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October 4, 2013

Dear Ms. Nasmith:

You asked me to review the documents pertaining to the Permit Application and draft Supplemental Environmental Impact Statement (DSEIS) for the Finger Lakes LPG, LLC (FLLPG) underground Liquid Petroleum Gas (LPG) Storage facility proposed for FLLPG's property along the southwest shore of Seneca Lake, approximately 3 miles north of Watkins Glen, New York. You provided me with relevant materials obtained from the New York State Department of Environmental Conservation (NYSDEC) through a Freedom of Information Law request by Gas Free Seneca.[1] These documents were heavily redacted and, in some cases, missing pages and/or appendices. I also reviewed various third-party materials on the geology of the area and other relevant topics.[2]

In addition to university teaching and academic research, my geologic experience has included the practical application of the geological sciences to diverse environmental problems for numerous state and Federal governmental agencies and several consulting firms. These activities have ranged from remote sensing, surficial geology, and landform analysis to groundwater contamination, water well location, hazardous waste site remediation, tunnel geology studies, and aspects of underground mining. Although I am not a "structural geologist" in the narrow academic sense, the relationship of rock structures to the occurrence and transmission of fluids through natural geologic systems in a wide variety of geologic settings has been a special interest throughout my career.

INTRODUCTION AND OVERVIEW

Based on my review of the materials provided, the geology of the FLLPG site is inadequately described and evaluated in the current application to NYSDEC or the DSEIS. The subsurface geology of New York State is poorly documented and many more structures, such as faults, folds, and miscellaneous fracture systems are present across the region of south-central New York than are shown on maps or known from published documents. These numerous geologic structures exist within a complex stress field produced by the geologic history of rock deformation, the existing dynamic state of stress (forces) in the Earth's crust, and the unusual lake-basin topography. All of these variables create anomalies in the perceived uniformity of the local rock

[1] These materials included:
Finger Lakes LPG, Underground Storage Permit Application (Oct. 9, 20090 (incomplete copy); NYSDEC, Notice of Incomplete Application to FLLPG (Jan. 11, 2010); Finger Lakes LPG, Revised Reservoir Suitability Report (May 14, 2010);NYSDEC, Second Notice of Incomplete Application, Finger Lakes LPG (Aug. 12, 2010); Response to Second Notice of Incomplete Application, FLLPG (Sept. 28, 2010); NYSDEC, Third Notice of Incomplete Application, FLLPG (Mar. 28, 2011); Proposed thickness blanket of LPG blanket for Galleries 1 and 2, FLLPG (July 20, 2011); Memo from geologists Dionisio and Istvan Re: Response to Public Comments (Jan. 19, 2012); Proposed Changes to FLLPG Storage (Jan. 20, 2012); Workplan to Evaluate International Gallery 10 and Well 29, FLLPG (Apr. 11, 2012); Correspondence with Sevenker concerning mechanical integrity of cavern (Jan. 22, 2013).
[2] These materials included:
Davidson, Faulting and Fluid flow through Salt, Geol. Soc. London, Attachment 18 (2009); R. Jacobi, Basement Faults and Seismicity, Tectonophysics, Attachment 19 (2002); C.H. Jacoby, International salt brine field at Watkins Glen, (1962); C.H. Jacoby, Effects of geology on hydraulic fracturing of salt (1965); C.H. Jacoby, Storage of hydrocarbons in cavities in bedded salt deposits formed by hydraulic fracturing (1969); C.H. Jacoby and Dellwig, Appalachian foreland thrusting in Salina salt Watkins Glen (1973); C.H. Jacoby et al., Earth Science aspects in disposal of inorganic wastes (1973); C.H. Jacoby, Recovery of Entrapped Hydrocarbons (1973).

strata. The primary structural anomalies, such as faults and folds, alter and otherwise influence the existing fracture pathways that define or create the fluid permeability in the sedimentary rock column, as well as those changes that may result from the proposed pressurized storage activities. The existing fracture systems can be expanded and reopened in complex ways, or new fractures can be created, by increased fluid pressures introduced by LPG storage.

Numerous additional geologic issues exist that are not adequately addressed in the FLLPG application materials. The existence of anomalously high horizontal stresses (forces) in the subsurface that exceed the weight of the overlying rocks is generally unrecognized and underappreciated. The combination of anomalies created by intersecting geologic structures, deep lake-basin topography, artificial stresses created during gas storage, the unrecognized stress fields present within the rock column, and the probable density of unrecognized, small-scale deformation features can all result in the unpredictable behavior of the presumed homogeneous geologic media when artificial stresses (LPG storage pressures) are applied. Past experience has demonstrated that fluids can escape to the surface, or enter the groundwater table during LPG storage.

The current FLLPG site needs much more geologic analysis, including better seismic exploration, to adequately define the detailed nature of the bedrock geology, especially the additional small-scale structures that are certain to be present onsite, as well as in the immediately surrounding area. Commonly available geophysical exploration methods could also better define and demonstrate whether proposed structures, approximately located on existing generalized maps, actually extend into or close to the site area. Fluid storage conditions under pressure in relatively thin-bedded salt deposits such as those being considered are likely to be very different from major salt dome sites (large, homogeneous, salt bodies) that are more commonly utilized for storage elsewhere in the U.S.A. or the world. Reported rubble zones in the existing cavities suggest that solution openings may not have sufficiently thick salt protection extending in all directions. Greater caution and geophysical exploration are needed to establish the details of the subsurface geology of the proposed site. The September 10, 2013, earthquake near a major structural intersection is a further indicator of the poorly documented geologic complexity resulting from the conditions described in the following report.

INADEQUATE GEOLOGIC DOCUMENTATION

My overall first impression of the incomplete and highly redacted materials made available for the FLLPG project, is the nearly complete lack of relevant (site-specific) geologic information and materials from which to form a scientific judgment concerning the important geologic details of the proposed site. I specifically refer to pages 3, 17, 18, and 19 and the overly generalized stratigraphic columns and maps in Exhibits 3 and 4 of the 2009 Application. This also includes a nearly complete lack of FLLPG responses (redacted) in the May 14, 2010 revised reservoir suitability document. The limited and generalized geologic information included does not provide a realistic means of analyzing the actual details of the site geology or forming a basic understanding of some of the controversial issues raised by the public or included in other documents listed in the attached references. Some of the incomplete documents provided to me lack page numbers or any comprehensible means of adequately interrelating the various sections of the submitted documents.

As a general comment on the availability of detailed and relevant geologic information in the State of New York I should first make the following observations. Unlike most modern State geological surveys, the New York State Geological Survey (NYSGS) has provided the public (and other State agencies) with little or no up-to-date information concerning the subsurface geology of New York State. From its early international reputation as one of the best and most active geological survey organizations prior to World War II, the NYSGS has failed to keep up with the modern trend in most State surveys of providing as much geologic information to the public and relevant industries as is available, from a wide variety of public and private sources. Much of the bedrock geologic quadrangle mapping in New York dates back to the turn of the last century (early 1900's), and is at an inadequate scale (1:62,500), as well as lacking adequate characterization of the surficial geology. The newer Surficial Geology Map of New York is at much too small a scale (1:250,000) to significantly improve this shortcoming. As a result of this long-term neglect, the State of New York has one of the most inadequate and outdated collections of marginally useful geologic information of all 50 states. This includes an inadequate database for groundwater resources, structural geology, and detailed surficial geologic mapping for routine environmental applications. A perusal of any other large state's "Geological Survey" website readily illustrates the comparative inadequacy of the available New York databases documenting the surface and subsurface geology of New York State. The subsurface structural geology of New York is probably one of the least well-known aspects of the State's inadequate geologic data base. In most states highly detailed maps of the geologic structures, constructed from public and private sources, are routinely compiled into detailed maps that are very useful in hazard assessment, not the least of which is assessment of earthquake hazards. New York State is in the unfortunate position of lacking such a viable database, as shown by the intense criticism directed at the draft environmental impact statement prepared for proposed statewide natural gas "fracking" activities.

Any attempt to understand the local geology of most commercial sites in New York must be viewed in the light of this comparative lack of useful, detailed geologic information at the most basic level. This grossly inadequate database has placed New York in the position of constantly having to react to various environmental issues by playing catch-up or spending large amounts of money on remediation efforts on a wide variety of environmental fronts. This shortcoming is a core inadequacy of the FLLPG application.

In addition, the prevailing practice of allowing corporations to claim that even the most basic geologic information is "proprietary" is a very backward and self-defeating practice. In most cases the "proprietary" claims by mining and other subsurface operations serve no useful or logical purpose, as the companies already own or lease the land in question, so that no competitor can make practical use of the information. In short, the "proprietary" exclusion allowances followed by New York State regulatory agencies serve no useful purpose either for the permit applicant or for the public, and merely serve to maintain New York State's outdated and inadequate position in the arena of natural and environmental resources.

The next most glaring deficiency in the limited documents that were provided to me is the nearly complete lack of discussion of up-to-date references concerning what **is** actually known and can be inferred about the structural geology of the local Finger Lakes region in New York State, especially the potentially higher density of subsurface faulting. The most glaring omissions in this regard are the lack of any serious discussion of the detailed structural geology studies and analyses by Dr. Robert Jacobi (SUNY Buffalo) and his various students and colleagues (See Selected References). Dr. Jacobi's widely-cited publications on the subsurface structures and faults in the region are a major contribution to the structural geology of NY, and provide new approaches to identifying and assessing the locations and nature of geologic fault and fracture systems. Another major reference dealing with the structural geology and limited subsurface seismic analyses in south-central New York is the 176-page USGS Open-File Report 82-319 by Podwysocki et. al. (1982). Both of these reports provide evidence of the existence of numerous faults that are present but not shown on most of the inadequate geologic structure maps that exist. As a result of this lack of detailed subsurface geologic data for the FLLPG storage site, it is not possible for a realistic appraisal of potentially complicating geological issues to be made. At the very least it would be advisable and appropriate to have detailed seismic reflection/refraction surveys of the site at scales that are adequate to detect subsurface structures with offsets down to the 1-foot range. Such surveys should be conducted across a region that is considerably larger than the immediate property where storage activities are planned. This would help to clarify whether overpressurization of geologic structures, such as small undetected faults, might occur, potentially at some distance on properties surrounding the site in question. Overpressurization or collapse of chamber roof materials could lead to the migration of fluids along newly opened or newly exposed fracture systems (faults, joints, bedding planes), thus allowing escape of fluids to the surface or into adjacent groundwater aquifers.

SIGNIFICANCE OF SUBSURFACE GEOLOGIC STRUCTURES

Faults, folds, joints and associated structural bedrock features should be an important focus of any study relating to the storage of fluids in natural or man-made cavities. In this regard, it is clear from my own field experience and from the work of Dr. Jacobi and others that central and western New York contain far more faults, large and small, than are shown on any of the few deficient and out-of-date geologic maps that are available to illustrate such natural features. In particular Jacobi's, and Stone & Webster's maps and figures show that both sides of Seneca Lake are the locations of several prominent structures (see attached Figures 7, 8, 11). Nearly every major rock quarry, large bedrock gully, roadcut, or tunnel excavation exposes such unmapped geologic structures. They are all important in the development of groundwater resources, as well as for understanding the potential for the spread of pollutants from landfills, abandoned industrial facilities, and subsurface mining, as well as underground fluid storage. Many small faults are not especially evident on the types of seismic survey lines typically run for oil and gas exploration, partly because the wavelengths or geophone spacing used are not adequate or intended to detect relatively small bedrock offsets. However, faults with small offsets are just as capable of transmitting fluids as are larger structures. One example of the density of faults in some locations is shown by the seismic profiles of the Gloade Corners Reservoir (see Figure 3 attached). The seismic line associated with this drawing obviously contains many more potentially smaller faults (offsets) than are selectively highlighted by the vertical blue lines. Other examples of unmapped faults are contained in the report by Podwysocki et al. (1982). To illustrate the types of small, unmapped structures I am referring to, I have attached several additional images of unmapped faults (Figure 1) and fault trends (Figure 2) in some of the areas where I have worked, researched, or studied in western NY. The large number of faults within the City of Rochester (Figure 2) is a good example of how little is known, even in areas where there is a long history of major engineering and construction projects. These small faults, or any similar fracture systems, could allow the migration of gasses or fluids away from the storage caverns and into local aquifers or up to the ground surface.

