EXHIBIT B

SEISMICITY AND TECTONIC STRUCTURE IN NORTHEASTERN OHIO: IMPLICATIONS FOR EARTHQUAKE HAZARD TO THE PERRY NUCLEAR POWER PLANT

A Report to the
Ohio Citizens for Responsible Energy, Inc.

Prepared by
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SEISMICITY AND TECTONIC STRUCTURE IN NORTHEASTERN OHIO: IMPLICATIONS FOR EARTHQUAKE HAZARD TO THE PERRY NUCLEAR POWER PLANT

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EXECUTIVE SUMMARY

At the request of the Ohio Citizens for Responsible Energy, we critically reviewed recent studies concerning the January 31, 1986 and other historically recorded earthquakes in northeastern Ohio having a bearing on the design basis for the Perry Nuclear Power Plant. This report discusses the results of this effort; shedding new light into the source of the January 31, 1986 earthquake and the probable relationship of this (magnitude 5.0 mb) and several other small to moderate size earthquakes to tectronic structure in northeastern Ohio.

Hypocentral locations and focal mechanism solutions for the larger aftershocks of the January 31, 1986 event define a near vertical, right-lateral strike-slip fault trending approximately N30°E; a result consistent with the focal mechanism solution for the main-shock. The rupture area associated with the 1986 event is inferred to be about 2 to 4 km², centered at a depth of about 6 km.

Apparently, surficial geologic data do not reveal the trace of such a fault in the epicentral area of the 1986 earthquake. Nevertheless, magnetic anomaly data for northeastern Ohio show a prominent magnetic boundary (Akron Magnetic Boundary), the location and the general trend of which agree remarkably well with the fault inferred from earthquake data.

Furthermore, we observe that the better located (epicentral uncertainty $\leq$ 10 miles) "macroearthquakes" of MM intensity $\geq$ IV, known to have occurred historically within 50 miles of the 1986 event, show a non-random distribution falling on or close to the Akron Magnetic Boundary.

These correlations strongly suggest that the Akron Magnetic Boundary in north-eastern Ohio marks the locus of a pre-existing fault or fault zone. The spatial extent of the correlated epicenters indicates that the active portion of this fault zone is at least 70 km in length and probably about 10 km in width down dip. Consequently, in our opinion, this fault must be considered capable of generating an earthquake much large than the magnitude 5.0 earthquake of January 31, 1986.

Theoretically, the inferred fault area available for rupture is large enough to accommodate a magnitude 7 or even larger earthquake. Conservatively, however, the occurrence of a magnitude 6.5 earthquake is in our opinion a realistic possibility for the purposes of determining a design basis earthquake for the Perry Nuclear Power Plant(PNPP).

Clearly, in light of these new findings, the design earthquake of MM intensity VII or mb 5.3 ± 0.5 adopted for PNPP on the basis of previous studies does not provide the margin of safety required for nuclear power plants. Unfortunately, this view is further strengthened by an indication in the data that the inferred fault (zone) probably passes within a few miles of the power-plant site; which potentially places PNPP within the near field of a strong earthquake generated by this fault.

INTRODUCTION

On January 31, 1986 an earthquake of magnitude 5.0 (NEIS) occurred in northeastern Ohio, about 18 km south of the Perry Nuclear Power Plant. This was the largest earthquake known to have occurred in the northeast Ohio region during historical times. The earthquake was widely felt, causing panic, minor injuries, and some damage approaching intensity VII on the Modified Mercali (MM) intensity scale [U.S. Geological Survey, 1986]. Both the U.S. Geological Survey (USGS) and Weston Geophysical Corporation (WGC), who conducted intensity surveys, assigned an epicentral MM intensity VI to the shock.

A rapid deployment of portable seismographs by several institutions or agencies resulted in the acquisition of data for 13 aftershocks ranging in magnitude from —0.5 to 2.5, of which two were felt [see e.g. USGS, 1986]. After a compilation of the data acquired by the participating institutions, the U.S. Geological Survey and Weston Geophysical Corporation independently determined source parameters for the aftershocks, including hypocentral locations and focal mechanism solutions. The results were published in two separate reports [USGS, 1986; WGC, 1986], that also discussed historical seismicity and attempted to tackle, among other issues, the significance of the 1986 shock and its relationship to tectonic structure.

Based on the mainshock—aftershock data, the U.S. Geological Survey did not reach any definitive conclusions as to the orientation of the fault responsible for the 1986 event; whereas Weston Geophysical Corporation concluded that the earthquake occurred on a near vertical, strike-slip fault trending NNE. The two studies, however, concurred that there was no obvious tectonic structure with which the 1986 event could be reasonably correlated. The USGS report, nevertheless, recommended additional geophysical investigations to understand the structural and tectonic conditions that led to the 1986 earthquake.

The licensing basis for PNPP was established prior to the occurrence of the 1986 shock, placing PNPP within the Central Stable Province with a design earthquake of MM intensity VII or mb 5.3 ± 0.5 [see e.g., WGC, 1986]. Concerned about the implications of the 1986 event on the level of seismic hazard for PNPP, the Ohio Citizens for Responsible Energy (OCRE) sought our professional opinion and made available to us the reports cited earlier along with some additional material.

Reviewing these reports, certain observations that had apparently been overlooked or missed began to emerge, which prompted us to thoroughly reappraise the data contained therein hoping to clarify some of the issues raised by the occurrence of the 1986 event. First, we realized the need to separate the data from the "noise" (so to speak) that may have needlessly masked or rendered ambiguous an otherwise clear result. Consequently, we consistently sought to extricate, for example, from the available seismicity data the more valuable events using such objective criteria as earthquake size and location uncertainty, and relied primarily on such data in reaching conclusions. Secondly, we derived new composite focal mechanism solutions for the aftershocks of the 1986 event based on the P-wave first motion data reported in these studies. We did not, however, seek or attempt to reanalize the primary source (e.g. seismograms, intensity reports) of the data contained therein. The results that follow are almost entirely based on the data compiled or obtained by previous workers. Primarily, our contribution is some important new observations and conclusions based thereupon.

First, we discuss the results of the 1986 mainshock-aftershock sequence of events, clarifying the nature of the source of the mainshock. Later, we discuss the correlation of the 1986 shock and the larger historical earthquakes to tectonic structure in the area, and its implications for earthquake hazard to PNPP.

THE 1986 EARTHQUAKE

Aftershock Data Base

As of April 15, 1986, thirteen aftershocks were recorded by a portable network of seismographs deployed by a number of institutions or agencies soon after the occurrence of the mainshock on January 31, 1986. The phase data compiled from the analysis of seismograms by the participating institutions, and the resulting source parameters for these aftershocks determined by the U.S. Geological Survey and Weston Geophysical Corporation (WGC) are tabulated in their respective reports [USGS, 1986; WGC, 1986].

An examination of the source data [e.g. Table 3, USGS, 1986] shows that the aftershocks can be separated into two distinct groups based on their size and displaying different temporal characteristics. First, we note that 7 of the 13 aftershocks had magnitudes $\geq$ 0.8 (0.8 to 2.4), whereas the remaining 6 were much smaller in size (magnitude —0.5 to 0.1), by almost 2 units of magnitude on the average. It is equally noteworthy that all but one of the larger aftershocks occurred within the first 10 to 11 days following the mainshock, whereas all but one of the smaller aftershocks occurred much later in time, i.e. on or after the 23rd day following the mainshock. Furthermore, as expected, the phase data for the larger aftershocks are in general more abundant and reliable than for the smaller shocks, resulting in overall better determined hypocentral locations and focal mechanism solutions [see e.g., USGS, 1986].

The aftershock locations obtained by the USGS and WGC using various velocity models differ little, excepting the focal depth determination that shows some dependence on the velocity model chosen. For the purposes of this report, we chose to use the hypocentral locations preferred by the USGS and obtained using a velocity model that attempts to take into account the structural complexity of the area. Table 1 (this study) lists the preferred locations for the 7 larger aftershocks determined by the USGS. The events are numbered in chronological sequence in Table 1.

For these larger aftershocks we determined composite or individual focal mechanism solutions, combining events 1, 3, 4 and 7 (magnitude ≥ 1.3) into one group, events 5 and 6 (magnitude $\simeq 1$) into another, and event 2 (the smallest) all by itself. The P-wave first motions reported in the USGS and WGC studies were used for this purpose, excepting a small number of arrivals that were indicated as emergent. The inclusion of these less reliable data does not, however, affect the focal mechanism solutions.

Figure 1 shows the hypocentral locations of the 7 aftershocks. The events are numbered in chronological sequence, and a different symbol is used for each group of events for which a focal mechanism solution was determined. The focal mechanism solutions are shown in Figures 2, 3 and 4. The star in Figure 1a indicates the location (41.650°N, 81.162°W) of the mainshock obtained by the USGS, holding the focal depth fixed at 10 km.

Source Characteristics

Long-period surface-wave data indicate that the mainshock occurred at a shallow depth (2 to 6 km), either on a right-lateral strike-slip fault trending approximately N28°E and dipping steeply ($\simeq$82°) to the west, or on a left-lateral strike-slip fault trending N115°E and dipping about 70° to the south [Hermann and Nguyen, 1986].

