

GEOPHYSICAL SIGNATURE OF CENTRAL AND WESTERN NEW YORK

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INTRODUCTION

Central and western New York encompasses part of the northwest portion of the Appalachian basin. The structure of this region is simple with Paleozoic rocks that overlie Precambrian crystalline basement dipping gently to the south. The interpretation of the rocks in the basement depends principally on analysis of the gravity, magnetic and heat flow anomalies. Locally, seismic surveys have detailed the Paleozoic structure. This paper includes maps of the Bouguer gravity, aeromagnetic, and temperature gradients of central and western New York with a brief interpretation. Description of regional heat flow, and seismicity along with a cross-section of seismic stratigraphy of Paleozoic rocks provides additional geophysical data for geologic interpretation.

REGIONAL GEOLOGY

Within the central and western portion of New York State the geologic structure is relatively simple with Cambrian through Devonian shales and limestones dipping gently to the south. The thickness of this sedimentary sequence is about 900 meters at the shore of Lake Ontario and thickens southward to over 3050 meters. Precambrian crystalline basement rocks underlie these Paleozoic sediments and a thin veneer of glacial debris covers most of the area; glacial material may reach a thickness of 300 meters in some valleys. The Precambrian basement of New York State is exposed in two areas, the Adirondack Mountains and Hudson Highlands. Precambrian rocks are also exposed directly to the north of Lake Ontario in Ontario.

The Precambrian rocks from Ontario and the Adirondacks were deformed and metamorphosed about 1,000 Ma B.P. during the Grenville Orogeny. The rock types that are found in the Grenville Group include metagabbros, meta-anorthosites, granitic, charnockitic, and syenitic gneisses; amphibolite; and meta-sedimentary marbles, calc-silicates, quartzite, and para-gneisses.

In central and western New York, Lower and Middle Cambrian rocks are absent with Late Cambrian or Early Ordovician rocks lying unconformably on the Precambrian basement. Lower Ordovician rocks are absent. The Late Ordovician Taconic Orogeny resulted in uplift of eastern New York while the rest of the State was inundated by the sea which deposited limestones that interfinger with shales and impure sandstones. The Taconic Orogeny reached its climax in the late Ordovician with the Taconic Mountains in

the east eroding and producing the sediment that forms the Queenston Delta, a delta that prograded west to midcontinent and south into Virginia. The Queenston Formation in central and western New York consists of sandstone and siltstones.

Deposition of the wind-blown Whirlpool Sandstone marks the beginning of the Silurian Period. During this time, the Taconic Mountains were uplifted and the Queenston Formation was eroded and redeposited to the west as the Medina Group. A white quartz sand (Thorold-Kodak) which terminates in the Oneida Conglomerate near Oneida, New York was deposited above the Medina Group. Subsequently, shales and anhydrites were deposited in the Clinton, Salina, and the Cayuga Series.

Early Devonian rocks (Helderberg Limestone) crop out between the Hudson River and Cayuga Lake; the Helderberg west of Cayuga Lake has been locally removed or is variable in thickness due to erosion. Subsequently deposited were the Oriskany and Glenerie Formations which are overlain by the shales and siltstones of the Esopus and Carlisle Center Formations.

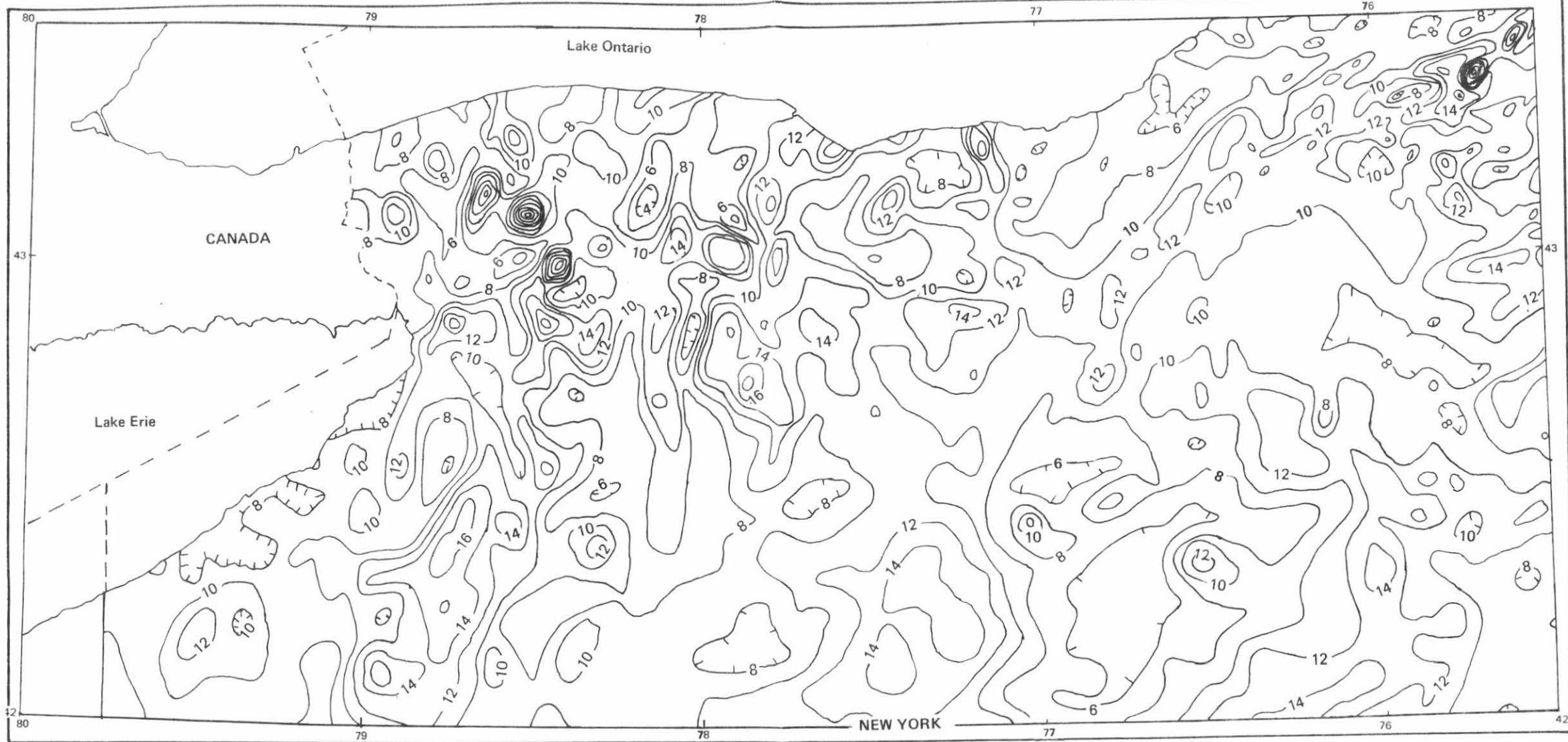
During Middle Devonian the Onondaga Limestone formed with deposition being terminated by the Acadian Orogeny which was centered in New England and the Canadian Maritime Provinces. Large amounts of material were eroded from the New Acadian Mountains and deposited as shale in a westward prograding delta called the Catskill Delta. A brief interruption in delta deposition occurred and the Tully Limestone was formed during this time. The delta resumed deposition and has been divided into eight groups which are principally composed of shale and are listed here from oldest to youngest: Hamilton, Genesee, Sonyea, West Falls, Java, Canadaway, Conneaut, and Conewango. The four oldest groups extend across the entire state, whereas the younger groups either were never deposited in the Catskills or were subsequently eroded after deposition.