STONE AND WEBSTER REPORT: STRUCTURES IN THE SENECA LAKE REGION

The application materials fail to provide a full account of the potential rock deformation structures in the Seneca Lake Region. Rock deformation structures could provide potential pathways for the LPG Finger Lakes intends to store in its FLLPG project. One of the few compilations of the geology of south central New York State is the somewhat outdated 1978 Stone and Webster report on the geology of the Salina Basin. However, this report does provide a comprehensive review of the regional geology and has important, if limited, information of relevance to the FLLPG site. This comprehensive, 3-volume, Stone and Webster Report identifies the Reading Center and Corbett Point areas (northwest and southeast of the site respectively) as including the Corbett Point syncline (an east-west fold) and two "domal" areas immediately north and south of the project area (Figure 8). Domes are more circular areas of raised deformation than the narrower and more elongate anticlinal folds. The northernmost Rock Stream dome has a structural closure (deformation) of 150 ft. (Stone and Webster, Fig. 2.3-1). One unnumbered figure showing faults and folds included in the FLLPG application is taken from Figure 2.3-1 of the Stone and Webster report, but the details are not readily obvious on the reproduced application copy. Modified portions of the Stone and Webster Figure 2.3-1 are attached to this discussion to highlight the major structures located near the proposed storage site area (Figures 8, 11). An additional east-west fold structure (Firtree Anticline) occurs only 3 miles to the north at Firtree Point.

All such rock deformation structures are potential sites of enhanced permeability, especially where the zones of deformed rock **intersect** from several directions. Permeability in this context includes the existence of all natural planar and/or intersecting folds, faults, joints, bedding planes, and related structures that constitute the means whereby fluids may migrate more readily through less permeable rock strata, such as shale. The Stone and Webster map (their Figure 2.3-1) illustrates just such areas of intersecting structural deformation, but ignores any unmapped, small-scale structures that accompany such deformation, and which are present in all rocks throughout the region.

The axis of a long north-south trending strike-slip fault (tear fault) is postulated to cross through the project area parallel to the Seneca Lake shoreline, intersecting these other bedrock deformation structures (see also Figure 9, attached updated map from PB Energy Storage Services,). This same fault has been implicated in the escape of pressurized brine solution further south at the Watkins Glen Brine Field (Stone and Webster, p. 2.3-8; Jacoby and Dellwig, 1973). Such domes, anticlines, synclines and faults are locations where bedrock has been subjected to anomalous deformation. Salt beds are thinned substantially over the axes of anticlines (Stone and Webster, p. 2.3-3), and anticlines typically show increased density of axial jointing due to extension. The evidence that some of these structures intersect or overlap one another near the FLLPG project area makes it even more likely that numerous, smaller, undetected fault structures must be more common in the immediate area of the solution cavities than is currently realized or resolved by the geophysical exploration techniques employed to date. This is in addition to the ubiquitous rock joints that are present in every sequence of sedimentary rocks, including the Finger Lakes region (as shown on the New York State joint system map of Isachsen and McKendree, 1977). These conditions all provide potential pathways for the transmission of liquids or gasses between the salt caverns and the surface, especially under untested pressures and temperatures for extended periods.

The report by Stone and Webster (1978) makes the important observation that some of the known faults in the southern Finger Lakes area do not show in structure contours **below** the salt beds, and are therefore directly related to shallower salt deformation, especially the strike-slip and tear faults which are interpreted to be related to shallow thrust faults at or above the salt interval, some of which have not been completely mapped or are not obvious at the surface (such as at the Myers Mine further east on Cayuga Lake). This condition exists because the more easily deformable salt beds have acted as planes of weakness during earlier geologic periods of horizontal compression. The Stone and Webster report summarizes the fault situation as follows:

> Much of the faulting in south-central New York can be attributed to the lateral compressive forces exerted during the Alleghenian orogeny. As described in Section 2.3.4, much of the faulting is confined to subsurface, and the displacements die out in the Upper Devonian shales. Some of the faults cut the surface rocks (see Table 2.3-1); displacements vary from 25 to 250 feet.

(Stone and Webster, p. 2.3-8). Jacobi and Lowenstein (2003) make similar observations about structures originating within the salt bed horizons. These observations make it all the more obvious that structural deformation is more complex in and above the salt formations, but that not all structural deformation can be seen or accurately measured at the surface. The existence and density of such unmapped structures make it imperative that more sophisticated geologic analyses are performed to determine whether such features are more common that currently revealed by existing or released data for the current site. The undetected presence of such structures should be a major concern with regard to the future integrity (potential leakage under pressure) of the proposed storage facility.

FLUID MIGRATION CONCERNS

Most successful salt storage cavity facilities outside New York (Table 3) are located in large volume salt domes, not in the much thinner horizontal salt layers than are often interbedded with commonly associated rock types, such as brittle, deformable shale. Solution cavities in such relatively homogeneous salt domes outside of this region can be very large. Typically, LPG (mostly a variable mixture of propane and butane) has a liquid-to-gas conversion volume ratio of approximately 1 to 250 (varies according to composition). Pure propane can be liquefied at a pressure of 32 psi at around 68 degrees F; whereas pure butane liquefies at a pressure of 320 psi at 131 degrees F. When LPG is stored underground the temperature and pressure conditions vary, depending on gas composition and the time-variable conditions within the particular reservoir as gas is either added or withdrawn. Salt storage literature by the industry admits that cavities used for storage that are formed in wider, thinner salt bed formations are more prone to deterioration. Such wide, thin salt beds represent the situation in the Finger Lakes region.

The major concern in the development of underground gas storage facilities in the Seneca Lake region should be the possibility of fluids being released along the existing and likely common but unmapped and undetected rock fractures (especially faults and joints) and escaping to the surface or contaminating groundwater resources. Although the pressures generally encountered may not be as high as those used in some “fracking” operations, there are examples in other states (and countries) where underground gas storage facilities have resulted in the release of the stored gas product to the surface (Hutchinson Kansas, 2001, being one of the most recent and most disastrous). As a related issue, should hydrofracturing of the Marcellus Formation become a widespread practice in New York State, the potential impact of such high-pressure development on contiguous storage cavities in Salina Group rocks also should be taken into consideration.

Example of Fluid Migration on local North-South Fault Reported by Jacoby and Dellwig (1973)

The following quotation is extracted from the PB Energy Storage Services report (2011), p. 14:

> Faulting has complicated both conventional underground mining and solution mining of salt in the vicinity of Seneca Lake in Schuyler, Yates and Tompkins Counties. Within the US Salt brine field area, Jacoby and Dellwig (1973) report a major, near vertical, north-south strike-slip fault located east of Wells 41, 37 and 29. Jacoby and Dellwig also describe a low angle “bedding” thrust fault which passes through the sequence of salt and shale beds which has been developed by solution mining. The thrust fault strikes east-northeast and dips southerly. In the southern part of the US Salt study area, Jacoby and Dellwig (1973) report a single fault which then divides into several faults proceeding northward. A considerable amount of hydrofracturing was done in the brine field to attempt to connect adjacent wells for solution mining purposes. Hydrofracturing, when successful, was conducted at the bottom of the Syracuse, generally in the D salt immediately above the Vernon. Hydrofracturing connected wells in the southern portion of the brinefield generally in an east-west alignment. In the northern portion of the field, wells were generally connected along a roughly north-south orientation. Because of the fault-disrupted beds in the brine field frac-connecting of wells was often difficult or unsuccessful.

In other words, fluid migration was unpredictable. The attempts to connect wells by hydrofracturing were unsuccessful because of the existing natural fractures or unanticipated stress conditions that provided alternative (unpredictable) pathways for fluid migration. The PB Energy Storage Services Report continues:

> Hydrofractures in some cases intersected faults in the brine field so leakage of fluids from the galleries could occur along natural or manmade breaks. Jacoby and Dellwig (1973) report that a hydrofracturing attempt in Well 29 resulted in a flow of brine to surface one-half mile to the north. They assumed the fluid traveled along the major north-south strike-slip fault.

The same 2011 report confirms the location of this north-south strike-slip fault in the vicinity of the proposed site (see attached Figure 9), as well as better defining the domal deformation overlapping the Corbett Point Syncline (PB Energy Storage Services, p. 12). These structures could present a real threat to the integrity of the proposed FLLPG storage facility, because unforeseen operating conditions could lead to the escape of fluids along such permeable structures, especially under increased pressures in the presence of other undetected fracture systems, such as rock joints.

IMPORTANCE OF HORIZONTAL ROCK STRESSES AT RELATIVELY SHALLOW DEPTHS

When rock strata are subjected to increasing artificial stresses, such as increased pressures or hydrofracturing, the rocks will eventually respond by opening existing fractures and/or creating new fractures in directions determined by the natural stresses already present within the rock column. Such new fractures open (expand) in a plane at right angles to the direction of least compression, where total stress (force) is divided into three mutually perpendicular directions (usually the vertical, plus two horizontal vectors at right angles). Most individuals (and many geologists) assume that the greatest stress (force) at various depths is vertical and solely due to the natural weight of the rock column. It is a little appreciated fact that the **horizontal** rock stresses to depths as great as 3000 feet are often **greater than vertical rock loads** (rock weight). For example, in the new American Rock Salt Mine in the Genesee Valley at depths of 600 to 800 feet, horizontal stresses were found to be up to 3 times the vertical rock loads (rock weight). Such conditions are probably related to the stresses produced by the lateral movement of the Earth's tectonic plates (Zoback and Zoback, 1980). Regardless of the cause, such stresses produce horizontal deformation in subsurface mines and cavities at these moderate depths, further adding to the possibility that such forces can produce unanticipated deformation and deterioration of underground openings. The surface expression of these horizontal forces is often manifested at the surface by so-called "pop-ups", especially when the vertical rock load is removed during rock quarry excavations (Figure 4, Gasport, New York). The implications of such dynamic stress fields is not adequately discussed or considered in the FLLPG application.

One of the significant aspects of the pervasive existence of such horizontal forces throughout this region is their potential impact on the development or reactivation (opening) of fractures during fluid pressurization activities (including activities such as hydrofracking). Given the fact that horizontal tectonic forces in the earth (trending roughly east-west in central New York) can be greater than rock loads (weight of the rocks) to depths of several thousand feet, the analysis of stress release (triaxial stress/strain analysis) dictates that new joints or fractures will preferentially form (or old structures will open), in the **vertical** plane, at right angles to the horizontal directions of maximum and intermediate stress. Simply put, this means that new rock fractures or existing faults and joints will tend to form or expand in the vertical direction, potentially increasing the pathways for the movement of fluids upwards toward the surface. This is determined by the direction of **least principal horizontal stress**, as described earlier.

For all the above reasons it is important to better determine the existence and locations of all potentially undetected small structures (faults, folds, prominent joint orientations) in and around the FLLPG storage site, as well as to understand the natural, in situ, stress field. These features and the existing dynamic forces encountered during storage-related activities will mutually determine the likely pathways for unpredictable fluid migration.

ABNORMAL VALLEY STRESS CONDITIONS

Stresses (forces) within the shallow Earth's crust (upper several thousand feet) are not uniform, due to the conditions introduced by the presence of valleys produced over geologic time by rivers or glacial erosion. Such natural depressions distort the stress (force) field, depending on the mutual orientations of the valleys with respect to the horizontal and vertical stresses. Such conditions are presented by the orientation of the relatively large Finger Lakes Valleys, which are approximately perpendicular to the prevailing east-west horizontal stress field. The interaction of the topographic features with the natural earth stresses creates another set of features that can produce and have produced additional fracture permeability (fluid migration routes) within the local rocks.

The most important issues related to these bedrock stress conditions near and beneath large valleys are related to the predictable fractures that parallel and underlie such topographic depressions, especially where the prevailing east-west stress field is oriented at right angles to the major north-south valley axes. The basic concepts of such valley-induced structures are described in Nieto and Young (1998), from which Figure 5 is included to show how increased rock permeability (fracture permeability) develops beneath and parallel to valleys in such locations, due to localized stress conditions. Fracture development is enhanced parallel to and beneath such topographic anomalies, requiring a more detailed awareness and analysis of any existing small-scale structures and anomalous stress fields.

