Relocation of Earthquake Epicenters Associated With a Class-1 Injection Well, Ashtabula Ohio

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Introduction

In July 1986, Reserve Environmental Services (RES) installed a Class-I waste-injection well, and began operations on the east side of the town of Ashtabula, Ohio. The injection well was about 1.8 km in depth and operated at a nearly uniform flow rate of 114 L/min and at an injection pressure of about 100 bars (Nicholson and Wesson, 1990). Between July, 1986 and July 1987, nearly 62 million L of waste was injected into the "Mt. Simon" Sandstone at a surface pressure of 10 MPa (Evans). On July 13, 1987, a 3.8 M earthquake occurred just east of Ashtabula and was followed by a large number of aftershocks, approximately 70 of which were recorded (Table 10). The epicenter of the mainshock was less than 1 km from the RES well. All of these earthquakes were located in a narrow cluster on an east-west-striking vertical fault about 1.5 km long that extended from 1.6 to 3.2 km in depth (Armbruster and others, 1987; Seeber and Armbruster, 1993).

This began a 14-year sequence of seismicity in the Ashtabula area. From 1987 to 2001, more than 100 earthquakes with magnitudes between 1.2 to 4.5 mbLg have been recorded by seismic networks in Canada and Ohio. No historic earthquakes are known to have occurred within 30 km of Ashtabula (Nicholson and Wesson, 1990; Seeber and Armbruster, 1993). This, coupled with the proximal location of numerous earthquakes near the well after it was installed, suggests that this seismicity has been induced by the injection fluid from the RES well.

Opposition to this interpretation has been stated by Gerrish and Nieto (MS, 2003) who suggest that the seismicity is not related to fluid injection for the reasons that 1. The earthquakes are not clustered but random, and 2. The injection pressure was not sufficient to cause failure on favorably oriented faults. The objective of this project is to address reason 1 by relocating the published earthquake epicenters in order to observe any association, or lack thereof, with the RES well. By doing these relocations with multiple seismic networks, we should see a reduction of the error ellipse inherent in doing initial earthquake locations with a single network.

It is important that we understand the mechanisms of induced seismicity in order to understand the dangers that are involved by triggering earthquakes. By examining this sequence of earthquakes, I hope to gain valuable insight into the pattern of earthquake epicenters. Their pattern near the vicinity of injection wells and their correlation to the regional geologic and tectonic setting is of great importance in earthquake hazard mitigation.

Geologic and Tectonic Setting

The Precambrian basement of northeastern Ohio consists of crystalline rocks of the Grenville province (fig. 1). This province represents the remnants of an orogenic event known as the Grenville orogeny, which occurred approximately one billion years ago, as the result of continental collision on the eastern edge of Laurentia, the landmass containing present day North America (Hansen, 1996). The basement is unconformably overlain by gentle east-dipping Paleozoic strata at a depth of approximately 1.8 km in the vicinity of Ashtabula.

For much of eastern North America, the direction of maximum horizontal stress, (σ_1, S_{Hmax}), is consistent (fig. 2). This stress field has been attributed primarily to plate motion or stress from the Mid-Atlantic Ridge (Sbar and Sykes, 1973; Zoback, 1992). In the region of this study, northeast Ohio, the direction of σ_1 is 74° (fig. 3) (Plankell, 2000). The best evidence of this stress has been demonstrated by the large number of earthquakes that have been recorded in the area near Ashtabula (fig. 4). Earthquake focal mechanisms are the primary tool for determining the orientation of maximum horizontal stress in seismically active areas. This seismicity is due in large part to reactivation of ancient deep faults due to this stress field (Lucius and Von Frese, 1988). These rocks are thought to be at or near failure and thus capable of producing earthquakes on faults oriented favorably with σ_1. These earthquakes have been shown, from precise location determinations by locally deployed portable seismometers, to be located along east-west-striking vertical faults. The earthquakes of 1987 were confined to an area about 1.5 km long by 0.25 km wide at a depth of 2 km (Hansen et. al., 2001). The sense of the movement on these faults was left-lateral strike-slip (Seeber and Armbruster, 1987, 1993) (fig 5).

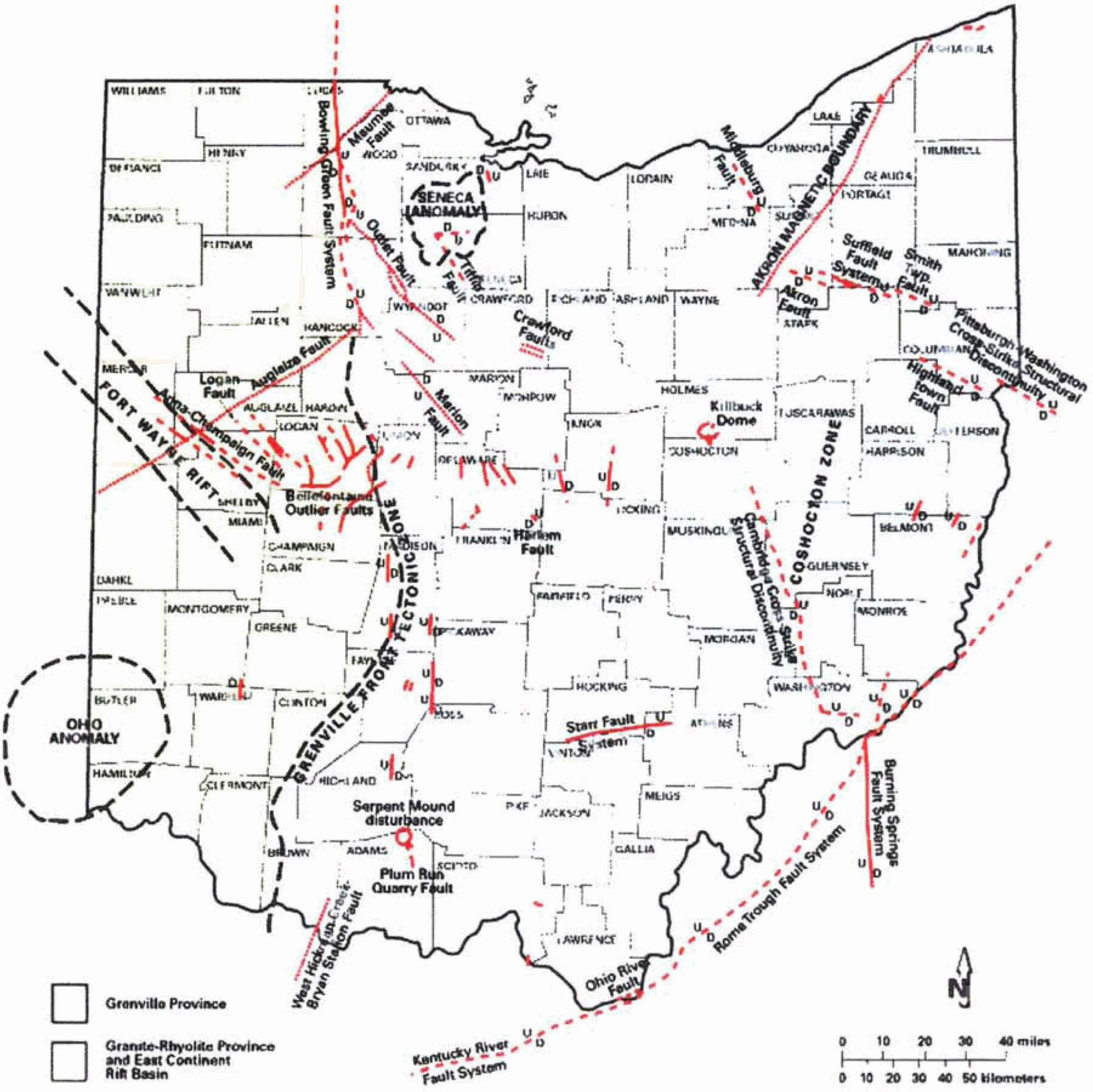

Figure 1. Basement structures in Ohio (modified from Division of Geological Survey Digital Chart and Map Series No. 7, 1991). This map portrays a number of deep faults and other structures that have been identified by a variety of geologic studies. Some faults are well known, whereas others are speculative. Very few of them are visible at the surface. The Anna, or Fort Wayne, rift in western Ohio is the site of numerous historic earthquakes.

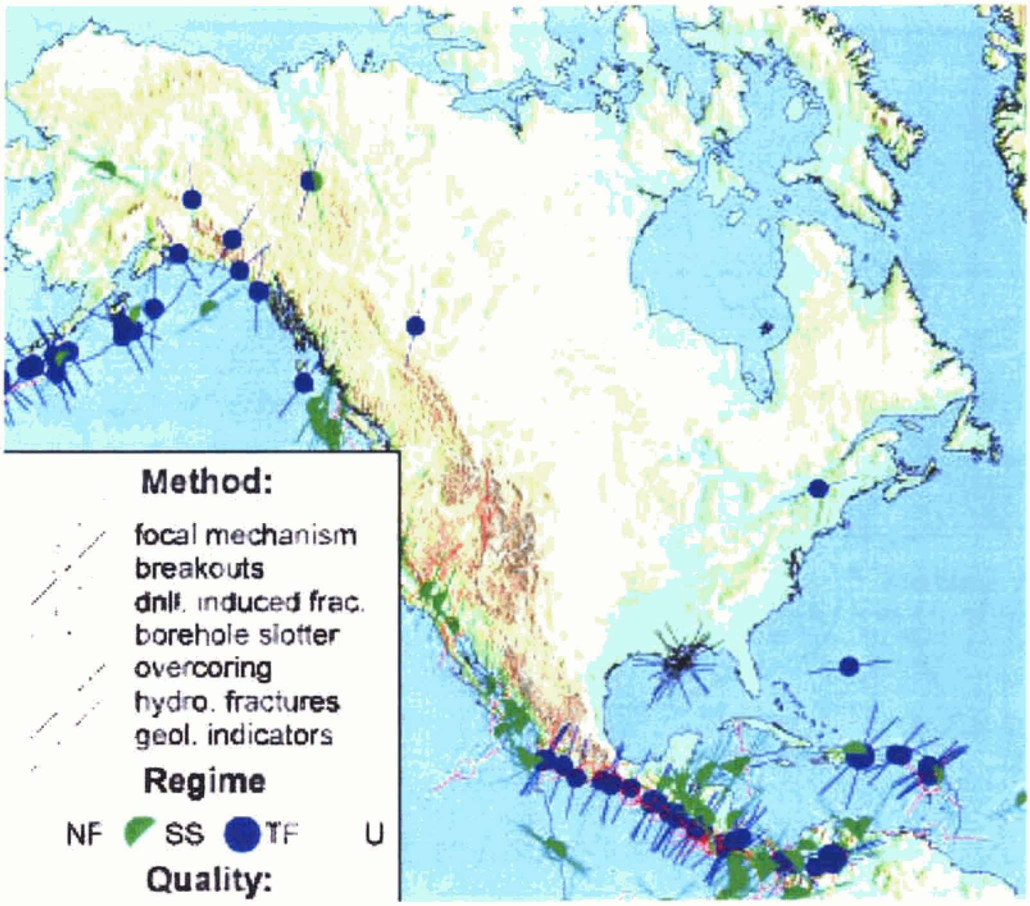

Figure 2. Orientation of principle stress for North America. *From The World Stress Map Project.*

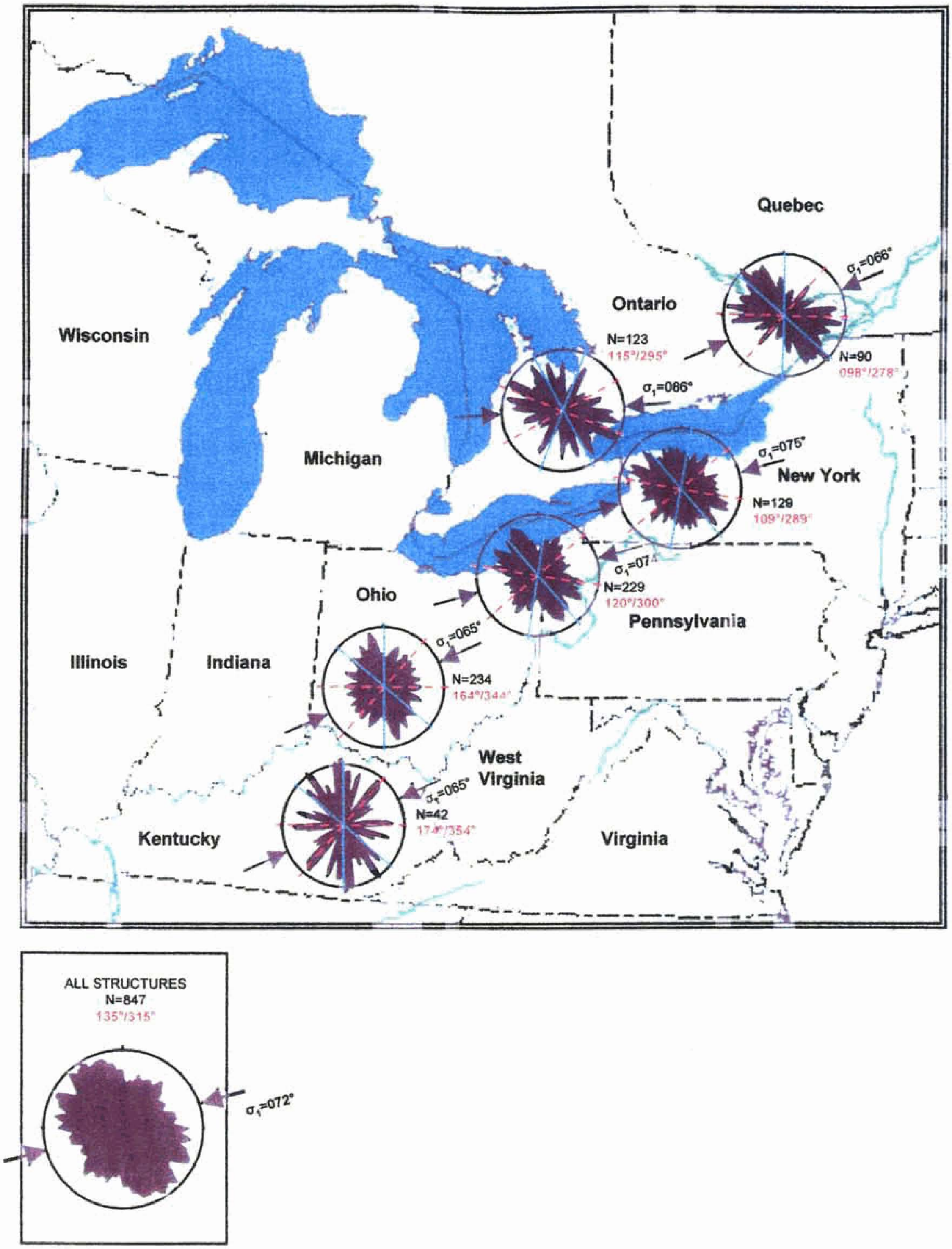

Figure 3. Regional map of eastern North America with superimposed rose diagrams showing structural orientations for 6 sub-regions. Dashed lines on rose diagrams represent +/-25° error associated with stress orientation (black arrows), solid lines represent 50° interval of preferred structural orientation. (Plankell, 2000).

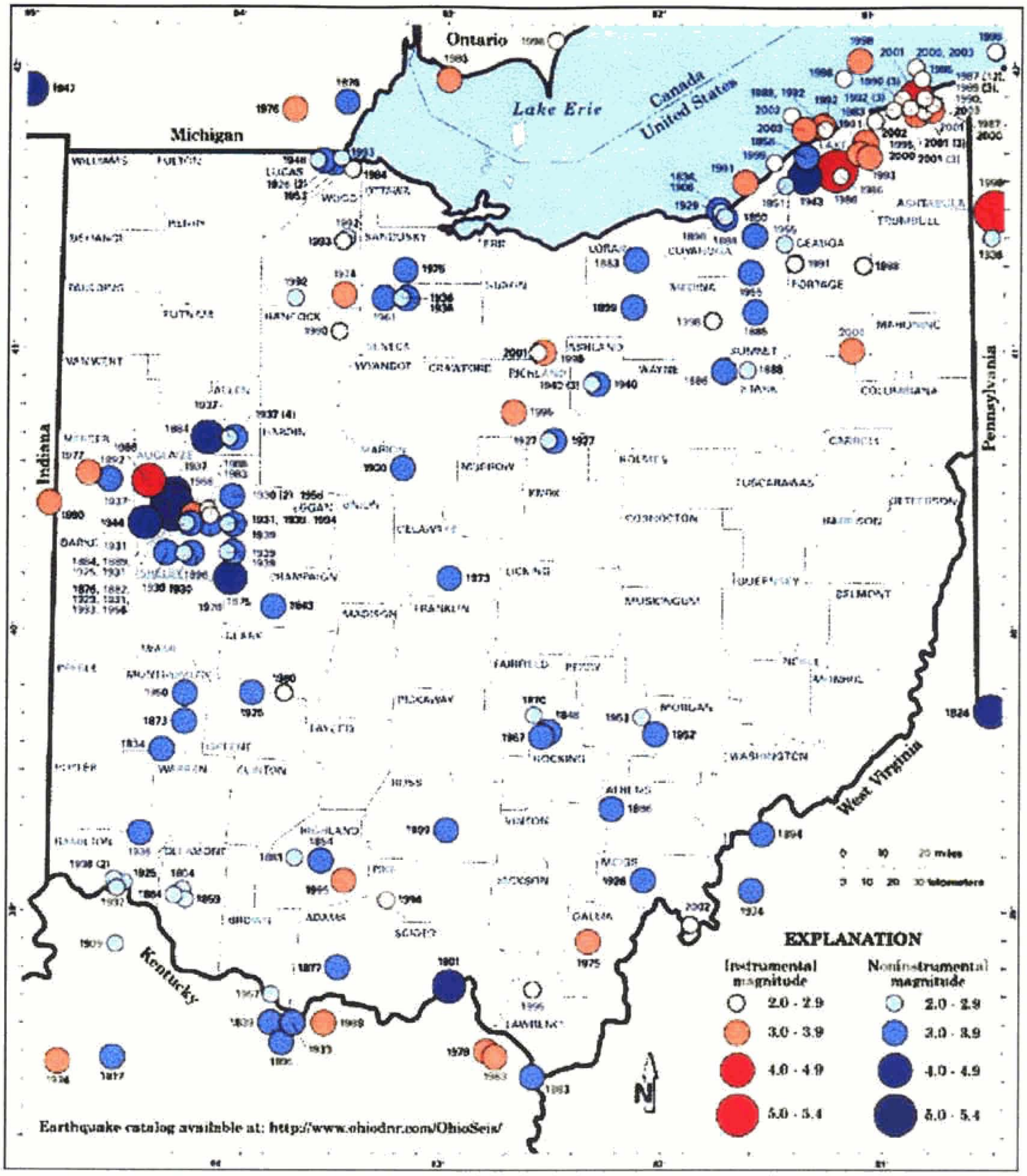

Figure 4. Map of earthquake epicenters in Ohio and adjacent areas.

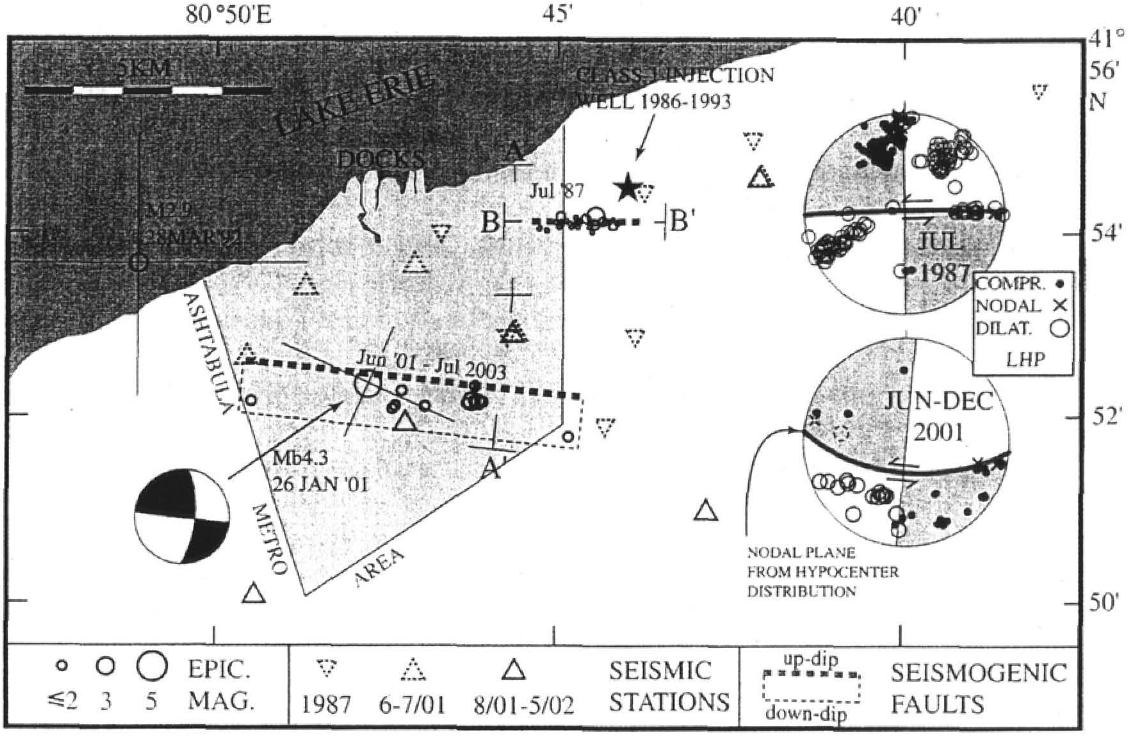

Figure 5. Accurate hypocenters and first motions in Ashtabula, Ohio from two short-term deployments of portable seismographs. Data from 1987 illuminated a vertical east-west-striking left lateral fault in the basement (Seeber and Armbruster, 1993). This activity was 0.7 – 2.0 km from the RES well (star) and started one year after the onset of injection. Several episodes of felt earthquakes during the following years were not monitored by local instruments. An mbLg 4.3 mainshock on 25 January 2001 caused light damage (MMVI). The focal mechanism and epicenter of this event were obtained from regional waveforms. Another fore-main-aftershock subsequence during June 2001 was captured with a local network. These data illuminate another fault (thick line is fault trace at unconformity) similar to the one in 1987, but 4 km south. The January 2001 mainshock is probably also from this source. The two dotted first motions are from the latest and westernmost hypocenter and are inconsistent with the composite focal mechanism. (Seeber, Armbruster, Kim).