The epicentral distribution of the aftershocks (Figure 1a) shows a rather clear north-northeasterly alignment, in agreement with the orientation of one of the nodal planes determined by Hermann and Nguyen [1986] for the mainshock. Also, in each of the three

Table I

Larger Aftershocks of 1986 Earthquake
[USGS, 1986]

Event NO.	Date Mo-Day	Latitude Deg Min	tude Deg Min	Depth km	ERH km	ERZ km	Mag.
1	02-01	41N38.82	81W9.42	4.97	0.45	0.80	1.4
2	02-02	41N38.75	81W9.53	4.99	0.25	0.23	0.8
3	02-03	41N38.90	81W9.61	6.93	0.26	0.36	1.8
4	02-06	41N38.57	81W9.64	5.89	0.28	0.41	2.4
5	02-07	41N39.06	81W9.25	4.64	0.29	0.22	1.0
6	02-10	41N39.16	81W9.27	4.97	0.29	0.42	0.9
7	03-24	41N38.05	81W9.97	4.92	0.45	0.40	1.3

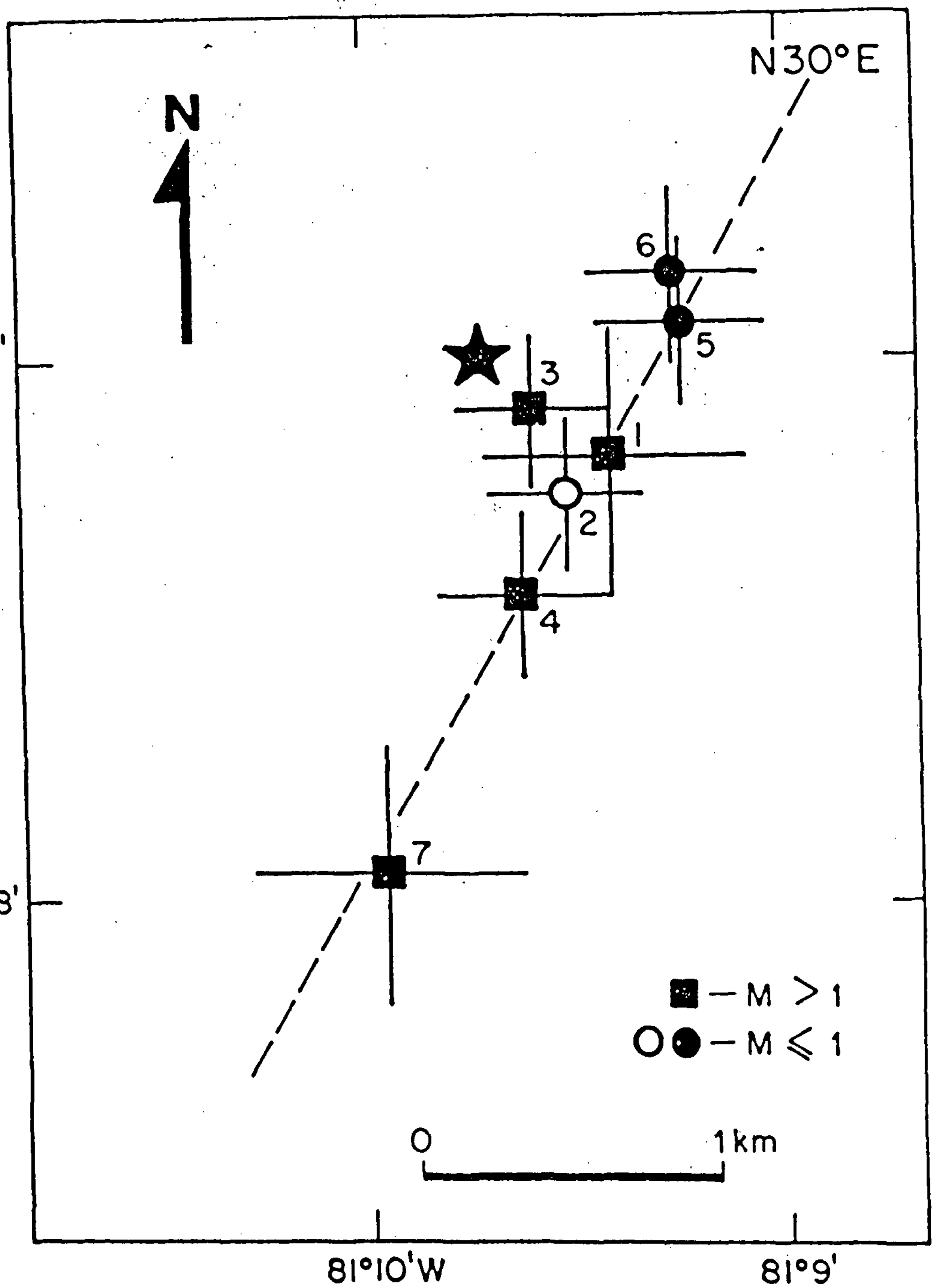


Fig. 1a — Epicentral locations (USGS, 1986) for the 1986 mainshock (star) and 7 largest aftershocks numbered in chronological sequence as in Table 1. For each group of aftershocks denoted by a common symbol, a focal mechanism solution was determined (Figs. 2, 3, and 4). The strike (N30°E) of one of the nodal planes in Fig. 2 is shown.

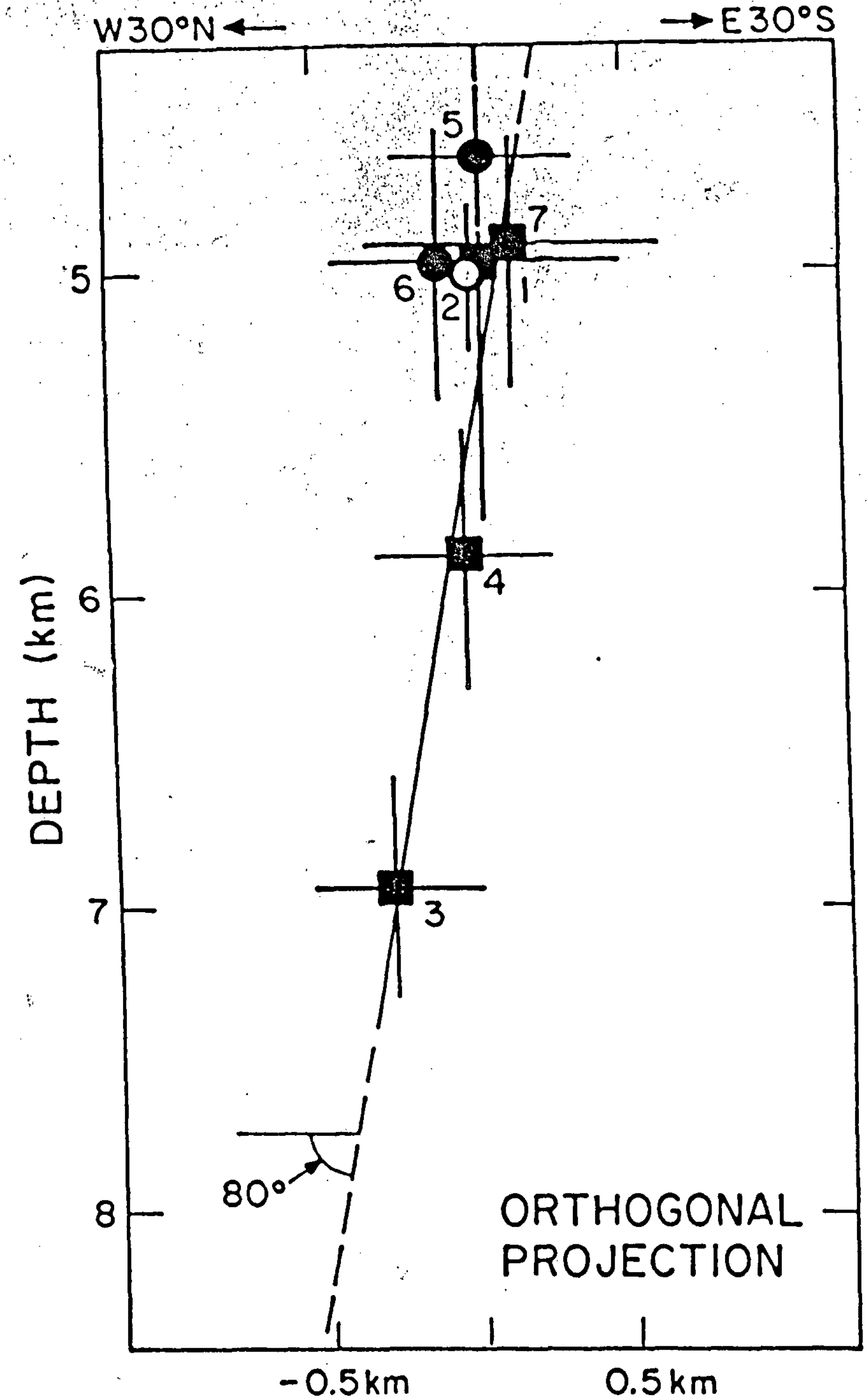


Fig. 1b — Vertical cross-section showing the focal depth distribution of the aftershocks on a plane perpendicular to N30°E, the trend observed in (a). Note that the earthquake foci show a near-vertical distribution consistent with the dip of the N30°E striking nodal plane in Fig. 2.