Figure 6 from a US Bureau of Mines study illustrates how such features under valleys in actual mine areas have complicated the geology and resulted in roof failures associated with anomalous fault/fracture concentrations. Further examples and discussion of the association of valleys with anomalous fracture concentrations (Figure 10) are contained in Wyrick and Borchers (1981), although their analysis does not include the effects of the potentially greater horizontal stress field. The combined conditions depicted in Figures 5, 6 and 10 are suggestive of how unanticipated fluid migration might be facilitated by the existence and/or reactivation by fluid pressure along such fracture pathways. These real-world models do provide one possible way that fluid migration toward or beneath Seneca Lake might be enhanced, despite the dismissive statements to the contrary in the memo from geologists Dionisio and Istvan (2012). The key to such potential migration is largely dependent upon the location and density of unknown subsurface structures and the unpredictable effects of long-term fluid storage under lower temperatures and higher pressure conditions.

Given the detailed studies published by R. D. Jacobi and his various coauthors (1996 to 2003), by Podwysocki et. al. (1982), and by Stone and Webster (1978) and the evidence that deformation near and under valleys is likely to be much more common and complex than generally appreciated, I conclude that the existing DSEIS is inadequate to determine whether the proposed facility includes or is located near bedrock structures or faults that are not revealed by the inadequate data and limited geophysical surveys made available to date.

RECENT SEPTEMBER 10, 2013, EARTHQUAKE UNDER SENECA LAKE

The recent tectonic stress release (earthquake) beneath Seneca Lake can be viewed as reinforcing some of the issues raised in this review. The magnitude 2.0 earthquake, centered beneath the lake, approximate 13 miles north of the FLLPG site, occurred at a location that is the obvious intersection of several deformational structures located in the vicinity of the towns of Himrod and Lodi (Figure 11). Although the approximate depth of the quake was reported as 3 miles (5 km), the existing stress field nearer the surface must have a complex influence on the overall stress field at depth. In other words, anomalous stress patterns nearer the surface could have an influence on how and where stress is released at greater depths (such as by an earthquake). It is likely that the September 10th earthquake could have a complex relationship to the anomalous stress conditions induced by one or more of the potential factors discussed in this review.

SUPPORTING INFORMATION AND WORLDWIDE STATISTICS

A British government (UK) worldwide review (Keeley, 2008) of underground gas storage sites found the following:

> Overall, 64 instances of problems at UGS (Underground Gas Storage) facilities have been found. Of these, 27 have been at salt cavern facilities, …eight deaths related to UGS have been found reported in the literature, with around 61 injured and circa 6700 evacuated. All reported deaths have occurred at salt cavern facilities and all of these have been in America.
>
> Incidents have been categorized according to their cause. Failure of the storage cavity relates to failure of the integrity of the cavity (i.e. geological failure) and includes migration of the gas out of the original cavity through either rock mass discontinuities or faults, failure of the cavity roof and salt creep leading to reduced cavity capacity.
>
> Three release pathways were described which account for the range of cavern failures identified:
>
> - **Rapid advective** release through a failed or leaky borehole (well/casing) impacting on the area immediately adjacent to the borehole works. This case also includes borehole valve failure and inadvertent intrusion via drilling into the gas cavern.
>
> - **Viscous dominated** release via rock mass discontinuities and/or fault zones, which covers cases where heterogeneities become routes for viscous gas migration of free gas or advection of dissolved gas through transmissive features. This case also covers failure of the cavern roof resulting in the disappearance of the impermeable salt barrier.
>
> - **Diffusive release** via dissolution of natural gas into brine surrounding the salt cavern or the porewater in the caprock, diffusion within the brine/porewater, and subsequent exsolution and hence release to near-surface.
>
> One other significant pathway, near-surface exsolution, exists when higher permeability materials are present. A pre-existing old borehole or massive cavern collapse could form a pathway enabling gas to migrate and dissolve in a near-surface aquifer. Once the gas has reached the aquifer, several possibilities exist for how the gas comes out of solution and migrates to the surface over a wide area (120 m by 10 m).

> A paper summarizing the history of salt cavern use (Thoms and Gehle, 2000) states that early salt cavern storage in the US was done in brine wells that had been solution mined without consideration for subsequent storage in the depleted caverns. This practice sometimes resulted in later problems for storage operations in retrofitted brine caverns. Because of this, it would be expected that new purpose built salt caverns would be less likely to fail compared to the ones that had been retrofitted for gas storage.

This Keeley report highlights key issues that are relevant to understanding the geologic conditions that are present in the region of the FLLPG application, and the issues that should be documented in more detail.

The Keeley (2008) publication also contains the following Table showing the distribution of worldwide gas storage sites:

Table 3 Summary of UGS sites worldwide

Type and Number of UGS Sites

Area	**Gas & Oil Fields**	**Aquifers**	**Salt Caverns**	**Other**	**Total**
Europe	64	23	27	3	**117**
Former Soviet Union	36	13	1		**50**
USA	320	44	30		**394**
Canada	44		8		**52**
South America	2				**2**
Asia	7				**7**
Australia	5				**5**
Total	**478**	**80**	**66**	**3**	**627**

SUMMARY

In view of the complex and poorly documented structural conditions for the bedrock in and around the proposed FLLPG site, and in view of past experience with solution mines in the vicinity, it would seem obvious that there is a significant and unpredictable potential for the accidental release of brine or stored LPG along undetected fracture-related pathways should the current plans be implemented. The potential for the existence of much more numerous and complex geologic structures than are currently mapped, on both a large and small scale, is a significant issue that does not appear to have been adequately addressed, based on the data provided to me. Furthermore, the very general nature of the inadequate data provided, and the numerous redactions, provide little geologic material of any substance with which to assess the details of the site geology. My field observations in the general Finger Lakes region lead me to conclude that small and intermediate structures, specifically faults and joints, are far more common than published sources and references indicate. In addition, the active stresses within the local rocks are likely to have created some of the conditions depicted in Figures 5, 6, and 10. The potential interconnectivity and undefined fracture permeability potential, potentially enhanced by LPG storage activities under such circumstances, should be of greater concern. The potential existence of undocumented structures near or within such relatively thin salt beds, the site location on the margin of a large topographic depression (Seneca Lake valley), the undocumented horizontal stress field at depth, and stresses that would be introduced by the proposal, all combine to produce a situation in which it is currently impossible to confidently predict an accurate or benign outcome. A much more detailed geophysical (seismic) exploration of the larger site area should be a minimal requirement before any further decision can be made concerning the long-term structural integrity of the project.

Submitted by:

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Stone and Webster Engineering Corporation, 1978, Regional Geology of the Salina Basin: Report of the Geologic Project Manager (for the Office of Nuclear Waste Isolation): 3 Volumes, Figures, Maps.

Thoms, R.L. and Gehle, R.M., 2002, A brief history of salt cavern use: Proceedings of 8th World Salt Symposium, Part 1, Elsevier B.V., p. 207-214.

Wyrick, G.G. and Borchers, J.W., 1981, Hydrologic effects of stress-relief fracturing in an Appalachian Valley: U.S. Geological Survey Water Supply Paper 2177, p. 1-51.

Zoback, M.L., and Zoback, M., 1980, State of Stress in the Conterminous United States: Journal of Geophysical Research, v. 85, no. 11B, p. 6113-6156.

IMAGES ATTACHED

Figure 1

Faults exposed in local quarries and bedrock exposures in western Finger Lakes region; generally unmapped in published documents.

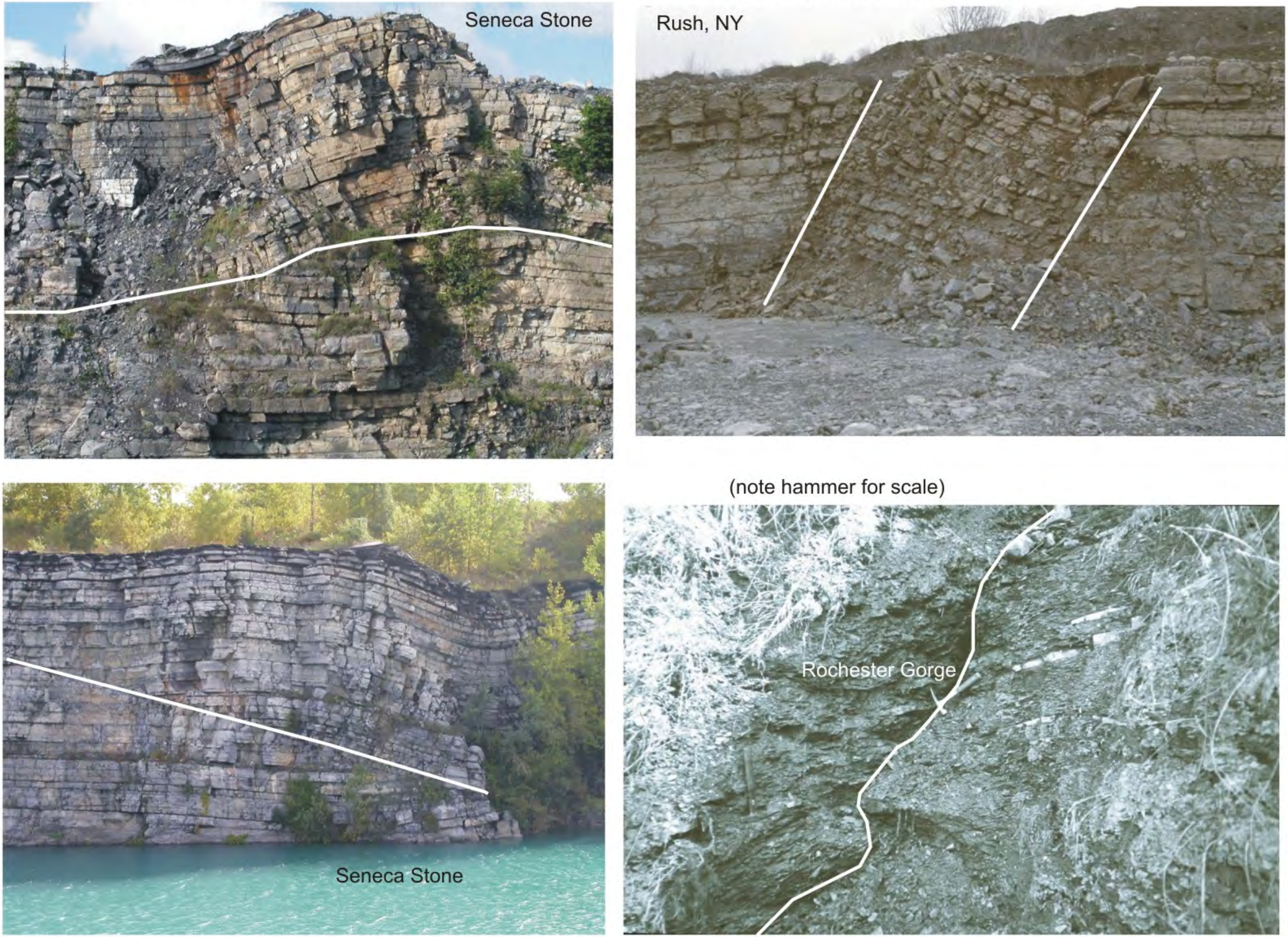


Figure 2. Faults and structural offsets discovered during drilling and construction of Rochester deep sewer tunnel project (CSOAP). Also see fault image in Rochester gorge on Figure1.