History of Seismicity

There are four anomalous aspects of the Ashtabula sequence that are very important to the conclusion of the origin of the seismicity: 1) Lack of demonstrable seismicity at Ashtabula prior to 1987. 2) Hypocentral depths of Ashtabula events at, just below, or just above the Precambrian/Paleozoic unconformity (associated with injection depth). 3) Abundant aftershock swarms, many of them felt, following comparatively small mainshocks. This is uncharacteristic of natural earthquakes in the region. 4) Presence of basement/Lower Paleozoic faults in the region where sufficient data are available (Hansen, 2003).

The 1987 Sequence

Ashtabula is located on the eastern North American platform and is considered to be in a stable continental region. As stated previously, no earthquakes have been recorded or are thought to have occurred within 30 km of Ashtabula prior to 1987, only one year after the beginning of fluid injection at the RES well. Furthermore, there is no evidence for seismicity near Ashtabula prior to 1987 despite intensive searches for historic data (Seeber and Armbruster, 1993; Hansen, 2003). Following the July 13, 1987 earthquake (3.8 mbLg), as many as 36 aftershocks were recorded by Lamont-Doherty Earth Observatory (LDEO) during a ten day period following the mainshock (Seeber and Armbruster, 1993) (fig. 6). These earthquakes were monitored with portable seismometers distributed throughout the city of Ashtabula. Seismometers from the John Carroll University seismic network, operating southwest of Ashtabula, recorded the larger events also, as too did the Geological Survey of Canada. These networks also recorded other sequences of earthquakes in 1990 and 1992, though some of these are thought to be associated with the Akron Magnetic Lineament (fig. 1). Northeast Ohio seismicity correlates spatially with the prominent Akron Magnetic Lineament, which coincides with a portion of the Akron Magnetic Boundary, a region that probably reflects different lithologies in the Precambrian basement (Seeber, and Armbruster, 1993). Other earthquakes recorded in the region occurred in 1995 and 2000 as well.

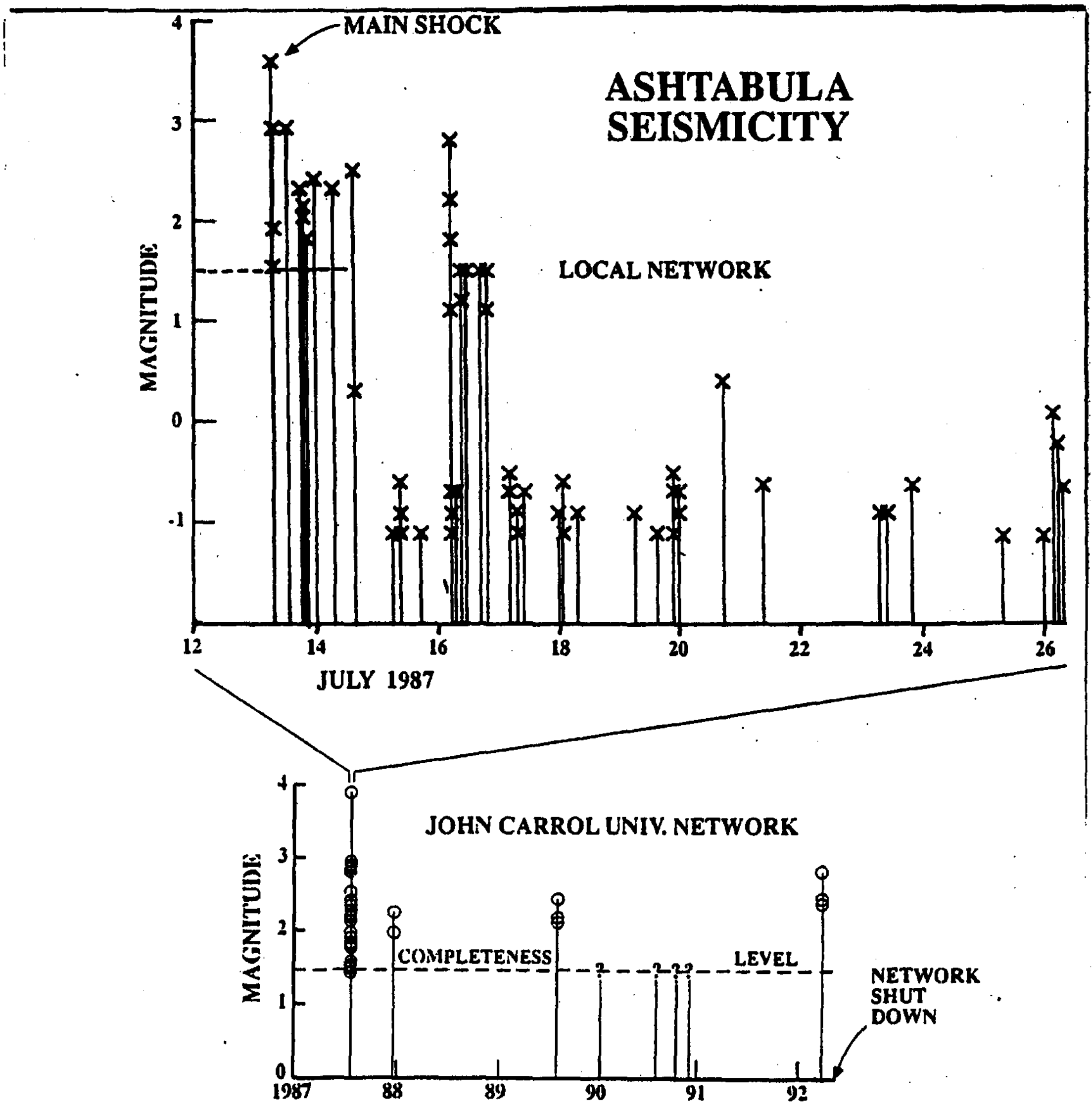

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Figure 6. Histogram of seismicity at Ashtabula. Data from the local network by LDEO above and data from JCU below.

The 2001 Sequence

On January 20, 2001, a small (2.0 mbLg) foreshock was followed by a 4.5 mbLg mainshock on January 26. This event resulted in about 50 reports of minor-to-moderate damage in Ashtabula, including breakage of two natural gas lines. The area affected by the earthquake was large (fig. 7) and was felt as far north as Ontario Canada. Isoseismal maps prepared by Margaret Hopper of the U.S. Geological Survey show the northward propagation of energy into Ontario (fig. 8). With the recent (1999) installation of the Ohio Seismic Network, the 2001 events were able to be determined even more precisely. These events had epicenters approximately 4.5 km south of the 1987 earthquakes; a location confirmed by another deployment of portable instruments from Lamont-Doherty for the June 3 aftershock (fig 6). The depths of these earthquakes were confirmed to be about 2.1 – 2.5 km in depth and situated on an east-west-oriented strike-slip fault (Hansen et. al., 2001; Seeber and Armbruster, 2004). There is considerable attenuation of seismic energy south into Ohio, along with a strong propagation of energy northward into Canada. The cause of this phenomenon is unknown.

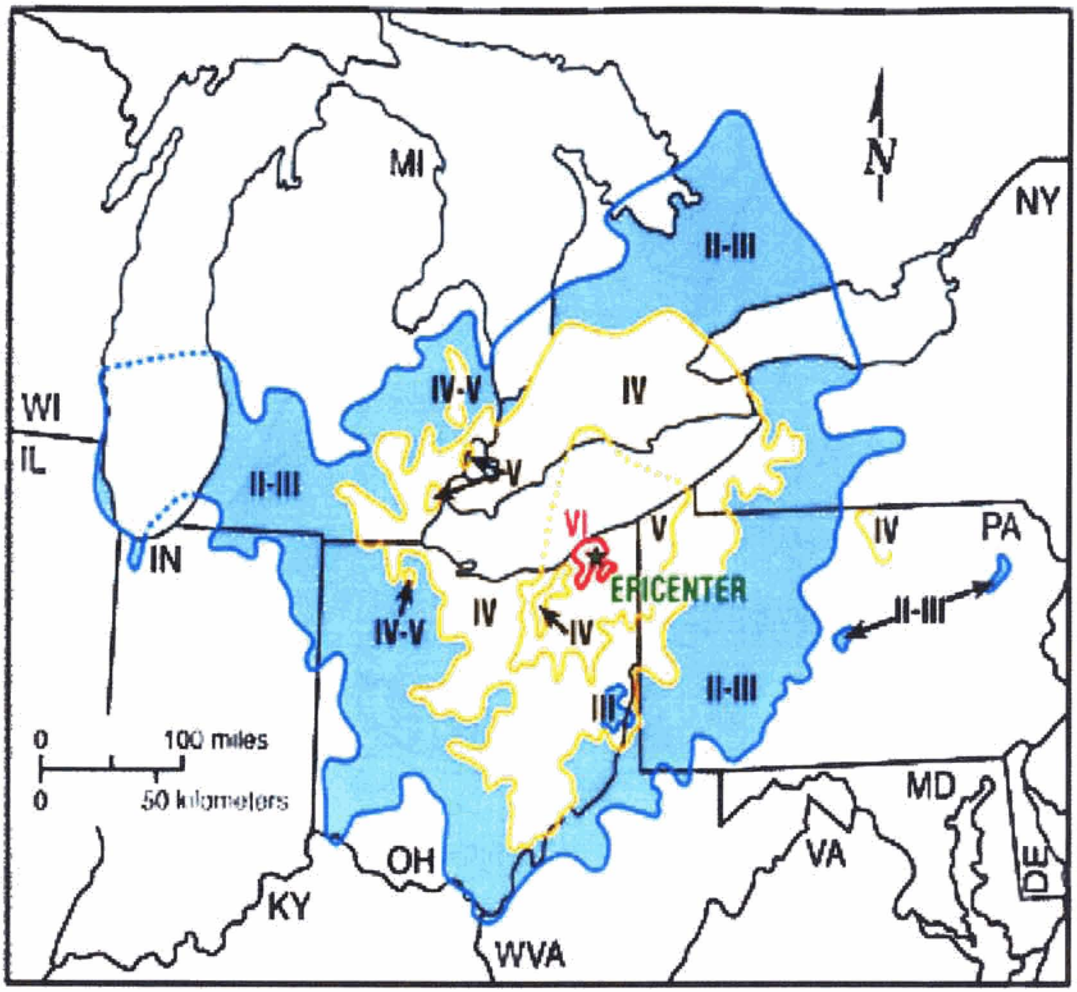

Figure 7. Modified Mercalli Intensity felt report area for the January 25, 2001 4.5mbLg mainshock. For a description of the Modified Mercalli scale, see appendix A.

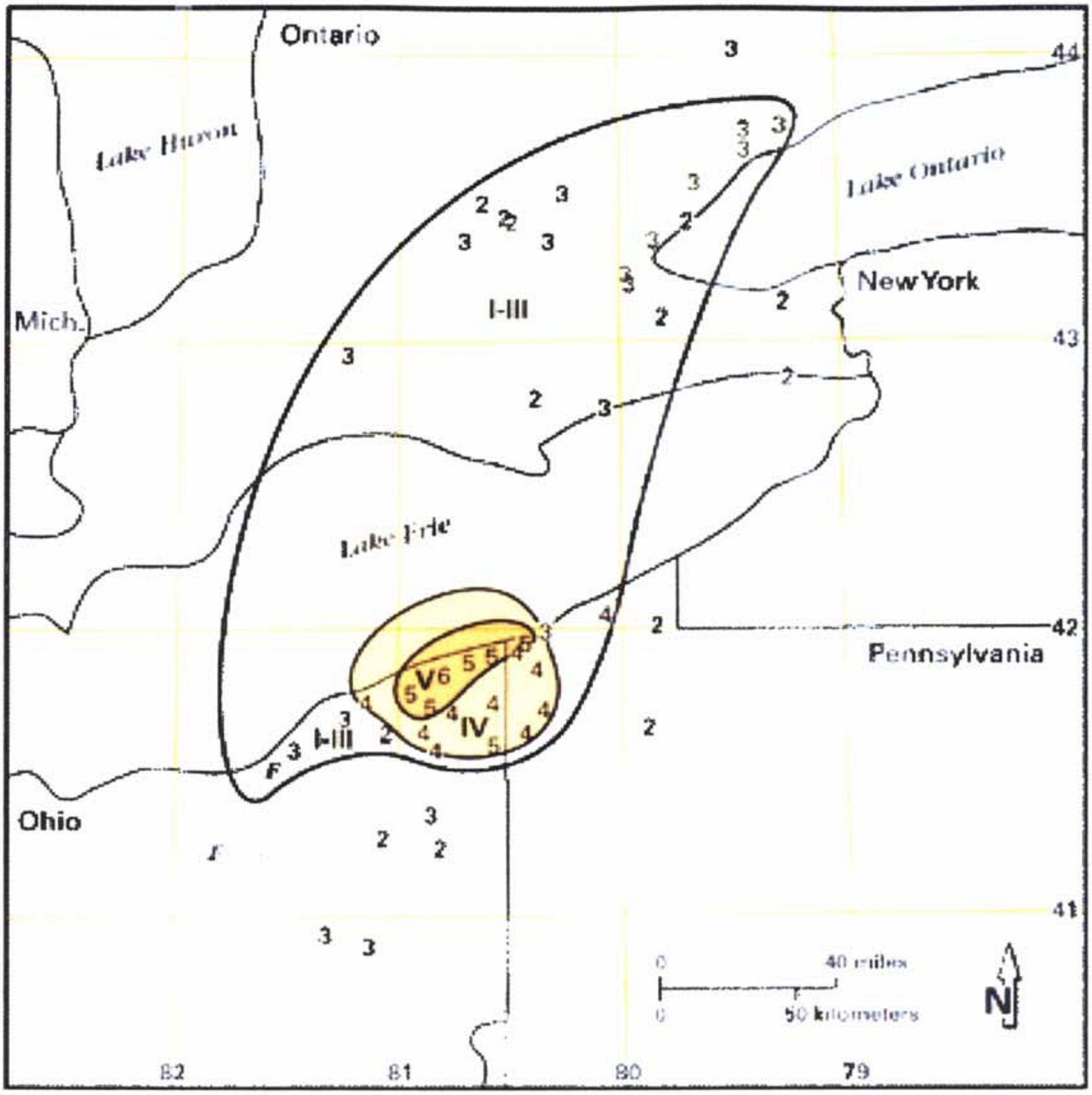

Figure 8. Isoseismal map for the January 25, 2001, mainshock at Ashtabula. The map depicts areas of approximately equal Modified Mercalli intensities as reported by residents in the areas which the earthquake was felt or caused damage. Maximum Modified Mercalli intensity was VI at some locations in Ashtabula. Map prepared by Margaret Hopper of U.S.G.S. Canadian intensities courtesy of Sylvia Hayek of the Geological Survey of Canada.

High-Pressure Fluid Injection

Flow in porous media

Fluids such a water, petroleum, and natural gas often flow through the Earth's crust. These fluids mainly flow through the interconnected passages of porous media such as sandstone and limestone and through fractures in these same rocks. For rocks that are not naturally porous, they can still be considered porous if they are extensively fractured. These fluids can flow through a porous medium under the influence of an applied pressure gradient. For laminar flow, which is characteristic of groundwater, the flow rate is linearly proportional to the pressure gradient and inversely proportional to the viscosity (Turcotte and Schubert, 2002).

The RES well

The RES well is located at 41.9078° N and 80.7322° W. The company began injecting 3.4 x 10^5 m^3 of calcium chloride brine, with a viscosity of 1.5 centipose at reservoir temperature (Gerrish and Nieto, 2003), into the base of the Mt. Simon Sandstone at a depth of approximately 1.8 km in May 1986 (fig. 9). Injection ceased on June 20, 1994. By the time the well ceased operations, the pressure increase was 8.53 MPa above the pressure before injection of 18.84 MPa (Gerrish and Nieto, 2003). Estimates of stress inferred from commercial hydrofracturing measurements suggest that the state of stress in northeast Ohio is close to the theoretical threshold for failure along favorably oriented faults. It has been suggested that nominal fluid injection pressures of as little as 11 MPa, in the zone immediately surrounding the well bottom would be in a critical stress state for favorably oriented fractures (Nicholson and Wesson, 1990).

Increasing pore fluid pressure quickly reduces the shear strength of rock. The simple Coulomb failure criterion, which presumes the effective normal stress acting on the fault, is given by the total normal stress minus the pore pressure and may adequately describe the shear strength of faults (Evans).

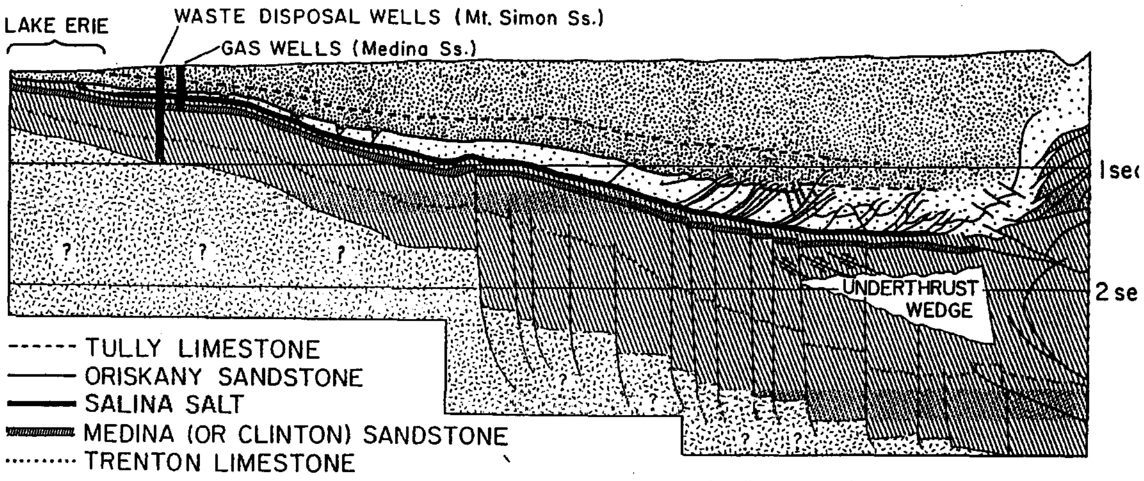

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Figure 9. Section running north-south from Lake Erie showing depth of injection and local stratigraphy. (Evans).

Analytical Procedure

The main goal of this work was to relocate epicenters of approximately 36 earthquakes above 2.0 magnitude that occurred in the Ashtabula region from 1987 to 2001 (Table 1). These events were initially located separately by at least two seismic networks each. The events from 1987 through 1990 were located by the Geological Survey of Canada (GSC), the John Carroll University Seismic Network (JCU), and the U.S. Geological Survey (USGS) and by portable seismometers installed by The Lamont-Doherty Earth Observatory (LDEO). For events from 1992 through 2000, the only data available were those from GSC and LDEO. From 2000 to 2001, data from The Ohio Seismic Network (OSN) were also available. For this thesis, only data from GSC, JCU and LDEO were used; however, for comparative purposes, epicenter locations from OSN have been introduced. For this study, I did not re-pick phase arrival times; they are original to the seismic networks that published them.

LDEO locations are the most precise because the portable seismometers were located in proximity to the mainshocks and were sensitive enough to detect numerous microearthquakes. Locations for individual earthquakes, determined by other seismic networks, have been inconsistent. For example, GSC locations for the Ashtabula earthquakes are all farther to the north than determined by the LDEO portables. The locations given by JCU correspond well with LDEO locations, but a few are farther to the west. These biases are mostly due to the large azimuthal gaps associated with network geometry. The locations of JCU instruments were to the west of Ashtabula, which would tend to 'pull' the earthquake locations in that direction. The location of GSC instruments, all to the north of Ashtabula, tends to 'pull' all of their locations to the north. It has also been suggested that the thinning of the Paleozoic rocks towards Canada and the corresponding shallower crystalline basement rocks, having higher P and S wave velocities, causes earlier than normal arrival times for these phases. This would cause the locations of the earthquakes to plot closer to Canadian stations and thus be inaccurately located farther to the north. Another reason for the inconsistency may be due to the difficulty of accurately determining the arrival of a wave phase amidst all the background noise recorded at a seismic station. At long distances, wave attenuation can significantly reduce the signal of the arriving phases, making it difficult to accurately pick the correct arrival time.