Early Mississippian rocks resemble the underlying Devonian sequences with deposition ending in the Middle Mississippian. Only one brief period of deposition occurred in Early Pennsylvanian, the Olean Conglomerate.

In the Mesozoic, vertical uplift and erosion predominated and during the Cenozoic Era the physiographic provinces of New York were shaped. The landscape has been modified by at least four major advances of ice during the Pleistocene.

BOUGUER GRAVITY ANOMALY MAP

The Bouguer gravity anomaly map of western New York (Fig. 1) indicates a series of gravity highs and lows extending north-northeast across New York State and Lake Ontario into southern Ontario, Canada. The magnitudes, gradients and wavelengths of these anomalies indicate that they are caused by density contrasts within the Precambrian basement. The overlying Paleozoic rocks appear to have little effect on the regional gravity contours. The gravity contours trend north-south while the contacts of the Paleozoic formations trend east-west.

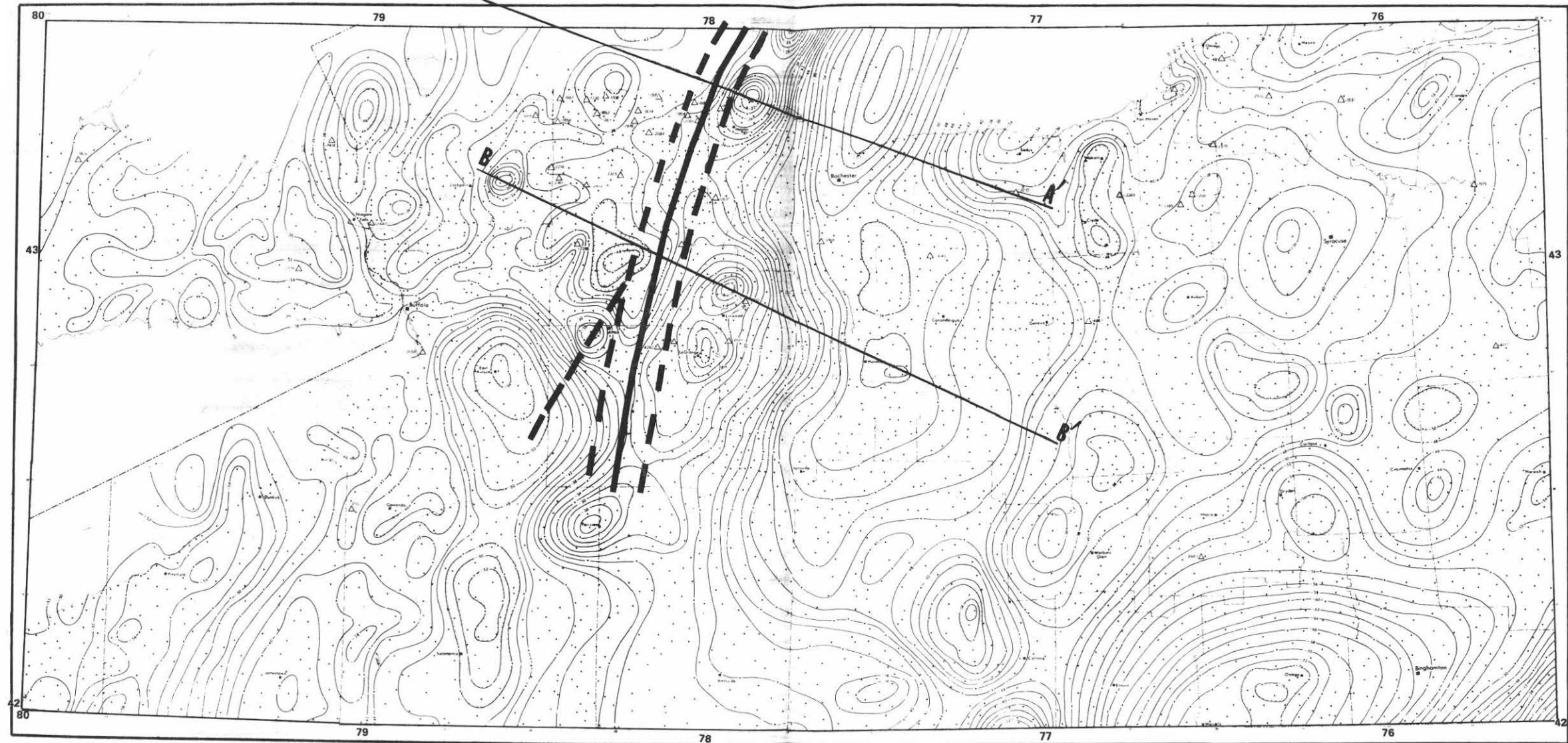


TOTAL MAGNETIC INTENSITY IN GAMMAS

Contour Interval 200 Gammas
 (After Zietz and Gilbert 1981)



Figure 5. Aeromagnetic map of central and western New York (after Zietz and Gilbert, 1981).



Simple Bouguer Gravity Anomaly Map of Western New York
(Covers area of Niagara and Finger Lakes Sheets of the 1961
and 1970 Editions of the Geologic Map of New York)

SCALE
0 30 KM

LEGEND

- Gravity Station
- 40 - Gravity Anomaly Contour

Figure 1. Bouguer Gravity map of central and western New York (after Diment and Revetta, 1971).

