, in the East, where recurrence rates in general are low, and rates along faults usually are not much higher, such curves are regarded as subject to high degrees of error and are seldom used (e.g., Geomatrix, 1997; Jacobi, et al., 1997; see reviews in Jacobi and Fountain, 2002, and Jacobi and Ebel, 2019). Never-the-less, three considerations discussed below can be used to make a crude estimation of the magnitude of a seismic event that could happen on the CLF.

1) AECB probabilistic studies that included the CLF (Geomatrix, 1977; Jacobi et al., 1997)
2) magnitude/recurrence rate curve for the CLF seismic zone (Jacobi and Fountain, 1996, 2002),
3) the Pymatuning 1998 seismic event that occurred in a region of perceived very low seismic risk

The probabilistic study by the AECB group suggested that the range of maximum magnitudes of earthquakes that might occur along the CLF is between M = 5.5 and M = 7.5, with the highest probability being an M= 6.5 event as the maximum seismic event that might occur along the CLF, including the southern extension.

A recurrence rate/seismic magnitude curve for the CLF seismic zone by Jacobi and Fountain (1996, 2002; Fig. 11), reveals that the seismicity within the CLF seismic zone has about an order
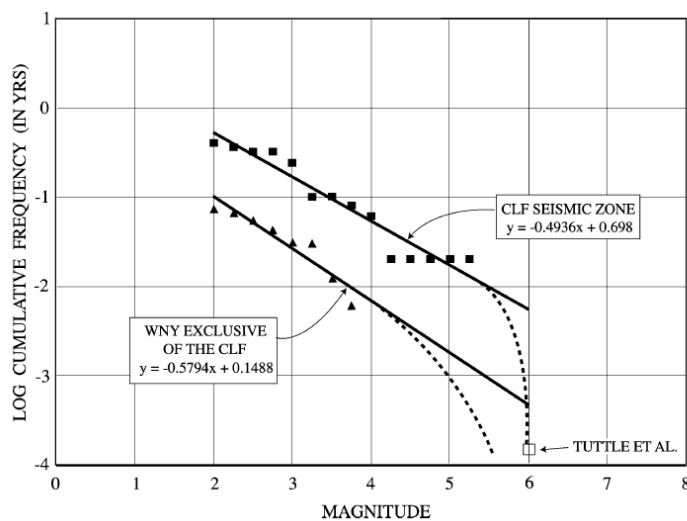

FIGURE 11. Recurrence rate/earthquake magnitude curves for the CLF seismic zone and for western New York State outside of the CLF seismic zone. See Figure 8 for the location of the CLF seismic zone. Figure from Jacobi and Fountain (1996, 2002).

of magnitude higher recurrence rate than in the western New York area outside the CLF seismic zone, and that the recurrence rate relation to seismic event magnitude is more stable than

might be expected for M < ~ 4-5. For higher magnitudes, this curve is very uncertain because of complications due to a lack of data and equivocal nature of some data in the neotectonic study (Tuttle et al., 1996, 2002; see review in Jacobi and Fountain, 1996, 2002). If the implications of Tuttle et al.'s (1996, 2002) neotectonic studies are correct, then the CLF has not sustained a seismic event as large as M = 6 since glacial times. In that case the recurrence rate/magnitude curve in Figure 12 must have the steep, dashed slope in Figure 12 to pass the box labelled "Tuttle et al." However, considerations reviewed in Jacobi and Fountain (1996, 2002), such as interpretations of equivocal deformation features, could indicate that a seismic event larger than M =6 did occur along the CLF in the past 10,000 years. The second alternative would be consistent with the AECB probabilistic study (Geomatrix, 1977; Jacobi et al., 1997).

The largest recorded earthquake in Pennsylvania, the M = 5.2 Pymatuning earthquake, occurred in western Pennsylvania in 1998 in a region that has a slightly lower seismic risk than the focus area in the western New York region, as portrayed on the 2014 USGS seismic risk map for a 2% probability of exceedance in 50 years of peak ground acceleration (Fig. 12).
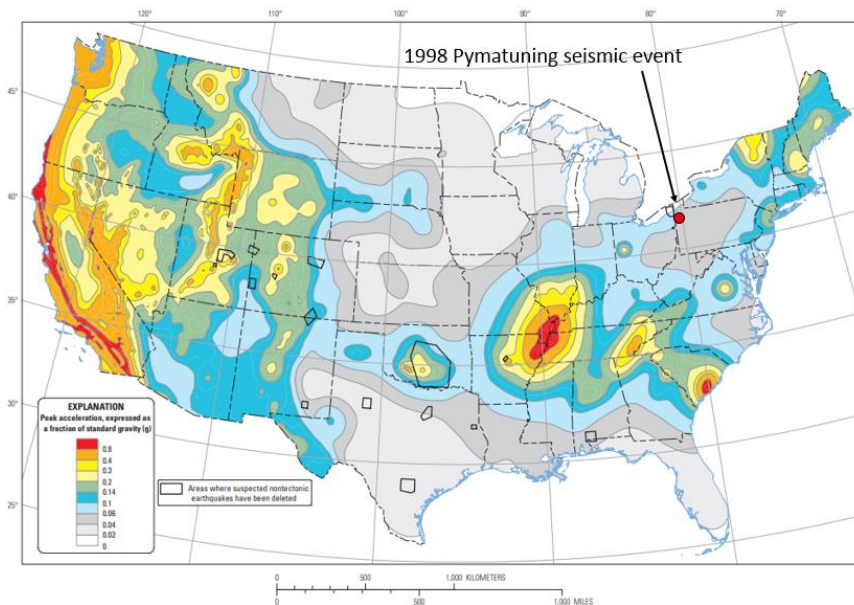