The Double Difference technique

To combat the apparent discrepancy in epicenter locations, I utilized the Double Difference technique of Waldhauser and Ellsworth (2000). This technique takes advantage of the fact that if the hypocentral separation between two earthquakes is small compared to the event-station distance and the scale length of velocity heterogeneity, then the ray paths between the source region and a common station are similar along almost the entire ray path (Frechet, 1985; Got et al., 1994). The residual between observed and calculated travel-time difference (or double difference) between two events at a common station, are related to adjustments in the relative position of the hypocenters and origin times through the partial derivatives of the travel times for each event with respect to the unknown. This approach is especially useful in regions with a dense distribution of seismicity, such as northeast Ohio. Dr. Larry J. Ruff of the University of

Michigan, seismic advisor to the Ohio Seismic Network, created a software program that performs this operation; it is called Epirelocator.

The technique calls for calculating the time difference in same phase arrival times for a common station for several different earthquakes, one a 'Master' and the rest 'Slaves' (tables 2, 4 and 5). For this technique, I designated a 'Master' earthquake by its larger magnitude and its accurate location determination from LDEO portable seismometers. The Master earthquake is the one in which all other earthquakes in that vicinity will be located relative to. For common stations between the Master-Slave events, I calculated the arrival time difference between the Master and Slave, seconds only, for each phase, P and S. The average of these arrival times is then entered as the origin time (OT) of the slave earthquake.

Ex.:

Station	Phase	Arrival time (s)	Δt with Master	Difference time (s)
Tyno	Pg	36.21	-21.45	8.55
Tyno	Sg	54.98	-22.37	7.63
Acto	Pg	12.01	-15.45	14.55
Acto	Sn	30.88	-15.22	14.78

If the slave – master time is negative, then add the same number of seconds to each Δt with master time, to obtain a positive number (for the above example 30 seconds were added to Δt). Then, take the average of the difference times and enter that as the origin time for the master event. Once all station and phase arrival information is entered and processed a new location for the earthquake (latitude and longitude) is calculated. (Tables 2, 4 and 5).

Correcting for residuals

As well as calculating a new location for the earthquake epicenter, Epirelocator also calculates the travel-time residual for each wave phase: P, Pg, S, and Sg (Appendix B). The residual is the time difference in seconds for the theoretical travel time, based on the velocity model used, and the observed travel time. An ideal residual would be ± 1.0 s or less. For this study, in general, any residual that was much higher than ± 1.0 was rejected from the solution process. These high residuals were probably the result of an erroneous pick, or a pick with poor quality, of the phase arrival time by the original network.

I then decided to determine epicentral locations based on these residuals as well. Adding these residual times to the original arrival times should give a more accurate arrival time. These new arrival times, in seconds, were then entered into another similar software package designed by Dr. Larry J. Ruff called Epilocator. These events were run and processed giving new locations in latitude and longitude. (Tables 3, 6, and 7)

Ex:

Station/phase	arrival time (s)	residual	corrected arrival time (s)
Tyno Pg	44.31	-0.09	44.22
Tyno Sg	58.55	0.16	58.71

For reasons not yet understood, this technique produced very erratic results in epicentral locations (Tables 3, 6, and 7). There was no rhyme or reason to the locations produced using this technique. Further information and research should be conducted to evaluate the validity of this approach. Unfortunately this is beyond the scope of this thesis and therefore, these data have been omitted.

Plots of Epicentral Locations

The maps depicting epicentral locations, Maps 1 - 7, were created using the Arc Map, GIS software package. I used the Ashtabula North 7.5-minute quadrangle topographic map overlain on a digital raster graph of a 3-D hill-shade map of the same area. Latitude and longitude of the epicenters were entered into a spreadsheet and then imported into Arc. For clarity, each event was then assigned a letter following the year that the event occurred, for example, 1987-D (Table 9). If GSC and JCU both recorded an event, the same letter was used between each network. Where several events occurred at the same location, multiple letters have been designated for that point.

Discussion

Plotting the epicentral locations from data obtained in this study indicates a few trends. As suspected, most original JCU epicentral locations were 'pulled' to the west toward their network and most GSC epicentral locations were 'pulled' to the north toward their network. After doing the relocations, almost all of the new slave epicentral locations were relocated closer to their respective master event (Maps 5 & 6). However, there have been a few erratic epicentral locations produced and I have analyzed them to try and determine the reason for this.

On Map 5, the following events were analyzed for their deviation from the trend of the rest of the data: 1987 B, 1987 H, 1987 J, and 1990 T. The common trend for all of these events is small earthquake magnitude, poor station coverage, geometry, and thus, large azimuthal gaps. Each of these events was only recorded at 3 – 4 stations, which is less than the common 5-station coverage for the other events. These aspects most likely led to the erratic behavior of the solution process and thus epicentral locations determined by the original network and by Epirelocator. We see on Map 6 that the only erratic event recorded and shown was relocated farther away from the master event than GSC's original location (1987 D). It was determined that the combination of high travel-time residuals and poor station coverage (only 3 recording stations) led to the erratic location. The original location of this same event by JCU places it very close to the master event and the new location determined by Epirelocator from JCU data, put it at the master event location.

The remainder of the earthquakes have been located more accurately and are closer to their respective master event location. For the event from 1992, (1992 J, Maps

4 & 6) the epicenter was relocated very far to the east from its original location determined by GSC. The event labeled 1990 R is thought to be associated with the NE – trending Akron Magnetic Lineament. This event was also only recorded by 3 stations, which may have led to a poor location solution. There are obvious error margins associated with the actual location of earthquake epicenters. For this study, most error ellipses, determined by Epirelocator, were oriented nearly NE – SW and their sizes are as follows: 0 – 1 km 31.60 %, 1 – 2 km 36.84 %, 2 – 3 km 10.50 %, 3 – 4 km 10.50 %, 4 – 5 km 10.50 % for the major axis, sigma 1 (Appendix C). The widths of the minor axes are approximately 0.10 km to 0.68 km.

The new locations of the earthquakes determined by Epirelocator, fit the proposed hypothesis. It was hypothesized that there would be a reduction of apparent epicenter 'scatter'. Although the locations of the earthquakes may never be known precisely, the relocation procedure places them, relative to their error ellipses, in a tight cluster near the master events located on the strike-slip faults noted by Seeber and Armbruster (1993, 2004) (Figure 5). It can also be seen from Maps 2, 4 and 7 that there is an apparent movement of earthquake epicenters away from the RES well with time. The epicenter locations from 1987 seem to be closest to the RES well, within the error of margin. Events in 1989 and 1990 are relatively in the same area. It is too difficult to see the exact distance these later epicenters have moved due to the error ellipses and the fact that there may have been very little distance traveled by the fluid from the well in only two to three years time. The 2001 events, are located farther to the south and west from the RES well and the earlier events. This would suggest that the pressure front is moving predominantly to the southwest, and intersecting the two strike-slip faults identified by Seeber and Armbruster (1993, 2004).

Conclusion and Future Studies

From these data, it is evident that previous epicentral locations were 'scattered', but not for the reasons stated by Gerrish and Nieto (2003). It has been shown (Maps 5 & 6) that after performing relocations using the Double-Difference technique, the epicenters are actually clustered in a smaller area near the precisely located master earthquakes. This demonstrates the accuracy and validity of using this approach for finding earthquake locations in areas of high seismicity. The apparent 'scatter' was due, in part to poor station coverage, geometry, and azimuthal gap. Epicenters were consistently relocated closer to the master events and thereby have shown a reduction of 'scatter'. These groups of epicentral locations are tight, within their error of margin, except for those thought to be associated with the Akron Magnetic Lineament.

There is a large amount of seismic data for this region that could also be analyzed. It would be beneficial for future studies of these data to be incorporated into this research. Also, by combining the phase arrival time data for each earthquake from multiple seismic networks into Epirelocator, further reduction of the error ellipses associated with epicenter locations could be achieved. This would most likely happen since the station coverage for each earthquake would increase substantially resulting in a smaller azimuthal gap and better station geometry. Unfortunately for this thesis, I did not have time to do this.

Earthquakes on the Akron Magnetic Lineament are associated with NE – SW strike-slip faulting whereas those in the immediate vicinity of Ashtabula are occurring on E – W strike-slip faults (Seeber and Armbruster, 2004). The Akron Magnetic Lineament has generated a few earthquakes in the past (Hansen, 2002). The earthquakes on March 26, 28, and 31, 1992 (Table 1) appear to be northwest of Ashtabula and are thought to be associated with the Akron Magnetic Lineament. The event on March 15 at 06:13, labeled 1992 J, was originally located considerably west of Ashtabula by GSC. Relocation of this event put the location on the east side of Ashtabula, within the cluster of events in this area. Data for 1992 events recorded by JCU could not be recovered from original data in time for this work. It would be beneficial for future work to be done using these data in order to better define the epicentral locations of these earthquakes and therefore to determine the structural features that they are related to. By having a clearer picture of which earthquakes are associated with Ashtabula seismicity and which earthquakes are associated with the Akron Magnetic Lineament, a better understanding of the pattern of earthquakes associated from induced mechanisms can be inferred. This would also serve to reduce the apparent 'scatter' of epicentral locations by showing a clear division of earthquakes associated with their respective structural features.

This work is important in the realm of earthquake-hazard reduction and mitigation. The abundance of earthquakes located in close proximity to a high-pressure fluid injection well, in an area previously devoid of seismic activity, clearly demonstrates the dangers associated with high-pressure waste disposal. More research is needed to investigate the role of fluids in fault zones, and care should be taken in choosing sites for waste-fluid injection. A thorough investigation and search for structural features such as hidden faults, especially in regions where the maximum horizontal stress is at or near failure, must be conducted. To ignore this advice could prove to be disastrous and costly. Although most earthquakes resulting from induced mechanisms are relatively small in magnitude, a few large ones have been recorded around M 5.5 (Nicholson & Wesson, 1990). It may only be a matter of time before another earthquake of this magnitude occurs due to fluid injection. As many fluid injection wells are located in or near large cities, an earthquake of such large magnitude could be devastating.

Acknowledgements

I would like to thank Dr. Michael C. Hansen, coordinator for the *Ohio Seismic Network*, for allowing me the opportunity to work with OhioSeis for the last three years, and for teaching me all the ins and outs of seismic network operations. Also, I would like to thank him for his help and guidance, and the access he granted me to all the available seismic data at OhioSeis used in this project. Finally and most importantly, I thank Mike for all the discussions and conversations over the years about seismology, geology and everything in between. He above all others taught me what it means to be a real scientist. For this I am most grateful. Thank you.

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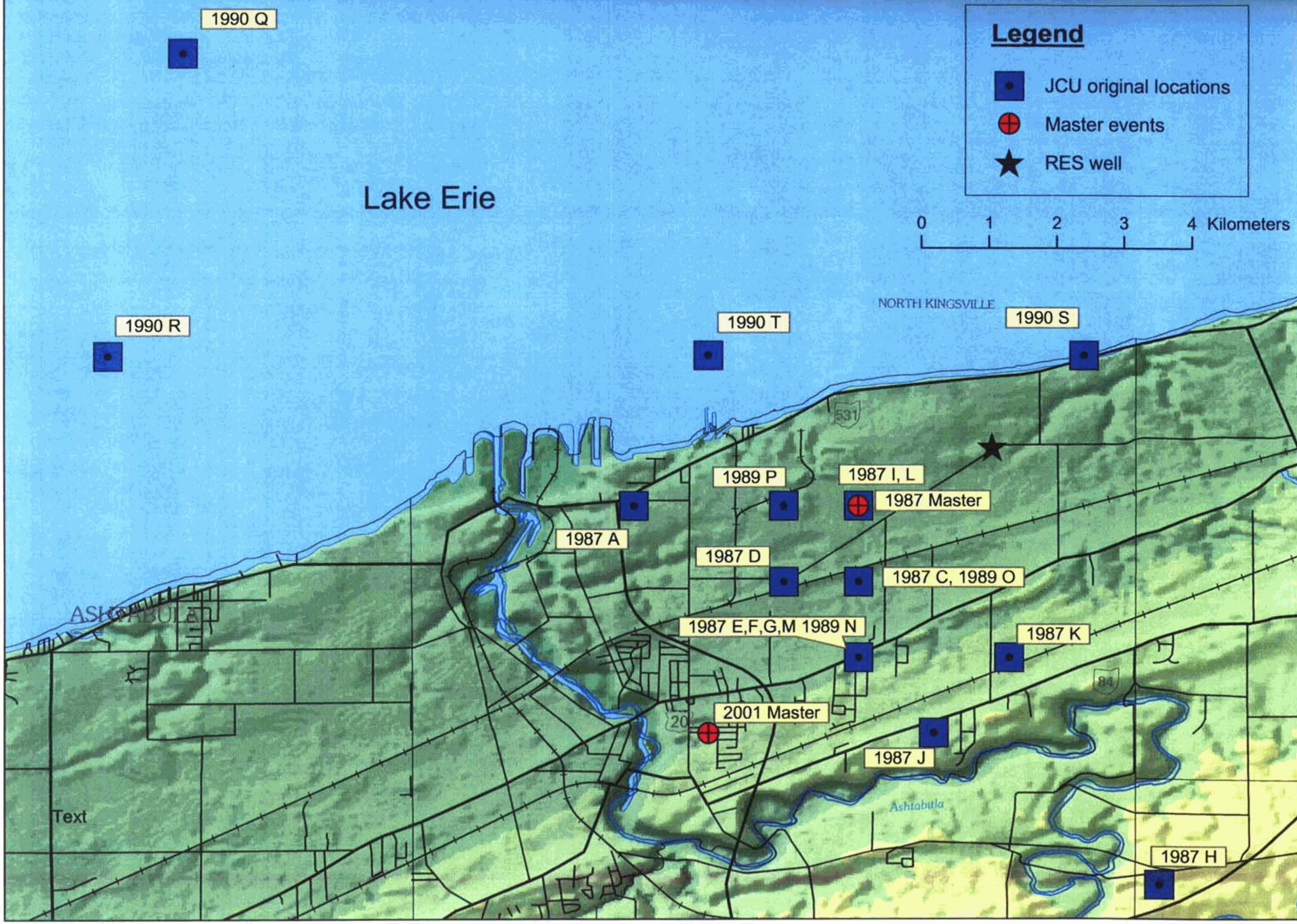
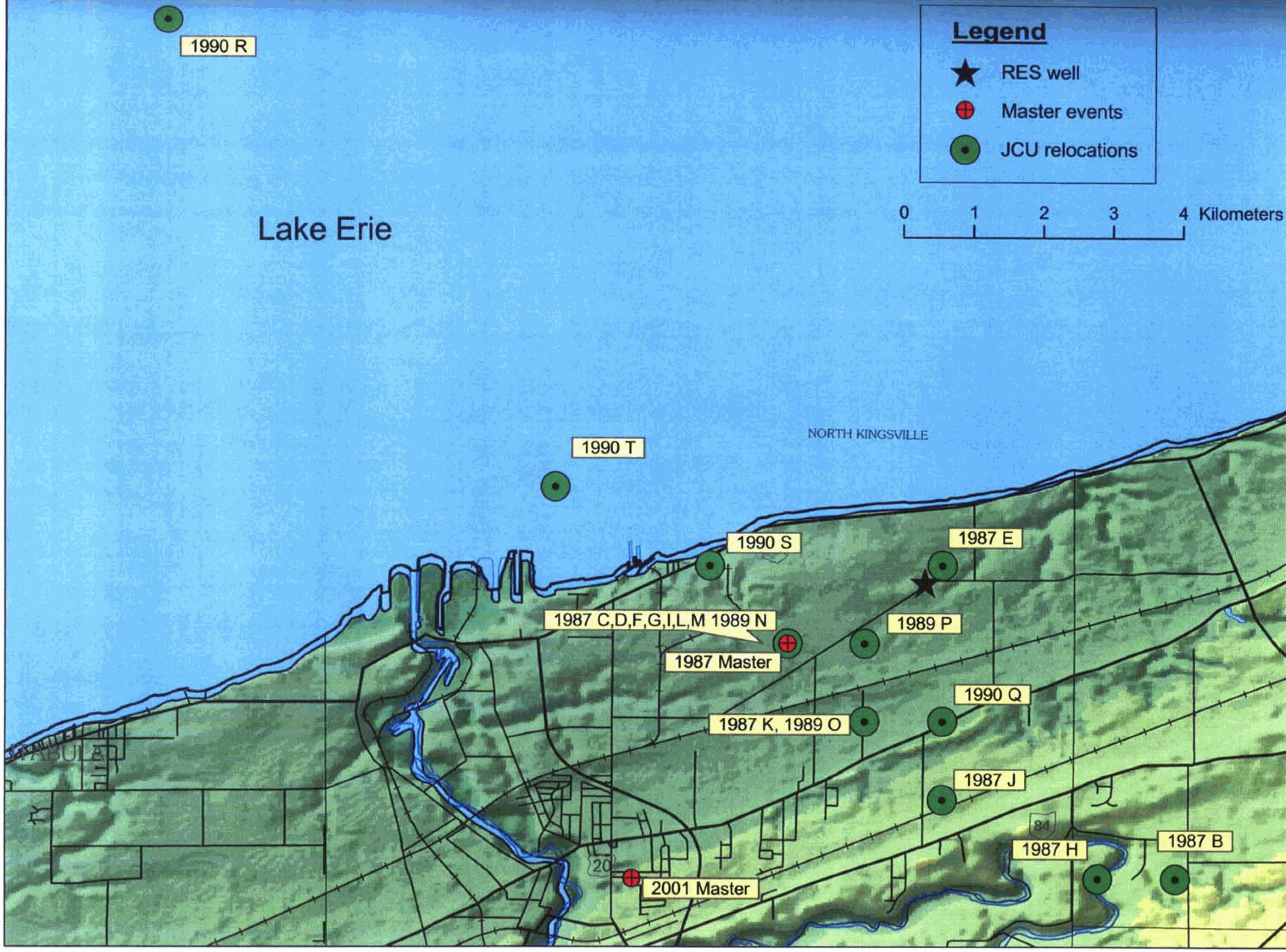
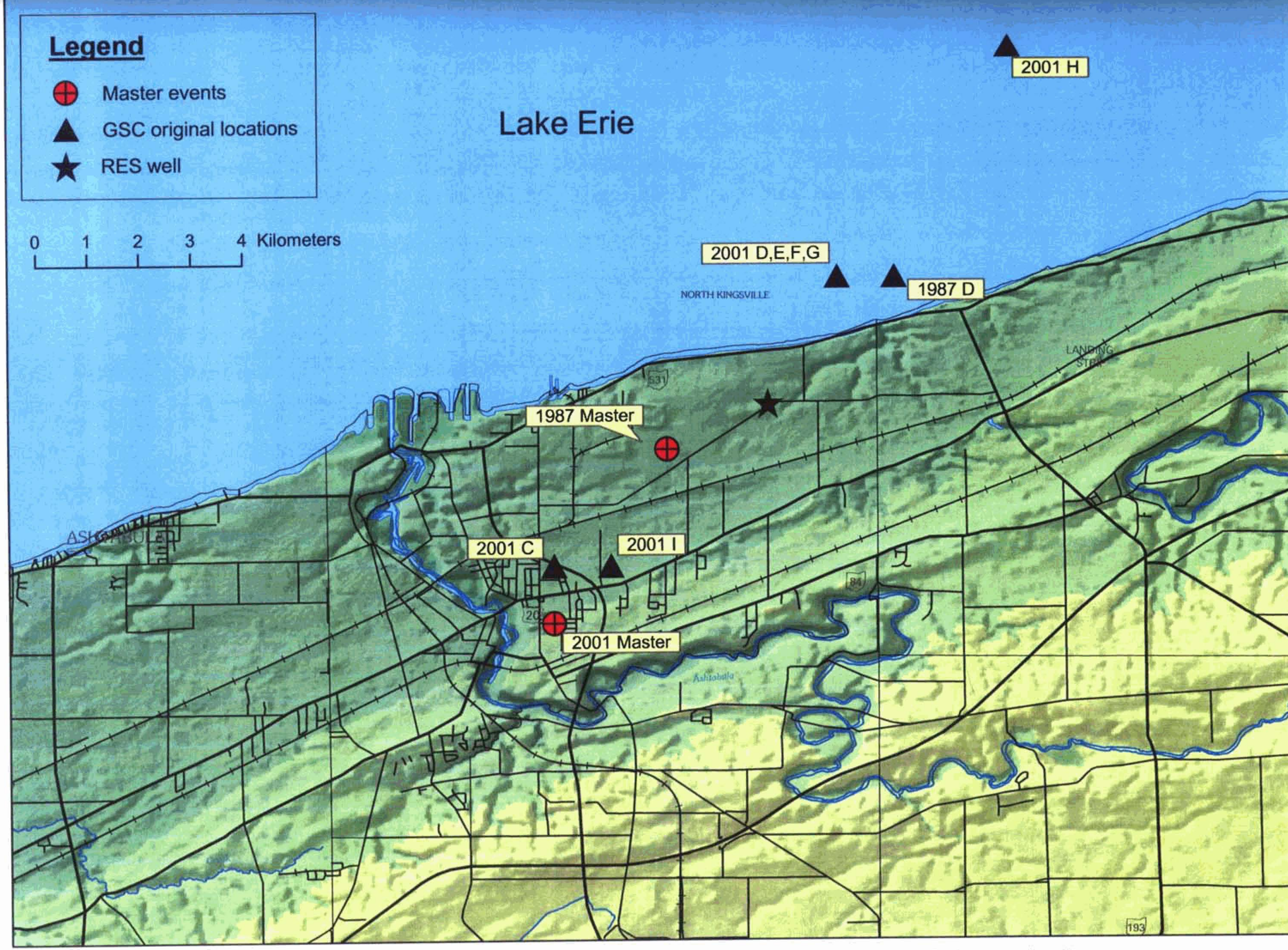


