EIGHTEENTH QUARTERLY REPORT

CEI Seismic Monitoring Network
April 1 Through September 30, 1991

Prepared for

CLEVELAND ELECTRIC ILLUMINATING COMPANY

February 1992

Weston Geophysical
CORPORATION

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1.0 INTRODUCTION

In accordance with its agreement with the U.S Nuclear Regulatory Commission, Cleveland Electric Illuminating (CEI) continues to monitor the seismic activity in a restricted region of Northeastern Ohio, encompassing the locale of the Perry Nuclear Power Plant, two deep injection wells operated by ICI Americas Inc., (formerly CALHIO), and the epicentral area of the January 31, 1986 earthquake. This eighteenth Quarterly Report covers the monitoring period from April 1 to September 30, 1991. In addition, Appendix A provides the volumetric data from the two injections wells for the two quarters; Appendix B gives a brief summary of the efforts made by CEI to verify the seismic crustal model used in its routine hypocentral determination.

This report also includes a summary of the conclusions reached since 1986 when CEI began its seismic monitoring. After almost six years of investigations, CEI believes it has acquired the data necessary to answer the original questions, and that further monitoring at the same low level will not add any substantial new information.

2.0 SEISMIC NETWORK

During the second and third quarter of 1991, the Automated Seismic Telemetering Recording System (AUTOSTAR) and the Geneva station performed with their usual reliability; the total uptime percentage was 93%. Most of the downtime was caused by telephone line problems.

3.0 OBSERVED SEISMICITY

3.1 Epicentral Area of the January 31, 1986 Earthquake

There was no seismic activity observed in the Leroy area during the six months of this monitoring period. For sake of review, Figure 1 and Table 1 presenting the cumulative observations since the main shock of 1986 are included.

3.2 The Corridor between the January 31, 1986 epicenter and the Injection wells.

During the six month period, several (10) small events occurred in the cluster located east and southeast of the injection wells. The two largest occurred on May 31, (Mc = 1.6 and 1.3), in the northeast corner of the cluster. Two very small ones (Mc = 0.1 and -.2) on September 24 and 27 were located within one kilometer north of the wells. The six others, with Mc between -0.4 and 1.2 occurred to the southeast of the wells. Figure 2 shows the activity observed during the six month period. The location parameters are included on Table 2 which lists all events recorded in this area and immediate vicinity since 1986.

3.3 Other events recorded by AUTOSTAR.

AUTOSTAR triggered on a 4.2 mblg earthquake from the Western Quebec zone on June 16 and on a 3.9 mblg from New York state on June 17. One event from the Ashtabula source (Mc=1.7) was recorded on May 2. A similar size event occurred on July 2, about 16 km east of Ashtabula. As in the past, some low level activity (Mc=0.3 and 1.6) was observed in the Lake, but the location accuracy for these small events outside the network aperture is not as good. Finally, one small event (Mc=0.6) occurred in the Fairport Harbor area on June 16. Figure 3 presents the cumulative seismicity as observed by the CEI net since January 31, 1986. Table 3 lists all events since 1986 outside the network aperture for which locations were calculated.

4.0 DISCUSSION AND REVIEW OF DATA ACQUIRED SINCE THE BEGINNING OF THE SEISMIC MONITORING.

The activity observed during the present reporting period is very similar to the usual pattern and thus no special comments seem necessary.

In the Quarterly Report no.13 dated March 1990, a review of four years of observations was presented; it included a summary evaluation of the local seismicity, a discussion of a possible relationship to deep well injection, and CEI conclusions. The additional two years of monitoring have not changed the observed patterns of seismic activity; as a consequence the conclusions remain the same. A brief summary of these findings follows.

4.1 The Leroy earthquake of January 31,1986.

The seismic monitoring of the Leroy epicentral area during almost six years has confirmed that the Leroy earthquake was most likely a purely tectonic event, with no causal relationship to the deep injection of fluids taking place ten kilometers away to the north. This hypothesis had been proposed during regulatory hearings after the main shock, although it received only limited support at the time. To a large extent, the task of local seismic monitoring was imposed on CEI for the purpose of collecting local data that would either validate or disprove this hypothesis of induced seismicity.