The gravity anomalies in western New York and Lake Ontario are due to an extension of the Precambrian rocks of the Bancroft-Madoc area of southern Ontario, Canada. The rocks in the area are part of the Ottawa River remanent, the most extensive and thickest metasedimentary-metavolcanic belts known in the Grenville province. The rocks exposed in the Bancroft-Madoc area include mafic plutons intruded into the Tudor mafic volcanic sequence. These in turn are surrounded by a marble rich metasedimentary group and granitic batholiths. The mafic plutons intruded into the mafic-metavolcanic sequence produce the gravity highs in western New York and Lake Ontario, while the granite batholiths cause the gravity lows. The intermediate gravity values are thought to be due to the marble rich metasedimentary group. This interpretation of the gravity anomalies is supported by several wells that have penetrated the Precambrian basement. The lithologies from the wells confirms that granite occurs in areas of low gravity.

The gravity anomalies of central New York between 75°30' and 77°45'W (Fig. 1) cover larger areas and have lower magnitudes and gradients than those in western New York. They indicate the Precambrian basement complex of central New York (Finger Lakes Sheet) is more homogeneous and consists of rock types that vary little in density. The area contains no major structural features such as the Clarendon-Linden fault and there is a relative absence of seismic activity. These characteristics indicate the basement complex of western New York is distinctly different from that in central New York.

Two gravity profiles were drawn across the northeast trending gravity anomalies; the Hamlin profile (AA') and the Linwood profile (BB'). The Hamlin gravity profile is shown in Figure 2. It lies along the south shore of Lake Ontario near the village of Hamlin, New York. This profile shows two prominent anomalies, a gravity high and a gravity low. The gravity high has an elliptical shape with gravity values reaching a high of -18 mgals. East of the Hamlin gravity high is a gravity low with Bouguer values as low as -62 mgals. A gabbro stock emplaced in mafic metavolcanics and extending to a depth of at least 5 kms below the basement would satisfy the observed anomaly. A magnetic high coincides with the Hamlin gravity high so the anomalous body has both high density and magnetization. The Victor gravity low is probably due to a granitic batholith. Steep gravity gradients occur along the western perimeter of the batholith at its contact with dense mafic metavolcanics. Figure 3 shows profile BB' across the Linwood gravity high. The anomaly is elliptical in shape with gravity values ranging from a high of -16 milligals to a low of -56 milligals. The gradient of the anomaly on its east and west flanks is 1.5 milligals per kilometer. The Linwood gravity high is attributed to a mafic pluton emplaced in mafic metavolcanics and extends to a depth of 5.0 kms. Based on these profiles and principally the gravity map a lithology map of the Precambrian basement is shown in Figure 4.

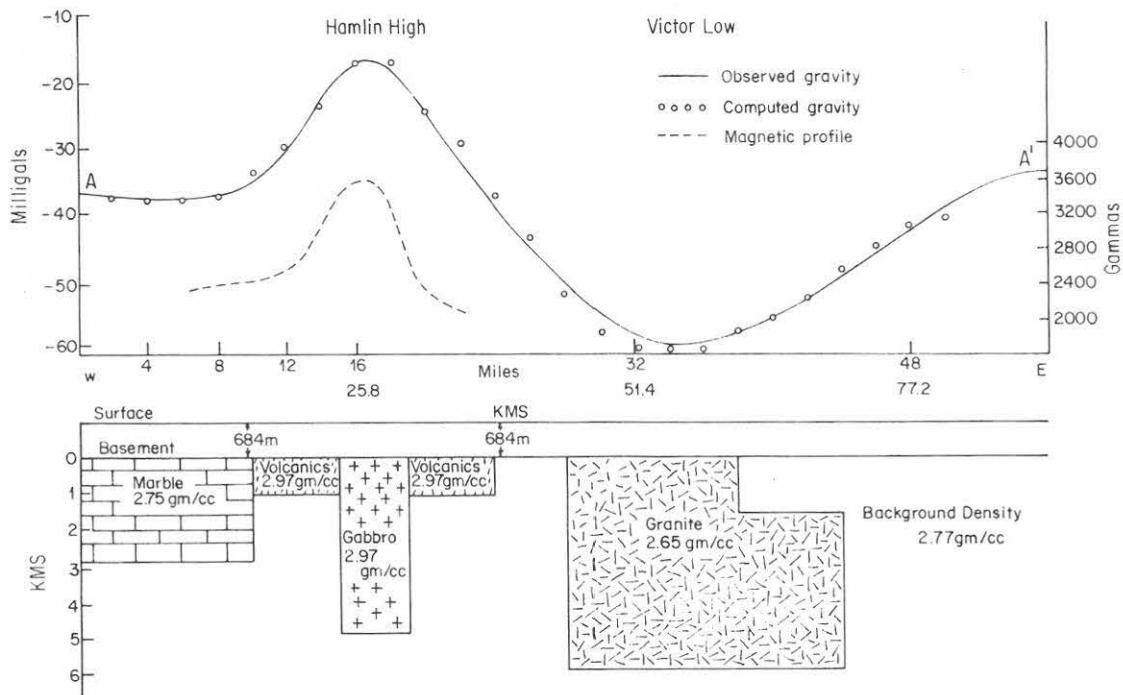


Figure 2. The Hamlin two-dimensional gravity profile AA'.

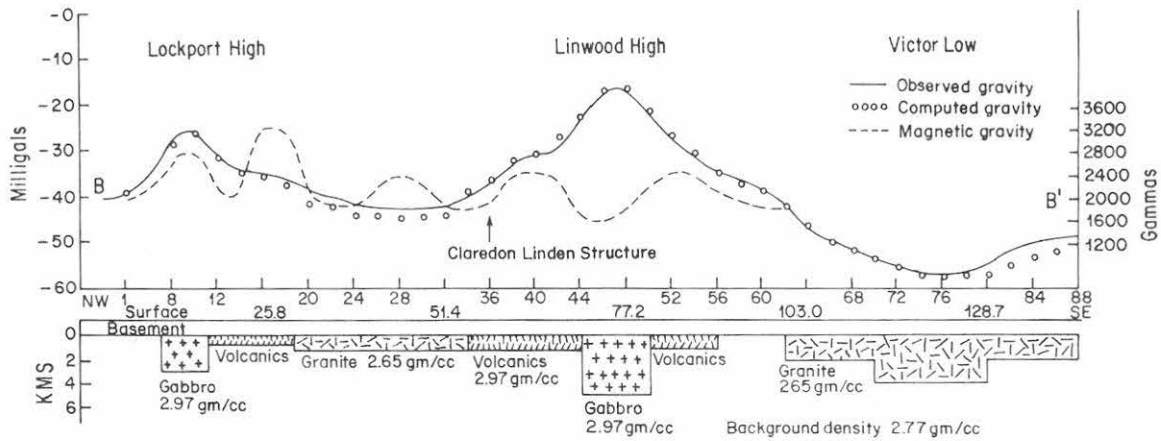


Figure 3. The Linwood two-dimensional gravity profile BB'.