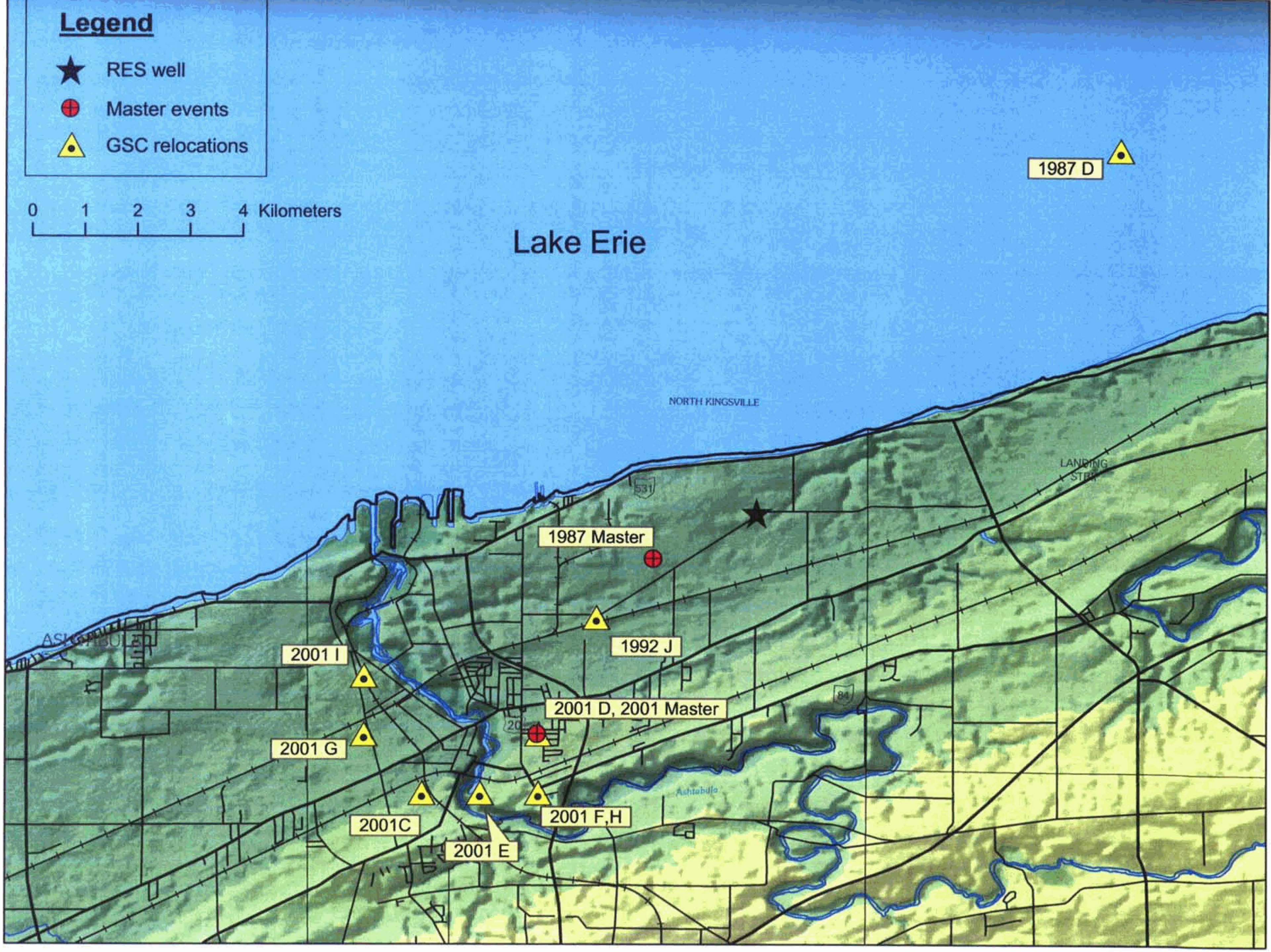
Map 1. Original epicenter locations from the John Carroll University Seismic Network. See Table 9 for letter explanations.



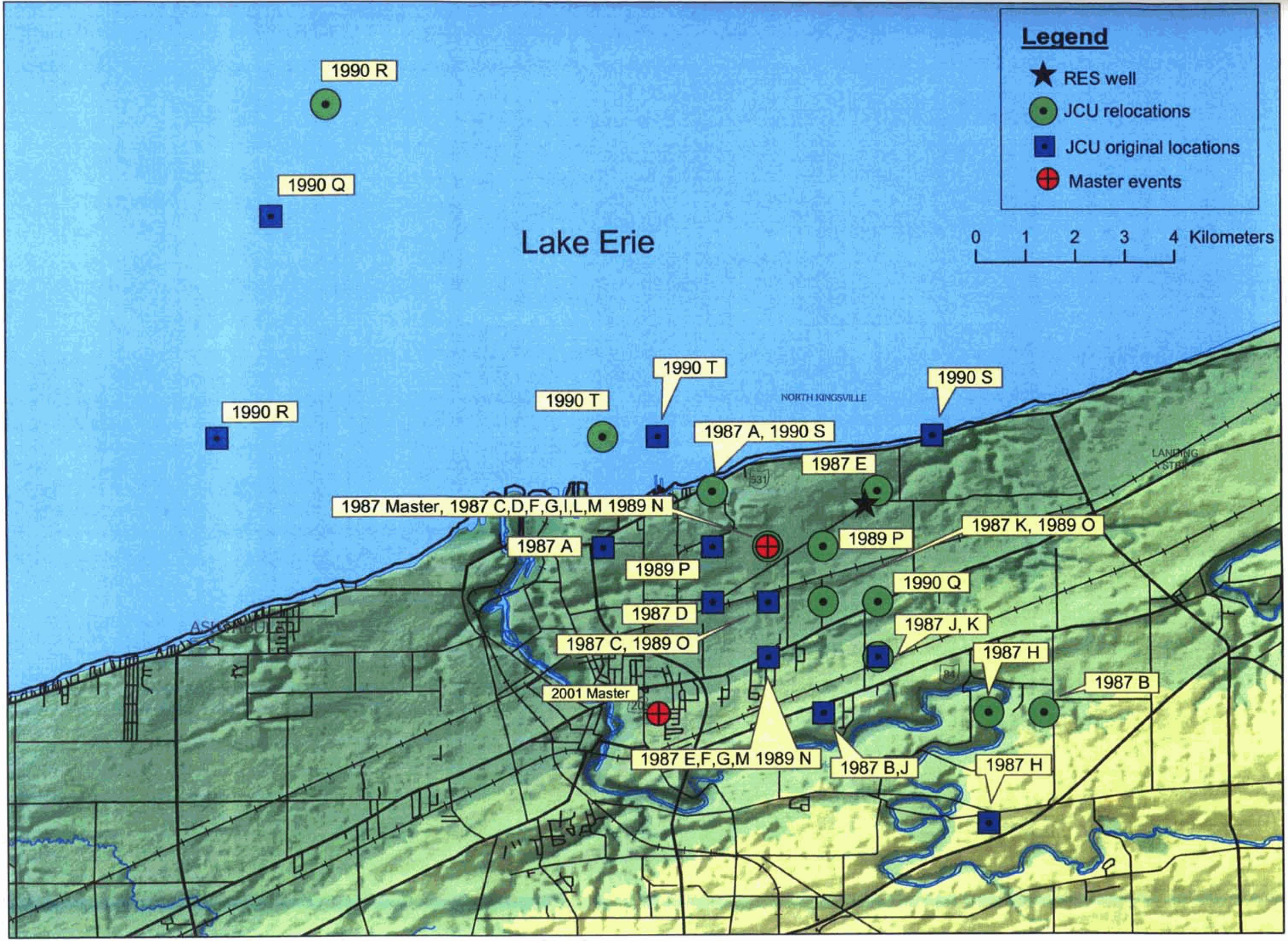
Map 2. Relocated epicenters from John Carroll University Seismic Network. See Table 9 for letter explanations.



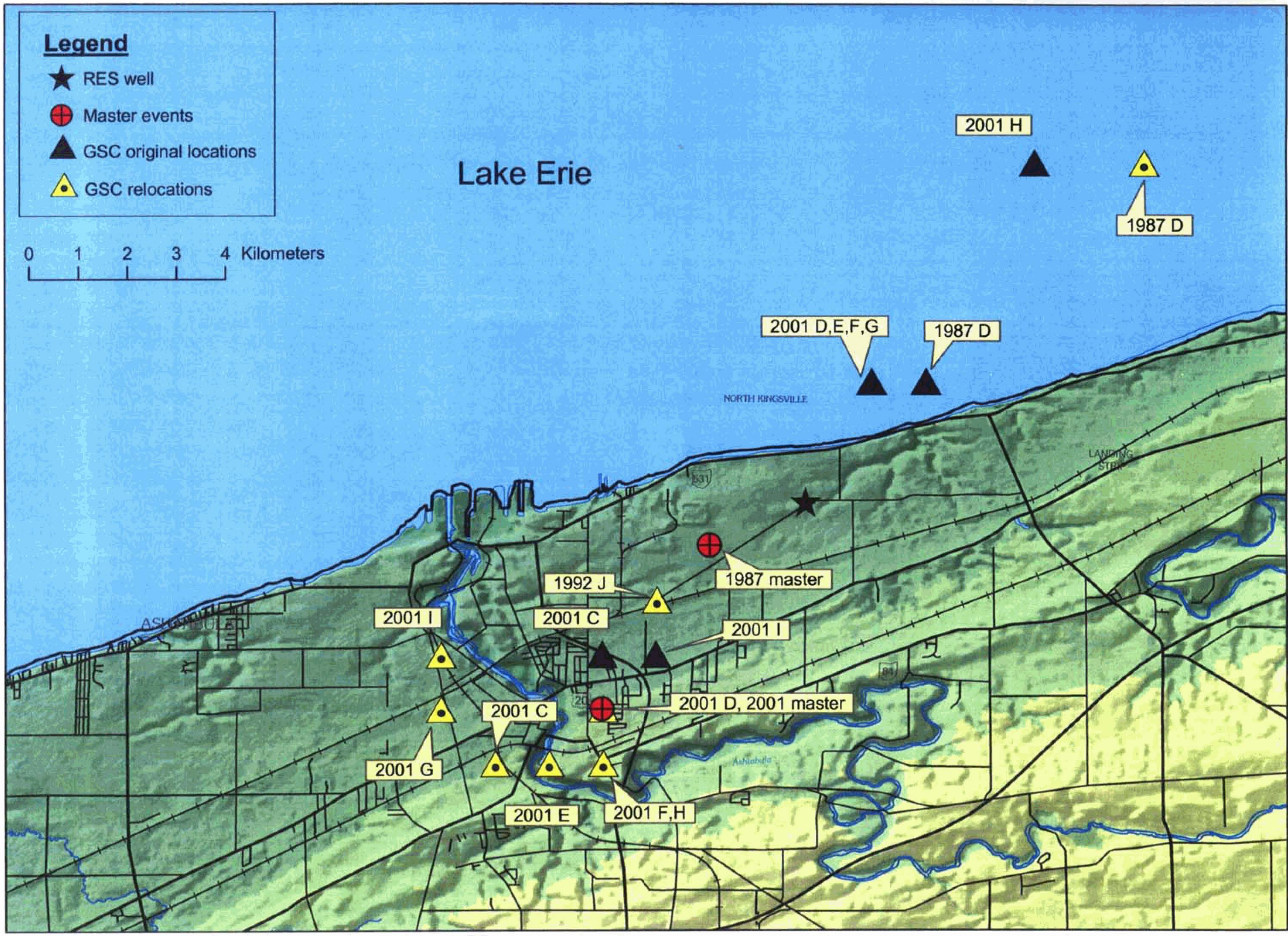
Map 3. Original epicenter locations determined by the Geological Survey of Canada Seismic Network. See Table 9 for letter explanations.



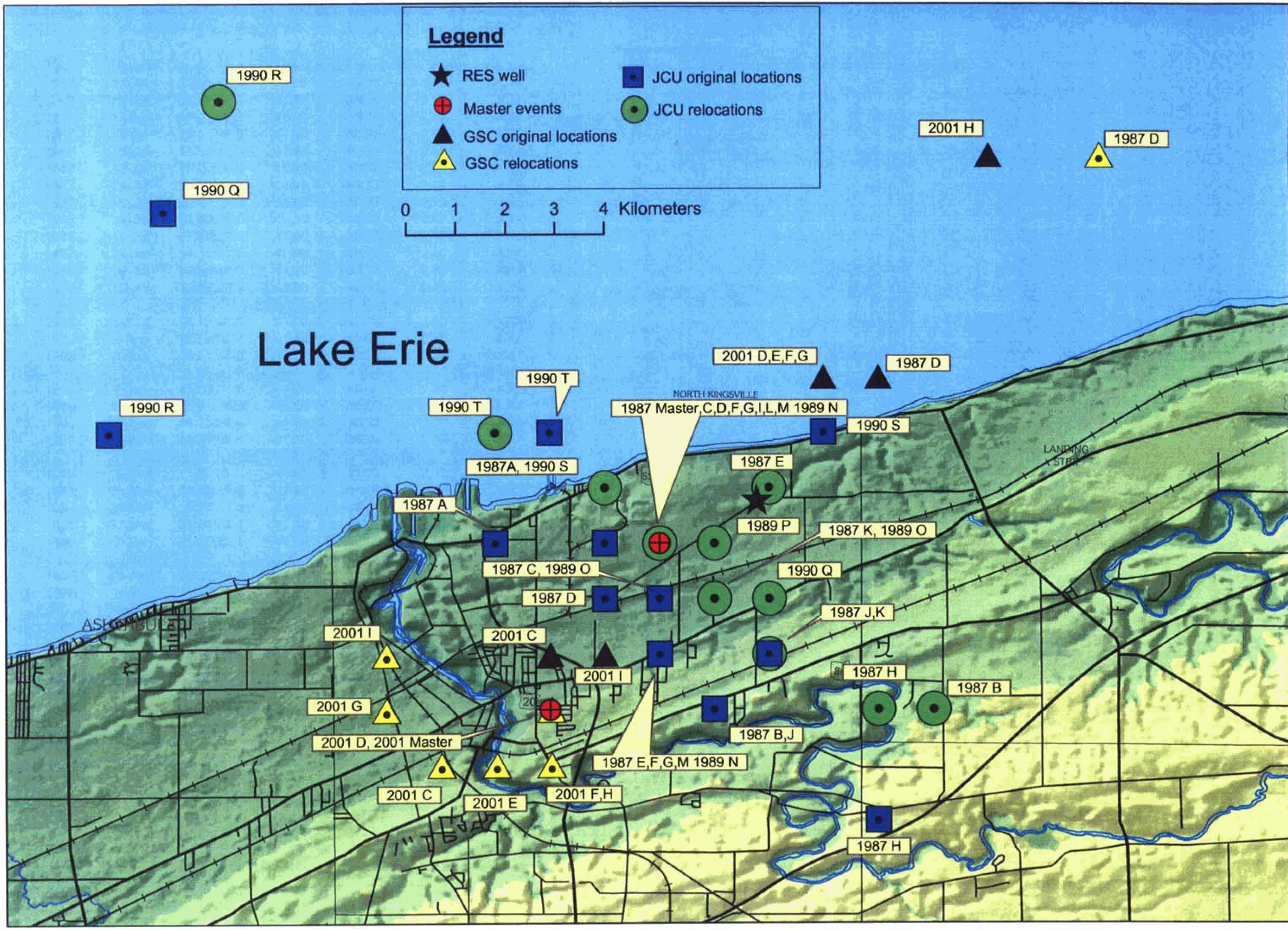
Map 4. Relocated epicenters from the Geological Survey of Canada Seismic Network. See Table 9 for letter explanations.



Map 5. Original and relocated epicenters from John Carroll University Seismic Network. See Table 9 for letter explanations.



Map 6. Original and relocated epicenters from Geological Survey of Canada Seismic Network. See Table 9 for letter explanations.



Map 7. Original and relocated epicenters from JCU Sesimic Network and the GSC Seismic Network. See Table 9 for letter explanations.

Earthquakes recorded by various seismic networks and used in this study.
An asterik (*) denotes an earthquake that was recorded by that network.
Lat./Long are original epicenter locations assigned by recording network.

							Seismic Networks				
Year	Date	Origin Time	Latitude	Longitude	Magnitude	Source	OSN	GSC	USGS	JCU	LDEO port.
1987	13-Jul	05:49:19.4	41.90	-80.76	3.80	JCU		*	*	*	
1987	13-Jul	05:58:52.3	41.88	-80.70	2.20	JCU				*	
1987	13-Jul	07:52:12.9	41.90	-80.76	3.00	JCU		*	*	*	
1987	13-Jul	13:05:23.6	41.90	-80.77	2.90	JCU		*	*	*	
1987	13-Jul	18:25:12.0	41.90	-80.77	2.80	JCU				*	
1987	13-Jul	19:00:08.5	41.90	-80.77	2.30	JCU				*	
1987	13-Jul	19:39:19.4	41.90	-80.77	2.10	JCU				*	
1987	13-Jul	20:53:05.5	41.90	-80.77	2.20	JCU				*	
1987	13-Jul	23:49:14.5	41.90	-80.75	2.40	JCU		*		*	
1987	14-Jul	07:47:27.3	41.90	-80.75	2.40	JCU				*	
1987	14-Jul	14:51:11.7	41.90	-80.75	2.80	JCU			*	*	
1987	16-Jul	04:49:40.7	41.90	-80.75	2.70	JCU		*	*	*	*
1987	16-Jul	06:02:25.5	41.90	-80.75	2.40	JCU				*	*
1989	1-Aug	16:12:48.8	41.90	-80.76	2.80	JCU				*	
1989	1-Aug	16:50:30.7	41.89	-80.75	2.90	JCU				*	
1989	3-Aug	04:07:48.6	41.90	-80.76	2.20	JCU				*	
1990	1-Jan	23:03:04.9	41.90	-80.80	2.20	JCU				*	
1990	24-Jul	23:04:38.0	41.90	-80.80	2.30	JCU				*	
1990	26-Sep	06:13:04.9	41.90	-80.75	2.30	JCU				*	
1990	18-Nov	09:20:52.8	41.90	-80.79	2.30	JCU				*	
1992	15-Mar	06:13	41.81	-81.22	3.70	GSC		*			
1992	26-Mar	03:43:15.3	41.87	-80.87	2.50	JCU		*			
1992	28-Mar	08:22:44.1	41.86	-80.91	2.90	JCU		*			
1992	31-Mar	01:54:52.1	41.86	-80.86	2.50	JCU					
1992	7-Apr	01:35:22.1	41.88	-80.85	2.00	JCU					
1995	23-Feb	09:32:12.0	41.87	-80.80	2.90	GSC		*	*		
1995	9-Apr	11:37:29.0	41.97	-80.75	2.40	GSC		*			
2001	20-Jan	02:05:07.0	41.88	-80.78	2.60	OSN	*	*	*		
2001	26-Jan	03:03:20.6	41.87	-80.76	4.50	OSN	*	*	*		
2001	26-Jan	03:11:30.0	41.87	-80.76	2.00	OSN	*	*			
2001	26-Jan	03:45:25.0	41.87	-80.76	2.20	OSN	*	*			
2001	26-Jan	05:11:05.0	41.87	-80.76	2.00	OSN	*	*			
2001	26-Jan	05:36:58.0	41.87	-80.76	3.20	OSN	*	*			
2001	3-Jun	22:36:46.4	41.87	-80.76	3.20	OSN	*	*	*		*
2001	5-Jun	08:27:15.0	41.88	-80.76	2.20	OSN	*	*			

OSN - The Ohio Seismic Network. GSC - The Geological Survey of Canada. JCU - John Carroll University Seismic Network.
LDEO - Lamont-Doherty Earth Observatory portable instruments. USGS - U.S. Geological Survey

Table 1.