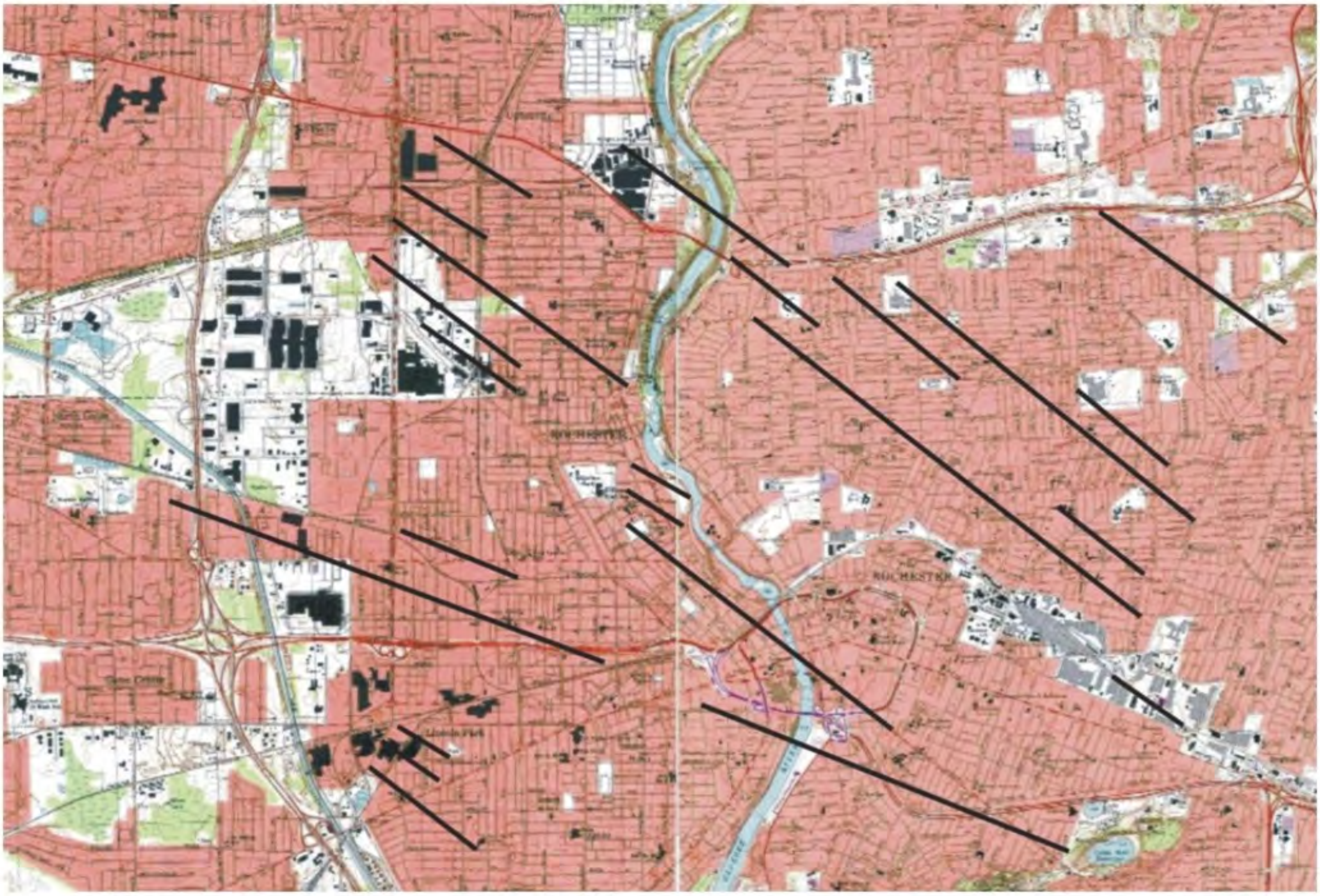


Figure 3. Geology and Seismic line for Gloade Corners, north of Pulteney, Keuka Lake, NY
Selected partial seismic line shows selected faults in blue; additional offsets are obvious.

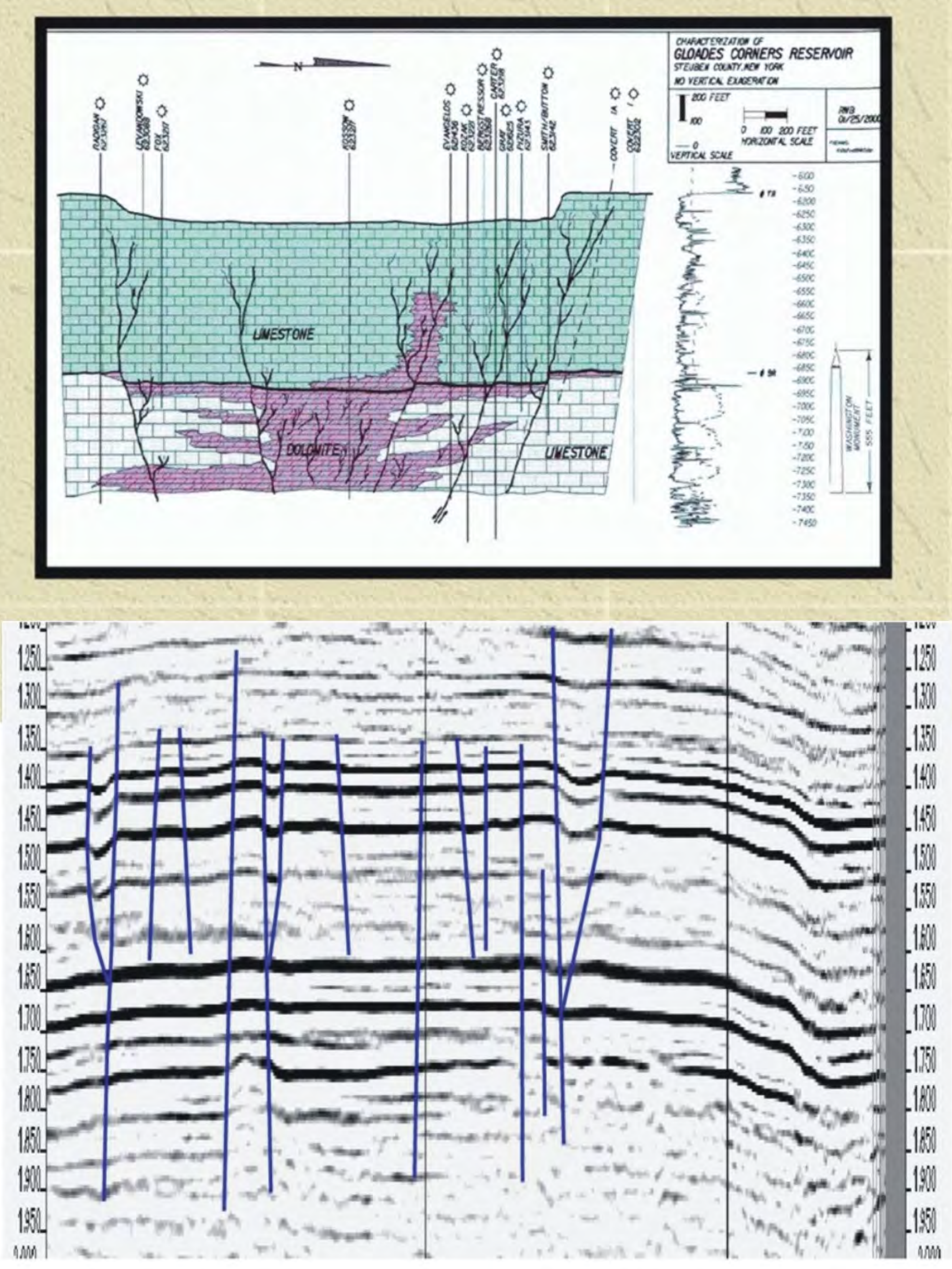


Figure 4. Pop-up structures illustrating unrelieved horizontal stresses typically present in near surface rocks to depths as great as 3000 ft.

Figure 5. Schematic drawing of effects of valley unloading stresses (valley anticline) combined with horizontal stresses.Example is located in Grand Canyon. See additional explanation in Nieto and Young,1998.

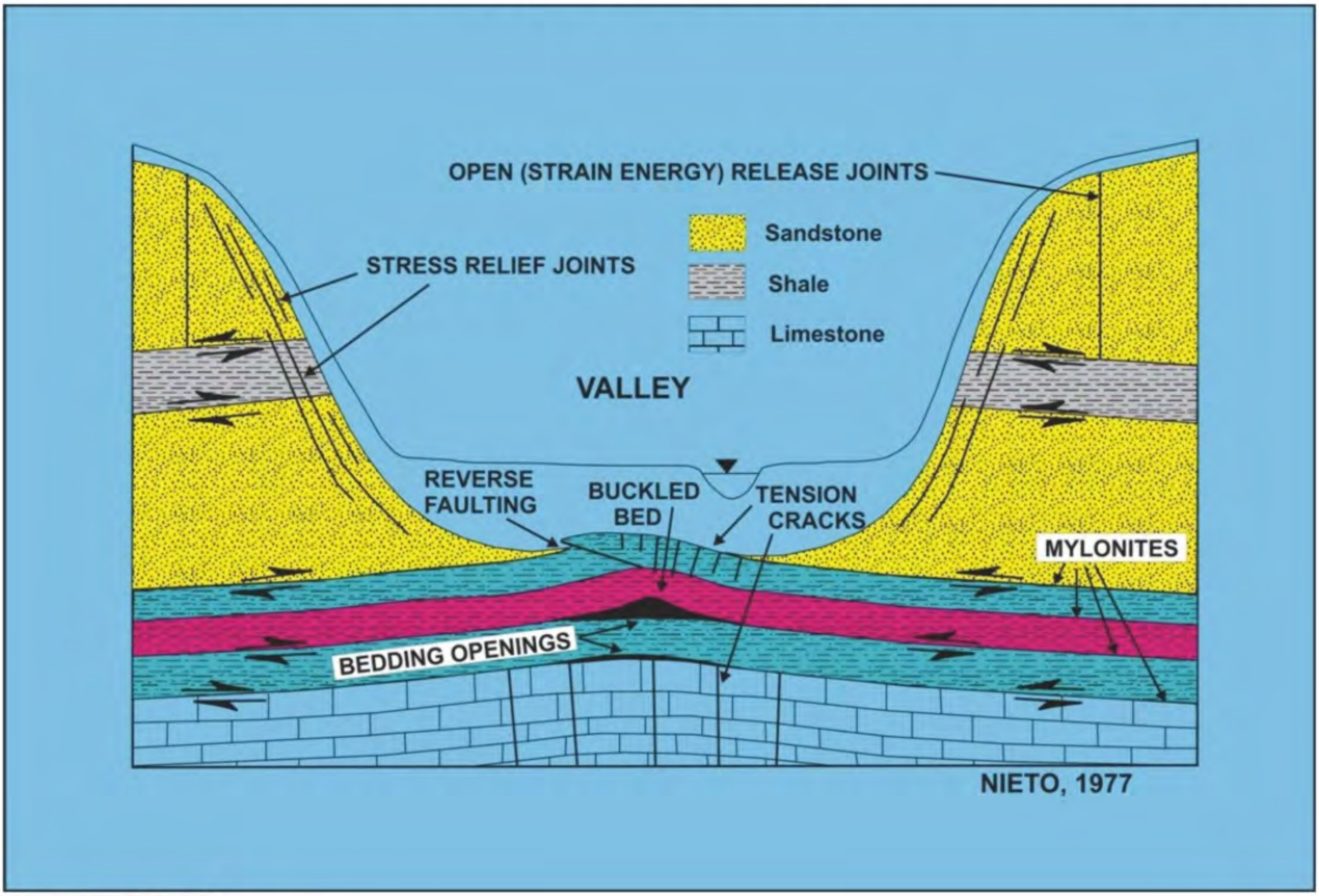


Figure 6. Examples of structural deformation in sedimentary rocks near and beneath valleys caused by a combinaiton of erosional unloading and horizontal stresses, From Molinda et. al, 1992.