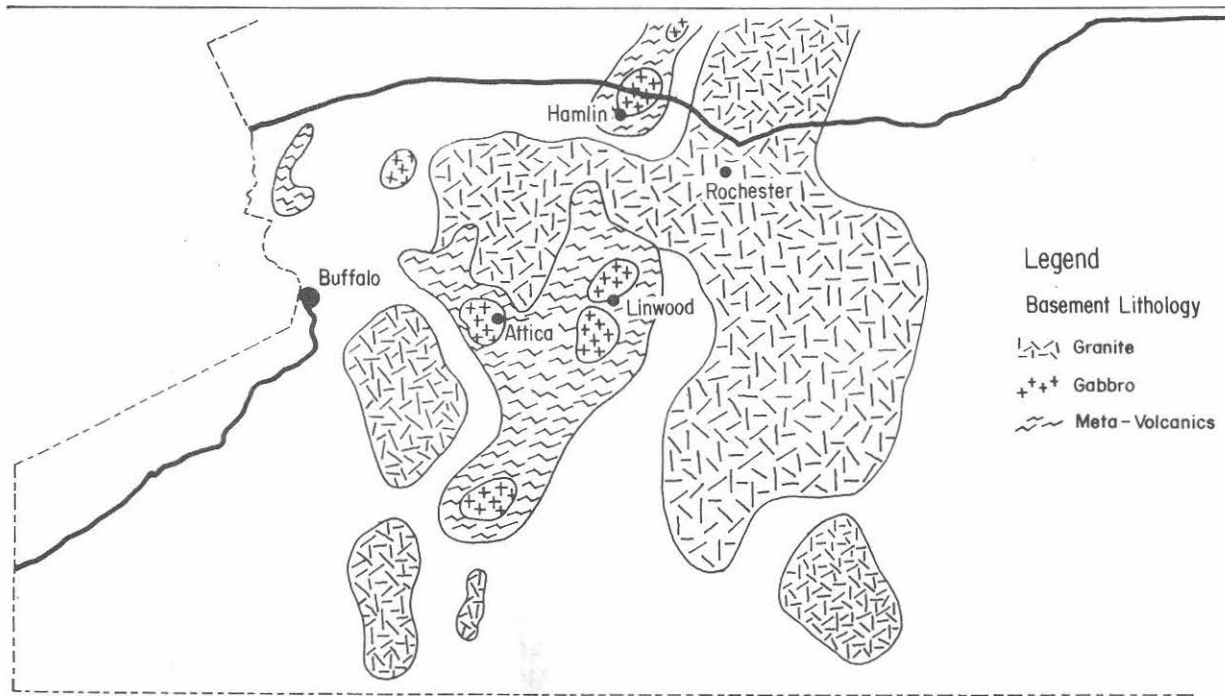


Figure 4. Lithologic map of Precambrian basement base on gravity and magnetic anomalies.

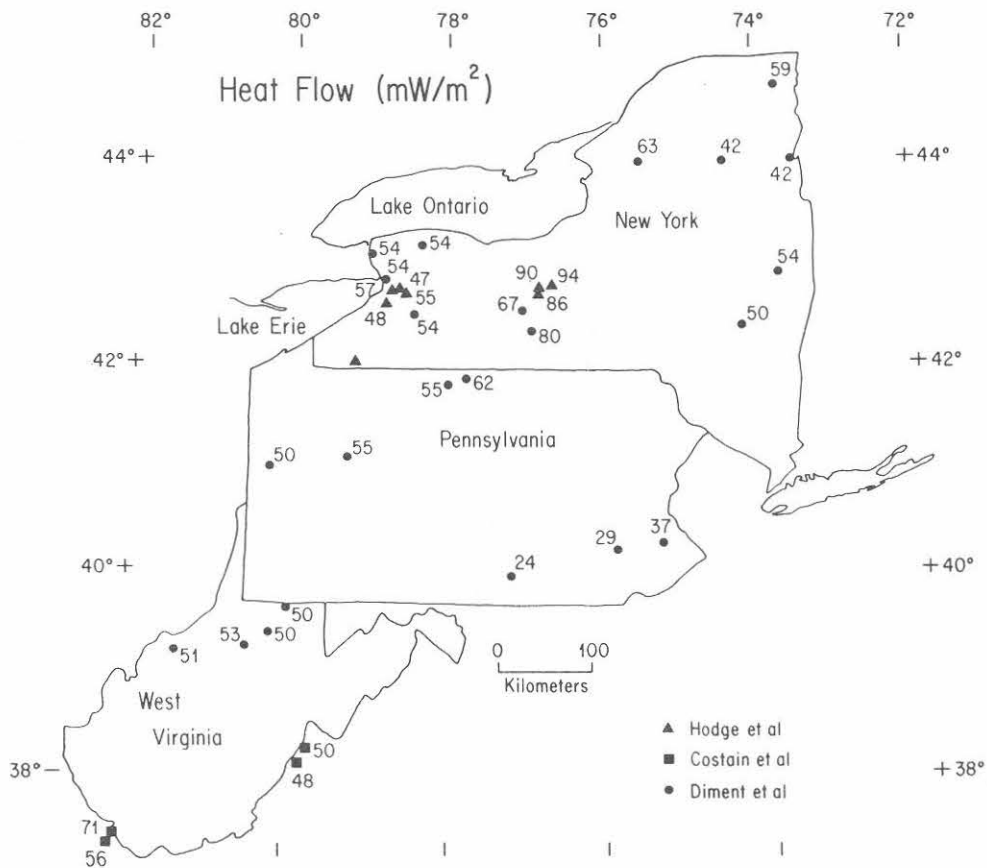


Figure 6. Heat flow determinations in New York, West Virginia, and Pennsylvania (after Hodge, et al., 1981).

AEROMAGNETIC MAP

The aeromagnetic map (Fig. 5) is modified from Zietz and Gilbert (1981). The magnetic highs generally correspond to the positive gravity anomalies that are associated with gabbro intrusions. The negative gravity anomalies that are underlain by granite in the basement, show broad low aeromagnetic anomalies. The pattern of magnetic anomalies west of the Clarendon-Linden fault zone shows numerous short wavelength anomalies whereas east of this zone the anomalies are broader. This contrast in the magnetic field suggests that the Clarendon-Linden fault zone separates distinctive basement terrains.

CLARENDON-LINDEN FAULT ZONE

The Clarendon-Linden fault is the most prominent structural feature in the Paleozoic rocks of western New York (Fig. 1). Chadwick (1920) suggested the existence of a large fault between the towns of Clarendon and Linden and found a displacement of the Onondaga and Niagara escarpments with the western side farther north. In the vicinity of Linden, the formations of the west were at a much lower elevation than those to the east. The southern portion is a monocline, the Linden monocline, and the northern part a fault called the Clarendon fault.