JCU Epirelocator runs 1987

station/phase	arrival time (s)	Δt (s)	diff. time (s)
Run : 1			
890801 16:50			
CHE S	48.46	-10.10	9.90
ECL P	38.70	-9.91	10.09
ECL S	44.54	-10.02	9.98
LER P	37.62	-9.95	10.05
LER S	43.02	-9.81	10.19
MEN P	40.44	-9.71	10.29
MEN S	47.56	-9.99	10.01
TOM P	36.20	-9.96	10.04
TOM S	40.44	-10.14	9.86
Origin Time			10.05
Latitude	Longitude		
41.89	-80.74	RMS: 0.14	

station/phase	arrival time (s)	Δt (s)	diff. time (s)
Run : 2			
890801 16:12			
CHE P	58.98	8.30	8.30
CHE S	66.60	8.04	8.04
ECL P	56.58	7.97	7.97
ECL S	62.60	8.04	8.04
LER P	55.68	8.11	8.11
LER S	60.74	7.91	7.91
MEN P	58.30	8.15	8.15
MEN S	65.52	7.97	7.97
TOM P	54.30	8.14	8.14
TOM S	58.66	8.08	8.08
Origin Time			8.07
Latitude	Longitude		
41.90	-80.75	RMS: 0.12	

station/phase	arrival time (s)	Δt (s)	diff. time (s)
Run : 3			
890803 04:07			
CHE S	66.48	7.92	7.92
ECL P	56.64	8.03	8.03
ECL S	62.34	7.78	7.78
LER P	55.46	7.89	7.89
TOM P	54.18	8.02	8.02
Origin Time			7.93
Latitude	Longitude		
41.90	-80.74	RMS: 0.14	

station/phase	arrival time (s)	Δt (s)	diff. time (s)
Run : 4			
870714 14:51			
CHE P	21.96	-28.76	1.24
CHE S	29.71	-28.85	1.15
ECL P	19.59	-29.02	0.98
ECL S	25.54	-29.02	0.98
LER P	18.59	-28.98	1.02
LER S	24.34	-28.49	1.51
MEN P	21.31	-28.84	1.16
MEN S	28.71	-28.84	1.16
TOM P	17.17	-28.99	1.01
TOM S	21.76	-28.82	1.18
Origin Time			1.14
Latitude	Longitude		
41.89	-80.74	RMS: 0.17	

Table 2.

station/phase	arrival time (s)	Δt (s)	diff. time (s)
Run : 5 870716 06:02			
CHE P	35.86	-14.82	5.18
CHE S	43.17	-15.39	4.61
ECL P	33.31	-15.30	4.70
ECL S	39.16	-15.40	4.60
LER P	32.30	-15.27	4.73
LER S	37.45	-15.38	4.62
MEN P	34.90	-15.25	4.75
MEN S	42.15	-15.40	4.60
TOM P	30.89	-15.27	4.73
TOM S			
Origin Time			4.72
Latitude	Longitude		
41.90	-80.75	RMS: 0.20	

station/phase	arrival time (s)	Δt (s)	diff. time (s)
Run : 6 870713 23:49			
CHE P	24.60	-26.08	3.92
CHE S	32.61	-25.95	4.05
ECL P	22.55	-26.06	3.94
ECL S	28.45	-26.11	3.89
LER P	21.50	-26.07	3.93
LER S	27.00	-25.83	4.17
MEN P	24.01	-26.14	3.86
MEN S	31.43	-26.12	3.88
TOM P	20.10	-26.06	3.94
TOM S	24.44	-26.14	3.86
Origin Time			3.94
Latitude	Longitude		
41.90	-80.75	RMS: 0.11	

station/phase	arrival time (s)	Δt (s)	diff. time (s)
Run : 7 870713 20:53			
CHE S	23.44	-35.12	4.88
ECL P	13.29	-35.32	4.68
ECL S	19.07	-35.49	4.51
LER P	12.36	-35.21	4.79
MEN P	15.17	-34.98	5.02
TOM P	10.95	-35.21	4.79
TOM S	15.22	-35.36	4.64
Origin Time			4.76
Latitude	Longitude		
41.87	-80.71	RMS: 0.06	

station/phase	arrival time (s)	Δt (s)	diff. time (s)
Run : 8 870713 19:39			
CHE P	29.24	-21.44	8.56
CHE S	37.05	-21.51	8.49
ECL P	27.14	-21.47	8.53
ECL S	32.97	-21.59	8.41
LER P	26.17	-21.4	8.60
MEN S	35.96	-21.59	8.41
TOM P	24.77	-21.39	8.61
TOM S	28.98	-21.6	8.40
Origin Time			8.50
Latitude	Longitude		
41.90	-80.75	RMS: 0.10	

Table 2 cont.

JCU Epirelocator runs 1987

station/phase	arrival time (s)	Δt (s)	diff. time (s)
Run : 9			
870713 19:00			
CHE S	26.28	-32.28	7.72
ECL P	16.29	-32.32	7.68
ECL S	22.08	-32.48	7.52
LER P	15.27	-32.30	7.70
MEN P	17.84	-32.31	7.69
MEN S	25.10	-32.45	7.55
TOM P	13.90	-32.26	7.74
TOM S	18.17	-32.41	7.59
Origin Time			7.65
Latitude	Longitude		
41.90	-80.75	RMS: 0.10	

station/phase	arrival time (s)	Δt (s)	diff. time (s)
Run : 10			
870713 18:25			
CHE P	21.71	-28.97	6.03
CHE S	29.66	-28.90	6.10
ECL P	19.80	-28.81	6.19
ECL S	25.60	-28.96	6.04
MEN P	21.35	-28.80	6.20
MEN S	28.70	-28.85	6.15
TOM P	17.32	-32.83	2.17
TOM S	21.76	-28.82	6.18
Origin Time			5.63
Latitude	Longitude		
41.91	-80.73	RMS: 0.19	

station/phase	arrival time (s)	Δt (s)	diff. time (s)
Run : 11			
870713 13:05			
CHE P	33.55	-17.13	2.87
CHE S	41.26	-17.30	2.70
ECL P	31.31	-17.30	2.70
ECL S	37.21	-17.35	2.65
MEN P	32.85	-17.30	2.70
MEN S	40.13	-17.42	2.58
TOM P	28.93	-17.23	2.77
TOM S	33.17	-17.41	2.59
Origin Time			2.70
Latitude	Longitude		
41.90	-80.75	RMS: 0.11	

station/phase	arrival time (s)	Δt (s)	diff. time (s)
Run : 12			
870713 07:52			
CHE P	22.91	-27.77	2.23
CHE S	30.78	-27.78	2.22
ECL P	20.81	-27.80	2.20
ECL S	26.70	-27.86	2.14
MEN P	22.28	-27.87	2.13
MEN S	29.57	-27.98	2.02
TOM P	18.29	-27.87	2.13
TOM S	22.65	-27.93	2.07
Origin Time			2.14
Latitude	Longitude		
41.90	-80.75	RMS: 0.08	

Table 2 cont.

station/phase	arrival time (s)	Δt (s)	diff. time (s)
Run : 13 870713 5:58			
CHE P	62.90	12.22	12.22
CHE S	71.09	12.53	12.53
ECL P	60.32	11.71	11.71
ECL S	66.78	12.22	12.22
LER P	59.72	12.15	12.15
LER S	65.33	12.50	12.50
TOM P	58.21	12.05	12.05
TOM S	62.87	12.29	12.29
Origin Time			12.21
Latitude	Longitude		
41.87	-80.70	RMS: 0.24	

station/phase	arrival time (s)	Δt (s)	diff. time (s)
Run : 14 870713 05:49			
CHE P	29.51	-21.17	8.83
CHE S	37.49	-21.07	8.93
ECL P	27.35	-21.26	8.74
ECL S	33.39	-21.17	8.83
MEN P	28.40	-21.75	8.25
MEN S	36.22	-21.33	8.67
TOM P	24.89	-21.27	8.73
TOM S	29.18	-21.40	8.60
Origin Time			8.70
Latitude	Longitude		
41.91	-80.76	RMS: 0.22	

station/phase	arrival time (s)	Δt (s)	diff. time (s)
Run : 15 870714 07:47			
CHE P	37.27	-13.41	6.59
CHE S	44.95	-13.61	6.39
ECL P	34.98	-13.63	6.37
ECL S	40.80	-13.76	6.24
LER P	33.97	-13.60	6.40
LER S	39.38	-13.45	6.55
MEN P	36.74	-13.41	6.59
MEN S	44.04	-13.51	6.49
TOM P	32.60	-13.56	6.44
TOM S	36.72	-13.86	6.14
Origin Time			6.42
Latitude	Longitude		
41.88	-80.73	RMS: 0.13	

station/phase	arrival time (s)	Δt (s)	diff. time (s)
Run : 16 900101 23:03			
CHE P	15.02	-35.66	4.34
CHE S	22.96	-35.60	4.40
ECL P	12.92	-35.69	4.31
ECL S	18.50	-36.06	3.94
LER P	11.64	-35.93	4.07
LER S	17.70	-35.13	4.87
MEN P	14.16	-35.99	4.01
TOM P	10.26	-35.90	4.10
TOM S	15.42	-35.16	4.84
Origin Time			4.32
Latitude	Longitude		
41.89	-80.73	RMS: 0.38	

Table 2 cont.

JCU Epirelocator runs 1987

station/phase	arrival time (s)	Δt (s)	diff. time (s)
Run : 17 900724 23:04			
CHE P	47.28	-3.40	6.60
CHE S	54.54	-4.02	5.98
			0.00
			0.00
MEN P	46.50	-3.65	6.35
MEN S	53.24	-4.31	5.69
TOM P	42.98	-3.18	6.82
TOM S	47.50	-3.08	6.92
Origin Time			6.39
Latitude	Longitude		
41.98	-80.83	RMS: 0.38	

station/phase	arrival time (s)	Δt (s)	diff. time (s)
Run : 18 900926 06:13			
CHE P	15.30	-35.38	4.62
CHE S	23.92	-34.64	5.36
ECL P	13.24	-35.37	4.63
ECL S	19.92	-34.64	5.36
MEN P	14.58	-35.57	4.43
MEN S	22.68	-34.87	5.13
TOM P	10.94	-35.22	4.78
TOM S	15.68	-34.90	5.10
Origin Time			4.93
Latitude	Longitude		
41.91	-80.76	RMS: 0.39	

station/phase	arrival time (s)	Δt (s)	diff. time (s)
Run : 19 901118 09:20			
CHE P	63.00	12.32	12.32
CHE S	70.88	12.32	12.32
ECL P	60.74	12.13	12.13
ECL S	67.08	12.52	12.52
MEN P	62.62	12.47	12.47
MEN S	69.18	11.63	11.63
TOM P	58.34	12.18	12.18
TOM S	62.90	12.32	12.32
Origin Time			12.24
Latitude	Longitude		
41.92	-80.78	RMS: 0.26	

Table 2 cont.

JCU Epicenter locations for corrected residuals re-run in Epilocator.

Station/phase	arrival time (s)	residual	corrected arrival time (s)
Run : 1 890801 16:50			
CHE S	48.46	-0.15	48.31
ECL P	38.70	0.04	38.74
ECL S	44.54	-0.07	44.47
LER P	37.62	0.00	37.62
LER S	43.02	0.14	43.16
MEN P	40.44	0.24	40.68
MEN S	47.56	-0.02	47.54
TOM P	36.20	-0.01	36.19
TOM S	40.44	-0.19	40.25
			corrected lat/long
	RMS: 0.24		41.88 -80.72

Station/phase	arrival time (s)	residual	corrected arrival time (s)
Run : 2 890801 16:12			
CHE P	58.98	0.23	59.21
CHE S	66.60	-0.03	66.57
ECL P	56.58	-0.10	56.48
ECL S	62.60	-0.03	62.57
LER P	55.68	0.04	55.72
LER S	60.74	-0.16	60.58
MEN P	58.30	0.08	58.38
MEN S	65.52	-0.10	65.42
TOM P	54.30	0.07	54.37
TOM S	58.66	0.01	58.67
			corrected lat/long
	RMS: 0.19		41.91 -80.74

Station/phase	arrival time (s)	residual	corrected arrival time (s)
Run : 3 890803 04:07			
CHE S	66.48	-0.01	66.47
ECL P	56.64	0.10	56.74
ECL S	62.34	-0.15	62.19
LER P	55.46	-0.04	55.42
TOM P	54.18	0.09	54.27
			corrected lat/long
	RMS: 0.21		41.89 -80.74

Station/phase	arrival time (s)	residual	corrected arrival time (s)
Run : 4 870714 14:51			
CHE P	21.96	0.10	22.06
CHE S	29.71	0.01	29.72
ECL P	19.59	-0.16	19.43
ECL S	25.54	-0.16	25.38
LER P	18.59	-0.12	18.47
LER S	24.34	0.37	24.71
MEN P	21.31	0.02	21.33
MEN S	28.71	0.02	28.73
TOM P	17.17	-0.13	17.04
TOM S	21.76	0.04	21.80
			corrected lat/long
	RMS: 0.31		41.89 -80.69

Table 3.

JCU Epicenter locations for corrected residuals re-run in Epilocator.

Station/phase	arrival time (s)	residual	corrected arrival time (s)
Run : 5 870716 06:02			
CHE P	35.86	0.46	36.32
CHE S	43.17	-0.11	43.06
ECL P	33.31	-0.02	33.29
ECL S	39.16	-0.12	39.04
LER P	32.30	0.01	32.31
LER S	37.45	-0.10	37.35
MEN P	34.90	0.03	34.93
MEN S	42.15	-0.12	42.03
TOM P	30.89	0.01	30.90
TOM S			
			corrected lat/long
	RMS: 0.25		41.89 -80.74

Station/phase	arrival time (s)	residual	corrected arrival time (s)
Run : 6 870713 23:49			
CHE P	24.60	-0.02	24.58
CHE S	32.61	0.11	32.72
ECL P	22.55	0.00	22.55
ECL S	28.45	-0.05	28.40
LER P	21.50	-0.01	21.49
LER S	27.00	0.23	27.23
MEN P	24.01	-0.08	23.93
MEN S	31.43	-0.06	31.37
TOM P	20.10	0.00	20.10
TOM S	24.44	-0.08	24.36
			corrected lat/long
	RMS: 0.16		41.91 -80.72

Station/phase	arrival time (s)	residual	corrected arrival time (s)
Run : 7 870713 20:53			
CHE P			
CHE S	23.44	0.12	23.56
ECL P	13.29	-0.08	13.21
ECL S	19.07	-0.25	18.82
LER P	12.36	0.03	12.39
MEN P	15.17	0.26	15.43
TOM P	10.95	0.03	10.98
TOM S	15.22	-0.12	15.10
			corrected lat/long
	RMS: 0.40		41.85 -80.74

Station/phase	arrival time (s)	residual	corrected arrival time (s)
Run : 8 870713 19:39			
CHE P	29.24	0.06	29.30
CHE S	37.05	-0.01	37.04
ECL P	27.14	0.03	27.17
ECL S	32.97	-0.09	32.88
LER P	26.17	0.10	26.27
MEN S	35.96	-0.09	35.87
TOM P	24.77	0.11	24.88
TOM S	28.98	-0.10	28.88
			corrected lat/long
	RMS: 0.16		41.90 -80.74

Table 3 cont.

JCU Epicenter locations for corrected residuals re-run in Epilocator.

Station/phase	arrival time (s)	residual	corrected arrival time (s)
Run : 9 870713 19:00			
CHE S	26.28	0.07	26.35
ECL P	16.29	0.03	16.32
ECL S	22.08	-0.13	21.95
LER P	15.27	0.05	15.32
MEN P	17.84	0.04	17.88
MEN S	25.10	-0.10	25.00
TOM P	13.90	0.09	13.99
TOM S	18.17	-0.06	18.11
			corrected lat/long
	RMS: 0.16		41.92 -80.75

Station/phase	arrival time (s)	residual	corrected arrival time (s)
Run : 10 870713 18:25			
CHE P	21.71	0.40	22.11
CHE S	29.66	0.47	30.13
ECL P	19.80	0.56	20.36
ECL S	25.60	0.41	26.01
MEN P	21.35	0.57	21.92
MEN S	28.70	0.52	29.22
TOM P	17.32	0.53	17.85
TOM S	21.76	0.55	22.31
			corrected lat/long
	RMS: 0.28		41.91 -80.72

Station/phase	arrival time (s)	residual	corrected arrival time (s)
Run : 11 870713 13:05			
CHE P	33.55	0.17	33.72
CHE S	41.26	0.00	41.26
ECL P	31.31	0.00	31.31
ECL S	37.21	-0.05	37.16
MEN P	32.85	0.00	32.85
MEN S	40.13	-0.12	40.01
TOM P	28.93	0.07	29.00
TOM S	33.17	-0.11	33.06
			corrected lat/long
	RMS: 0.17		41.91 -80.75

Station/phase	arrival time (s)	residual	corrected arrival time (s)
Run : 12 870713 07:52			
CHE P	22.91	0.09	23.00
CHE S	30.78	0.08	30.86
ECL P	20.81	0.06	20.87
ECL S	26.70	0.00	26.70
MEN P	22.28	-0.01	22.27
MEN S	29.57	-0.12	29.45
TOM P	18.29	-0.01	18.28
TOM S	22.65	-0.07	22.58
			corrected lat/long
	RMS: 0.21		41.91 -80.75

Table 3 cont.

JCU Epicenter locations for corrected residuals re-run in Epilocator.

Station/phase	arrival time (s)	residual	corrected arrival time (s)
Run : 13 870713 5:58			
CHE P	62.90	0.01	62.91
CHE S	71.09	0.32	71.41
ECL P	60.32	-0.50	59.82
ECL S	66.78	0.01	66.79
LER P	59.72	-0.06	59.66
LER S	65.33	0.29	65.62
TOM P	58.21	-0.16	58.05
TOM S	62.87	0.08	62.95
			corrected lat/long
	RMS: 0.19		41.87 -80.59

Station/phase	arrival time (s)	residual	corrected arrival time (s)
Run : 14 870713 05:49			
CHE P	29.51	0.13	29.64
CHE S	37.49	0.23	37.72
ECL P	27.35	0.04	27.39
ECL S	33.39	0.13	33.52
MEN P	28.40	-0.45	27.95
MEN S	36.22	-0.03	36.19
TOM P	24.89	0.03	24.92
TOM S	29.18	-0.10	29.08
			corrected lat/long
	RMS: 0.40		41.96 -80.73

Station/phase	arrival time (s)	residual	corrected arrival time (s)
Run : 15 870714 07:47			
CHE P	37.27	0.17	37.44
CHE S	44.95	-0.03	44.92
ECL P	34.98	-0.05	34.93
ECL S	40.80	-0.18	40.62
LER P	33.97	-0.02	33.95
LER S	39.38	0.13	39.51
MEN P	36.74	0.17	36.91
MEN S	44.04	0.07	44.11
TOM P	32.60	0.02	32.62
TOM S	36.72	-0.28	36.44
			corrected lat/long
	RMS: 0.15		41.87 -80.70

Station/phase	arrival time (s)	residual	corrected arrival time (s)
Run : 16 900101 23:03			
CHE P	15.02	0.02	15.04
CHE S	22.96	0.08	23.04
ECL P	12.92	-0.01	12.91
ECL S	18.50	-0.38	18.12
LER P	11.64	-0.25	11.39
LER S	17.70	0.55	18.25
MEN P	14.16	-0.31	13.85
TOM P	10.26	-0.22	10.04
TOM S	15.42	0.52	15.94
			corrected lat/long
	RMS: 0.66		41.89 -80.60

Table 3 cont.

JCU Epicenter locations for corrected residuals re-run in Epilocator.

Station/phase	arrival time (s)	residual	corrected arrival time (s)
Run : 17 900724 23:04			
CHE P	47.28	0.21	47.49
CHE S	54.54	-0.41	54.13
MEN P	46.50	-0.04	46.46
MEN S	53.24	-0.70	52.54
TOM P	42.98	0.43	43.41
TOM S	47.50	0.53	48.03
			corrected lat/long
	RMS: 0.38		42.00 -80.94

Station/phase	arrival time (s)	residual	corrected arrival time (s)
Run : 18 900926 06:13			
CHE P	15.30	-0.31	14.99
CHE S	23.92	0.43	24.35
ECL P	13.24	-0.30	12.94
ECL S	19.92	0.43	20.35
MEN P	14.58	-0.50	14.08
MEN S	22.68	0.20	22.88
TOM P	10.94	-0.15	10.79
TOM S	15.68	0.17	15.85
			corrected lat/long
	RMS: 0.35		41.99 -80.67

Station/phase	arrival time (s)	residual	corrected arrival time (s)
Run : 19 901118 09:20			
CHE P	63.00	0.08	63.08
CHE S	70.88	0.08	70.96
ECL P	60.74	-0.11	60.63
ECL S	67.08	0.28	67.36
MEN P	62.62	0.23	62.85
MEN S	69.18	-0.61	68.57
TOM P	58.34	-0.06	58.28
TOM S	62.90	0.08	62.98
			corrected lat/long
	RMS: 0.48		41.96 -80.79

Table 3 cont.

GSC Epicenter locations 1987 from DD-method

Station/phase	arrival time (s)	Δt (s)	diff. time (s)
Run : 2G 870713 13:05			
LDN P	44.28	-17.12	2.88
LDN S	60.08	-16.72	3.28
ELF P	47.08	-17.11	2.89
ELF S	65.12	-17.32	2.68
WEO P	70.52	-17.09	2.91
WEO S	108.22	-9.33	10.67
Origin Time			4.22
Latitude	Longitude		
41.97	-80.67	RMS: 0.62	

Station/phase	arrival time (s)	Δt (s)	diff. time (s)
Run : 3G 870713 07:52			
DLA P			
DLA S			
LDN P	Too	Few	Stations
LDN S			
ELF P			
ELF S			
WEO P	56.50	-31.11	8.89
WEO S	96.37	-21.18	18.82
Origin Time			13.85
Latitude	Longitude		
		RMS:	

Station/phase	arrival time (s)	Δt (s)	diff. time (s)
Run : 4G 870713 05:49			
LDN P	40.28	-21.12	8.88
LDN S	55.80	-21.00	9.00
ELF P	43.08	-21.11	8.89
ELF S	60.00	-22.44	7.56
WEO P	63.03	-24.58	5.42
Origin Time			7.95
Latitude	Longitude		
41.95	-80.45	RMS: 1.04	

Table 4.