FIGURE 12. USGS 2014 seismic risk map. The approximate location of the 1998 Pymatuning seismic event is shown as the red dot. Base map can be accessed at: https://earthquake.usgs.gov /static/lfs/nshm/contermino us/2014/2014pga2pct.pdf

Two-percent probability of exceedance in 50 years map of peak ground acceleration

The Pymatuning 1998 earthquake occurred in a region where *NO* seismic events were recognized for *130* years. An uninstrumented earthquake was felt in Meadville in 1852, about 12 km from the 1998 Pymatuning mainshock (Armbruster et al., 1999). No other earthquakes were recorded in the region until 1985, over 130 years after the seismic event felt in Meadville. Only two events had been recorded in the 1980s, both with magnitudes less than M = 3.3. Indeed, the 1993 USGS catalog of seismicity in the United States from 1568 to 1989 (Stover and Coffman, 1993) shows no seismic events in western Pennsylvania (the map has an threshold of

M = 3.3). The low number and small magnitude of the seismic events in the region over a 130 year period "*…did not suggest that this area of northwestern Pennsylvania was capable of generating a magnitude-5 earthquake*" (Ohio Geological Survey, 2001, p. 1), and yet the M = 5.2 earthquake (Armbruster et al., 1999, Maceira, 2000) did occur in this region that was previously judged to be seismically quiet.

The Pymatuning 1998 event occurred where *NO* faults were known at the time of the seismic event. Since that time, subsurface well log studies suggested a NW-trending fault near the epicenter (Alexandrowicz, 1999; Alexandrowicz and Cole, 1999). Lineaments suggest that a northerly trending fault is also located in the area, and a detailed study of the seismic event suggests that the earthquake epicenter was located near the northerly trending lineament (Maceira, 2000). This lineament orientation is consistent with Maceira's (2000) determination that the earthquake was caused by primarily strike-slip motion on a steeply dipping, northerly or northwesterly trending fault at shallow depths (2.5 or 5 km). That the event occurred near where these two probable fault systems (NW and N-striking) intersect is probably no coincidence, since the strength of the bedrock is more compromised where fault systems intersect.

Implications of the Pymatuning 1998 earthquake for western New York State seismic risk considerations are summarized below.
1) No detailed mapping had been conducted in the region of the Pymatuning earthquake when the seismic event occurred, so no faults were known to exist. Thus, in the absence of detailed geological mapping in an area, it cannot be assumed that no faults exist. In parts of western New York State where detailed mapping has not been accomplished, it may be that faults actually exist and may reactivate.
2) The Ohio Geological Survey pointed out that the past seismicity in the region did not suggest that such a large earthquake would occur in the region. Thus, the lack of recorded earthquakes in specific areas in western New York is not necessarily a predictor of future seismicity quiescence in these local areas.
3) There may not be much advance warning for a moderate-sized seismic event, since the Pymatuning area had not experienced an earthquake above M = 3.3 for 130 years. That no seismic event has been recorded is therefore again not a guarantee that such an event will not occur with few to no seismic events preceding a moderate seismic event in western New York.
4) The Pymatuning earthquake occurred where it is now recognized that NW and N-striking faults intersect. Such intersections, where the bedrock may be weaker, are found in western New York along the CLF from Attica south into Allegany County.

The facts that 1) an M = 5.2 earthquake can strike in a region where USGS defines the seismic risk as less than in the focus area, 2) where no faults were even recognized prior to the event, and 3) where no significant warning buildup of events occurred prior to the event, strongly suggests that the bare minimum level of seismic risk that should that associated with the focus area is the effects of an M = 5.5 event directly beneath the focus area. The AECB consideration discussed above increases that estimate to perhaps an M = 6.5, as do some of the recurrence/seismic magnitude considerations.

3. CONCLUSIONS

1) Detailed geological investigations have shown that the CLF extends south into Allegany County and west at least as far as the western boundary of Allegany County. These faults cross the eastern part of the ACWE project area.
2) No faults were recognized in northern Allegany County before the detailed, integrated mapping program carried out by Jacobi and Fountain (1993, 1996, 2002). It is probable that detailed mapping immediately to the west in the remainder of the ACWE project area will reveal fault systems similar to those found in Allegany County. Similar fault systems have been recognized across New York State (e.g., Jacobi, 2002).
3) The CLF is seismically active.
4) The southern part of the CLF is seismically capable, even though earthquakes have not been recorded in much of the area.
5) The lowest maximum magnitude earthquake that may occur along faults of the CLF is an M = 5.5, and an M = 6.5 is a more reasonable value. The M = 5.5 value is supported by the M = 5.2 Pymatuning (PA) event that occurred in a region of perceived very low seismic risk (lower than that in the ACWE area), and in an area where no faults were thought to exist prior to the event.

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