The Clarendon-Linden fault lies along the western flank of a series of gravity highs and the eastern flank of a magnetic low. These gravity and magnetic anomalies are due to Precambrian basement rocks so it is believed that the Clarendon-Linden fault is controlled a Precambrian basement fault at depth.

Gravity anomalies associated with the structure extend into Lake Ontario and this fact together with similar faults occurring on the north shore of Lake Ontario led Revetta (1970) to suggest a possible northeastward extension of the structure across Lake Ontario. Recently, more than 400 km of high resolution seismic and magnetic data collected by Hutchison and others (1979) indicate a possible lakeward continuation of the Clarendon-Linden fault of western New York. Their geophysical evidence suggest a west facing bedrock ridge known as the Scotch Bonnet Rise is a continuation of the Clarendon-Linden structure beneath the Lake.

HEAT FLOW AND TEMPERATURE GRADIENTS

Summary of heat flow of the U.S. indicates that the eastern U.S. has a lower average heat flow compared to the more tectonically active western U.S. In New York, Urban (1970) reported heat flow values of approximately 50 mW/m^2 (1.2 HFU) near Buffalo and two values of 54 mW/m^2 (1.29 HFU) and 67 mW/m^2 (1.6 HFU) in the Finger Lakes region. In the crystalline rocks of the Adirondacks, heat flow values range from 38 mW/m^2

(0.9 HFU) to 54 mW/m^2 (1.29 HFU) with the lowest value found over anorthosite rocks. In an area of sedimentary rocks in northern Pennsylvania, Joyner (1960) determined near normal heat flow values of 55 mW/m^2 (1.3 HFU) and 62 mW/m^2 (1.5 HFU), (Figure 6). Lateral variation in heat flow in New York and Pennsylvania ranges from 33 mW/m^2 (0.8 HFU) to 88 mW/m^2 (2.1 HFU).

In regions of gas and oil production temperature estimates of gradients are obtained from bottom-hole and surface temperatures. The American Association of Petroleum Geologists in cooperation with the USGS published a temperature gradient map of the U.S. using 25,000 temperature gradients; 125 sites were used to establish the gradient map in New York. Hodge et al. (1980) evaluated the temperature gradient using over 1490 sites in western and central New York. Temperature gradients, corrected for a drilling temperature disturbance, range from 24°C/km to over 38°C/km in local areas (Fig. 7). Temperature gradients may be strongly affected by thermal conductivity changes in the outer layer of the crust and there seems to be a distinct correlation between thermal conductivity and stratigraphic lithology in central and western New York. A detailed temperature log is shown in Figure 8 that illustrates this relationship; the heat flow at this site is 57 mW/m^2 (Urban, 1970). Surface temperatures for the gradient calculation in this study were estimated from mean annual temperature compiled at 73 NOAA recording stations located throughout the state. The temperature gradients were calculated by taking the BHT's (Bottom hole temperatures) temperatures measured during routine logging runs, minus the estimated surface temperature, divided by the well depth. Because of transient temperature disturbances during drilling, the bottom-hole temperatures recorded by routine electric logging are likely to be slightly lower than the undisturbed equilibrium temperatures of the host rock due to recent circulation of fluids and air associated with drilling processes. A correction procedure was adopted (Hodge et al., 1981) and figure 7 is the temperature gradient contour map. Contoured gradients show values for the East Aurora, Cayuga, and Elmira regions to be 36, 38, and 36°C/km respectively. These regions show higher than normal temperature gradients.

SEISMICITY OF WESTERN NEW YORK

Western New York, isolated from the stress that accompanies being located near a plate boundary, has nevertheless experienced numerous seismic events. These events have ranged from microearthquakes to strong earthquakes as high as VIII on the Modified Mercalli Intensity Scale (MMS). An earthquake of intensity VIII occurred near Attica, N.Y. in 1929. This earthquake and the frequency of seismic events indicate in western New York is an area of moderate seismicity. Frequency of events and location near a fault system, the Clarendon-Linden Fault system.

The map of epicenter locations in the Northeast U.S. and adjacent parts of Canada, Fig. 9, indicates several zones of seismic activity. These include the Hudson River-Lake Champlain zone, St. Lawrence River Valley

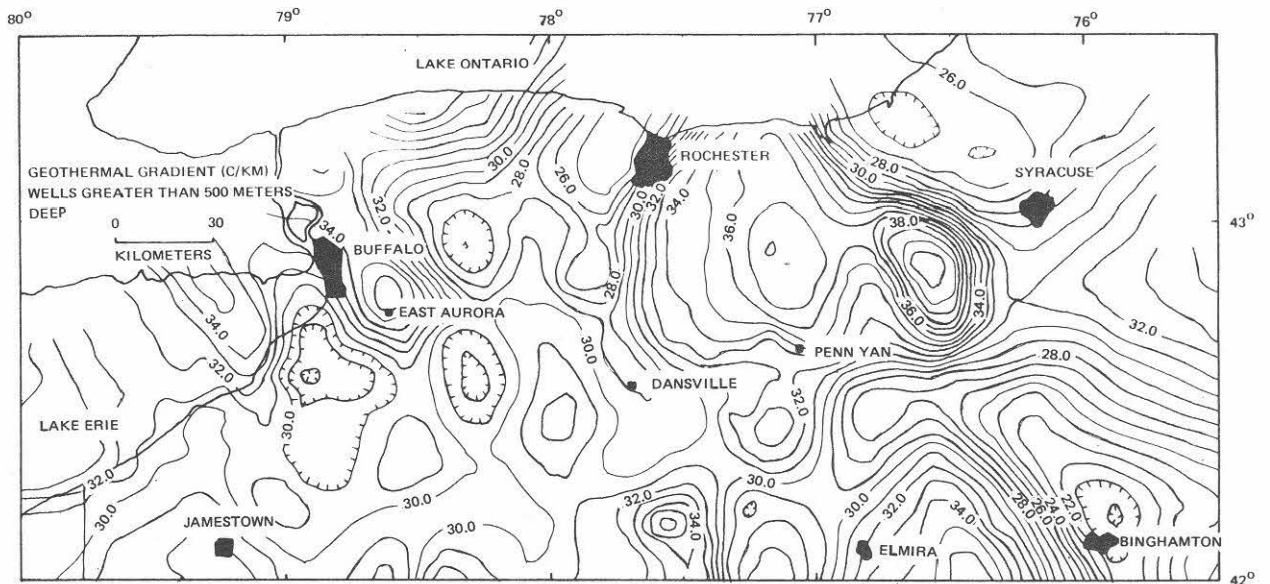


Figure 7. Contoured temperature gradients ($^{\circ}\text{C}/\text{km}$) for wells with depth greater than 500 meters assuming a drilling disturbance correction (after Hodge, et al., 1981).