GSC Epicenter locations (2001) from DD-method

Station/phase	arrival time (s)	Δ t (s)	diff. time (s)
Run: 1G 010605 08:27			
TYNO Pg	41.18	-30.40	4.60
TYNO Sg	58.94	-31.47	3.53
RD03 Pg	43.48	-29.02	
RD03 Sg	61.65	-29.75	5.25
RD04 Pg	42.74	-30.83	4.17
RD04 Sg	62.47	-30.78	4.22
RD02 Sg	64.92	-30.43	4.57
STCO Sn	71.09	-29.69	5.31
ACTO Sg	72.25	-30.62	4.38
BRCO Sg	89.35	-31.53	3.47
Origin Time			4.39
Latitude	Longitude		
41.88	-80.81	RMS: 0.50	

Station/phase	arrival time (s)	Δ t (s)	diff. time (s)
Run: 2G 010126 05:36			
TYNO Pg	76.32	4.74	4.74
TYNO Sg	95.22	4.81	4.81
RD03 Pg	77.13	4.63	4.63
RD03 Sg	95.84	4.44	4.44
EFO Pg	80.34	4.69	4.69
EFO Sg	100.00	3.78	3.78
STCO Pn	82.93	4.72	4.72
STCO Sn	105.67	4.89	4.89
ACTO Pn	83.60	4.62	4.62
ACTO Sg	107.74	4.87	4.87
BRCO Sg	124.98	4.10	4.10
Origin Time			4.57
Latitude	Longitude		
41.86	-80.77	RMS: 0.38	

Station/phase	arrival time (s)	Δ t (s)	diff. time (s)
Run: 3G 010126 05:11			
TYNO Sg	48.58	-41.83	3.17
RD03 Pg			
RD03 Sg	50.28	-41.12	3.88
RD04 Pg			
RD04 Sg	51.80	-41.45	3.55
RD02 Sg	53.37	-41.98	3.02
EFO Pg	33.77	-41.88	3.12
EFO Sg	55.14	-41.08	3.92
RD01 Pg	35.31	-41.31	3.69
RD01 Sg	57.00	-41.50	3.50
STCO Sn	60.32	-40.46	4.54
ACTO Pn	37.45	-41.53	3.47
ACTO Sg	60.56	-42.31	2.69
BRCO Sg	78.66	-42.22	2.78
Origin Time			3.44
Latitude	Longitude		
41.87	-80.80	RMS: 0.46	

Station/phase	arrival time (s)	Δ t (s)	diff. time (s)
Run: 4G 010126 03:45			
TYNO Sg	66.99	-23.42	1.58
RD03 Sg	68.92	-22.48	2.52
RD04 Sg	70.37	-22.88	2.12
RD02 Sg	73.47	-21.88	3.12
EFO Pg	53.08	-22.57	2.43
EFO Sg	73.79	-22.43	2.57
RD01 Sg	77.02	-21.48	3.52
BRCO Sg	98.17	-22.71	2.29
Origin Time			2.52
Latitude	Longitude		
41.86	-80.77	RMS: 0.70	

Table 5.

GSC Epicenter locations (2001) from DD-method

Station/phase	arrival time (s)	Δ t (s)	diff. time (s)
Run: 5G			
010126 03:11			
TYNO Pg	53.45	-18.13	1.87
TYNO Sg	73.10	-17.31	2.69
RD03 Pg	54.94	-17.56	2.44
RD03 Sg	74.22	-17.18	2.82
RD04 Pg	57.87	-15.70	4.30
RD04 Sg	75.48	-17.77	2.23
EFO Pg	57.94	-17.71	2.29
EFO Sg	79.78	-16.44	3.56
STCO Sn	84.63	-16.15	3.85
BRCO Sg	103.38	-17.50	2.50
Origin Time			2.86
Latitude	Longitude		
41.86	-80.78	RMS: 0.88	

Station/phase	arrival time (s)	Δ t (s)	diff. time (s)
Run: 6G			
010126 03:03			
TYNO Pg	45.99	-25.59	4.41
TYNO Sg	64.89	-25.52	4.48
RD03 Pg	47.05	-25.45	4.55
RD03 Sg	66.11	-25.29	4.71
RD04 Pg	47.92	-25.65	4.35
RD04 Sg	67.57	-25.68	4.32
RD02 Pg	49.25	-25.64	4.36
RD02 Sg	69.61	-25.74	4.26
EFO Sg	71.09	-25.13	4.87
RD01 Pg	50.96	-25.66	4.34
RD01 Sg	72.54	-25.96	4.04
STCO Pn	52.68	-25.53	4.47
STCO Sn	75.75	-25.03	4.97
ACTO Pn	53.35	-25.63	4.37
BRCO Sg	94.65	-26.23	3.77
Origin Time			4.42
Latitude	Longitude		
41.87	-80.77	RMS: 0.22	

Station/phase	arrival time (s)	Δ t (s)	diff. time (s)
Run: 7G			
010120 02:05			
RD03 Pg	33.21	-39.29	5.71
RD03 Sg	52.94	-38.46	6.54
RD04 Pg	34.18	-39.39	5.61
RD04 Sg	54.24	-39.01	5.99
RD02 Pg	36.11	-38.78	6.22
RD02 Sg	56.71	-38.64	6.36
EFO Pg	36.85	-38.80	6.20
EFO Sg	58.16	-38.06	6.94
RD01 Pg	38.35	-38.27	6.73
RD01 Sg	59.91	-38.59	6.41
STCO Pn	39.61	-38.60	6.40
ACTO Pn	39.95	-39.03	5.97
ACTO Sg	63.98	-38.89	6.11
BRCO Sg	81.44	-39.44	5.56
Origin Time			6.19
Latitude	Longitude		
41.86	-80.79	RMS: 0.40	

Station/phase	arrival time (s)	Δ t (s)	diff. time (s)
Run: 8G			
920315 06:13			
DLA Pg	75.59	16.13	16.13
LDN Pg	78.99	17.59	17.59
LDN Sg	95.00	18.20	18.20
ELF Pg	81.19	17.00	17.00
ELF Sg	99.60	17.16	17.16
WEO P	104.40	16.79	16.79
WEO S	141.20	23.65	23.65
Origin Time			17.15
Latitude	Longitude		
41.89	-80.76	RMS: 0.86	

Table 5 cont.

GSC 1987 Epicenter locations for corrected residuals re-run in Epilocator

Station/phase	arrival time (s)	residual	corrected arrival time (s)
Run : 2G 870713 13:05			
DLA P			
DLA S			
LDN P	44.28	-1.34	42.94
LDN S	60.08	-0.94	59.14
ELF P	47.08	-1.33	45.75
ELF S	65.12	-1.54	63.58
WEO P	70.52	-1.31	69.21
WEO S	108.22		
			corrected latt/long
	RMS: 0.32		41.82 -81.00

Station/phase	arrival time (s)	residual	corrected arrival time (s)
Run : 3G 870713 07:52			
DLA P			
DLA S			
LDN P	Too few stations.		
LDN S			
ELF P			
ELF S			
WEO P	56.50		
WEO S	96.37		
			corrected latt/long
			n/a

Station/phase	arrival time (s)	residual	corrected arrival time (s)
Run : 4G 870713 05:49			
DLA P			
DLA S			
LDN P	40.28	0.93	41.21
LDN S	55.80	1.05	56.85
ELF P	43.08	0.94	44.02
ELF S	60.00	-0.39	59.61
WEO P	63.03	-2.53	60.50
WEO S			
			corrected latt/long
	RMS: 0.18		42.17 -80.21

Table 6.

Station/phase	arrival time (s)	residual	corrected arrival time (s)
Run: 1G 010605 08:27			
TYNO Pg	41.18	0.05	41.23
TYNO Sg	58.94	-1.02	57.92
RD04 Pg	42.74	-0.38	42.36
RD04 Sg	62.47	-0.33	62.14
RD02 Pg			
RD02 Sg	64.92	0.02	64.94
EFO Pg			
EFO Sg			
RD01 Pg			
RD01 Sg			
STCO Pn			
STCO Sn	71.09	0.76	71.85
ACTO Pn			
BRCO Pg			
BRCO Sg	89.35	-1.08	88.27

RMS: 0.06

corrected lat/long
41.94 -80.90

Station/phase	arrival time (s)	residual	corrected arrival time (s)
Run: 2G 010126 05:36			
TYNO Pg	76.32	0.17	76.49
TYNO Sg	95.22	0.24	95.46
RD03 Pg	77.13	0.06	77.19
RD03 Sg	95.84	-0.13	95.71
EFO Pg	80.34	0.12	80.46
EFO Sg	100.00	-0.79	99.21
STCO Pn	82.93	0.15	83.08
STCO Sn	105.67	0.32	105.99
ACTO Pn	83.60	0.05	83.65
ACTO Sg	107.74	0.30	108.04
BRCO Sg	124.98	-0.47	124.51

RMS: 0.33

corrected lat/long
41.92 -80.82

Station/phase	arrival time (s)	residual	corrected arrival time (s)
Run: 3G 010126 05:11			
TYNO Sg	48.58	-0.27	48.31
RD03 Sg	50.28	0.44	50.72
RD04 Sg	51.80	0.11	51.91
RD02 Sg	53.37	-0.42	52.95
EFO Pg	33.77	-0.32	33.45
EFO Sg	55.14	0.48	55.62
RD01 Pg	35.31	0.25	35.56
RD01 Sg	57.00	0.06	57.06
STCO Sn	60.32	1.10	61.42
ACTO Pn	37.45	0.03	37.48
ACTO Sg	60.56	-0.75	59.81
BRCO Sg	78.66	-0.66	78.00

RMS: 0.74

corrected lat/long
41.91 -80.89

Station/phase	arrival time (s)	residual	corrected arrival time (s)
Run: 4G 010126 03:45			
TYNO Sg	66.99	-0.94	66.05
RD03 Sg	68.92	0.00	68.92
RD04 Sg	70.37	-0.40	69.97
RD02 Sg	73.47	0.60	74.07
EFO Pg	53.08	-0.09	52.99
EFO Sg	73.79	0.05	73.84
RD01 Sg	77.02	1.00	78.02
BRCO Sg	98.17	-0.23	97.94

RMS: 0.55

corrected lat/long
41.90 -80.79

Table 7.

Station/phase	arrival time (s)	residual	corrected arrival time (s)
Run: 5G 010126 03:11			
TYNO Pg	53.45	-0.99	52.46
TYNO Sg	73.10	-0.17	72.93
RD03 Pg	54.94	-0.42	54.52
RD03 Sg	74.22	-0.04	74.18
RD04 Pg	57.87	1.44	59.31
RD04 Sg	75.48	-0.63	74.85
EFO Pg	57.94	-0.57	57.37
EFO Sg	79.78	0.7	80.48
STCO Sn	84.63	0.99	85.62
BRCO Sg	103.38	-0.36	103.02
			corrected lat/long
	RMS: 0.61		41.90 -80.88

Station/phase	arrival time (s)	residual	corrected arrival time (s)
Run: 6G 010126 03:03			
TYNO Pg	45.99	-0.01	45.98
TYNO Sg	64.89	0.06	64.95
RD03 Pg	47.05	0.13	47.18
RD03 Sg	66.11	0.29	66.40
RD04 Pg	47.92	-0.07	47.85
RD04 Sg	67.57	-0.1	67.47
RD02 Pg	49.25	-0.06	49.19
RD02 Sg	69.61	-0.16	69.45
EFO Sg	71.09	0.45	71.54
RD01 Pg	50.96	-0.08	50.88
RD01 Sg	72.54	-0.38	72.16
STCO Pn	52.68	0.05	52.73
STCO Sn	75.75	0.55	76.30
ACTO Pn	53.35	-0.05	53.30
BRCO Sg	94.65	-0.65	94.00
			corrected lat/long
	RMS: 0.28		41.93 -80.86

Station/phase	arrival time (s)	residual	corrected arrival time (s)
Run: 7G 010120 02:05			
RD03 Pg	33.21	0.07	33.28
RD03 Sg	52.94	0.9	53.84
RD04 Pg	34.18	-0.03	34.15
RD04 Sg	54.24	0.35	54.59
RD02 Pg	36.11	0.58	36.69
RD02 Sg	56.71	0.72	57.43
EFO Pg	36.85	0.56	37.41
EFO Sg	58.16	1.3	59.46
RD01 Pg	38.35	1.09	39.44
RD01 Sg	59.91	0.77	60.68
STCO Pn	39.61	0.76	40.37
ACTO Pn	39.95	0.33	40.28
ACTO Sg	63.98	0.47	64.45
BRCO Sg	81.44	-0.08	81.36
			corrected lat/long
	RMS: 0.48		41.86 -80.90

Table 7 cont.

Epicenter locations for each earthquake determined by each network showing original locations, relocations, and corrected residual locations.

	870713 05:49		870713 05:58		870713 07:52		870713 13:05	
	latitude	longitude	latitude	longitude	latitude	longitude	latitude	longitude
GSC orig	41.93	-80.71					41.93	-80.71
GSC reloc	41.95	-80.45					41.97	-80.67
GSC loc	42.17	-80.21					41.82	-81.00
[redacted]								
JCU orig	41.90	-80.78	41.87	-80.74	41.89	-80.75	41.89	-80.76
JCU reloc	41.91	-80.76	41.87	-80.70	41.90	-80.75	41.90	-80.75
JCU loc	41.96	-80.73	41.87	-80.59	41.91	-80.75	41.91	-80.75
[redacted]								
LDEO orig								

	870713 18:25		870713 19:00		870713 19:39		870713 20:53	
	latitude	longitude	latitude	longitude	latitude	longitude	latitude	longitude
GSC orig								
GSC reloc								
GSC loc								
[redacted]								
JCU orig	41.88	-80.75	41.88	-80.75	41.88	-80.75	41.85	-80.71
JCU reloc	41.91	-80.73	41.90	-80.75	41.90	-80.75	41.87	-80.71
JCU loc	41.91	-80.72	41.92	-80.75	41.90	-80.74	41.85	-80.74
[redacted]								
LDEO orig								

Table 8.

Epicenter locations for each earthquake determined by each network showing original locations, relocations, and corrected residual locations.

	870713 23:49		870714 07:47		870714 14:51		870716 04:49	
	latitude	longitude	latitude	longitude	latitude	longitude	latitude	longitude
GSC orig							41.93	-80.71
GSC reloc								
GSC loc							Master Earthquake	
[redacted]								
JCU orig	41.90	-80.75	41.87	-80.74	41.88	-80.73	41.90	-80.75
JCU reloc	41.90	-80.75	41.88	-80.73	41.89	-80.74	41.90	-80.75
JCU loc	41.91	-80.72	41.87	-80.70	41.89	-80.69	41.90	-80.75
[redacted]								
LDEO orig							41.90	-80.75

	870716 06:02		890801 16:12		890801 16:50		890803 04:07	
	latitude	longitude	latitude	longitude	latitude	longitude	latitude	longitude
GSC orig								
GSC reloc								
GSC loc								
[redacted]								
JCU orig	41.88	-80.75	41.88	-80.75	41.89	-80.75	41.90	-80.76
JCU reloc	41.90	-80.75	41.90	-80.75	41.89	-80.74	41.90	-80.74
JCU loc	41.89	-80.74	41.91	-80.74	41.88	-80.72	41.89	-80.74
[redacted]								
LDEO orig								

Table 8 cont.

Epicenter locations for each earthquake determined by each network showing original locations, relocations, and corrected residual locations.

	900101 23:03		900724 23:04		900926 06:13		901118 09:20	
	latitude	longitude	latitude	longitude	latitude	longitude	latitude	longitude
GSC orig								
GSC reloc								
GSC loc								
[redacted]								
JCU orig	41.96	-80.84	41.92	-80.85	41.92	-80.72	41.92	-80.77
JCU reloc	41.89	-80.73	41.98	-80.83	41.91	-80.76	41.92	-80.78
JCU loc	41.89	-80.60	42.00	-80.94	41.99	-80.67	41.96	-80.79
[redacted]								
LDEO orig								

	920326 03:43		920328 08:22		950223 09:32		950409 11:37	
	latitude	longitude	latitude	longitude	latitude	longitude	latitude	longitude
GSC orig	42.11	-80.84	41.92	-80.81	41.86	-80.83	41.98	-80.69
GSC reloc								
GSC loc								
[redacted]								
JCU orig								
JCU reloc								
JCU loc								
[redacted]								
LDEO orig								

Table 8 cont.

Epicenter locations for each earthquake determined by each network showing original locations, relocations, and corrected residual locations.

	010120 02:05		010126 03:03		010126 03:11		010126 03:45	
	latitude	longitude	latitude	longitude	latitude	longitude	latitude	longitude
GSC orig	41.88	-80.77	41.93	-80.72	41.93	-80.72	41.93	-80.72
GSC reloc	41.85	-80.83	41.87	-80.77	41.86	-80.78	41.86	-80.77
GSC loc	41.86	-80.90	41.93	-80.86	41.90	-80.88	41.90	-80.79
[redacted]								
JCU orig								
JCU reloc								
JCU loc								
[redacted]								
LDEO orig								

	010126 05:11		010126 05:36		010603 22:36		010605 08:27	
	latitude	longitude	latitude	longitude	latitude	longitude	latitude	longitude
GSC orig	41.93	-80.72	41.97	-80.69	41.87	-80.75	41.88	-80.76
GSC reloc	41.87	-80.80	41.86	-80.77			41.88	-80.80
GSC loc	41.91	-80.89	41.92	-80.82			41.94	-80.90
[redacted]								
JCU orig					Master Earthquake			
JCU reloc								
JCU loc								
[redacted]								
LDEO orig					41.87	-80.77		

Table 8 cont.

Epicenter locations for each earthquake determined by each network showing original locations, relocations, and corrected residual locations.

	920315 06:13	
	latitude	longitude
GSC orig	41.81	-81.22
GSC reloc	41.89	-80.76
GSC loc		

Table 8 cont.

Letter designations for each earthquake

Date/Time	Latitude	Longitude	Network	Letter
870713 05:49	41.93	-80.71	GSC orig	A
870713 05:49	41.95	-80.45	GSC reloc	A
870713 13:05	41.93	-80.71	GSC orig	D
870713 13:05	41.97	-80.67	GSC reloc	D
870716 04:49	41.90	-80.75	Master	
010120 02:05	41.88	-80.77	GSC orig	C
010120 02:05	41.85	-80.83	GSC reloc	C
010126 03:03	41.93	-80.72	GSC orig	K
010126 03:03	41.87	-80.77	GSC reloc	K
010126 03:11	41.93	-80.72	GSC orig	E
010126 03:11	41.86	-80.78	GSC reloc	E
010126 03:45	41.93	-80.72	GSC orig	F
010126 03:45	41.86	-80.77	GSC reloc	F
010126 05:11	41.93	-80.72	GSC orig	G
010126 05:11	41.87	-80.80	GSC reloc	G
010126 05:36	41.97	-80.69	GSC orig	H
010126 05:36	41.86	-80.77	GSC reloc	H
010603 22:36	41.87	-80.77	Master	
010605 08:27	41.88	-80.76	GSC orig	I
010605 08:27	41.88	-80.80	GSC reloc	I

Table 9.

Letter designations for each earthquake

Date/Time	Latitude	Longitude	Network	Letter
920315 06:13	41.81	-81.22	GSC orig	J
920315 06:13	41.89	-80.76	GSC reloc	J
870713 05:49	41.90	-80.78	JCU orig	A
870713 05:49	41.91	-80.76	JCU reloc	A
870713 05:58	41.87	-80.74	JCU orig	B
870713 05:58	41.87	-80.70	JCU reloc	B
870713 07:52	41.89	-80.75	JCU orig	C
870713 07:52	41.90	-80.75	JCU reloc	C
870713 13:05	41.89	-80.76	JCU orig	D
870713 13:05	41.90	-80.75	JCU reloc	D
870713 18:25	41.88	-80.75	JCU orig	E
870713 18:25	41.91	-80.73	JCU reloc	E
870713 19:00	41.88	-80.75	JCU orig	F
870713 19:00	41.90	-80.75	JCU reloc	F
870713 19:39	41.88	-80.75	JCU orig	G
870713 19:39	41.90	-80.75	JCU reloc	G
870713 20:53	41.85	-80.71	JCU orig	H
870713 20:53	41.87	-80.71	JCU reloc	H
870713 23:49	41.90	-80.75	JCU orig	I
870713 23:49	41.90	-80.75	JCU reloc	I
870714 07:47	41.87	-80.74	JCU orig	J
870714 07:47	41.88	-80.73	JCU reloc	J

Table 9 cont.

Letter designations for each earthquake

Date/Time	Latitude	Longitude	Network	Letter
870714 14:51	41.88	-80.73	JCU orig	K
870714 14:51	41.89	-80.74	JCU reloc	K
870716 04:49	41.90	-80.75	JCU orig	L
870716 04:49	41.90	-80.75	JCU reloc	L
870716 06:02	41.88	-80.75	JCU orig	M
870716 06:02	41.90	-80.75	JCU reloc	M
890801 16:12	41.88	-80.75	JCU orig	N
890801 16:12	41.90	-80.75	JCU reloc	N
890801 16:50	41.89	-80.75	JCU orig	O
890801 16:50	41.89	-80.74	JCU reloc	O
890803 04:07	41.90	-80.76	JCU orig	P
890803 04:07	41.90	-80.74	JCU reloc	P
900101 23:03	41.96	-80.84	JCU orig	Q
900101 23:03	41.89	-80.73	JCU reloc	Q
900724 23:04	41.92	-80.85	JCU orig	R
900724 23:04	41.98	-80.83	JCU reloc	R
900926 06:13	41.92	-80.72	JCU orig	S
900926 06:13	41.91	-80.76	JCU reloc	S
901118 09:20	41.92	-80.77	JCU orig	T
901118 09:20	41.92	-80.78	JCU reloc	T

Table 9 cont.