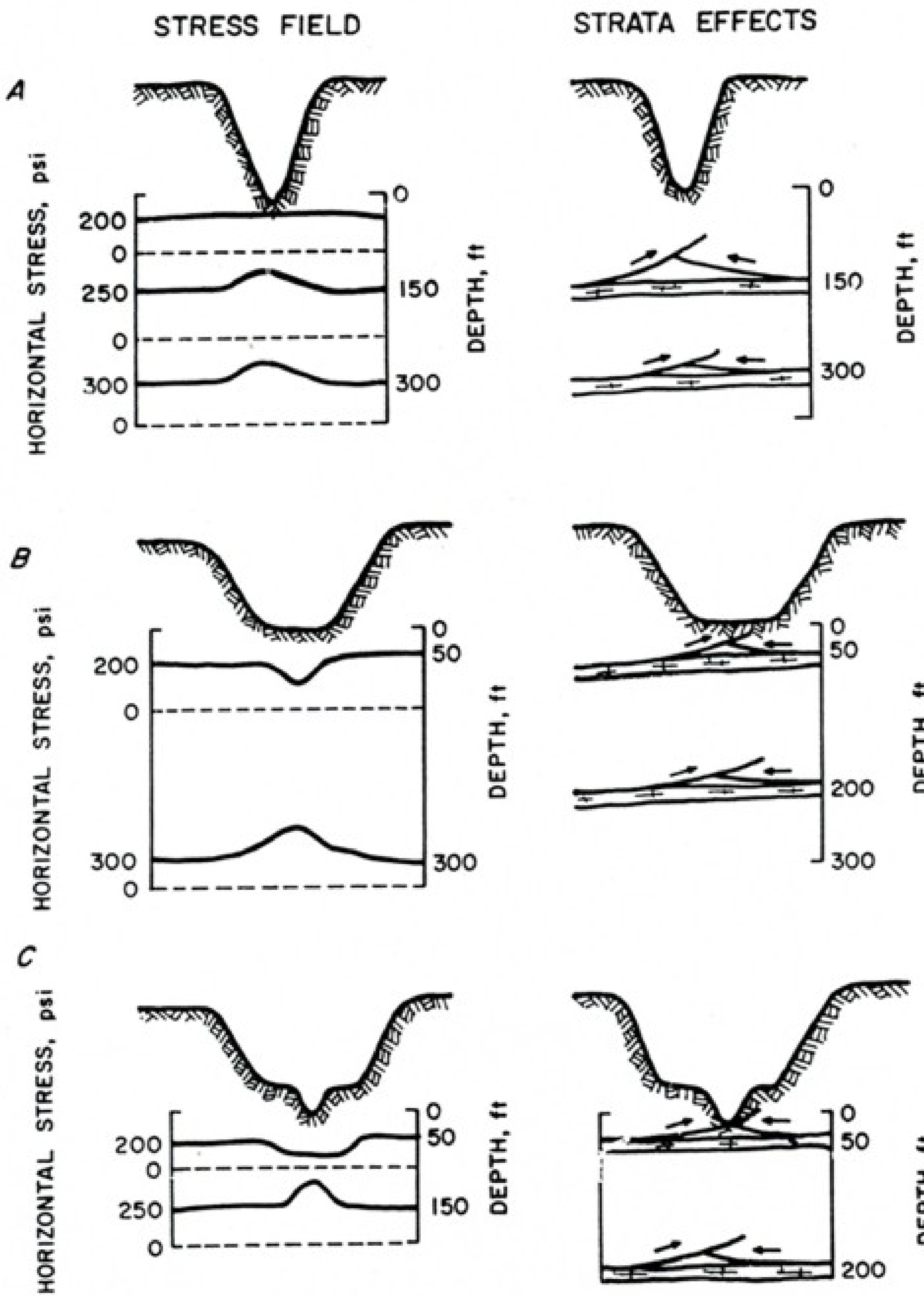


Figure 26.—Representation of modeled stress field and roof effects beneath Valleys No. 9 and No. 12. *A*, Valley No. 9; *B*, Valley No. 12; *C*, rejuvenated Valley No. 12.

Figure 7. Jacobi fault map

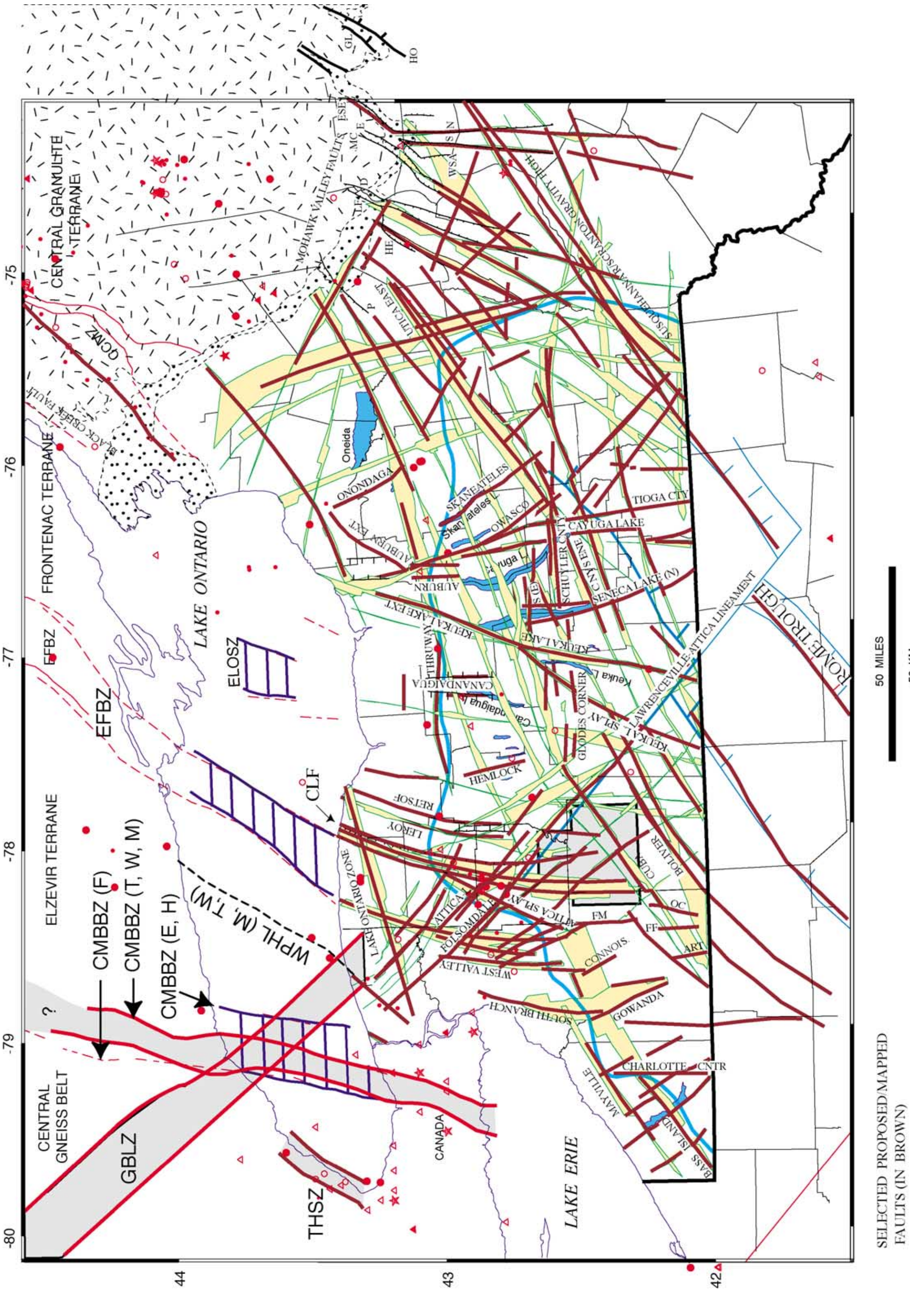
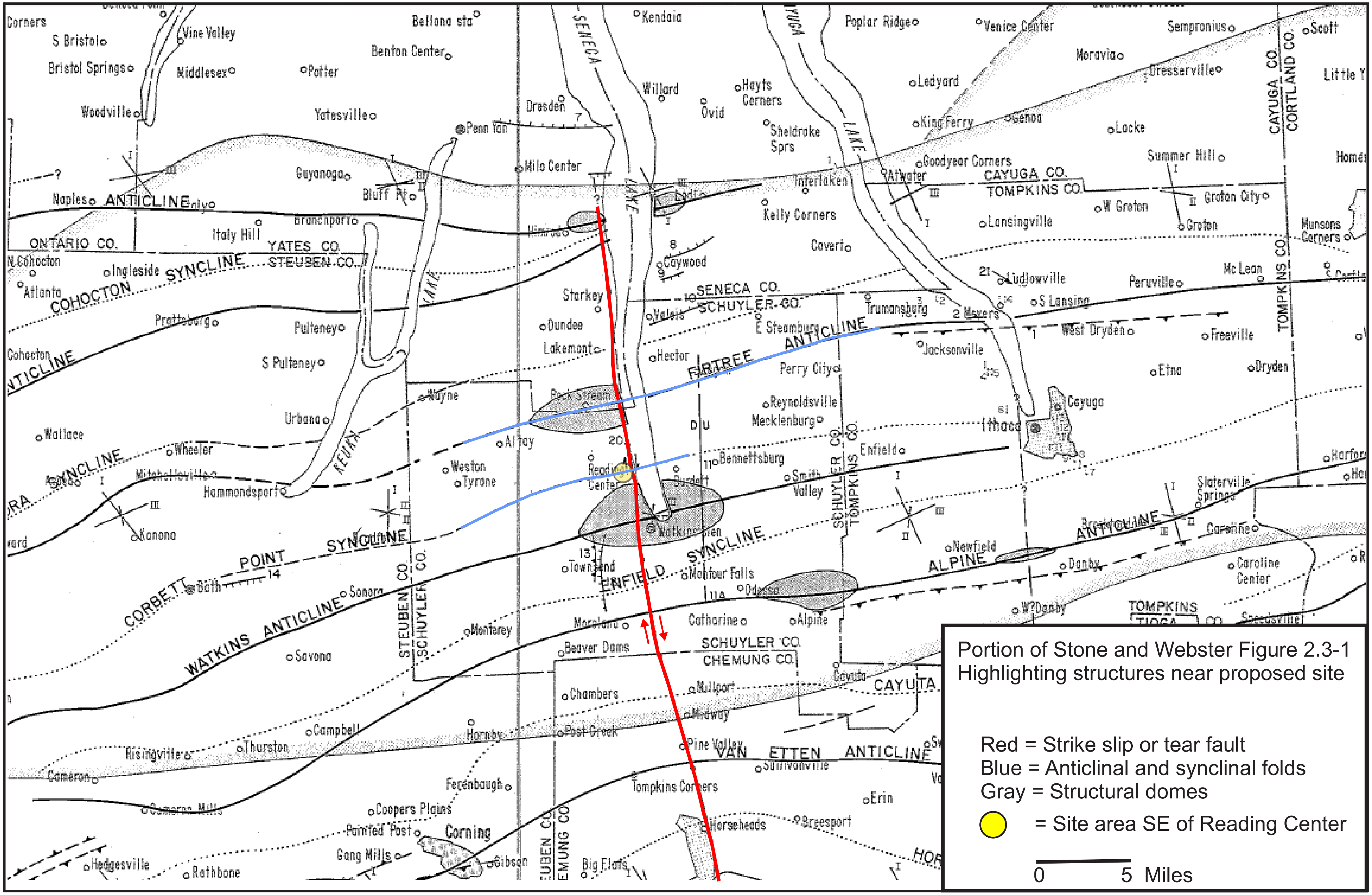
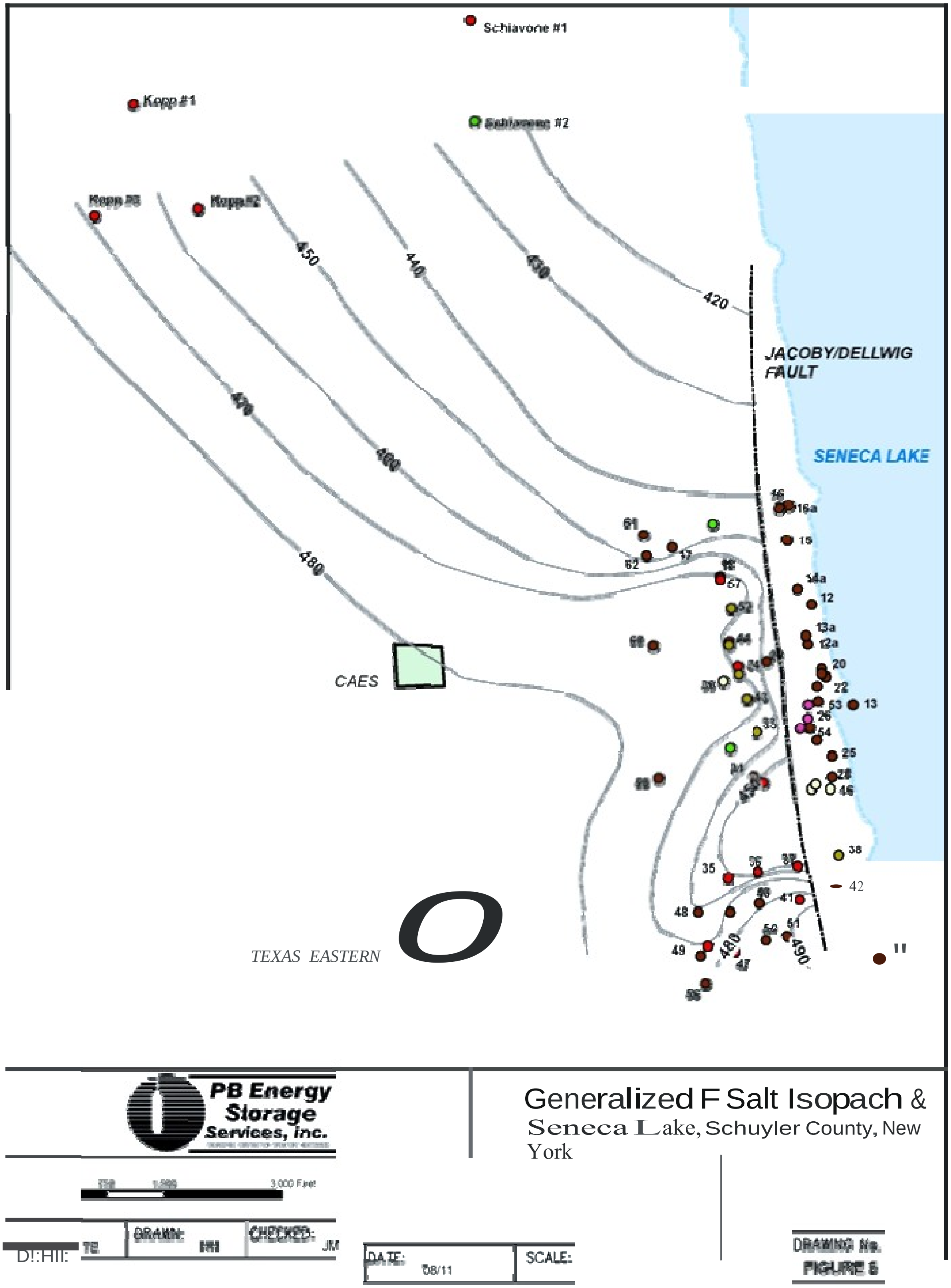