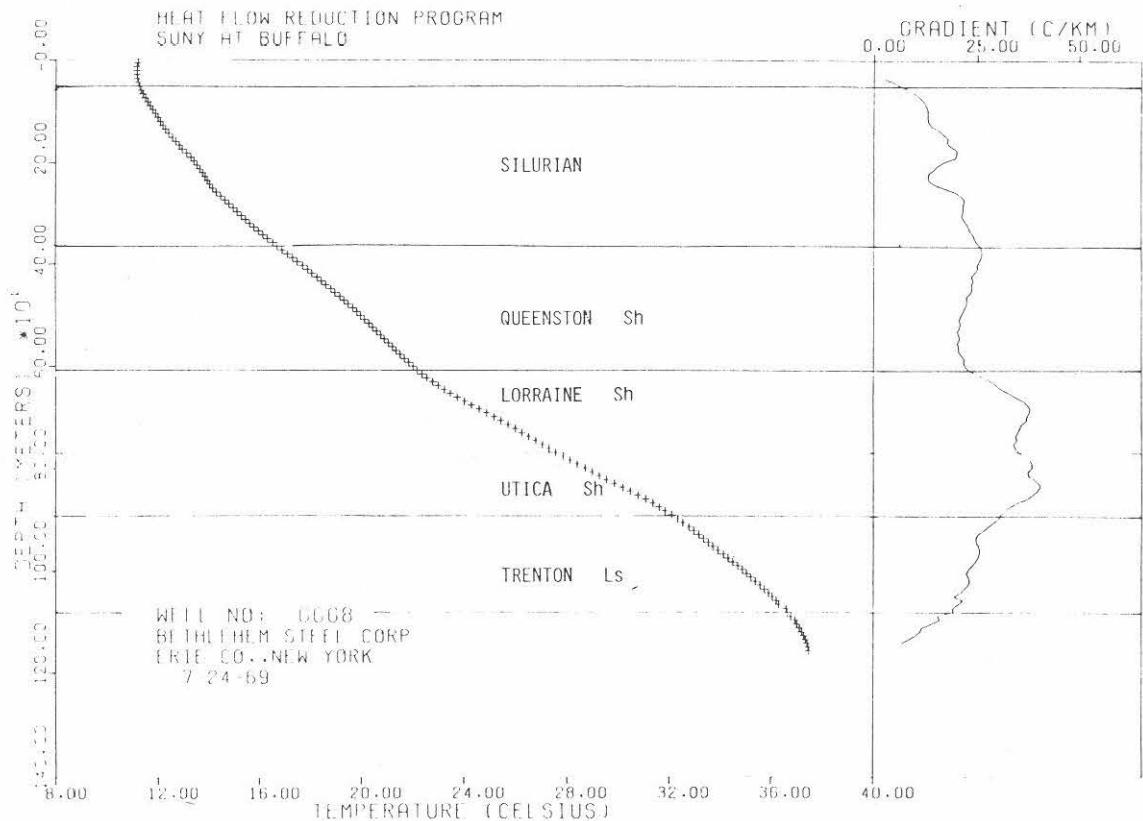


Figure 8. Temperature-depth plot of well #6668, Bethlehem Steel Corp., Buffalo, New York.

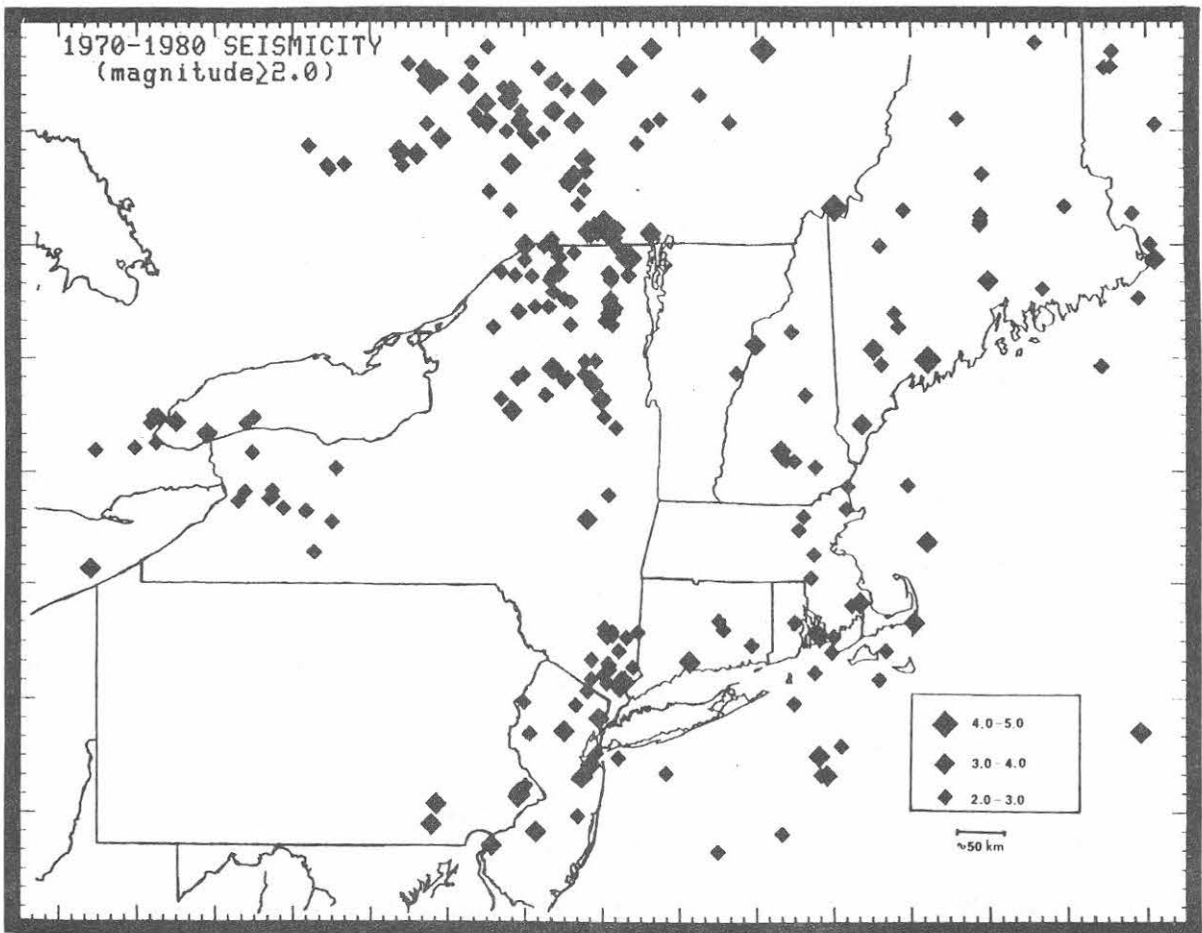


Figure 9. Location of earthquake epicenters for eastern U.S. from 1970-1980 after Schlesinger-Miller and Burstow, 1980).