Epicentral locations as determined by the LDEO portable instruments.

Yr mo da	origin	lat. N	lon. W	depth	rms.	erh	erz	gap	xmag	fmag
87- 7-14	1451 11.30	41 54.19	80 44.92	1.95	0.01	0.69	31.61	260		
87- 7-14	1524 20.52	41 54.13	80 45.08	2.29	0.00	0.60	1.58	262		
87- 7-15	736 26.09	41 54.00	80 44.74	3.40	0.01	1.80	1.25	52		
87- 7-15	911 10.21	41 54.15	80 45.33	1.93	0.01	0.73	31.61	269		
87- 7-15	921 44.49	41 54.11	80 45.07	1.91	0.00	0.67	31.61	262		
87- 7-15	930 53.22	41 55.00	80 44.49	4.82	0.46	5.46	31.61	272		
87- 7-15	17 2 34.57	41 54.24	80 44.49	1.91	0.01	0.79	31.61	249		
87- 7-16	449 40.20	41 54.16	80 44.46	2.58	0.01	0.14	0.88	157		
87- 7-16	453 32.88	41 54.26	80 44.63	1.99	0.04	0.23	31.61	165		
87- 7-16	453 46.10	41 54.13	80 44.44	2.57	0.01	0.15	0.90	155		
87- 7-16	519 16.84	41 54.11	80 44.37	2.00	0.01	0.15	31.61	153		
87- 7-16	536 59.35	41 54.11	80 44.22	1.73	0.01	0.13	0.09	151		
87- 7-16	556 38.65	41 54.09	80 44.52	2.78	0.01	0.15	0.88	154		
87- 7-16	622 4.93	41 54.04	80 44.17	2.00	0.00	0.14	31.61	146		
87- 7-16	6 4 21.18	41 54.12	80 44.27	2.42	0.01	0.14	0.83	153		
87- 7-16	636 18.60	41 54.13	80 44.59	2.67	0.01	0.15	0.89	158		
87- 7-16	719 37.91	41 54.12	80 44.21	2.55	0.01	0.15	0.87	152		
87- 7-16	720 11.27	41 54.14	80 44.19	1.78	0.00	0.13	0.09	153		
87- 7-16	918 17.42	41 54.16	80 44.20	2.02	0.09	0.47	31.61	154		
87- 7-16	921 17.69	41 54.13	80 44.36	2.92	0.00	0.15	0.83	154		

Table 10.

Yr mo da	origin	lat. N	lon. W	depth	rms.	erh erz gapxmagfmag
87- 7-16	1143 7.51	41 54.11	80 44.45	1.82	0.01	0.13 31.61 155
87- 7-16	1554 50.51	41 54.17	80 44.47	2.00	0.01	0.14 31.61 158
87- 7-16	1836 8.85	41 54.16	80 44.59	3.26	0.01	0.17 0.88 158
87- 7-16	1911 43.74	41 54.18	80 44.54	2.60	0.00	0.38 0.90 253
87- 7-17	4 6 1.29	41 54.10	80 44.81	2.75	0.01	0.14 0.85 158
87- 7-17	4 6 10.95	41 54.11	80 44.71	3.10	0.01	0.16 0.88 157
87- 7-17	4 6 20.88	41 54.11	80 44.79	2.82	0.01	0.14 0.84 158
87- 7-17	633 25.10	41 54.15	80 44.35	3.26	0.01	0.18 0.82 156
87- 7-17	648 48.45	41 54.11	80 44.40	3.20	0.01	0.17 0.91 154
87- 7-17	923 42.44	41 54.09	80 44.48	3.38	0.01	0.17 0.85 154
87- 7-17	949 35.31	41 54.09	80 44.54	3.34	0.01	0.16 0.85 154
87- 7-17	2354 15.98	41 54.16	80 44.58	2.83	0.01	0.15 0.87 158
87- 7-18	139 41.35	41 54.10	80 44.76	1.77	0.01	0.22 0.08 157
87- 7-18	158 46.21	41 54.12	80 44.72	2.73	0.01	0.14 0.88 157
87- 7-18	626 15.22	41 54.17	80 44.77	2.54	0.01	0.17 0.91 161
87- 7-19	6 2 39.47	41 54.04	80 45.27	2.84	0.01	0.20 0.81 158
87- 7-19	1515 41.58	41 54.12	80 44.90	2.48	0.00	0.24 0.80 219
87- 7-19	1540 0.16	41 54.09	80 44.47	2.52	0.01	0.14 0.82 153
87- 7-19	2124 15.00	41 54.22	80 44.71	1.86	0.02	0.16 31.61 164
87- 7-19	2137 22.43	41 54.13	80 44.57	1.75	0.01	0.16 0.08 157

Table 10 cont.

Yr mo da	origin	lat. N	lon. W	depth	rms.	erh	erz	gap	xmag	fmag
87- 7-19	2138 47.77	41 54.11	80 44.61	2.45	0.01	0.14	0.98	156		
87- 7-19	2224 0.07	41 54.13	80 44.53	2.33	0.01	0.13	0.87	156		
87- 7-19	2319 10.54	41 54.05	80 45.11	2.15	0.01	0.31	0.97	232		
87- 7-20	1718 26.37	41 54.15	80 44.95	2.27	0.02	0.38	1.09	242		
87- 7-21	939 32.64	41 54.07	80 45.36	2.83	0.01	0.22	0.81	160		
87- 7-23	629 44.70	41 54.15	80 44.66	2.23	0.01	0.15	0.40	159		
87- 7-23	827 41.17	41 54.19	80 44.56	2.62	0.01	0.14	0.42	160		
87- 7-23	1847 0.06	41 54.19	80 44.64	2.31	0.01	0.15	0.44	162		
87- 7-25	749 59.18	41 54.20	80 44.87	2.80	0.03	0.34	1.11	227		
87- 7-25	750 18.04	41 54.14	80 44.87	2.26	0.01	0.23	0.67	218		
87- 7-25	2225 51.11	41 54.16	80 44.79	2.23	0.01	0.14	0.42	161		
87- 7-26	3 5 12.76	41 54.09	80 45.01	2.18	0.00	0.13	0.50	159		
87- 7-26	530 35.77	41 54.10	80 44.97	2.32	0.01	0.13	0.49	159		
87- 7-26	711 6.50	41 54.08	80 44.76	1.79	0.01	0.11	0.06	156		
89- 8- 5	054 46.99	41 54.11	80 45.10	2.80	0.01	0.15	0.55	161		

Table 10 cont.

Appendix A

Average peak velocity (centimeters per second)	Intensity value and description	Average peak acceleration (g is gravity=9.80 meters per second squared)
	I. Not felt except by a very few under especially favorable circumstances. (I Rossi-Forel scale)	
	II. Felt only by a few persons at rest, especially on upper floors of buildings. Delicately suspended objects may swing. (I to II Rossi-Forel scale)	
	III. Felt quite noticeably indoors, especially on upper floors of buildings, but many people do not recognize it as an earthquake. Standing automobiles may rock slightly. Vibration like passing of truck. Duration estimated. (III Rossi-Forel scale)	
1-2	**IV.** During the day felt indoors by many, outdoors by few. At night some awakened. Dishes, windows, doors disturbed; walls make creaking sound. Sensation like heavy truck striking building. Standing automobiles rocked noticeably. (IV to V Rossi-Forel scale)	0.015g-0.02g
2-5	**V.** Felt by nearly everyone, many awakened. Some dishes, windows, and so on broken; cracked plaster in a few places; unstable objects overturned. Disturbances of trees, poles, and other tall objects sometimes noticed. Pendulum clocks may stop. (V to VI Rossi-Forel scale)	0.03g-0.04g
5-8	**VI.** Felt by all, many frightened and run outdoors. Some heavy furniture moved; a few instances of fallen plaster and damaged chimneys. Damage slight. (VI to VII Rossi-Forel scale)	0.06g-0.07g
8-12	**VII.** Everybody runs outdoors. Damage negligible in buildings of good design and construction; slight to moderate in well-built ordinary structures; considerable in poorly built or badly designed structures; some chimneys broken. Noticed by persons driving cars. (VIII Rossi-Forel scale)	0.10g-0.15g
20-30	**VIII.** Damage slight in specially designed structures; considerable in ordinary substantial buildings with partial collapse; great in poorly built structures. Panel walls thrown out of frame structures. Fall of chimneys, factory stack, columns, monuments, walls. Heavy furniture overturned. Sand and mud ejected in small amounts. Changes in well water. Persons driving cars disturbed. (VIII + to IX Rossi-Forel scale)	0.25g-0.30g
45-55	**IX.** Damage considerable in specially designed structures; well-designed frame structures thrown out of plumb; great in substantial buildings, with partial collapse. Buildings shifted off foundations. Ground cracked conspicuously. Underground pipes broken. (IX + Rossi-Forel scale)	0.50g-0.55g
More than 60	**X.** Some well-built wooden structures destroyed; most masonry and frame structures destroyed with foundations; ground badly cracked. Rails bent. Landslides considerable from river banks and steep slopes. Shifted sand and mud. Water splashed, slopped over banks. (X Rossi-Forel scale)	More than 0.60g
	XI. Few, if any, (masonry) structures remain standing. Bridges destroyed. Broad fissures in ground. Underground pipelines completely out of service. Earth slumps and land slips in soft ground. Rails bent greatly.	
	XII. Damage total. Waves seen on ground surface. Lines of sight and level distorted. Objects thrown into the air.	

Appendix B

Explanation of nomenclature:

mbLg: Magnitude (Determined from maximum amplitude of Lg waves)

Wave phases

P or Pn: P – wave in the mantle
S or Sn: S – wave in the mantle
Pg: P – wave in the crust
Sg: S – wave in the crust
Lg: Surface waves

From Appendix C

RMS: Root Mean Square
Sigma 1: The major axis of the error ellipse
Sigma 2: The minor axis of the error ellipse
Res: Residual time in seconds

Run 1 Epi RE locator
1989 August 01
2.9 mbLg event at 16:50

Station/Lat./Long./Phase/Arrival time (s)/Quality/Used in soln. y/n

ler 41.667 -81.158 P 10.05 a Y
ler 41.667 -81.158 S 10.19 a Y
tom 41.692 -81.047 S 9.86 a Y
tom 41.692 -81.047 P 10.04 a Y
ecl 41.547 -81.102 P 10.09 a Y
ecl 41.547 -81.102 S 9.98 a Y
men 41.684 -81.404 S 10.03 a Y
men 41.684 -81.404 P 10.29 a Y
che 41.561 -81.362 S 9.90 a Y

Sta Phas X Azi Res Res(nuEpi)
ler P 0.38 232.59 0 0.01
ler S 0.38 232.59 0.14 0
tom S 0.3 226.78 -.19 -.03
tom P 0.3 226.78 -.01 -.01
ecl P 0.44 216.67 0.04 -.04
ecl S 0.44 216.67 -.07 -.07
men S 0.53 246.25 -.02 0.08
men P 0.53 246.25 0.24 0.05
che S 0.57 233.52 -.15 0

RMS: 0.14
sigma 1: 1.19
sigma 2: 0.21
Original loc : 41.893 -80.75
New loc : 41.89 -80.74

Run 2 Epi RE locator
1989 August 01
2.8 mbLg event at 16:12

```
Station/Lat./Long./Phase/Arrival time (s)/Quality/Used in soln. y/n

che 41.561 -81.362 P 8.30 a Y
che 41.561 -81.362 S 8.04 a Y
ecl 41.547 -81.102 P 7.97 a Y
ecl 41.547 -81.102 S 8.04 a Y
ler 41.667 -81.158 P 8.11 a Y
ler 41.667 -81.158 S 7.91 a Y
men 41.684 -81.404 P 8.15 a Y
men 41.684 -81.404 S 7.97 a Y
tom 41.692 -81.047 P 8.14 a Y
tom 41.692 -81.047 S 8.08 a Y


Sta Phas X Azi Res Res(nuEpi)
che P 0.57 233.52 0.23 0
che S 0.57 233.52 -.03 0
ecl P 0.44 216.67 -.1 0
ecl S 0.44 216.67 -.03 -.01
ler P 0.38 232.59 0.04 0
ler S 0.38 232.59 -.16 0
men P 0.53 246.25 0.08 0.01
men S 0.53 246.25 -.1 0.01
tom P 0.3 226.78 0.07 0
tom S 0.3 226.78 0.01 0


RMS: 0.12
sigma 1:  1.04
sigma 2:  0.17
Original loc : 41.88  -80.75
new loc : 41.90  -80.75
```

Run 3 Epi RE locator
1989 August 03
2.2 mbLg event at 4:07

Station/Lat./Long./Phase/Arrival time (s)/Quality/Used in soln. y/n

ler 41.667 -81.158 P 7.89 a Y
tom 41.692 -81.047 P 8.02 a Y
ecl 41.547 -81.102 P 8.03 a Y
ecl 41.547 -81.102 S 7.78 a Y
che 41.561 -81.362 S 7.92 a Y

Sta Phas X Azi Res Res(nuEpi)
ler P 0.38 232.59 -.04 0.02
tom P 0.3 226.78 0.09 0.01
ecl P 0.44 216.67 0.1 -.01
ecl S 0.44 216.67 -.15 -.03
che S 0.57 233.52 -.01 0.02

RMS: 0.14
sigma 1: 2.07
sigma 2: 0.29
Original loc: 41.90 -80.761
new loc: 41.90 -80.74

```
Run 4 Epi RE locator
1987 July 14
2.8 mbLg event at 14:51

Station/Lat./Long./Phase/Arrival time (s)/Quality/Used in soln. y/n

che 41.561 -81.362 P 1.24 a Y
che 41.561 -81.362 S 1.15 a Y
ecl 41.547 -81.102 S 0.98 a Y
ecl 41.547 -81.102 P 0.98 a Y
ler 41.667 -81.158 P 1.02 a Y
ler 41.667 -81.158 S 1.51 a Y
men 41.684 -81.404 S 1.16 a Y
men 41.684 -81.404 P 1.16 a Y
tom 41.692 -81.047 P 1.01 a Y
tom 41.692 -81.047 S 1.18 a Y


Sta Phas X Azi Res Res(nuEpi)
che P 0.57 233.52 0.1 0
che S 0.57 233.52 0.01 0.01
ecl S 0.44 216.67 -.16 -.1
ecl P 0.44 216.67 -.16 -.07
ler P 0.38 232.59 -.12 0
ler S 0.38 232.59 0.37 0.01
men S 0.53 246.25 0.02 0.13
men P 0.53 246.25 0.02 0.06
tom P 0.3 226.78 -.13 -.02
tom S 0.3 226.78 0.04 -.03


RMS:  0.17
sigma 1:  1.39
sigma 2:  0.23
original loc:  41.88  -80.73
new loc:  41.89  -80.74
```

```
Run 5 Epi RE locator
1987 July 16 event at 6:02

Station/Lat./Long./Phase/Arrival time (s)/Used in soln. y/n

che 41.561 -81.362 P 5.18 a Y
che 41.561 -81.362 S 4.61 a Y
ecl 41.547 -81.102 S 4.60 a Y
ecl 41.547 -81.102 P 4.70 a Y
ler 41.667 -81.158 P 4.73 a Y
ler 41.667 -81.158 S 4.62 a Y
men 41.684 -81.404 P 4.75 a Y
men 41.684 -81.404 S 4.60 a Y
tom 41.692 -81.047 P 4.73 a Y

Sta Phas X Azi Res Res(nuEpi)
che P 0.57 233.52 0.46 0.01
che S 0.57 233.52 -.11 -.01
ecl S 0.44 216.67 -.12 -.02
ecl P 0.44 216.67 -.02 0
ler P 0.38 232.59 0.01 0.01
ler S 0.38 232.59 -.1 -.01
men P 0.53 246.25 0.03 0.02
men S 0.53 246.25 -.12 0.01
tom P 0.3 226.78 0.01 0


RMS:  0.20
sigma 1:  1.73
sigma 2:  0.31
Original loc:  41.88  -80.75
new loc:  41.90  -80.75
```

Run 6 Epi RE locator
1987 July 13 event
2.4 mbLg event at 23:49

```
Station/Lat./Long./Phase/Arrival time (s)/Quality/Used in soln. y/n

che 41.561 -81.362 P 3.92 a Y
che 41.561 -81.362 S 4.05 a Y
ecl 41.547 -81.102 P 3.94 a Y
ecl 41.547 -81.102 S 3.89 a Y
ler 41.667 -81.158 P 3.93 a Y
ler 41.667 -81.158 S 4.17 a Y
men 41.684 -81.404 P 3.86 a Y
men 41.684 -81.404 S 3.88 a Y
tom 41.692 -81.047 S 3.86 a Y
tom 41.692 -81.047 P 3.94 a Y


Sta Phas X Azi Res Res(nuEpi)
che P 0.57 233.52 -.02 0
che S 0.57 233.52 0.11 0
ecl P 0.44 216.67 0 0
ecl S 0.44 216.67 -.05 0
ler P 0.38 232.59 -.01 0
ler S 0.38 232.59 0.23 0
men P 0.53 246.25 -.08 0
men S 0.53 246.25 -.06 0
tom S 0.3 226.78 -.08 0
tom P 0.3 226.78 0 0


RMS:  0.11
sigma 1:  0.91
sigma 2:  0.15
original loc:  41.90  -80.75
new loc:  41.90  -80.75
```

```
Run 7 Epi RE locator
1987 July 13
2.2 mbLg event  at 20:53

Station/Lat./Long./Phase/Arrival time (s)/Quality/Used in soln. y/n

che 41.561 -81.362 S 4.88 a Y
ecl 41.547 -81.102 P 4.68 a Y
ecl 41.547 -81.102 S 4.51 a Y
ler 41.667 -81.158 P 4.79 a Y
men 41.684 -81.404 P 5.02 a Y
tom 41.692 -81.047 P 4.79 a Y
tom 41.692 -81.047 S 4.64 a Y

Sta Phas X Azi Res Res(nuEpi)
che S 0.57 233.52 0.12 0.09
ecl P 0.44 216.67 -.08 -.13
ecl S 0.44 216.67 -.25 -.22
ler P 0.38 232.59 0.03 0.06
men P 0.53 246.25 0.26 0.22
tom P 0.3 226.78 0.03 0
tom S 0.3 226.78 -.12 -.03


RMS:  0.06
sigma 1:  0.71
sigma 2:  0.11
original loc:  41.85  -80.71
new loc:  41.87  -80.71
```

```
Run 8 Epi RE locator
1987 July 13
2.1 mbLg event at19:39

Station/Lat./Long./Phase/Arrival time (s)/Quality/Used in soln. y/n

che 41.561 -81.362 P 8.56 a Y
che 41.561 -81.362 S 8.49 a Y
ecl 41.547 -81.102 P 8.53 a Y
ecl 41.547 -81.102 S 8.41 a Y
ler 41.667 -81.158 P 8.60 a Y
men 41.684 -81.404 S 8.41 a Y
tom 41.692 -81.047 P 8.61 a Y
tom 41.692 -81.047 S 8.40 a Y


Sta Phas X Azi Res Res(nuEpi)
che P 0.57 233.52 0.06 0
che S 0.57 233.52 -.01 0
ecl P 0.44 216.67 0.03 0.01
ecl S 0.44 216.67 -.09 0
ler P 0.38 232.59 0.1 0
men S 0.53 246.25 -.09 -.01
tom P 0.3 226.78 0.11 0.01
tom S 0.3 226.78 -.1 0


RMS:  0.10
sigma 1:  0.88
sigma 2:  0.15
original loc:  41.88  -80.75
new loc:  41.90  -80.75
```

Run 9 Epi RE locator
1987 July 13
2.3 mbLg event at 19:00

```
Station/Lat./Long./Phase/Arrival time (s)/Quality/Used in soln. y/n

che 41.561 -81.362 S 7.72 a Y
ecl 41.547 -81.102 P 7.68 a Y
ecl 41.547 -81.102 S 7.52 a Y
ler 41.667 -81.158 P 7.70 a Y
men 41.684 -81.404 P 7.69 a Y
men 41.684 -81.404 S 7.55 a Y
tom 41.692 -81.047 P 7.74 a Y
tom 41.692 -81.047 S 7.59 a Y

Sta Phas X Azi Res Res(nuEpi)
che S 0.57 233.52 0.07 0
ecl P 0.44 216.67 0.03 -.01
ecl S 0.44 216.67 -.13 -.02
ler P 0.38 232.59 0.05 0
men P 0.53 246.25 0.04 0.01
men S 0.53 246.25 -.1 0.01
tom P 0.3 226.78 0.09 0
tom S 0.3 226.78 -.06 -.01


RMS:  0.10
sigma 1:  0.80
sigma 2:  0.15
original loc:  41.88  -80.75
new loc:  41.90  -80.75
```