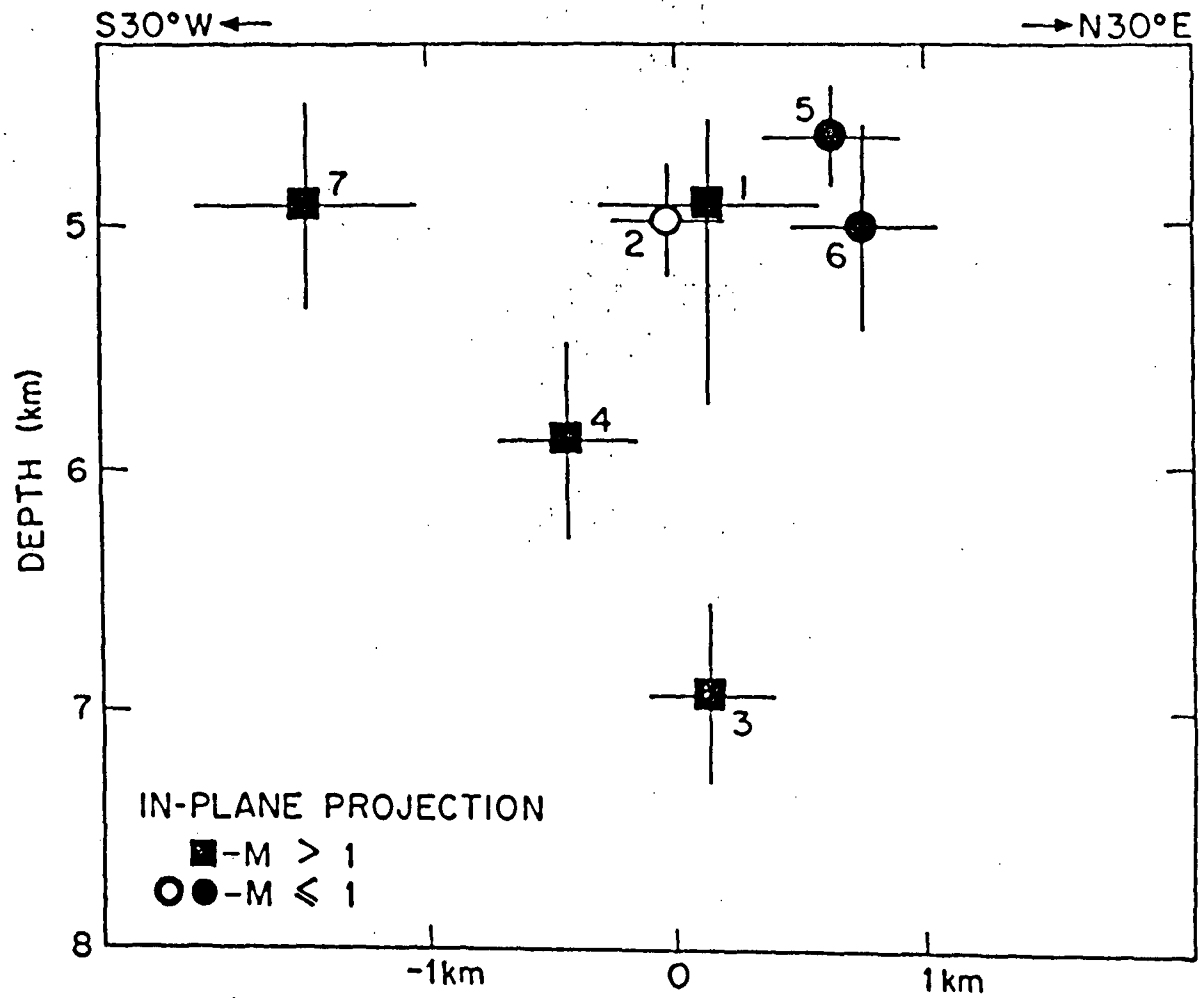


Fig. 1c — Vertical cross-section showing the focal depth distribution of aftershocks on a plane striking N30°E, parallel to the trend observed in (a). Note that the focal depth (2 to 6 km) of the mainshock (not plotted) is consistent with the depth distribution of the aftershocks.

focal mechanism solutions for the aftershocks (Figures 2, 3 and 4) one of the nodal planes trends NNE (N15°E to N32°E), although its dip varies considerably.

It is remarkable that the composite focal mechanism solution (Figure 2) for the four largest aftershocks (squares, Figure 1) is almost identical to the focal mechanism solution for the mainshock. Both the strike and the dip of the NNE trending plane in Figure 2 are in excellent agreement with that determined by Hermann and Nguyen (1986) for the mainshock using surface-wave data. The composite focal mechanism solution (Figure 3) for the next two largest aftershocks (events 5 and 6, Figure 1) is also essentially similar to that of the mainshock. Only the smallest (event 2, Figure 1) of the 7 aftershocks apparently shows a substantially different focal mechanism solution (Figure 4). Note, however, that in this case also one of the nodal planes trends NNE.

Figures 1b and 1c show the focal depths of the aftershocks projected on vertical planes orthogonal and parallel to N30°E, the strike of one of the nodal planes in Figure 2. The orthogonal projection (Figure 1b) shows a near-vertical distribution, in excellent agreement with the dip of the NNE striking nodal plane in Figure 2, the focal mechanism solution closest to that of the mainshock. The parallel projection (Figure 1c), in contrast, shows a rather random distribution.

The above results leave little doubt that the mainshock occurred on a near-vertical fault trending NNE. The sense of motion is deduced to be right-lateral strike slip. The rupture area associated with the mainshock is inferred from the in-plane projection (Figure 1c) to be about 2 to 4 km^2, depending on whether one chooses to exclude or include event number 7 that appears to be somewhat isolated from the rest of the aftershocks. In either case we conclude that the fault (as opposed to the rupture zone) responsible for the 1986 event is at least 2 km long, as indicated by the epicentral distribution of the aftershocks (Figure 1a) having similar focal mechanism solutions (Figures 2 and 3).

The observation that event number 2 apparently shows a thrust mechanism (Figure 4), in contrast to the strike-slip mechanisms for the other aftershocks (Figures 2 and 3), is not surprising. Its location (Figure 1), and the fact that one of the nodal planes trends NNE (Figure 4), suggest that this event probably also occurred on the same fault as the other aftershocks. A fault plane is not expected to be a smooth surface, and such small events are likely to occur on slight "bumps" on the fault surface where stresses may concentrate after a sizeable earthquake. More importantly, however, the focal mechanism solution for the mainshock as well as its aftershocks indicate that these events occurred in response to a stress system in which the maximum principal stress axis is nearly horizontal and oriented ENE.

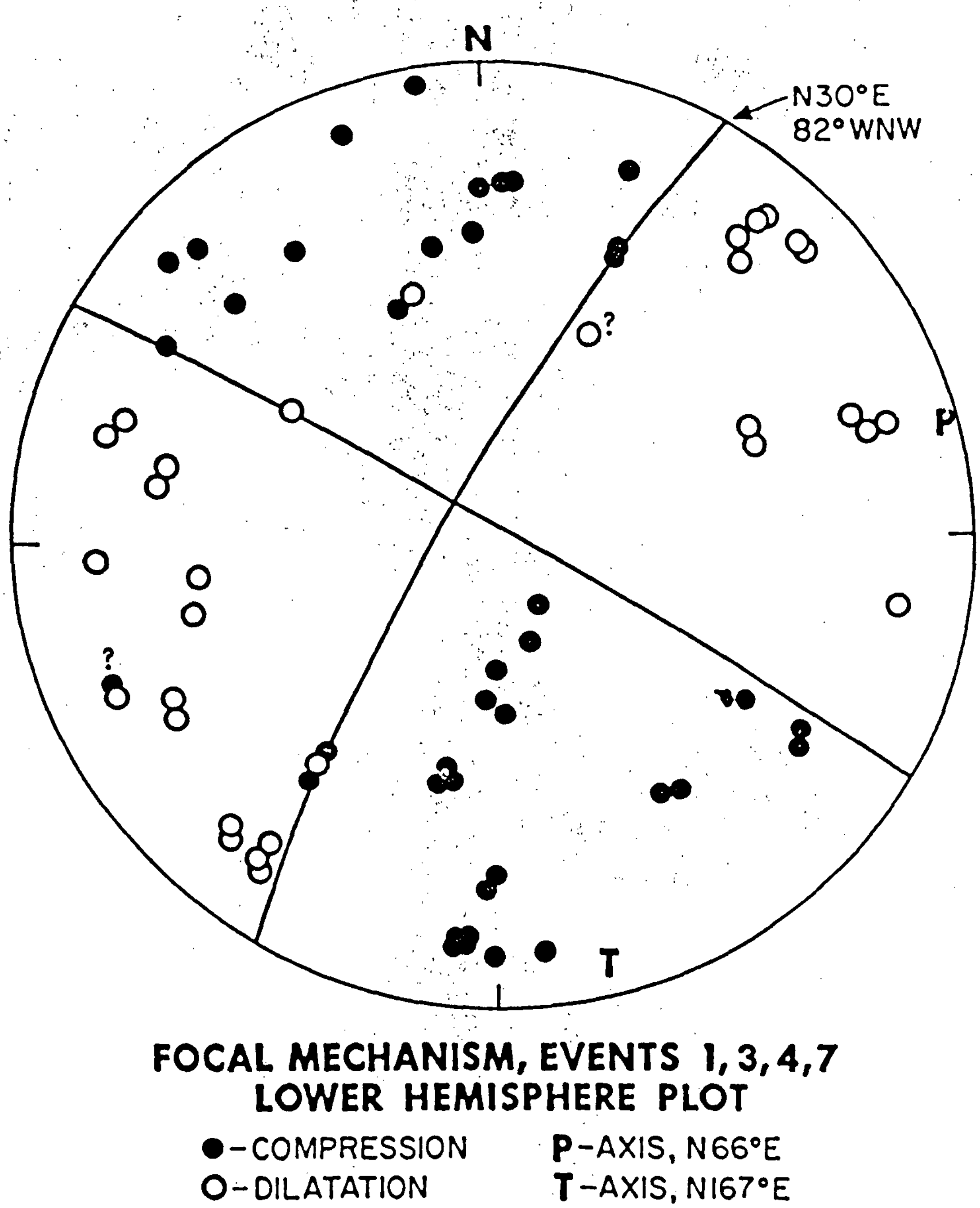
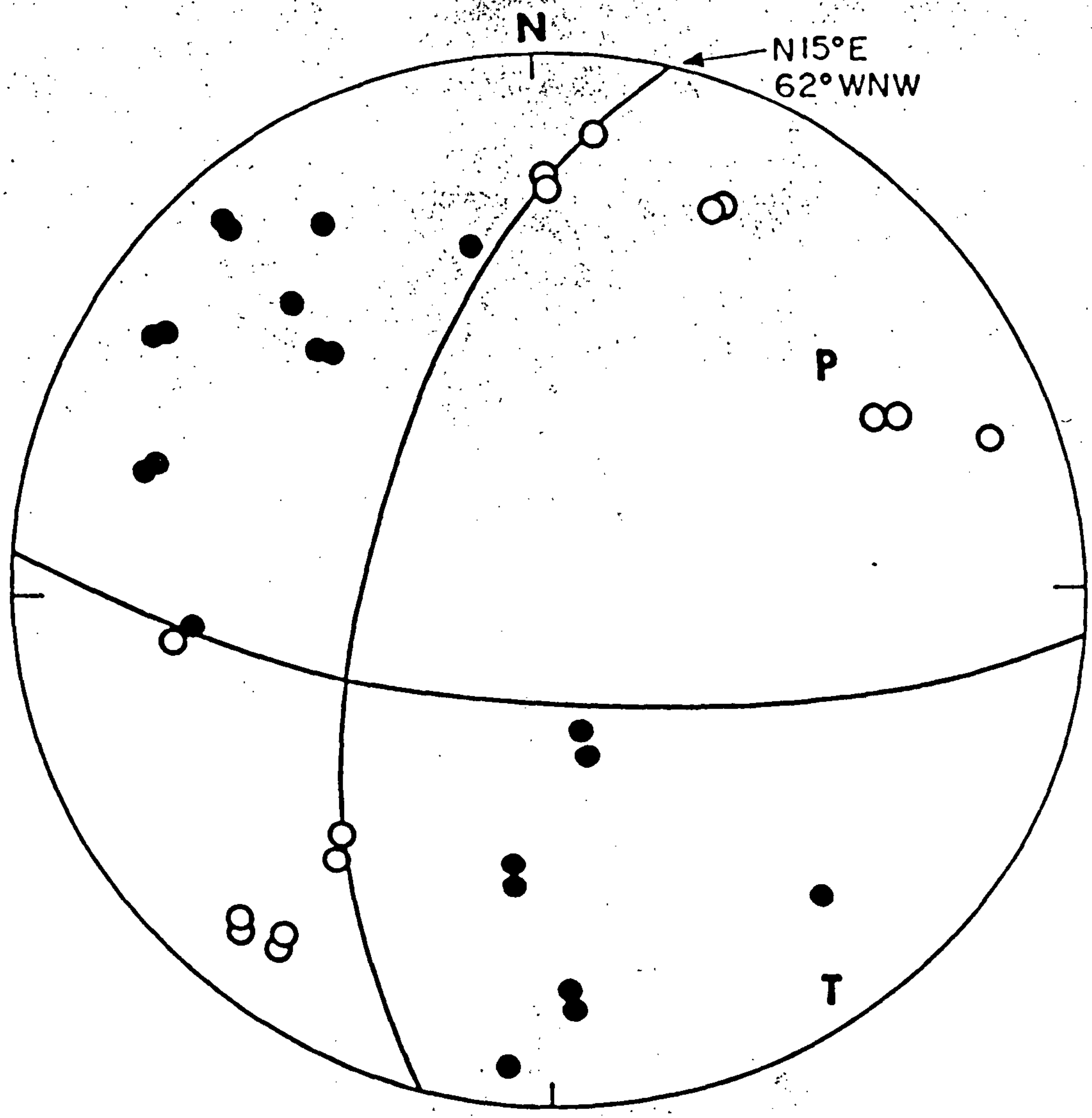