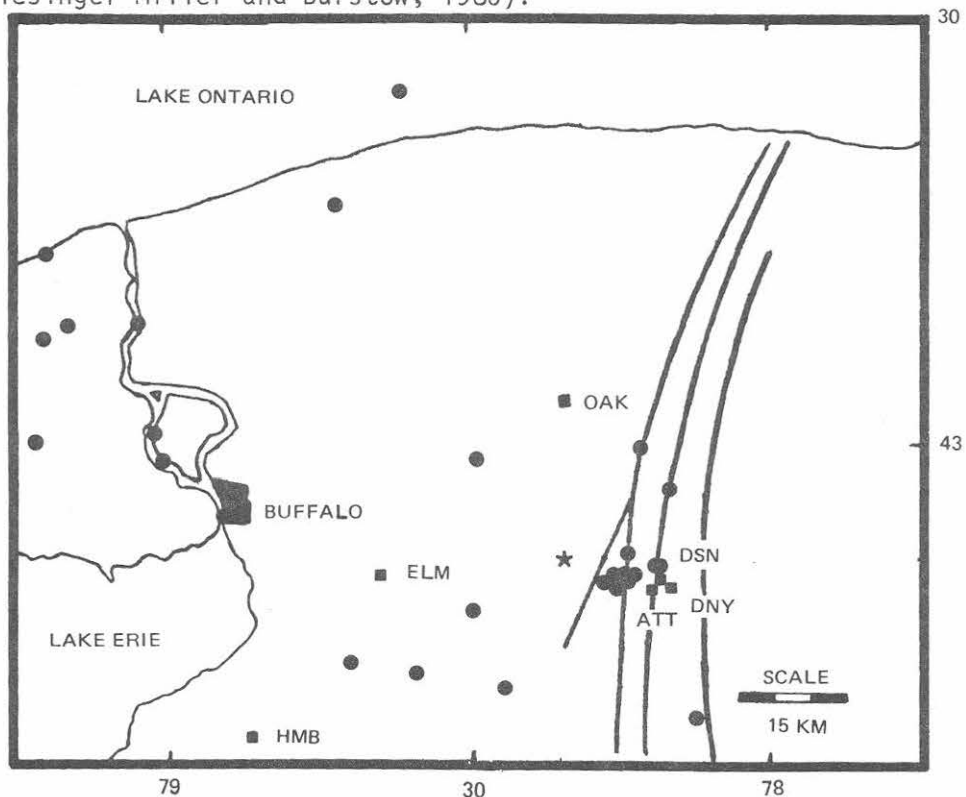


Figure 10. Location of earthquake epicenters for western New York. The 1929 earthquake is noted by a star (after Fletcher and Sykes, 1977).

region and the Buffalo-Attica region. The St. Lawrence River region has had the strongest shocks as well as the most far reaching in terms of affected areas. Earthquakes near Quebec in 1883 and 1925 had intensities of IX or X (MMS) or approximately 7.0 on the Richter Scale. The Buffalo and western New York area experienced intensities of IV (MMS) from these shocks. The St. Lawrence region has experienced at least nine other earthquakes of intensities greater than VIII all of which affected the western New York area as well.

The western New York region has not experienced earthquakes of intensity VIII as frequently as the St. Lawrence region, however, several quakes with intensities greater than VI have been centered in Attica and Niagara Falls. Figure 10, shows the distribution of epicenters in western New York and as might be expected, there is a concentration of events along the Clarendon-Linden Structure near Attica. The strongest shock in western New York (star on Fig. 10) occurred near Attica on August 12, 1929. An intensity of about VIII (MMS) was determined and the quake affected an area of about 50,000 square miles. Further shocks of less intensity occurred in 1929, 1935, 1955, 1966, and in 1967 indicating continued activity in this region (see table 1).

Smaller earthquakes have occurred between Attica and Buffalo and into the Niagara Peninsula of Ontario, Canada. The Lockport earthquake of 1857 is included in this group of shocks and it attained an intensity of VI (MMS). As of yet, no major earthquake has occurred along the Buffalo-Attica zone west of the Clarendon-Linden structure, however, since the area is far more populated than other parts of western New York, the potential risk of extensive damage must be considered.

TABLE 1. EARTHQUAKES AFFECTING THE WESTERN NEW YORK REGION (1928-1959)*

340.	1928 March 18, 15:20, 7-VI, M_s 4.1 determined from a Shawinigan Falls seismogram.) $44^{\circ}30'$, $74^{\circ}30'$. Saranac Lake, NY. Detectible over 12,000 square miles.	453.	1929 December 2, 22:14, IV, $42^{\circ}30'$, $78^{\circ}30'$. Attica, NY.	652.	1946 November 10, 11:41:23, M_s 3.1, $42^{\circ}52'N$, $77^{\circ}27'W + 18'$. About 25 miles southwest of Rochester, NY.
411.	1918 November 2, 14:31:58, M_s 5.4, $47^{\circ}14'N + 10'$, $78^{\circ}10'W + 15'$. About 56 miles northeast of Timiskaming, Que. This tremor was felt in Ontario (at Fitchner, Birch Bay, Owen Sound and Toronto), in New York (at Buffalo and Rochester) and in Pennsylvania (at State College).	454.	1929 December 3, 12:50, IV, $42^{\circ}30'$, $78^{\circ}30'$. Attica, NY.	715.	1955 August 16, 7:35, V, $42^{\circ}52'N$, $78^{\circ}17'W$. Attica, NY.
448.	1929 August 12, 6:00 to 7:00, VII, $42^{\circ}2'N$, $77^{\circ}3'W$. Between Little Valley and Binghamton, NY. Probably a foreshock of No. 439.	457.	1939 January 17, p.m. I, $42^{\circ}30'$, $78^{\circ}30'$. Attica, NY.		
449.	1929 August 12, 11:24:32, VIII, M_s 5.3, $42^{\circ}52'N$, $78^{\circ}17'W$. (a) Near Attica, New York. The shock was felt in the northeast corner of Ohio, northern Pennsylvania, most of New York and parts of New Hampshire, Vermont, Massachusetts and Connecticut.	475.	1931 April 22, IV, $42^{\circ}30'$, $78^{\circ}30'$. "A strong earthquake was felt in Buffalo, NY, and surrounding cities on April 22nd, causing panic."		
		478.	1931 June 7, 0:00, II, $43^{\circ}2'N$, $77^{\circ}6'W$. Rochester, NY.		
		561.	1939 February 24, 0:20, III, $42^{\circ}52'N$, $78^{\circ}17'W$. Attica, NY.		
		619.	1943 March 9, 3:25:34, M_s 5.5, $42^{\circ}2'N$, $80^{\circ}30'W$. Lake Erie.		
		628.	1944 January 16, 10:00, II, $43^{\circ}09'N$, $77^{\circ}37'W$. Rochester, NY.		