Run 10 Epi RE locator
1987 July 13
2.8 mbLg event at 18:25

Station/Lat./Long./Phase/Arrival time (s)/Quality/Used in soln. y/n

che 41.561 -81.362 P 6.03 a Y
che 41.561 -81.362 S 6.10 a Y
ecl 41.547 -81.102 P 6.19 a Y
ecl 41.547 -81.102 S 6.04 a Y
men 41.684 -81.404 P 6.20 a Y
men 41.684 -81.404 S 6.15 a Y
tom 41.692 -81.047 P 6.16 a Y
tom 41.692 -81.047 S 6.18 a Y

Sta Phas X Azi Res Res(nuEpi)
che P 0.57 233.52 0.4 0.39
che S 0.57 233.52 0.47 0.63
ecl P 0.44 216.67 0.56 0.36
ecl S 0.44 216.67 0.41 0.59
men P 0.53 246.25 0.57 0.4
men S 0.53 246.25 0.52 0.65
tom P 0.3 226.78 0.53 0.38
tom S 0.3 226.78 0.55 0.62

RMS: 0.19
sigma 1: 1.54
sigma 2: 0.29
original loc: 41.88 -80.75
new loc: 41.91 -80.73

```
Run 11 Epi RE locator
1987 July 13
2.9 mbLg event at 13:05

Station/Lat./Long./Phase/Arrival time (s)/Quality/Used in soln. y/n

che 41.561 -81.362 P 2.87 a Y
che 41.561 -81.362 S 2.70 a Y
ecl 41.547 -81.102 P 2.70 a Y
ecl 41.547 -81.102 S 2.65 a Y
men 41.684 -81.404 P 2.70 a Y
men 41.684 -81.404 S 2.58 a Y
tom 41.692 -81.047 P 2.77 a Y
tom 41.692 -81.047 S 2.59 a Y

Sta Phas X Azi Res Res(nuEpi)
che P 0.57 233.52 0.17 0
che S 0.57 233.52 0 -.01
ecl P 0.44 216.67 0 0.01
ecl S 0.44 216.67 -.05 0
men P 0.53 246.25 0 -.01
men S 0.53 246.25 -.12 -.03
tom P 0.3 226.78 0.07 0
tom S 0.3 226.78 -.11 -.01


RMS:  0.11
sigma 1:  0.89
sigma 2:  0.17
original loc:  41.89  -80.76
new loc:  41.90  -80.75
```

```
Run 12 Epi RE locator
1987 July 13
3.0 mbLg event at 07:52

Station/Lat./Long./Phase/Arrival time (s)/Quality/Used in soln. y/n

che 41.561 -81.362 P 2.23 a Y
che 41.561 -81.362 S 2.22 a Y
ecl 41.547 -81.102 P 2.20 a Y
ecl 41.547 -81.102 S 2.14 a Y
men 41.684 -81.404 P 2.13 a Y
men 41.684 -81.404 S 2.02 a Y
tom 41.692 -81.047 P 2.13 a Y
tom 41.692 -81.047 S 2.07 a Y

Sta Phas X Azi Res Res(nuEpi)
che P 0.57 233.52 0.09 0
che S 0.57 233.52 0.08 0
ecl P 0.44 216.67 0.06 0.03
ecl S 0.44 216.67 0 0.04
men P 0.53 246.25 -.01 -.02
men S 0.53 246.25 -.12 -.05
tom P 0.3 226.78 -.01 0.01
tom S 0.3 226.78 -.07 0.01


RMS:  0.08
sigma 1:  0.65
sigma 2:  0.12
original loc:  41.89  -80.75
new loc:  41.90  -80.75
```

Run 13 Epi RE locator
1987 July 13
2.2 mbLg event at 5:58

```
Station/Lat./Long./Phase/Arrival time (s)/Quality/Used in soln. y/n

che 41.561 -81.362 P 12.22 a Y
che 41.561 -81.362 S 12.53 a y
ecl 41.547 -81.102 P 11.71 a Y
ecl 41.547 -81.102 S 12.22 a Y
ler 41.667 -81.158 P 12.15 a Y
ler 41.667 -81.158 S 12.50 a Y
tom 41.692 -81.047 P 12.05 a Y
tom 41.692 -81.047 S 12.29 a Y


Sta Phas X Azi Res Res(nuEpi)
che P 0.57 233.52 0.01 0.07
che S 0.57 233.52 0.32 0.14
ecl P 0.44 216.67 -.5 -.16
ecl S 0.44 216.67 0.01 -.25
ler P 0.38 232.59 -.06 0.07
ler S 0.38 232.59 0.29 0.14
tom P 0.3 226.78 -.16 -.01
tom S 0.3 226.78 0.08 -.01


RMS:  0.24
sigma 1:  3.16
sigma 2:  0.37
original loc:  41.88  -80.69
new loc:  41.87  -80.70
```

Run 14 Epi RE locator
1987 July 13
3.8 mbLg event at 05:49

```
Station/Lat./Long./Phase/Arrival time (s)/Quality/Used in soln. y/n

che 41.561 -81.362 P 8.83 a Y
che 41.561 -81.362 S 8.93 a Y
ecl 41.547 -81.102 P 8.74 a Y
ecl 41.547 -81.102 S 8.83 a Y
men 41.684 -81.404 P 8.25 a Y
men 41.684 -81.404 S 8.67 a Y
tom 41.692 -81.047 P 8.73 a Y
tom 41.692 -81.047 S 8.60 a Y

Sta Phas X Azi Res Res(nuEpi)
che P 0.57 233.52 0.13 -.01
che S 0.57 233.52 0.23 -.01
ecl P 0.44 216.67 0.04 0.06
ecl S 0.44 216.67 0.13 0.12
men P 0.53 246.25 -.45 -.08
men S 0.53 246.25 -.03 -.15
tom P 0.3 226.78 0.03 0.01
tom S 0.3 226.78 -.1 0.04


RMS:  0.22
sigma 1:  1.86
sigma 2:  0.35
original loc:  41.90  -80.78
new loc:  41.91  -80.76
```

```
Run 15 Epi RE locator
1987 July 14
2.4 mbLg event at 07:47

Station/Lat./Long./Phase/Arrival time (s)/Quality/Used in soln. y/n

che 41.561 -81.362 P 6.59 a Y
che 41.561 -81.362 S 6.39 a Y
ecl 41.547 -81.102 P 6.37 a Y
ecl 41.547 -81.102 S 6.24 a Y
ler 41.667 -81.158 P 6.40 a Y
ler 41.667 -81.158 S 6.55 a Y
men 41.684 -81.404 P 6.59 a Y
men 41.684 -81.404 S 6.49 a Y
tom 41.692 -81.047 P 6.44 a Y
tom 41.692 -81.047 S 6.14 a Y


Sta Phas X Azi Res Res(nuEpi)
che P 0.57 233.52 0.17 0.01
che S 0.57 233.52 -.03 0.01
ecl P 0.44 216.67 -.05 -.09
ecl S 0.44 216.67 -.18 -.16
ler P 0.38 232.59 -.02 0.01
ler S 0.38 232.59 0.13 0.01
men P 0.53 246.25 0.17 0.1
men S 0.53 246.25 0.07 0.18
tom P 0.3 226.78 0.02 -.02
tom S 0.3 226.78 -.28 -.06


RMS:  0.13
sigma 1:  1.05
sigma 2:  0.18
original loc:  41.87  -80.74
new loc:  41.88  -80.73
```

```
Run 16 Epi RE locator
1990 January 01
2.2 mbLg event at 23:03

Station/Lat./Long./Phase/Arrival time (s)/Quality/Used in soln. y/n

che 41.561 -81.362 P 4.34 a Y
che 41.561 -81.362 S 4.40 a Y
ecl 41.547 -81.102 P 4.31 a Y
ecl 41.547 -81.102 S 3.94 a Y
ler 41.667 -81.158 P 4.07 a Y
ler 41.667 -81.158 S 4.87 a Y
men 41.684 -81.404 P 4.01 a Y
tom 41.692 -81.047 P 4.10 a Y
tom 41.692 -81.047 S 4.84 a Y


Sta Phas X Azi Res Res(nuEpi)
che P 0.57 233.52 0.02 0.01
che S 0.57 233.52 0.08 0.04
ecl P 0.44 216.67 -.01 -.06
ecl S 0.44 216.67 -.38 -.08
ler P 0.38 232.59 -.25 0.01
ler S 0.38 232.59 0.55 0.04
men P 0.53 246.25 -.31 0.06
tom P 0.3 226.78 -.22 -.02
tom S 0.3 226.78 0.52 -.01


RMS:  0.38
sigma 1:  4.20
sigma 2:  0.58
original loc:  41.96  -80.84
new loc:  41.89  -80.73
```

```
Run 17 Epi RE locator
1990 July 24
2.3 mbLg event at 23:04

Station/Lat./Long./Phase/Arrival time (s)/Quality/Used in soln. y/n

che 41.561 -81.362 P 6.60 a Y
che 41.561 -81.362 S 5.98 a Y
men 41.684 -81.404 P 6.35 a Y
men 41.684 -81.404 S 5.69 a Y
tom 41.692 -81.047 P 6.82 a Y
tom 41.692 -81.047 S 6.92 a Y


Sta Phas X Azi Res Res(nuEpi)
che P 0.57 233.52 0.21 0.11
che S 0.57 233.52 -.41 0.16
men P 0.53 246.25 -.04 -.29
men S 0.53 246.25 -.7 -.63
tom P 0.3 226.78 0.43 0.27
tom S 0.3 226.78 0.53 0.47


RMS:  0.38
sigma 1:  4.83
sigma 2:  0.68
original loc:  41.92  -80.85
new loc:  41.98  -80.83
```

```
Run 18 Epi RE locator
1990 September 26
2.3 mbLg event at 06:13

Station/Lat./Long./Phase/Arrival time (s)/Quality/Used in soln. y/n

che 41.561 -81.362 P 4.62 a Y
che 41.561 -81.362 S 5.36 a Y
ecl 41.547 -81.102 P 4.63 a Y
ecl 41.547 -81.102 S 5.36 a Y
men 41.684 -81.404 P 4.43 a Y
men 41.684 -81.404 S 5.13 a Y
tom 41.692 -81.047 P 4.78 a Y
tom 41.692 -81.047 S 5.10 a Y

Sta Phas X Azi Res Res(nuEpi)
che P 0.57 233.52 -.31 -.03
che S 0.57 233.52 0.43 0.01
ecl P 0.44 216.67 -.3 0.04
ecl S 0.44 216.67 0.43 0.11
men P 0.53 246.25 -.5 -.09
men S 0.53 246.25 0.2 -.11
tom P 0.3 226.78 -.15 -.01
tom S 0.3 226.78 0.17 0.05


RMS:  0.39
sigma 1:  3.28
sigma 2:  0.62
original loc:  41.92  -80.72
new loc:  41.91  -80.76
```

```
Run 19 Epi RE locator
1990 November 18
2.3 mbLg event at 09:20

Station/Lat./Long./Phase/Arrival time (s)/Quality/Used in soln. y/n

che 41.561 -81.362 P 12.32 a Y
che 41.561 -81.362 S 12.32 a Y
ecl 41.547 -81.102 P 12.13 a Y
ecl 41.547 -81.102 S 12.52 a Y
men 41.684 -81.404 P 12.47 a Y
men 41.684 -81.404 S 11.63 a Y
tom 41.692 -81.047 P 12.18 a Y
tom 41.692 -81.047 S 12.32 a Y


Sta Phas X Azi Res Res(nuEpi)
che P 0.57 233.52 0.08 -.02
che S 0.57 233.52 0.08 -.03
ecl P 0.44 216.67 -.11 0.13
ecl S 0.44 216.67 0.28 0.21
men P 0.53 246.25 0.23 -.14
men S 0.53 246.25 -.61 -.28
tom P 0.3 226.78 -.06 0.03
tom S 0.3 226.78 0.08 0.06


RMS:  0.26
sigma 1: 2.17
sigma 2:  0.41
original loc:  41.92  -80.77
new loc:  41.92  -80.78
```

```
Run 1G Epi RE locator
1987 July 13
2.4mbLg event at 23:49

Station/Lat./Long./Phase/Arrival time (s)/Quality/Used in soln. y/n

dla 42.858 -81.573 Pg 3.84 a Y
dla 42.858 -81.573 Sg 3.88 a Y
ldn 43.04 -81.183 Pg 3.97 a Y
ldn 43.04 -81.183 Sg 3.92 a Y
elf 43.193 -81.315 Pg 3.93 a Y
elf 43.193 -81.315 Sg 3.76 a Y
weo 44.016 -78.374 P 3.90 a Y
weo 44.016 -78.374 Sg 3.74 a Y


Sta Phas X Azi Res Res(nuEpi)
dla Pg 1.13 327.97 -.03 0.03
dla Sg 1.13 327.97 0.01 0.04
ldn Pg 1.18 344.55 0.1 0.01
ldn Sg 1.18 344.55 0.05 0.01
elf Pg 1.36 342.41 0.06 0.01
elf Sg 1.36 342.41 -.11 0.01
weo P 2.74 38.51 0.03 -.03
weo Sg 2.74 38.51 -.13 -.07


RMS:  0.09
sigma 1:  0.33
sigma 2:  0.15
original loc: 41.93  -80.71
new loc:  41.90  -80.75
```

Run 2g
870713 13:05
2.9 mbLg event

Station/Lat./Long./Phase/Arrival time (s)/Quality/Used in soln. y/n

ldn 43.04 -81.183 P 2.88 b Y
ldn 43.04 -81.183 S 3.28 b Y
elf 43.193 -81.315 P 2.89 b Y
elf 43.193 -81.315 S 2.68 b Y
weo 44.016 -78.374 P 2.91 b Y
weo 44.016 -78.374 S 10.67 d n

Sta Phas X Azi Res Res(nuEpi)
ldn P 1.18 344.55 -.05 0
ldn S 1.18 344.55 0.35 0
elf P 1.36 342.41 -.04 0
elf S 1.36 342.41 -.25 0
weo P 2.74 38.51 -.02 0

RMS: 0.31
latt: 41.90
long: -80.75

Run 4g
2001 January 26 03:45
2.2 mbLg event

```
Station/Lat./Long./Phase/Arrival time (s)/Quality/Used in soln. y/n

tyno 43.095 -79.87 Sg 1.58 a Y
rd03 41.183 -79.944 Sg 2.52 a Y
rd04 43.152 -79.699 Sg 2.12 a Y
rd02 43.315 -79.877 Sg 3.12 a Y
efo 43.092 -79.312 Pg 2.43 a Y
efo 43.092 -79.312 Sg 2.57 a Y
rd01 43.411 -79.836 Sg 3.52 a Y
brco 44.244 -81.442 Sg 2.29 a Y
```

```
Sta Phas X Azi Res Res(nuEpi)
tyno Sg 1.4 27.87 -.94 0
rd03 Sg 0.92 137.42 0 -.01
rd04 Sg 1.51 30.98 -.4 0
rd02 Sg 1.6 23.94 0.6 0
efo Pg 1.63 40.52 -.09 0
efo Sg 1.63 40.52 0.05 0
rd01 Sg 1.7 23.5 1 0
brco Sg 2.43 348.63 -.23 -.01
```

RMS: 0.70
sigma 1: 2.22
sigma 2: 1.02

Run 5g
2001 January 26 03:11
2.0 mbLg event

Station/Lat./Long./Phase/Arrival time (s)/Quality/Used in soln. y/n

```
tyno 43.095 -79.87 Pg 1.87 a Y
tyno 43.095 -79.87 Sg 2.69 a Y
rd03 41.183 -79.944 Pg 2.44 a Y
rd03 41.183 -79.944 Sg 2.82 a Y
rd04 43.152 -79.699 Pg 4.30 a Y
rd04 43.152 -79.699 Sg 2.23 a Y
efo 43.092 -79.312 Pg 2.29 a Y
efo 43.092 -79.312 Sg 3.56 a Y
stco 43.208 -79.171 S 3.85 a Y
brco 44.244 -81.442 Sg 2.50 a Y
```

```
Sta Phas X Azi Res Res(nuEpi)
tyno Pg 1.4 27.87 -.99 -.03
tyno Sg 1.4 27.87 -.17 0.02
rd03 Pg 0.92 137.42 -.42 -.03
rd03 Sg 0.92 137.42 -.04 0.03
rd04 Pg 1.51 30.98 1.44 -.03
rd04 Sg 1.51 30.98 -.63 0.02
efo Pg 1.63 40.52 -.57 -.01
efo Sg 1.63 40.52 0.7 0.05
stco S 1.79 40.51 0.99 0.05
brco Sg 2.43 348.63 -.36 -.13
```

RMS: 0.88
sigma 1: 2.42
sigma 2: 1.32

```
Run 6g
2001 January 26  03:03
4.5 mbLg event

Station/Lat./Long./Phase/Arrival time (s)/Quality/Used in soln. y/n

tyno 43.095 -79.87 Pg 4.41 a Y
tyno 43.095 -79.87 Sg 4.48 a Y
rd03 41.183 -79.944 Pg 4.55 a Y
rd03 41.183 -79.944 Sg 4.71 a Y
rd04 43.152 -79.699 Pg 4.35 a Y
rd04 43.152 -79.699 Sg 4.32 a Y
rd02 43.315 -79.877 Pg 4.36 a Y
rd02 43.315 -79.877 Sg 4.26 a Y
efo 43.092 -79.312 Sg 4.87 a Y
rd01 43.411 -79.836 Pg 4.34 a Y
rd01 43.411 -79.836 Sg 4.04 a Y
stco 43.208 -79.171 P 4.47 a Y
stco 43.208 -79.171 S 4.97 a Y
acto 43.609 -80.063 P 4.37 a Y
brco 44.244 -81.442 Sg 3.77 a Y

Sta Phas X Azi Res Res(nuEpi)
tyno Pg 1.39 27.34 -.01 -.04
tyno Sg 1.39 27.34 0.06 -.05
rd03 Pg 0.91 138.12 0.13 0.28
rd03 Sg 0.91 138.12 0.29 0.52
rd04 Pg 1.51 30.5 -.07 -.03
rd04 Sg 1.51 30.5 -.1 -.02
rd02 Pg 1.59 23.46 -.06 -.06
rd02 Sg 1.59 23.46 -.16 -.09
efo Sg 1.62 40.14 0.45 0.09
rd01 Pg 1.69 23.05 -.08 -.08
rd01 Sg 1.69 23.05 -.38 -.09
stco P 1.78 40.16 0.05 0.04
stco S 1.78 40.16 0.55 0.09
acto P 1.82 15.81 -.05 -.13
brco Sg 2.44 348.3 -.65 -.43

RMS:  0.22
sigma 1:  0.61
sigma 2:  0.27
```

Run 7g
2001 January 20 02:05
2.6 mbLg event

Station/Lat./Long./Phase/Arrival time (s)/Quality/Used in soln. y/n

tyno 43.095 -79.87 Pg 1.86 a n
tyno 43.095 -79.87 Sg 1.65 a n
rd03 41.183 -79.944 Pg 5.71 a Y
rd03 41.183 -79.944 Sg 6.54 a Y
rd04 43.152 -79.699 Pg 5.61 a Y
rd04 43.152 -79.699 Sg 5.99 a Y
rd02 43.315 -79.877 Pg 6.22 a Y
rd02 43.315 -79.877 Sg 6.36 a Y
efo 43.092 -79.312 Pg 6.20 a Y
efo 43.092 -79.312 Sg 6.94 a y
rd01 43.411 -79.836 Pg 6.73 a Y
rd01 43.411 -79.836 Sg 6.41 a Y
stco 43.208 -79.171 P 6.40 a Y
acto 43.609 -80.063 P 5.97 a Y
acto 43.609 -80.063 Sg 6.11 a Y
brco 44.244 -81.442 Sg 5.56 a Y

Sta Phas X Azi Res Res(nuEpi)
rd03 Pg 0.92 137.42 -.48 0.13
rd03 Sg 0.92 137.42 0.35 0.28
rd04 Pg 1.51 30.98 -.58 -.01
rd04 Sg 1.51 30.98 -.2 0.03
rd02 Pg 1.6 23.94 0.03 -.03
rd02 Sg 1.6 23.94 0.17 -.02
efo Pg 1.63 40.52 0.01 0.04
efo Sg 1.63 40.52 0.75 0.1
rd01 Pg 1.7 23.5 0.54 -.03
rd01 Sg 1.7 23.5 0.22 -.02
stco P 1.79 40.51 0.21 0.04
acto P 1.82 16.24 -.22 -.07
acto Sg 1.82 16.24 -.08 -.06
brco Sg 2.43 348.63 -.63 -.26

RMS: 0.40
latt: 41.86
long: -80.79

```
1992 run 8G
920315  06:13

Station/Lat./Long./Phase/Arrival time (s)/Quality/Used in soln. y/n

dla 42.858 -81.573 Pg 16.13 b Y
ldn 43.04 -81.183 Pg 17.59 b Y
ldn 43.04 -81.183 Sg 18.20 b Y
elf 43.193 -81.315 Pg 17.0 b Y
elf 43.193 -81.315 Sg 17.16 b Y
weo 44.016 -78.374 P 16.79 b Y
weo 44.016 -78.374 S 23.65 b n


Sta Phas X Azi Res Res(nuEpi)
dla Pg 1.13 327.97 -1.02 -.09
ldn Pg 1.18 344.55 0.44 -.02
ldn Sg 1.18 344.55 1.05 0.06
elf Pg 1.36 342.41 -.15 -.03
elf Sg 1.36 342.41 0.01 0.05
weo P 2.74 38.51 -.36 0.04


RMS:  0.86
latt:  41.89
long: -80.76
```