Fig. 2 — Composite focal mechanism solution for the four largest aftershocks of the 1986 event. The event numbers correspond to those in Fig. 1 and Table 1. The strike and the dip of the nodal plane inferred to be the fault plane are indicated. P and T respectively denote the Pressure and Tension axes.



FOCAL MECHANISM, EVENTS 5,6
LOWER HEMISPHERE PLOT

●–COMPRESSION   **P**–AXIS, N52°E
O–DILATATION   **T**–AXIS, N148°E

Fig. 3 — Composite focal mechanism solution for events 5 and 6 (Fig. 1, Table 1), aftershocks of the 1986 event. Symbols as in Fig. 2.

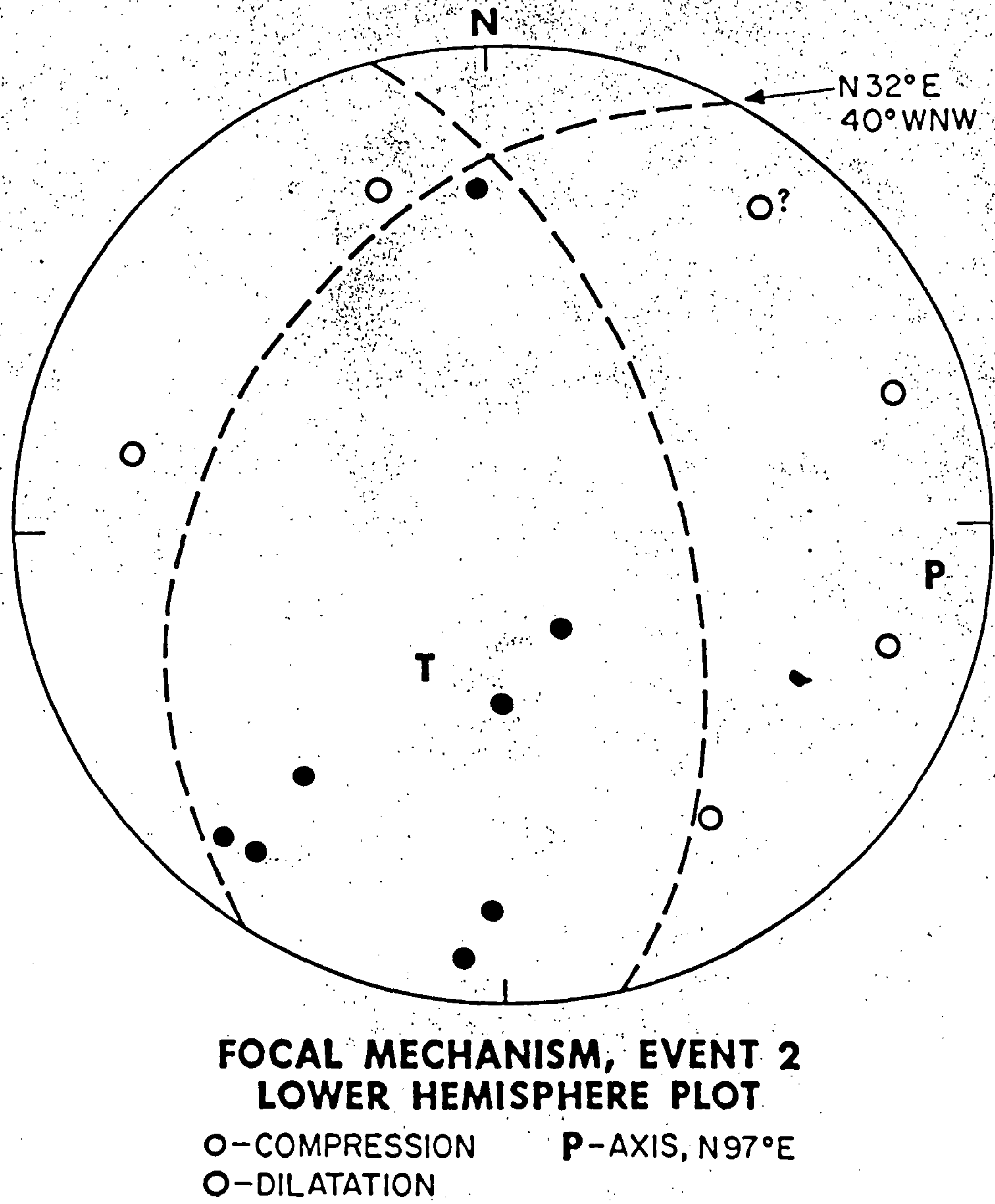


Fig. 4 — Focal mechanism solution for event 2 (Fig. 1, Table 1), the smallest of the 7 largest aftershocks of the 1986 earthquake. The solution is not well constrained. Symbols as in Fig. 2.

Mainshock Magnitude

The National Earthquake Information Service (NEIS) calculated the magnitude (mb) for the 1986 event using telesismic P-wave arrivals at 16 stations. The individual mb values range from 4.1 to 5.9, yielding an average value of 5.0 (5.03) for the 16 readings. Initially, NEIS had assigned a preliminary mb value of 4.9 based on readings from 10 stations.

The Earth Physics Branch (EPB) of Energy, Mines and Resources Canada obtained mbLg values for 24 stations in the Canadian Network. These data are tabulated (Appendix A3.2) in the WGC report [1986]. Figure 5 shows the mbLg (Mn) obtained from the Canadian Network as a function of station azimuth. A remarkably clear dependence of mbLg on azimuth emerges from this plot. The peak near N30°E is rather well defined and is in excellent agreement with the focal mechanism solution of the mainshock, from which one would expect maximum aptitudes for Lg waves at stations located along the strike (NNE) of the fault plane responsible for the 1986 event.

The individual values for mbLg range from 4.9 to 5.7, and the average value is 5.3 (5.28). The difference between the mb magnitude (5.0) and the mbLg magnitude (5.3) is not surprising in light of the azimuthal dependence of mbLg observed here. The higher mbLg magnitude is attributed to the fact that almost a half of the Canadian stations reporting mbLg values lie within about 20° of the strike of the fault plane responsible for the 1986 event (Figure 5), thus resulting in near maximum amplitudes for Lg waves recorded at these stations.

STRUCTURAL RELATIONSHIP

Historical Seismicity

Apart from the 1986 sequence of events, some 25 earthquakes, apparently located within approximately 50 miles of PNPP, have occurred in the northeast Ohio region since 1823 [Table 3-2, WGC, 1986]. Most of these events are, poorly located and as such are of little use in understanding the relationship of seismicity to tectonic structure in the area. Among the larger (MM intensity ≥ IV, or magnitude ≥ 3) events, however, there are several that are relatively well located (uncertainty ≤ 10 miles) according to the data compiled by Weston Geophysical [1979, 1986]. The epicentral locations of these events along with that of the 1986 mainshock are shown in Figure 6. We discuss these events briefly in their chronological sequence going backward in time.