Figure 8. Portion of Stone and Webster 1978 map highlighting (color) structural trends and features near Inergy Project (yellow)



Geologic Structures

Figure 9. Updated structure contour map and fault location.



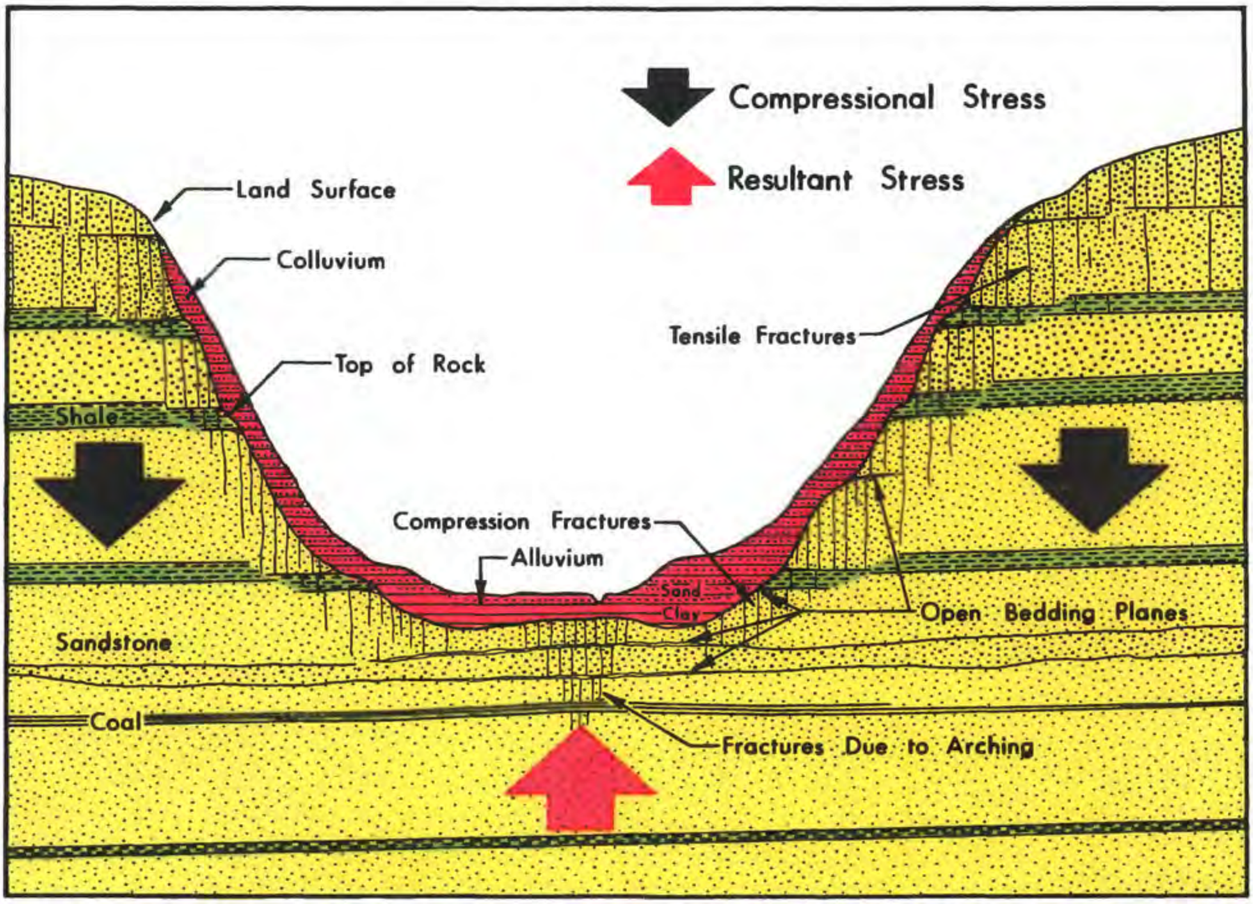


Figure 3.2-1. Generalized geologic section showing features of stress-relief fracturing [after Ferguson (1974)]

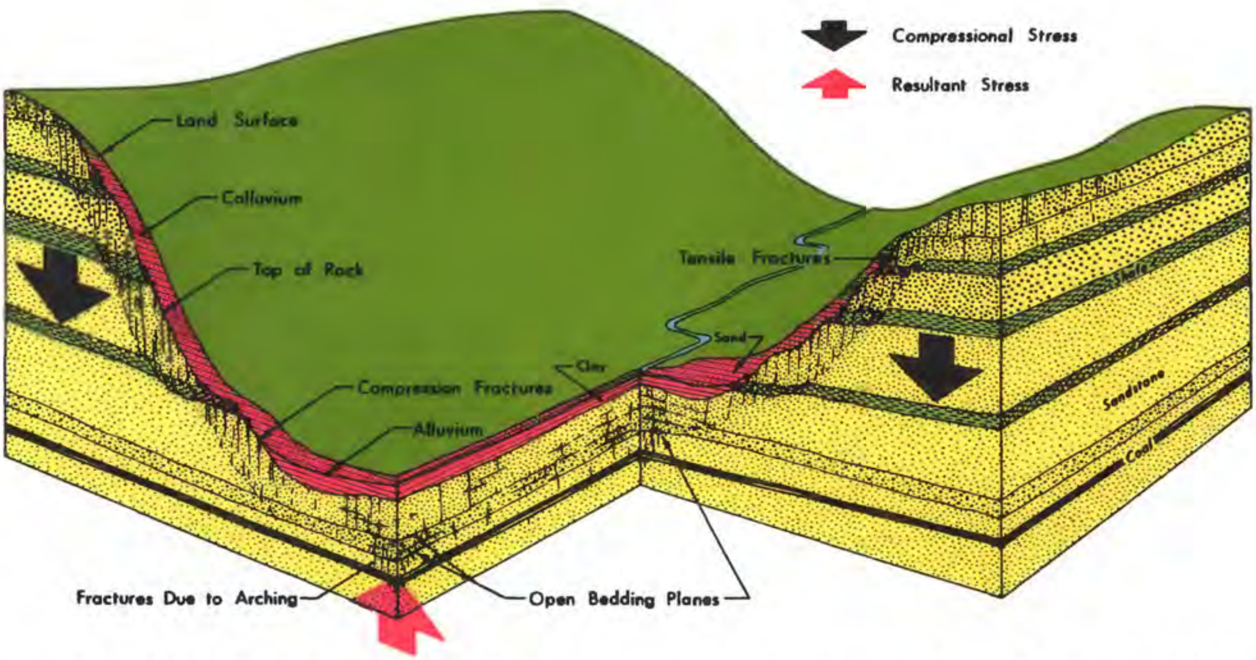


Figure 3.2-2. Block diagram of generalized geologic section showing features of stress-relief fracturing [after Ferguson (1974)]

13

Figure 10. Valley fracture conditions modeled for simple vertical stresses (Wyrick and Borchers, 1981)

Yellow = Earthquake location   Red dot = LPG site

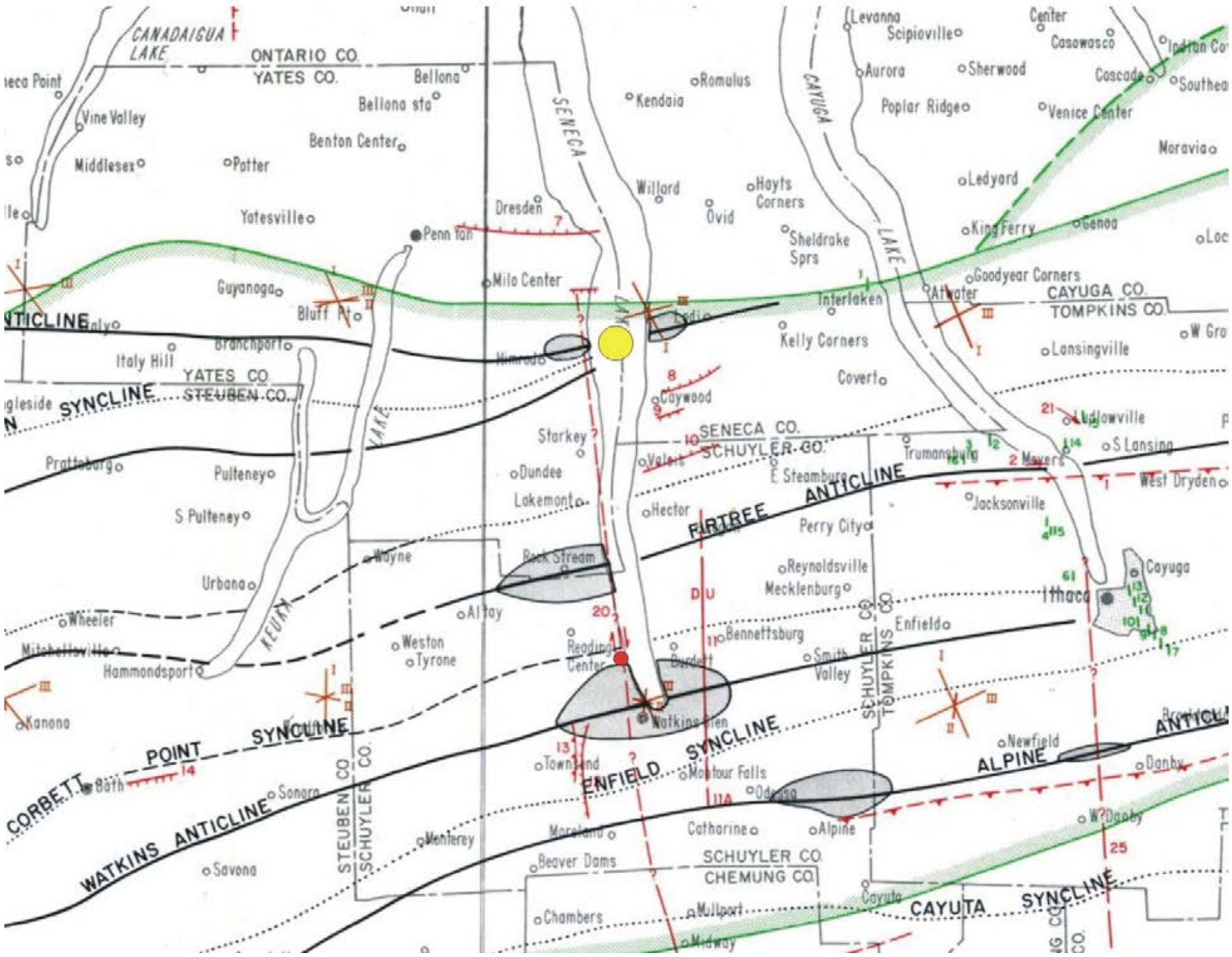


Figure 11. Location of September 10, 2013, magnitude 2.0 earthquake (yellow circle) near intersection of multiple geologic structures at Seneca Lake, approximately 13 miles north of FLLPG site (red dot). Partial of Figure 3.2-1 from Stone and Webster (1978).