* From the Canada Department of Mines and Technical Surveys, Observatories branch, Publications of the Dominion Observatory, Ottawa, Volume XXXII, No. 1, Earthquakes of Eastern Canada and Adjacent Area 1928-1959, W.L.L. Smith.

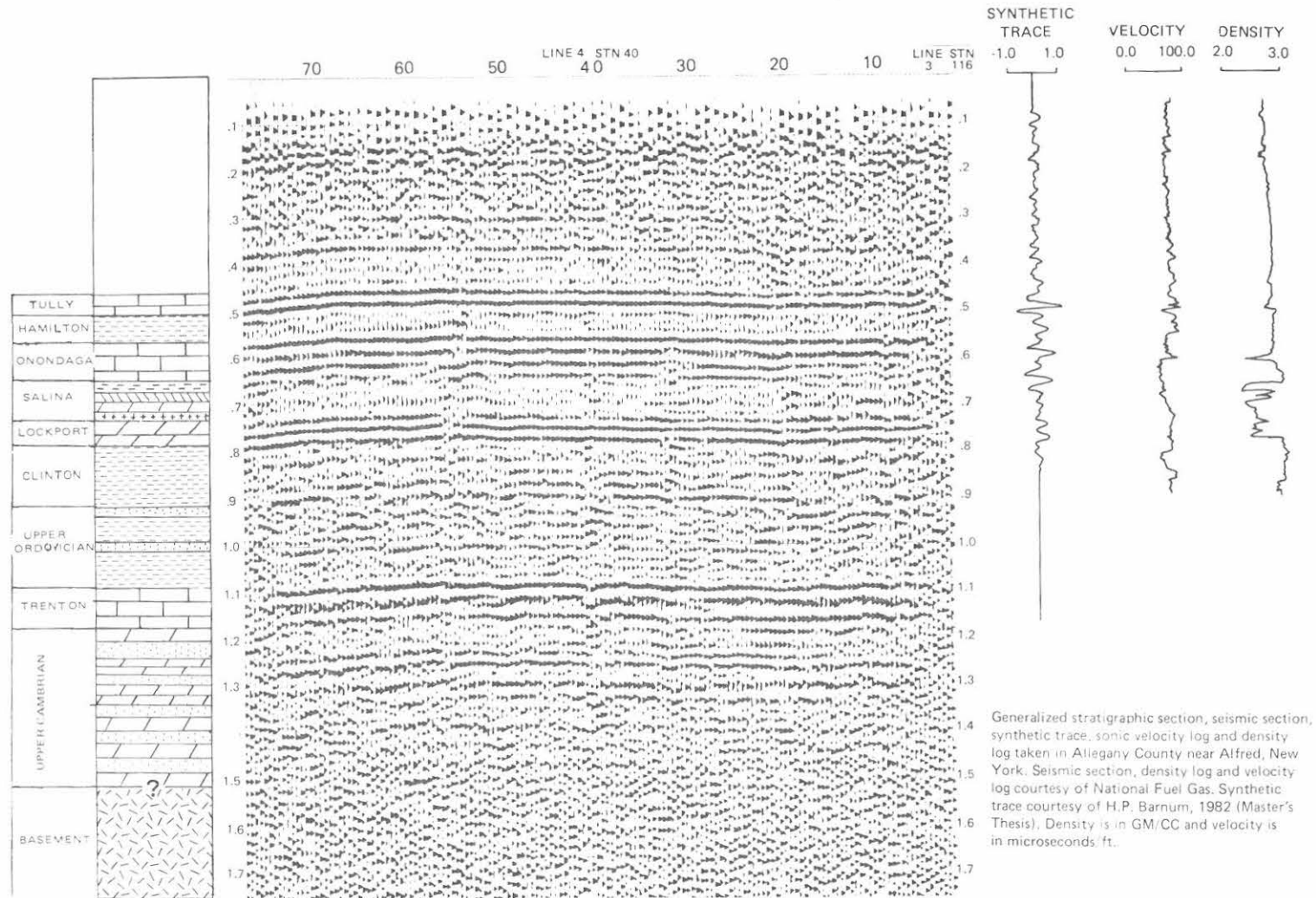


Figure 11. Seismic reflection cross section from Alleghany Co. N.Y. that shows that seismic stratigraphy in the Paleozoic rocks. Vertical density and sonic velocity distribution from well #6213, Alleghany county is shown compared to the seismic time section. A synthetic seismogram using these logs is also shown (Barnum, 1982).

SEISMIC STRATIGRAPHY

The seismic stratigraphy of western New York is relatively uniform throughout the region and there is a direct correlation to the lithologic units. Seismic exploration has become increasingly important in western New York (WNY) with conventional exploration techniques such as Vibroseis yielding good seismic sections.

In Figure 11 a seismic section, courtesy of National Fuel Gas, is from a survey done near the town of Alfred in southern WNY. This survey was done using the Vibroseis method. The principle reflections shown by the dark bands that occur at various times throughout the section are produced by the limestones and dolostones that are present in the upper Cambrian, Ordovician, Silurian, and Lower Devonian units. Lithologies and names of some units are shown to the left of the seismic section.

Also shown in Figure 11 to the right of the seismic section are a synthetic trace, velocity log, and density log. The velocity and density logs are courtesy of National Fuel Gas and were taken from a well in Almond township, Allegheny County. The synthetic waveform is produced by relating rock density and seismic velocity throughout a vertical section. The acoustic impedance of a layer can be defined as the product of density (ρ) and p-wave velocity (v) and when a seismic wave strikes an interface between two media with differing acoustic impedances, part of the wave is reflected and part is transmitted. The synthetic seismogram of vertical incidence reflections matches well with the strong reflections corresponding to the previously mentioned limestones and dolostones.

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