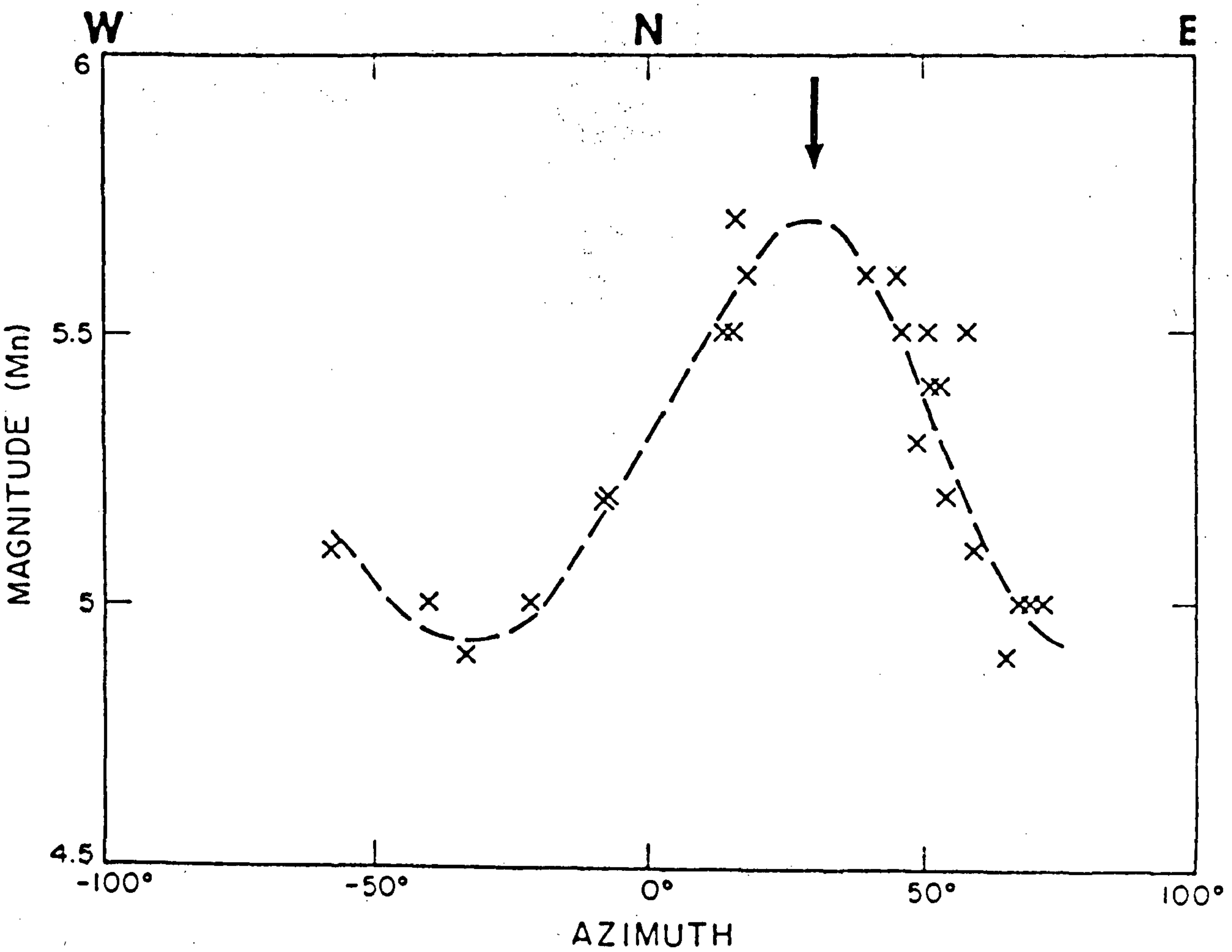


Fig. 5 — Plot showing magnitude (mbLg or Mn) determinations for the 1986 mainshock as a function of station azimuth for the Canadian Network obtained by the Earth Physics Branch. The curve shows an approximate fit to the data. The arrow indicates the strike (N30°E) of the fault plane inferred for the 1986 event; note the peak at or near this azimuth.

The 1983 event that occurred on January 22 was recently relocated by Weston Geophysical using instrumental data in addition to those used initially by NEIS and ISC (International Seismological Centre) or EPB. The epicenter was relocated at 41.765°N, 81.110°W with an estimated uncertainty of about 3 km [WGC, 1986]. This event was not felt. NEIS assigned a magnitude 2.7 mbLg to this event, whereas EPB (Ottowa) obtained a value of 3.3. In each case, the magnitude is based on readings from only a few stations. Hence, in our opinion, an average of the two determinations (3.0) is a better measure of the magnitude of this event than any one of the two values.

The 1943 event was recently relocated by J. Dewey [USGS, 1986] using instrumental data. Its revised location (41.628°N ± 14 km, 81.309°W ± 10 km) is essentially similar to that (41.6°N, 81.3°W) listed by Coffman and von Hake [1973]. This event was widely felt and Weston Geophysical assigned an MM intensity V to it. Its instrumentally determined magnitude of 4.7 mbLg is identical to that estimated from the felt area [see, WGC 1979].

Two events occurred in 1955, one on May 26 and another on June 29. Both of these events were relocated at 41.33°N, 81.40°W by Weston Geophysical on the basis of the distribution of felt reports compiled and analyzed by WGC [1979]. Seismograms for these events from John Caroll University station (Fig. 6), however, provide instrumental control on the epicentral locations. Weston Geophysical [1979] noted that the locations are in good agreement with the epicentral distance ($\simeq$ 20 km) and azimuth (southeast of John Carroll) estimated by Dr. E. Walter from seismograms (see also Fig.6). This agreement suggests that the epicentral uncertainties are probably ($\simeq$ 10 km) somewhat less than those (10 miles) assigned by Weston Geophysical on the basis of intensity data alone. Weston Geophysical [1979, 1986] assigned an MM intensity IV-V to the May 26 event and intensity IV to the June 29 shock, and lists a magnitude (mbLg) 3.6 for both events. A check of the short-period seismograms at the Lamont-Doherty Geological Observatory revealed that both shocks were recorded at Palisades, N.Y.; which suggests that perhaps some other stations in North America may also have recorded this event. We did not, however, make an effort to obtain any such data.

The Dec. 3, 1951 (MM intensity IV, mbLg 3.2) was located (41.60°W, 81.40°W) by Weston Geophysical [1979, 1986] on the basis of felt reports, with an estimated uncertainty of 5 miles. The event was felt in an area less than 10 miles in radius around Willoughby, and was recorded on a 3-component short-period station operated by John Carroll University [WGC 1979]. The seismograms indicate an epicentral distance of about 30 km [WGC, 1979], whereas the epicentral distance from the WGC location is only about 15 km (See Figure 6). This discrepancy, combined with the observation that the shock was apparently not felt at Painesville or in Cleveland (Figure 6), suggests that the epicenter should be approximately 15 to 20 km ESE of the WGC location or possibly to the NW of Willoughby in Lake Erie. Consequently, in our judgement the WGC location is in error or uncertain by 10 miles or more.

In view of the fact that for events occurring relatively close to Lake Erie soil amplification effects and population density distribution would tend to bias (towards the lake) epicentral locations based solely on felt reports, it is not surprising that the WGC location for the 1951 event is not in accord with the instrumental data. In contrast, it is noteworthy that the WGC locations for the 1955 events discussed earlier are in good agreement with instrumental data; which suggests that for events occurring relatively far from Lake Erie their locations are not significantly affected by soil amplification or population concentration along Lake Erie's south shore.

Lastly, two events occurred near Akron about 85 km SSW of PNPP (Figure 6). The 1932 event (MM intensity IV) that occurred on Jan 21 was felt only on the west shore of Lake Summit situated within the city limits of Akron [WGC, 1979]. Accordingly, Weston Geophysical assigned to its epicenter the coordinates (41.08°N, 81.50°W) of the lake as determined by Docekal [see WGC, 1979], and later adopted the epicenter (41.10°N, 81.60°W) obtained by EPB [see Table 3-2, WGC, 1986]. The two locations are similar, and the relatively small difference appears to be due to rounding off errors in the coordinates (41.06°N, 81.55°W) of the lake. Weston Geophysical [1979] did not assign an epicentral uncertainly to this event. Judging from the observation that the event was apparently felt in a rather localized area within an urban environment, it is our opinion that the uncertainty in the epicentral location (41.06°N, 81.55°W) is probably 10 km or less.

Weston Geophysical lists another earthquake on Jan. 22, 1932 (magnitude 3.6) at essentially the same location (41.10°N, 81.50°W) as that on Jan. 21, 1932 referring to Nuttli as the source [see Table 3-2, WGC, 1986], but does not mention this event in its 1979 report. It is not clear whether the two events are one and the same earthquake with a possible error in the date in one of the catalogs, or two separate events one of which might have been initially missed by WGC in its 1979 catalog. In Figure 6, however, we have plotted

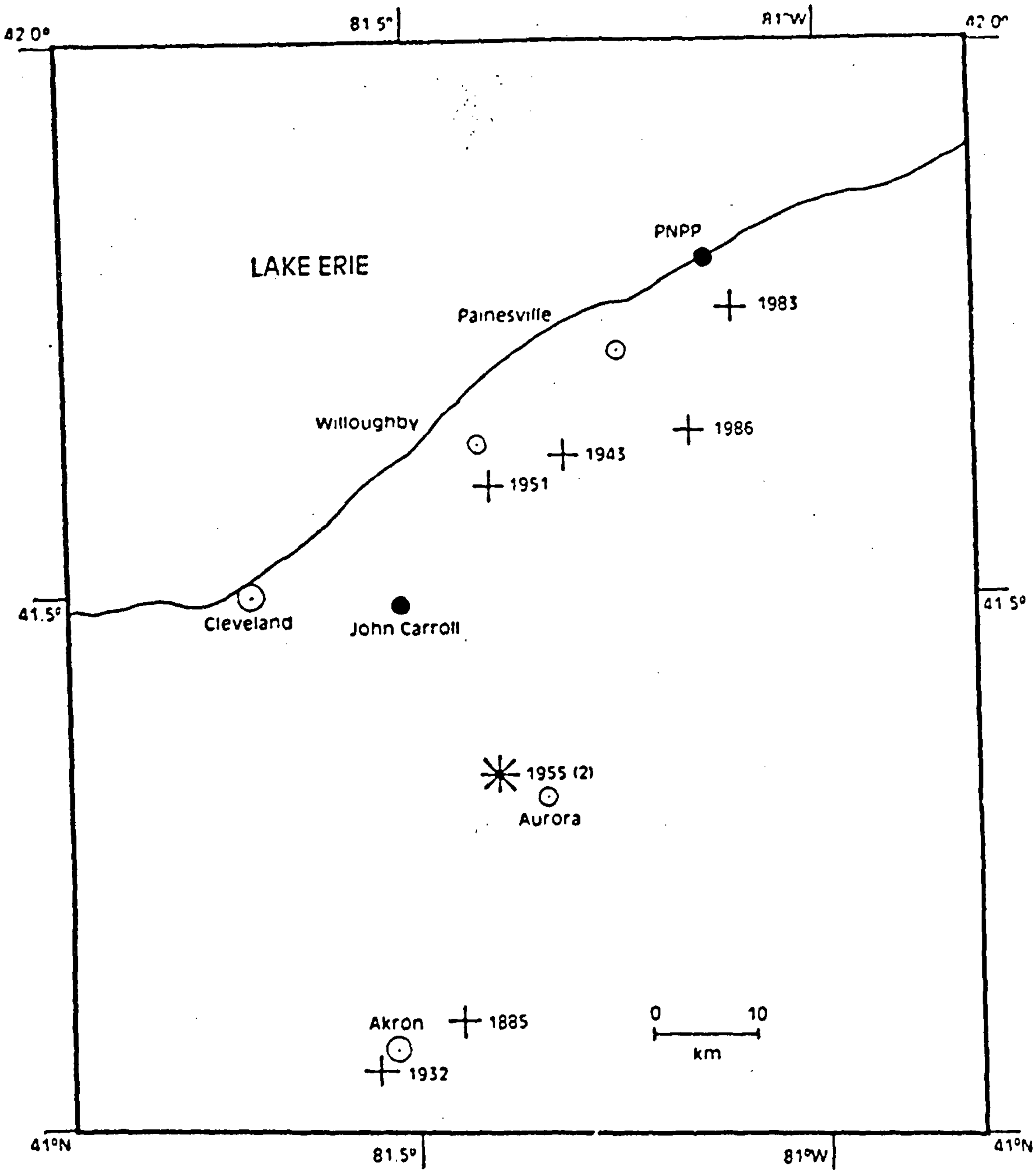


Fig. 6 — Map of Northeastern Ohio showing the epicenters (WGC, 1979, 1986; USGS, 1986) of local earthquakes (within 50 miles of PNPP) of MM intensity ≥ IV or mag. ≥ 3, located with an uncertainty ≤ 10 miles excepting the 1951 event (see text). Note the rather clear NNE trend in epicenters.

only one event using the coordinates of Summit Lake as its epicenter, and have assigned to it an uncertainty of 10 km.