GEOLOGICAL SCIENCES

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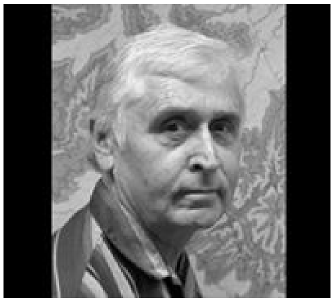

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Ph.D. Washington (St. Louis)
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EDUCATION:

Cornell University , B.A. Geology, 1962

Washington University (St. Louis), Ph.D., Geology, 1966

Dissertation: ***Cenozoic Geology along the Edge of the Colorado Plateau in NW Arizona.*** (Hualapai Indian Reservation and adjacent areas)

ACADEMIC POSITIONS, APPOINTMENTS, AND AWARDS:

2004 President's Award for Excellence in Research and Creative Endeavors

2002 Awarded SUNY Chancellor's Research Recognition Award (Albany , October 2002).

1991-present Appointed Distinguished Service Professor of Geological Sciences, State University of New York by SUNY Chancellor (at SUNY, Geneseo)

1990 Appointed Faculty Exchange Scholar, SUNY, by Chancellor Johnstone

1979-1991 Professor, Department of Geological Sciences, SUNY College of Arts and Science, Geneseo , New York

1977-1986 Chairman, Department of Geological Sciences, SUNY College of Arts and Science, Geneseo , New York

1966-1977 Assistant and Associate Professor of Geological Sciences, SUNY College of Arts and Science, Geneseo , New York

SELECTED PROFESSIONAL AND CONSULTING POSITIONS:

1994-present Consultant to NY State Attorney General's Office (Peter Skinner, Tim Hoffman) on issues related to Retsof Mine collapse. Also, water-well pollution at Bennett Heights subdivision, Batavia NY .

1977-1993 Hydrologist with U.S. Geological Survey , Ground Water Branch, Ithaca , NY . W.A.E. Status for glacial, ground water, and sedimentological studies in the Genesee Valley region. IJC Studies of Great Lakes pollution and National Urban Runoff Program (NURP).

1980-present Occasional geologic consultantto H & A of New York, Inc. Including: Pure Waters Combined Sewer Overflows and Abatement Project (CSOAP) (structural deformation in deep sewer tunnels). Gravel Pit evaluation and court testimony; Iroquois Gas Transmission Pipeline photogeologic route analysisand field evaluation (St. Lawrence to Hudson River).

1994 Hualapai Indian Tribe, Grand Canyon . Geologic Consultant during Environmental Impact Studies, western Grand Canyon Trip, October 1994

1993 -1996 Consultant to P. Hartnett, Esq., Tully Valley Salt Mine (Mud Boils) Lawsuit

1983-1994 Geologic consultant to IMS Engineers, Superfund Hazardous Waste site geologist, Moyer Landfill , Pennsylvania (Subcontract to NUS Corp.). Also additional projects on occasional basis. 1992-3 Scoffield Barracks (U.S. Army base), Oahu , Hawaii , Groundwater contamination studies of base facilities, hydrogeology.

1985-1986 Consultant to Rochester Gas & Electric/Morrison-Knudson Engineers for hydrogeologic data evaluation of Lower Falls hazardous waste site, Rochester , NY .

1986-1992 Geologic consultant to U.S. Bureau of Indian Affairs (Truxton Canyon Agency , Arizona) and Hualapai Tribe for water well site selection on Hualapai and Havasupai Indian Reservations.

1978-present Geologic consultant to Monroe County Environmental Management Council, Landfill Review Committee and Monroe County Health Department, Waste Site Advisory Committee). Including funding from N.Y.S.D.E.C. and U.S.E.P.A. for location and evaluation of county-wide abandoned waste sites (Published as U.S.E.P.A. Document EPA-600/4-83-050, 1983).

1985-1987 Field reconnaissance reviews for N.Y. State Geological Survey, Surficial Geologic Map of N.Y., Niagara and Finger Lakes Sheets.

1977-1978 Geologic consultant, Town of Caledonia , NY , Monroe-Livingston Landfill litigation (see publications).

1976 Geologic mapping for N.Y. State Geological Survey, Genesee River Watershed Mapping Project (Jointly funded by USGS, NYSDEC).

1972-1975 Principal Investigator Contract for Apollo Missions 15-17 Photogeologic Analysis: Eastern Maria Data Analysis Experiment, NASA Contract NAS 9-12770, Manned Spacecraft Center , Houston .

1966 Geologic consultant to Ocean Science and Engineering, Inc. on U.S. Army contract to locate rock quarries in S. Vietnam . Electrical Resistivity and Seismic surveys, Rock drilling and evaluation.

1962-1964 Geologic research contract at Museum of Northern Arizona , Cenozoic Geology,Hualapai Reservation (Developed into PhD dissertation, mapping project 1962-1966).

CURRENT PROFESSIONAL SOCIETIES:

Geological Society of America (Fellow)

RESEARCH AWARDS AND GRANTS:

Museum of Northern Arizona (Summers 1962-1964).

Geological Society of America Penrose Bequest Grant (1964).

SUNY Research Foundation, Faculty Fellowship (1971).

NASA Contract NAS 9-12770, Photogeologic Analysis Apollo Projects 15-17 (1972-1975).

SUNY Research Foundation, Faculty Fellowship and Grant-in-Aid (1975).

Collaborations in Art, Science, and Technology (CAST) N.Y. State Council on the Arts. Use of ERTS satellite imagery with M.J. Teres (Exhibit at Syracuse University, 1975).

NYS Geological Survey, Mapping project, Genesee Valley (1975-1976).

USEPA (Las Vegas Environmental Systems Lab) Jointly with Monroe County Environmental Management Council for pilot study, development of manual to evaluate abandoned waste sites (1981-1983).

NYS/UUP Experienced Faculty Travel Awards, 1985 and 1987, Arizona-Colorado Plateau Field Research.

Geneseo Foundation , Arizona Research, Decade of North American Geology project.

Cole Memorial Research Grant , Geological Society of America , 1988, Research on Colorado Plateau, Grand Canyon.

SUNY Geneseo Research Development Award, Genesee Valley Pleistocene Chronology, 1992.

Monroe County , NY , Chronology of Irondequoit Bay Pleistocene History, 1992.

Monroe County Health Department Study of Irondequoit Creek (Ellison Park) submergence (1996)

Monroe County Health Department Study of rates of Genesee River meander migration (1997)

SUNY Geneseo Spencer Roemer Summer Research Fellowship, $5000 (1999)

US Corps of Engineers study of Genesee River erosion history, $64,000, (2002-2003)

Univ. of Arizona , 2004, (cooperative research with George Burr) 25 radiocarbon ages ($400 each, normal charge)

TEACHING AND RESEARCH INTERESTS:

Tectonic geomorphology, fluvial geomorphology, general geology, lunar and planetary geology, glacial geology, remote sensing and geographic information systems (GIS), environmental geology, sedimentation, Cenozoic geology of Colorado Plateau/Grand Canyon, structural controls of ground water, Hawaii & New York (global stadial and interstadial glacial events).

TRAVEL AND FIELD EXPERIENCE:

New Zealand, South Vietnam, Southwestern U.S., Hawaii, New England, Big Horn Mts., Wyoming, Ozarks, Central and western N.Y., Nevada Test Site, Scotland. Coleader, Geological Society America , Colorado River-Grand Canyon Geological Society of America Geoventure Trip (WGBH-NOVA) J.W. Powell Video Program, 1992.

PROFESSIONAL COMMITTEES:

Resource Group Member Ad Hoc Lunar Photography and Cartography Committee, Lunar and Planetary Science Inst., Johnson Space Center .

Crater Analysis Techniques Working Group, NASA, Office of Space Science, Washington , D.C.

International Geodynamics Committee (Working Group 7) Organizing Committee for Plateau Uplift Symposium and Associate Editor for Proceedings, Johnson Space Center .

Crater Analysis Methodologies Workshop, USGS/NASA, Flagstaff , AZ , NASA Tech. Mem. 79730, Icarus, v. 37, p. 467- 474.

MAJOR CONFERENCES (INVOLVING ORGANIZATION PARTICIPATION, WORKSHOPS, AND PUBLICATIONS):

Lunar and Planetary Science Conferences (Annual) 3rd through 8th, 10th, 12th, 15th (papers in proceedings).

NASA Lunar Utilization Conference: Utilization of Unique Mare Stratigraphy for determination of lunar surface material properties and location of subsurface operations facilities (Paper at Special Session of 7th Lunar Science Conference, 1976).

15th Annual Binghamton Geomorphology Symposium (publication, Tectonics, Colorado Plateau-Grand Canyon).

Interdisciplinary Aspects of Radioactive Waste Generated by Nuclear Power Plants (SUNY Cortland, 1983, Speaker).

Till facies workshop: Glacial Deposits in the Northeast, N.Y. State Geological Survey, 1983.

Risk Assessment at Hazardous Waste Sites, American Chemical Society Symposium, Las Vegas (1982, paper in proceedings, hardbound text, American Chemical Society).

The Impact of Waste Storage and Disposalon Groundwater Resources, U.S. Geological Survey, Ithaca , (paper in proceedings).

Symposium: Mesozoic and Cenozoic Tectonics of the Lower Colorado River Region, Geological Society of America , Anaheim, CA, Paper in Anderson-Hamilton Volume, 1982.

Tectonic framework of the Mohave-Sonoran Deserts , California and Arizona , Panelist, Paper in proceedings, 1980.

Rochester Academy of Science Centennial Meeting on Geology of Genesee Valley, Co-chairman, Paper in proceedings, 1981.

N.Y. State Geological Survey Conference: Status of the N.Y. Surficial Geologic Map (1981).

First National Groundwater Monitoring Conference and Exposition, Ohio State University , 1981.

Crater Analysis Methodologies Workshop, NASA/USGS, Flagstaff , 1977.

International Geodynamics Committee Plateau Uplifts Conference, Field trip co-leader, Las Vegas to Flagstaff , paper in proceedings, 1978, Tectonophysics, V. 61.

Regional Geophysics and Tectonics of the Intermountain West, Geological Society of America Penrose Conference, Alma , Utah , 1975.

Hawaiian Planetology Conference, Hilo , Hawaii , NASA, 1974, Mars Mapping Conference.

Pleistocene Stratigraphy in the Northeast, Geological Society of America Penrose Conference, Univ. of Mass. , 1974.

Pacific to Arizona Crustal Experiment (PACE), USGS, Flagstaff , 1985.

Lunar and Planetary Institute Topical Conference on Heat and Detachment in Crustal Extension on Continents and Planets, (speaker) Sedona , Arizona , 1985.

Field-trip co-leader for "Structure and Geomorphic Character of Western Colorado Plateau in the Grand Canyon-Lake Mead Region", Geological Society of America Rocky Mt. Section Meeting, Flagstaff , 1986.