The other event near Akron (Figure 6) occurred on January 18, 1885. This event (MM intensity IV) was relocated by Weston Geophysical [1979] on the basis of the distribution of felt reports. The WGC location (41.10°N, 81.45°W) is similar to that (41.10°N, 81.40°W) listed in the EPRI catalog with an epicentral intensity MM IV and magnitude 3.8 [see Table 3-1, WGC, 1986]. The epicentral uncertainty of $\pm$ 10 miles estimated by Weston Geophysical appears to be adequate, although the distributions of felt reports suggests that the epicenter should be somewhat to the west or NW of the WGC epicenter plotted in Fig. 6 [see WGC, 1979].

All of the "local" earthquakes discussed above occurred during the past 100 years (1885-1986). During this time period there were possibly two additional local shocks (Sept. 29, 1928; Oct. 29, 1934) of MM intensity $\geq$ IV, both of which are not used in this study. Not only is the location of the 1928 event poorly known, but also its nature (earthquake?) remains a mystery [WGC, 1979]. The 1934 earthquake (MM V) was located (42.0°N, 80.2°W) by WGC [1979] at or near Erie, Pennsylvania, on the basis of felt reports from Erie obtained from newspapers in northeastern Ohio. The uncertainty in the location of this event is, however, unknown or difficult to estimate in the absence of felt reports from sources in Pennsylvania. Similarly, the locations of four much older (1836, 1850, 1857, and 1858) local earthquakes of MM $\geq$ IV are in general poorly constrained [see WGC, 1979], and hence these events are also not used here.

Correlations

The epicentral distribution of earthquakes in Figure 6 shows a rather strong NNE trend or alignment. Clearly, the uncertainties in individual locations ($\leq$ 16 km except for the 1951 event) discussed earlier are much smaller than the lateral extent (about 80 km) of the epicenters defining a NNE trend. Secondly, the distribution of population in northeastern Ohio does not exhibit a particular pattern that could reasonably be correlated with the trend observed in earthquake epicenters. Also, note that all but one (1951) of the events are either instrumentally located (1943, 1983, 1986) or occurred relatively far from Lake Erie (1885, 1932, and 2 in 1955). Consequently, biases resulting from soil amplification effects or population density along the lake shore cannot be invoked to either assign larger uncertainties to the locations or explain the trend in the epicentral locations. Furthermore, these events are among the largest earthquakes known to have occurred in northeastern Ohio. We conclude that the NNE trend observed in the epicentral locations is not simply fortuitous, but represents an important if not a fundamental characteristic of the seismicity in this region.

In Figure 7 the epicenters of the better located events (uncertainty ≤ 16 km) are superimposed on a magnetic anomaly map of northeastern Ohio region compiled by Hildenbrand and Kucks (1984). Note that the 1951 event (Figure 6) which is less well located, as discussed earlier, is not plotted in Figure 7. The shaded area indicates the approximate location and the general trend of the northeastern Ohio section of a prominent magnetic boundary (Akron Magnetic Boundary) that separates an area of relatively smooth magnetic anomalies to the east from the region of rapidly varying magnetic anomalies to the west.

In Figure 7 we observe that the NNE trend in earthquake epicenters corresponds rather well with the general trend (NNE) of the magnetic boundary. Also, we note that the earthquake epicenters are located on or close to the magnetic boundary, and within the uncertainties of the data the earthquake epicenters correlate well with the location of the boundary.

This correlation is particularly clear where the data are the most precise. For example, in the case of the 1986 event the strike ($\simeq$N30°E) of its fault plane, inferred earlier from seismological data, is almost identical to the trend of the Akron Magnetic Boundary just south of the epicenter where the boundary trend is particularly well defined (Figure 7). Also, the epicenter of this event having a probable uncertainty of only about 1 km [WCC, 1986, also Figure 1a] is essentially located on the magnetic boundary (within the uncertainties inherent in the demarcation of the boundary). We note that the correlation of the 1986 event with this magnetic boundary was also observed by Seeber [1986].

The next best located event is perhaps the 1983 (January 22) earthquake that was recently relocated by Weston Geophysical [1986] with an uncertainty of about 3 km using instrumental data. Figure 8 shows the location of this event in relation to that of the 1986 shock. The box denotes the epicenter of the 1983 event obtained by Weston Geophysical [1986] by averaging the various epicenters (crosses) computed with different velocity models and/or different weighting schemes. Figure 8 shows that the epicenter of the 1983 shock is located essentially on strike of the fault plane for the 1986 event some 13 km north of the later. Unfortunately, the P-wave first motions for the 1983 earthquake recorded at several stations [see seismograms, WCC, 1986] are not clear

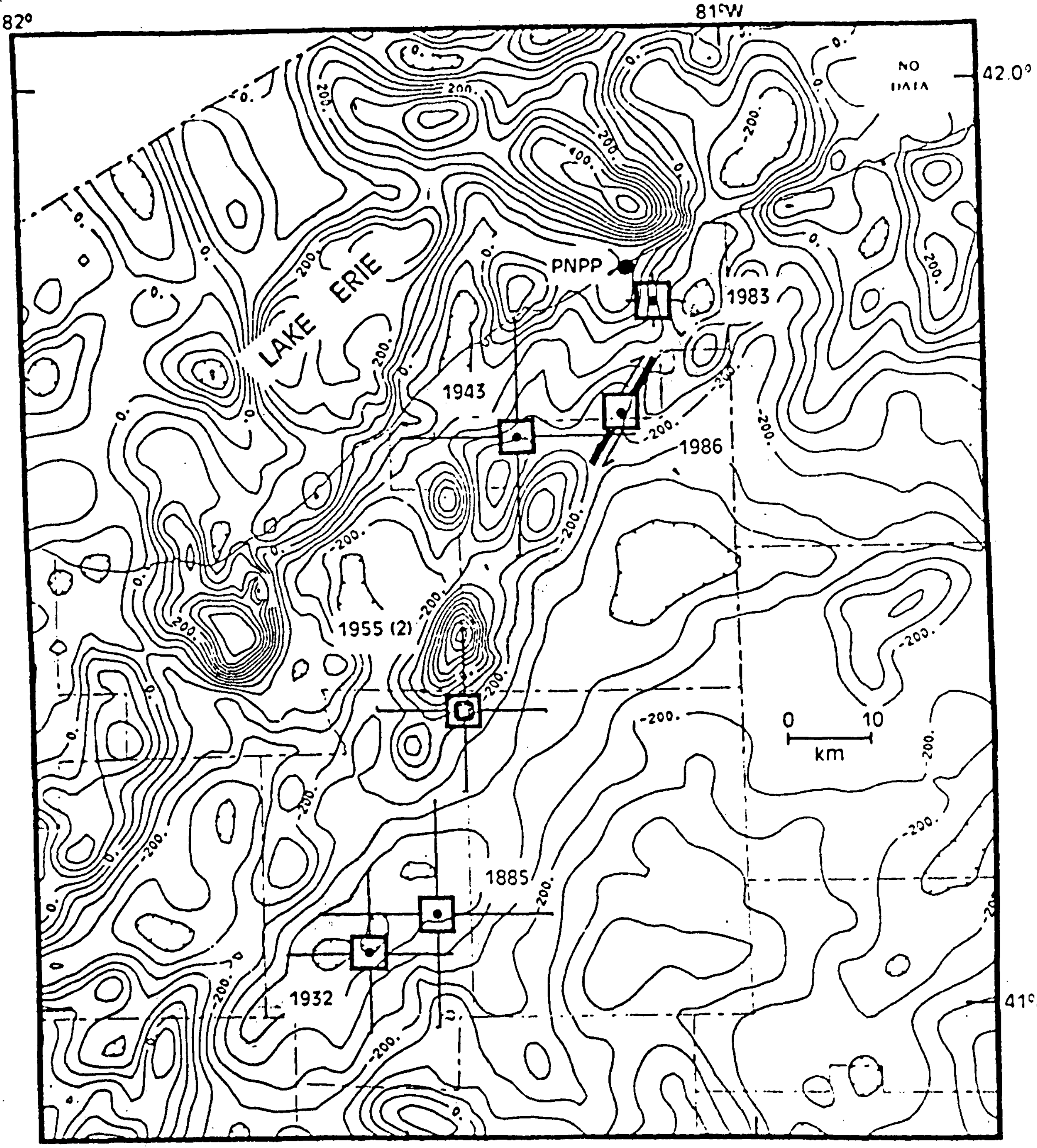


Fig. 7 — Residual total magnetic map of northeastern Ohio region (Hildenbrand and Kucks, 1984). Epicenters (WCC, 1979, 1986; USGS, 1986) of the better located (uncertainty ≤ 16 km) local earthquakes (within 50 miles of PNPP) of MM intensity ≥ IV or mag. ≥ 3 are superimposed on the magnetic map. The strike of the fault plane and the sense of motion on it for the 1986 shock are shown. The shaded area shows the approximate location of the magnetic boundary observed in the data. Note that the epicenters are located on or close to this boundary.

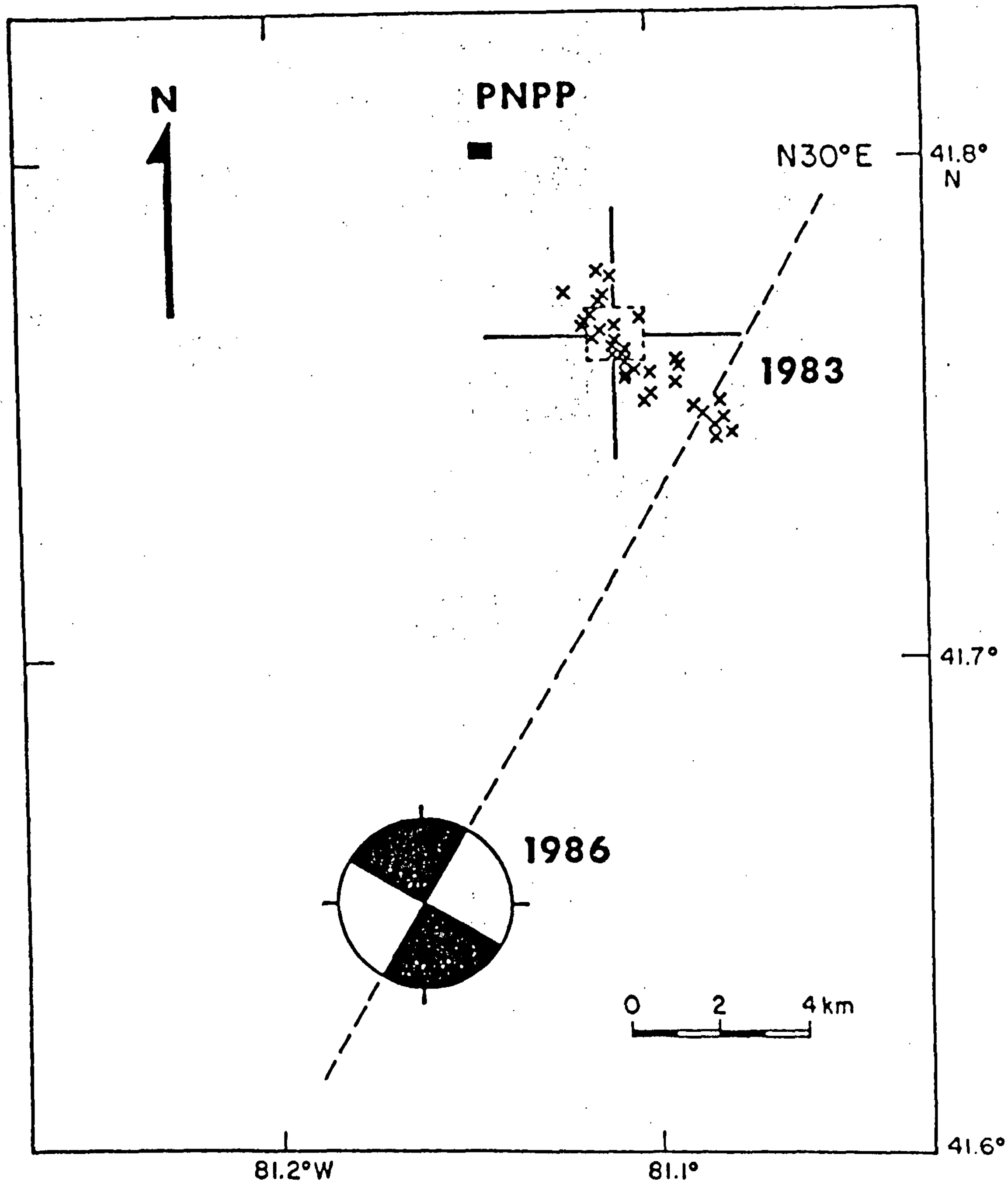


Fig. 8 — Map showing the location of the January 22, 1983 event (WGC, 1986) in relation to that of the 1986 earthquake and its focal mechanism. Crosses indicate individual locations of the 1983 event obtained using different velocity models and/or weighting schemes, and the box indicates the average of these solutions with its uncertainty (bars) adopted by Weston as the epicenter of the 1983 event. Note that the 1983 event lies essentially on strike (broken line) of the 1986 fault plane.

enough to determine whether or not the first motions are consistent with the right-lateral strike-slip motion determined for the 1986 event.

It is also noteworthy that the epicenters of the two earthquakes in 1955, although less well constrained ($\pm$ 10 km), are apparently located on the magnetic boundary. Since these events were recorded by the John Carroll station, the epicentral distances ($\simeq$ 20 km for both events) from this station provide constraints on the locations of these events in the NW-SE direction (see Figure 6). As discussed earlier the locations of the 1955 events are in good agreement with the instrumental data. This constraint and the distribution of the intensity data [WCC, 1979] indicate that the uncertainty is largely in the NE-SW direction or basically along the magnetic boundary; which strengthens the correlation of these events with the magnetic boundary.

The three older events (1885, 1932 and 1943) are located sufficiently close to the magnetic boundary with uncertainties acceptably small as to render their correlation with the magnetic boundary reasonably credible (Figure 7). The 1943 event (mbLg 4.7) is the second largest earthquake known to have occurred in this region, and its instrumentally determined location is close to that of the 1986 event (Figure 7). The 1932 event was felt only on the west shore of Lake Summit (discussed earlier) located near the western edge of Akron, the city that lent its name to the magnetic boundary. Lastly, the distribution of the intensity data for the 1885 event (see WCC, 1979) suggests, as discussed earlier, that this event probably occurred somewhat to the west or northwest of the WCC epicenter shown in Figure 7, which would place it even closer to the magnetic boundry.

The above observations strongly suggest a causal relationship between seismicity and the Akron Magnetic Boundary in northeastern Ohio, indicating that the magnetic boundary marks the locus of a pre-existing fault or fault zone. Surficial geologic data apparently do not show the trace of such a fault, and its presence at depth is probably masked by the sedimentary cover. The magnetic data, in contrast, reflect changes in the basement rocks aiding in the understanding of the structure of the upper crust. In this context, it is noteworthy that the well constrained hypocentral locations of the aftershocks of the 1986 event show focal depths of 4 to 7 km (Figure 1); implying that the events occurred in the basement below the sedimentary cover.

The lateral (NNE) extent of the epicenters in Figure 7 suggests that the active portion of this fault (zone) is at least about 70 km long. Judging from the focal mechanism solutions for the 1986 event and its aftershocks, it appears that this fault is predominantly a right-lateral strike-slip fault, and probably has a down-dip width of 10-15 km as is generally the case for major strike-slip faults.

IMPLICATIONS

The preceeding results raise important safety issues and concerns regarding the level of earthquake hazard to which PNPP might be exposed. The design basis or the safe-shutdown earthquake (SSE) for PNPP was established prior to the 1986 event on the basis of the tectonic province approach detailed in Appendix A, 10 CFR 100 of the Nuclear Regulatory commission. This approach is used in the absence of "capable faults", and/or where locations of historically reported earthquakes of highest intensity cannot be reasonably correlated with tectonic structures. In our opinion the results of this study demonstrate with reasonably certainty i) that a major active fault or fault zone exists in the proximity of PNPP, and ii) that an SSE of MM intensity VII or mb about 5.3 adopted for PNPP does not provide the margin of safety required for nuclear power plants.

It is clear that the SSE for PNPP is only marginally larger than the 1986 event, bearing in mind that the intensity of the latter approached VII, albeit in a few places. More importantly, however, Appendix A mandates that *in the event seismological and geological data warrant, the SSE shall be larger than that derived by use of the procedures set forth in section IV and V of the appendix* (see paragraph IV, section V). These procedures include the tectonic province approach. Hence, notwithstanding the issue of whether or not the fault zone identified here on the basis of seismological and magnetic data is a "capable fault" as defined in Appendix A, it is clear that the results of this study warrant an SSE substantially larger than that adopted for PNPP regardless of the approach used.

The rupture area associated with the 1986 event (mb 5.0) was inferred to be about 2 to 4 km². In contrast, the estimated fault area ($\simeq$ 70 x 10 km²) potentially available for rupture is more than 2 orders of magnitude larger than that associated with the 1986 event. Theoretically, the available fault area is sufficient to accommodate a magnitude 7 or even larger earthquake. Conservatively, however, the occurrence of a magnitude 6.5 earthquake must be considered a realistic possibility for the purposes of determining an SSE for PNPP. Furthermore, Figure 7 suggests that the fault zone extends NNE of the 1986 event passing close to PNPP, which potentially places PNPP within the near field of a strong earthquake generated by this fault. The likelihood of occurrence of such an earthquake is, however difficult to quantify, and any efforts to do the same would be meaningless in light of the shortness of the historical record of earthquakes and the absence of geological data extending the record backward in time.

As to whether the fault zone identified here is a "capable fault" within the context and meaning of Appendix A, we are of the opinion that the evidence favors such a designation. According to Appendix A if *macro-seismicity instrumentally determined with records of sufficient precision demonstrates a direct relationship with a fault*, then that fault must be considered to be a capable fault. First, the events used in our correlation (Figure 7) range in magnitude from about 3.0 to 5.0, and hence constitute macro-seismicity. Secondly, the locations of the 1986, 1983 and 1943 earthquakes are instrumentally determined and those of the two 1955 events are partially constrained by instrumental data. As to whether these locations are determined with "sufficient precision to demonstrate a direct relationship", it is a matter of opinion, and we leave it to the reader to draw his or her own conclusions.

RECOMMENDATIONS

We recommend that the following confirmatory studies be undertaken to both verify the results of this study and seek geologic evidence (which might or might not be available) for the existence of the fault zone discerned here on the basis of the association of earthquakes with the Akron Magnetic Boundary.

i) The magnetic data for northeastern Ohio should be reexamined in an effort to define the magnetic boundary as accurately as possible. In particular, the trend and the extension of this boundary north of the 1986 event should be defined (if possible) more accurately than at present.

ii) Using the magnetic data as a reference, the structural geology along this boundary should be studied carefully not only in the epicentral area of the 1986 event but also elsewhere. Sites that might be suitable for this purpose are rivers, streams and lakes that apparently follow the boundary. Some examples are: Bass Lake and the river associated with it just SW of Chardon, the river and lakes or ponds between the towns of Geauga Lake and Burg just NW of Aurora, and a NNE trending river (we do not know the name) about 5 km west of Akron.

iii) Several high resolution seismic reflection profiles should be conducted across the magnetic boundary. It appears that the inferred fault zone is essentially vertical and its possible that vertical displacements may have occurred on it during its geologic history. Such vertical displacements, if substantial, should be discernable on the seismic profiles. Tentatively we recommend four such profiles: NW of Akron, near Aurora, near the epicenter of the 1986 event, and near Madison east of PNPP.

iv) We also recommend that an attempt be made to further reduce uncertainties in the locations of earthquakes that occurred prior to 1980.