Field-trip co-leader for "Geomorphology and Structure of the Colorado Plateau/Basin and Range Transition Zone , Arizona ,100th Annual Meeting of the Geological Society of
America , Phoenix , AZ , 1987.

Symposium Organizer, Chronology and Style of Laramide and Early Tertiary Events in the Southern Great Basin and

Adjacent Colorado Plateau Transition Zone , Geological Society of America Cordilleran Meeting, Las Vegas , March 1988.

Co-author, Geological Society of America Decade of North American Geology Volume (DNAG), Geomorphic Systems of North America , Special Volume 2 (Colorado Plateau Tertiary history), 1987

PACE/CACTIS Conference , U.S. Geological Survey, Flagstaff , AZ , 1988 (Pacific-Arizona Crustal Experiment). 28th International Geological Congress, Washington , DC , July 1989, Symposium presentation and poster session, Colorado Plateau.

Geological Society of America , Northeastern Section Meetings, Buffalo , 1996, Organizer: Symposium on Early and Middle

Wisconsin Events in the Great Lakes-Eastern North America Region (pending, Fall 1996).

Geological Society of America Annual Meeting, Denver , 1996, Cretaceous-Tertiary Uplift of the SW Colorado Plateau: Abstracts with Programs, v. 28, no.7, p. A514. (paper presented)

Geological Society of America Northeastern Section Meeting , Portland Maine , 1998, Bedrock-Till deformation structure along the Clarendon-Linden fault zone near Linden , NY : Abstracts with Programs, v. 31, no. 2, p. 85, paper presented.

Geological Society of America Northeastern Section Meeting, Providence , RI , 1999, Regional Hydrologic impact of a large salt mine collapse beneath a deep, ice-scoured, drift-filled bedrock valley, west-central, NY State, Abstracts with Programs, v. 31, no., 2, p. A-81,paper presented.

Geological Society of America Annual Meeting, Denver , October 1999, Paper accepted for presentation in Theme Session, Terrestrial Signature of Heinrich Event (H4) in Western NY .

Workshop for western NY Secondary School Teachers, Letchworth Park, October 18, 1999; Lecture and Field Trip (Ideas and materials for teaching glacial geology topics).

Chair and organizer of Symposium on Origin of Grand Canyon/Colorado River: June 2000, Grand Canyon National Park , Sponsors: Grand Canyon National Park , Grand Canyon Association, US Geological Survey, Northern Arizona Univ., Arizona Geological Survey, Nevada Geological Survey, SUNY Geneseo Geological Sciences Department (monograph published 2004)

The Mackin Conference , 2001, Invited Symposium: “The Geologic Transition, High Plateaus to Great Basin – A symposium and Field Guide”. Utah Geologic Association Publication 30 (Pacific Section AAPG Guidebook 78), publication listed below.

PUBLICATIONS OTHER THAN ABSTRACTS AND SHORT PAPERS:

Young, R.A., Crow, R., and Peters, L., 2010 (in press), Oligocene tuff corroborates older Paleocene-Eocene age of Hualapai Plateau basal Tertiary section. In Beard and others, USGS Open File Report (in preparation), Results of Colorado River Symposium, June 2010, Flagstaff , Arizona: https://sites.google.com/site/crevolution2/home

Young, R.A., and Hartman, J. H.,2010 (in press), Early Cenozoic “Rim Gravel” of Arizona: Age, Distribution and Geologic Significance. In Beard, S. and others, USGS Open File Report (in preparation), Results of Colorado River Symposium, June 2010, Flagstaff, Arizona: https://sites.google.com/site/crevolution2/home

Young, R.A., 2008, Pre-Colorado River drainage in western Grand Canyon: Potential influence on Miocene stratigraphy in Grand Wash Trough. In: Late Cenozoic Drainage History of the SW Great basin and Lower Colorado River Region: Geologic and Biotic Perspectives, (eds. Rehis, M.C., Hershler, R., and Miller, D.M.) Geological Society of America Special Paper 439,p. 319-333.

Young, R.A., and Burr, G. S., 2006, Middle Wisconsin glaciation in the Genesee Valley, NY: A stratigraphic record contemporaneous with Heinrich Event, H4: Geomorphology, v. 75, Issues 1-2, p. 226-247.

Young, R.A. and Briner, J.P., 2006, Quaternary Geology and Landforms between Buffalo and the Genesee Valley. Guidebook for N.Y. State Geological Association 78th Annual Meeting, SUNY Buffalo, p. 435-464. (Compiler: Robert Jacobi).

Young, R.A. , 2004, The Laramide-Paleogene History of the western Grand Canyon Region: Setting the Stage: In: The Colorado River : Origin and Evolution: (eds. Young, R.A. and Spamer, E.), Gran d Canyon Association Monograph No. 12, Chapter 1(p. 7-16), Grand Canyon Association, Grand Canyon National Park , Arizona , 280 p.

Young, R.A ., 2003, (Research Report) Recent and Long-term Sedimentation and Erosion along the Genesee River Floodplain In Livingston and Monroe Counties, NY , US Army Corps of Engineers, Buffalo District, 36 pages plus appendices, maps, digital images (includes 2000+ river channel images on 5 CD's).

Young, R.A. , 2001, Geomorphic, Structural, and Stratigraphic Evidence for Laramide Uplift of the Southwestern Colorado Plateau Margin of NW Arizona: In: The Mackin Volume, The Geologic Transition, High Plateaus to Great Basin – A Symposium and Field Guide Eds. (eds.Erskine et al.) Utah Geological Association Pu b. 30 and AAPG Guidebook GB 78, p. 227-237 .

Billingsley, G.H., Wenrich, K.J., Huntoon, P.W., and Young, R.A., 1999, Breccia Pipe and Geologic Map of the SW pa rt of Hualapai Indian Reservation and Vicinity, Arizona : U,S. Geological Survey Misc. Investigations Series Map I-2554, 2 maps with phamphlet (Appendix: pages 21-50, Nomenclature and Ages of Late Cretace ous(?) – Tertiary Strata in the Hualapai Plateau Region, NW Arizona by R.A. Young).

Young, R.A., 1998, The Postglacial Tilting of Lake Ontario : Rochester Committee for Scientific Information Bull. 322, 7 pp., Figs., Rochester , NY . (Also reprinted in Rochester Engineer magazine)

Nieto, A. and Young, R.A., 1998, Retsof Salt Mine Collapse and Aquifer Dewatering, Genesee Va lley , Livingston County , NY : In: Poland Symposium Volume: Land Subsidence, (J. Borchers, Ed.), Spec. Pub. 8, Assoc. Engineering Geologists, Star Publishers, Belmont, CA., p. 309-325.

Lundgren, L. and Young, R.A., 1995, Mine failure, subsidence, and environmental impacts, Retsof Salt Mine, Livingston County , NY , 1994: New York Earth Science and the Environment, v.1, no. 1, p. 5-17.

Young, R.A. and Sirkin, Les, 1994, Subsurface Geology of the lower Genesee River Valley Region: A progress report on the evidence for Middle Wisconsin sediments and implications for ice sheet erosion models: N Y State Geological Association Field Trip Guidebook, 66th Annual Meeting, University of Rochester, p. 89-126. (ongoing research)

Young, R.A ., and Burton , R., 1993, Bluff erosion along Irondequoit Creek in Linear Park: Roch. Comm. for Scientific Info., Bull. 315, 6pp, Figs., Rochester , NY .

Elston, D.P. and Young, R.A., 1991, Cretaceous-Eocene (Laramide) Landscape Development Oligocene-Pliocene

Drainage Reorganization of Transition Zone and Colorado Plateau , Arizona , Jour. Geophysical Research, V. 96, No. B7, pp. 12,389-12,406.

Mansue, L.M., Young, R.A., and Miller, T.S, 1991, Sources of movement and sediment in the Canaseraga Creek Basin , Dansville , New York : In: U.S. Environmental Protection Agency Report #EPA-905/9-91-005D, pp. III-1 to III-48.

Mansue, L.M., Young, R.A., and Soren, J., 1991, Hydrogeologic Influences on Sediment Transport Patterns in the Genesee River Basin, New York: In: Genesee River Watershed Study, Vol. IV, Part II, U.S. Environmental Protection Agency Report #EPA-905/9-91-005D, 1 plate, 2 figs., 8 tables pp. II-1 to II-33.

Kappel, W.M. and Young, R.A., 1989, Glacial History and Geohydrology of the Irondequoit Creek Valley, Monroe Co., NY. U.S. Geological Survey, Water Resources Investigations Report 88-4145, 34 pages, maps.

Surficial Geologic Map of New York , Niagara Sheet (revision) 1988, field and map review by R.A. Young and others (published by New York Geological Survey, Map and Chart Series #40).

Elston, D.P., Billingsley, G.H., and Young, R.A. (Eds.), 1989, Geology of Grand Canyon, Northern Arizona: Fieldtrip Guidebook T115/315, 28th International Geological Congress, American Geophysical Union, Washington, DC, 240 p.

Elston, D.P., Young, R.A., McKee, E.D., and Dennis, M.L., 1989, Paleontology, Clast Ages, and Paleomagnetism of Upper Paleocene Gravel and Limestone Deposits, Colorado Plateau and Transition Zone, Northern and Central Arizona: In: Geology of Grand Canyon, Northern Arizona: Eds. D.P. Elston, G.H. Billingsley, and R.A. Young, 28th International Geological Congress, Guidebook T115/315, American Geophysical Union, Wash., D.C., p. 154-165.

Elston, D.P. and Young, R.A., 1989, Development of Cenozoic Landscape of central and Northern Arizona; Cutting of Grand Canyon: In: Geology of Grand Canyon, Northern Arizona: Eds. D.P. Elston, G.H. Billingsley, and R.A. Young, 28th International Geological Congress, Guidebook T115/315, American Geophysical Union, Wash., D.C., p. 145-154.

Young, R.A. , 1989, Paleogene-Neogene Deposits of Western Grand Canyon, Arizona: In: Geology of Grand Canyon, Northern Arizona: Eds. D.P. Elston, G.H. Billingsley, and R.A. Young, 28th International Geological Congress, Guidebook T115/315, American Geophysical Union, Washington, DC, p. 166-173.

Young, R.A. , 1988, Pleistocene Geology of Irondequoit Bay: In: W.J. Brennan (Ed.) Late Wisconsinan Deglaciation of the Genesee Valley, Guidebook 51st Annual Meeting Friends of the Pleistocene, Geneseo (SUNY), New York, p. 73-87.

Muller, E., Young, R.A., Braun, D., and Wilson , M., 1988, Morphogenesis of the Genesee Valley, (Pleistocene and recent history of the Genesee River Basin), Northeastern Geology, v. 10, no. 2, p. 112-133.

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IN PREPARATION:

Manuscript (journal/book chapter in press): for 34 th Annual Binghamton Geomorphology Symposium, " Ice Sheet Geomorphology: Past and Present Processes and Landforms" (October 2003), Title: Middle Wisconsin glaciation in the Genesee Valley, NY: A stratigraphic event contemporaneous with Heinrich Event H4:Invited participant for Annual Symposium, publisher Elsevier (Jour. of Geomorphology and bound text). Organizers, Dr. P.L.K. Knuepfer (SUNY Binghamton) and Dr. P. Jay Fleisher (SUNY, Oneonta), Coauthor, George Burr, Univ. of Arizona , Radiocarbon Lab.

RESEARCH AND PROJECTS IN PROGRESS (2005):

Geologic chronology of late Cretaceous-Tertiary sedimentary rocks in northern Arizona using microfossils and mammal teeth (with Dr. Jeff Eaton, Weber State University , Utah). Field work June 2002. Continuation of long-term AZ research.

Radiocarbon chronology of unique Middle Wisconsin glacial advances in the Genesee Valley circa 35,000 years BP and correlation with marine Heinrich events in the North Atlantic region.

Development of highly sinuous channel forms without superposition in massive carbonates in the Grand Canyon region.

DEPARTMENTAL INTERSESSION PROGRAM, SUNY GENESEO (ORGANIZER)

Arizona : Spring 1991

Hawaii : 1995

California-Nevada: 1997

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OTHER:

Elected Board of Directors, Rochester Committee for Scientific Information, Spring 1990-present

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