- The 1943 event should be relocated using the 1986 earthquake as a master event. The inclusion of data from John Carroll station would be useful for this purpose.
- The available seismograms for the 1955 events should be procured and analyzed, and the events should be relocated using both the instrumental and intensity data.
- The felt reports for the older historical earthquakes of MM $\geq$ IV should be reanalyzed and where possible additional data procured. The relocations should be obtained using computer based programs, and uncertainties should be ascertained taking into account the population distribution prevailing close to the time of the occurrence of the event.

Lastly, this study clearly reiterates the desirability and need of seeking a spectrum of professional opinions, especially from those investigators not party to the issues involved. Bearing this in mind, we strongly recommend that the unprocessed data resulting from any confirmatory investigations be made available to disinterested investigators and that funds be provided by governmental agencies to such investigators to facilitate the analyses and interpretation of the data.

NOTES AND ACKNOWLEDGEMENTS

We did not address the issue of whether or not the 1986 and 1983 events were triggered by injection of fluids at Calhio wells because of lack of sufficient funds. It is our opinion, however, that in order to clarify this issue and understand any spatio-temporal relationships of these earthquake to fluid injection, one must take into account the location of the fault zone identified here and its possible influence on fluid flow.

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APPENDIX B

SEISMIC CAPABILITY OF THE 8x8 FUEL SPACER

General Electric's 1975 Nuclear Reactor Study, known as the Reed Report, identifies the fuel as having the smallest seismic margin in the BWR/6. See attached page 39 of the Nuclear Systems Task Final Report. The fuel spacer is required to withstand an acceleration of 0.3 g. Doubt is expressed by GE as to whether the BWR/6 design would meet seismic design requirements in excess of 0.3 g. In NUREG-1285, "NRC Staff Evaluation of the General Electric Company Nuclear Reactor Study ("Reed Report")", it is stated that fuel spacer failure could result in loss of core coolability during a loss of coolant accident (LOCA) (p. 22). That GE's standard plant design, GESSAR II, has as its maximum site SSE an acceleration of 0.3 g is indicative of this continuing seismic limitation in the BWR/6 design. (NUREG-0979, p. 15-2)

To illustrate that a near-field magnitude 6.5 earthquake would likely result in accelerations greater than 0.3 g, OCRE used the same correlations relied upon by the licensees in the FSAR. Represented graphically in FSAR Figure 2.5-74 (attached) are the relationships between acceleration and Modified Mercalli intensity developed by Trifunac and Brady (Reference 2 in FSAR Section 2.5), Gutenberg and Richter (FSAR Reference 151) and Newman (FSAR Reference 218). To correlate magnitude with epicentral Modified Mercalli intensity a number of relationships were employed. These are listed in Table 1. The mean of the values of intensity calculated for an earthquake of mb = 6.5 is 9.5. From FSAR Figure 2.5-74, a Modified Mercalli intensity of 9.5 yields an acceleration of 500 cm/sec2 for the relationship of Gutenberg and Richter, of 700 cm/sec2 for that of Trifunac and Brady, and of 800 cm/sec2 for that of Newman. Taking 1.0 g to be 980 cm/sec2, these values translate to 0.51 g, 0.71 g, and 0.82 g.

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Reed Report

There are at least five major areas that have a direct bearing on the overall safety with regard to seismic design. These areas are: definition of seismic loads, mathematical models, analysis procedures, design criteria and assuring quality control during fabrication and construction. Statistical data is lacking on which to assess the accuracy of assumptions in these areas in any design. Therefore conservatism is appropriate.

BWRSD and BWRPD currently exercise parallel responsibilities in some areas of seismic design since BWRPD is responsible for the STRIDE design which is currently being developed through C. F. Braun. BWRSD has responsibility for the requisitions plants and most of the areas of responsibility regarding seismic design. However, within BWRSD these responsibilities are diffused since some are assigned to development, others to design engineering, with essential responsibility assigned to the responsible design engineer even though he may not be sufficiently cognizant of the "state of the art" design basis that is characteristic of seismic design.

The component of BWR/6 having the smallest seismic margin for the present method of RPV support is the fuel. The fuel-spacer-channel combination is required to meet the 0.3g ground acceleration seismic requirements. Since it has been difficult to design the spacer to meet seismic margin together with thermal and nuclear design requirements, there is question whether the BWR/6 design would meet seismic conditions for sites where the requirements are in excess of 0.3g. Because many models (mostly analytical) and not many tests have been used to establish this seismic design, future tests will be required to verify adequacy should it be discovered that one of the models exercised in the fuel performance trade-off study is inadequate. While the seismic analyses have concluded that the fuel-spacer-channel design is adequate for 0.3g, tests performed for 0.3g seismic conditions indicate some deformation which is not in accordance with the design criteria, therefore, the criteria, test conditions or the spacer design must change.

In many cases, seismic requirements are specified by GE for GE supplied equipment but the A/E has control over how (or if) the requirements are met.

The PWR design is inherently more seismic resistant because of lower reactor vessel placement and the need to design for larger LOCA loadings.

4.4.4 Radiological Contamination

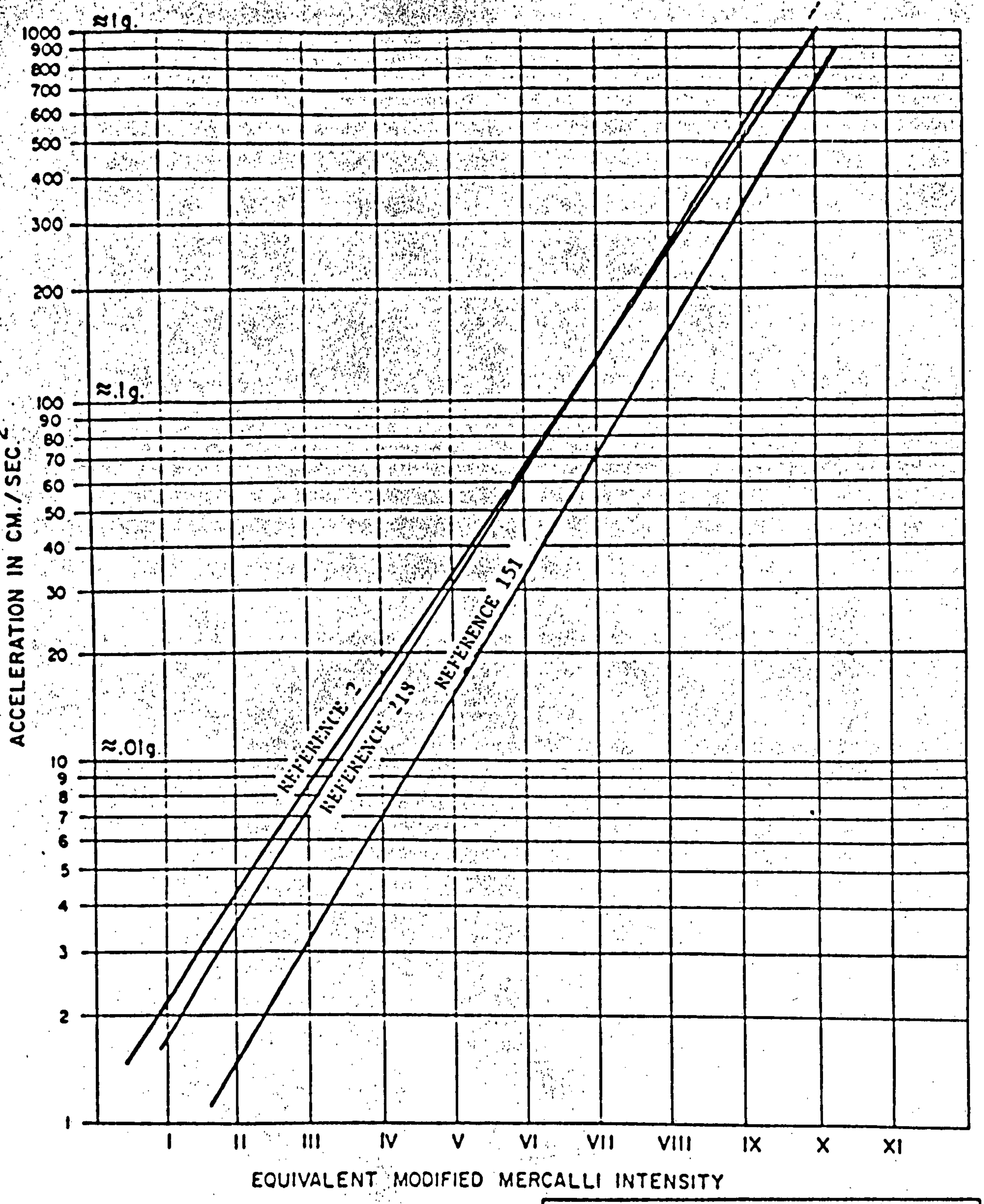
Finding:

The uncovered suppression pool of Mark III causes Mark III to be more susceptible than previous designs to loss of availability due to present occupational dose limits and a fortiori to more stringent regulations which are anticipated. Mark I and Mark II designs may also be affected by increased difficulty in performing required maintenance and backfit if required.

TABLE 1

Relationship	Reference	Io for mb=mbLg=6.5
mbLg= 0.49Io + 1.66 or Io= 2.04 mbLg - 3.39	Eq. 8, p. 605 of Street & Turcotte	9.87
Io= 2.07 mb - 3.97	Eq. 16a, p. 15 of NUREG/CR-3839	9.49
Io= 1.98 mb - 3.41	Eq. 16b, p. 15 of NUREG/CR-3839	9.46
Io= 2 mb - 3.5	Eq. 19, p. 18 of NUREG/CR-3839	9.5
Io= 2.16 mbLg - 4.4	p. A-67 of NUREG/CR-3756	9.64
mb= 0.44 + 0.67 Io or Io= 1.49 mb -0.657	p. A-75 of NUREG/CR-3756	9.03

Mean Io = 9.5



PERRY NUCLEAR POWER PLANT
THE CLEVELAND ELECTRIC ILLUMINATING COMPANY

Intensity Acceleration Relationships

Figure 2.5-74