The complete and accurate recording of the aftershock sequence followed by occasional small microearthquakes in the same epicentral area during the next four years (Table 1 and Figure 1) suggest that the Leroy seismic activity is very similar to what is observed in other areas of the Northeast where other magnitude 5 events have occurred and where the absence of injection wells or local reservoirs preclude the possibility of induced earthquakes. The magnitude 5.0 Leroy event had relatively few aftershocks, and most of them within a month. After a year, there was a long period of silence of eighteen months, suggesting the end of the sequence. Later, few isolated small events have occurred, none with aftershocks. This pattern seems characteristic of moderate size tectonic events in the East. It clearly contrasts with the seismicity pattern usually observed in several cases of induced seismicity, in which even smaller main shocks are followed by relatively large number of tremors.

Because of the low detection and location thresholds achieved by AUTOSTAR, CEI was able to compare several instances of induced seismic sequences occurring near Ashtabula with the local activity at Leroy. This comparative analysis was included in Quarterly Report no.13. In addition, several short and smaller sequences of what is most likely induced seismicity were observed in the vicinity of the Calhio wells. In all of these cases, the focal depths observed were all typically shallower (about two kilometers) than those associated with the Leroy source (between 5 and 6 kilometers). These comparisons lead to distinguishing two different seismic regimes, tectonic and induced.

Finally, a seismic gap that separates the activity at Leroy from other local events has been observed since the very end of 1986. The lack of continuity in the seismicity pattern observed between some small events that are probably associated with the injection wells

and the active Leroy area reinforces CEI's position expressed early on that the Leroy earthquake was purely tectonic and not induced by the distant injection wells.

In terms of local tectonics, CEI considers that the Leroy event occurred during a strain release at the corner of a small crustal block. The concept of small crustal blocks was gradually developed by observing the stereographic three-dimensional projection of the Leroy hypocenters (USAR 1992, Figure 2.5 - 69), certain lineations of small events occurring in the cluster associated with the ICI wells, and noting the multiplicity of short wavelength anomalies in the aeromagnetic data that are mostly influenced by relatively near surface geology.

4.2 The corridor between Leroy and the Calhio wells, including the immediate vicinity.

The hypothetical causal relation between the injection wells and the Leroy earthquake focused the attention on the corridor connecting the wells and the epicenter. When proposed, the hypothesis disregarded the fact that all microseismicity observed after the main shock was remarkably tightly clustered around the hypocenter, ten kilometers away. The frequently observed "smoking gun" trail was not present between the wells and the epicenter. On March 12, 1986, a very small event (Mc=-0.3) was detected by one digital unit of the USGS left near the wells. This occurrence was interpreted as supporting the hypothesis of induced seismicity. In consequence, CEI accepted the task to monitor the corridor between the wells and Leroy at the very low threshold of Mc= -.5. The temporary deployment of portable seismographs for monitoring the aftershocks was reconfigured to include this nortn-south corridor until a more permanent telemetered network could be installed in spring 1987.

On September 28,1986, a small event (Mc=0.3) was located five kilometers east of the wells. Over the next few months, other microearthquakes in the range -0.5 and 0.5 occurred in that same general area, at the average rate of one event per month, gradually forming a northeast trending cluster. With time, exceptions occurred south and north of the wells, but the expected north-south alignment never materialized. The largest Mc magnitude of these events surrounding the wells and vicinity never exceeded 1.9, during all six years.

For the purpose of investigating any possible causal relationship between the deep injection and the occurrence of small events, detailed information on the daily volumes of fluids

injected and the pressures used were obtained from CalHio. These data plotted against nearby seismicity were presented in the Quarterly Reports, starting with no. 4, and synthesized in Quarterly Report no.13. No clear temporal correlation was found, even taking into account some time lags required for diffusion. Although an occasional seismic event seemed to be related to a specific injection pulse, it was never possible to establish a one-to-one correlation valid for all observed events.

Despite the lack of a strict temporal correlation from which a cause-and-effect relation could be surely inferred, the fluid injection is still considered to be probably responsible, in some manner, for those events occurring in the vicinity around the wells, and for the group of events forming a northeasterly trending cluster about four kilometers to the southeast. This view is based on the spatial correlation and on the fact that all these events have roughly the same shallow focal depth, about 2 km, very similar to the injection depth (1.85 km), given the focal depth uncertainty. Since the Paleozoic-Precambrian interface is dipping gently to the southeast, fluid migration is facilitated in that direction. A system of fractures and joints usually pervasive in rocks subjected to various episodes of tectonism and several glaciation cycles can safely be postulated. This constitutes an adequate environment for pore pressure changes and reduction of the frictional forces to allow sudden releases of strain energy.

The close examination of the epicentral distribution of these events suggests indeed the presence of sublineations, possibly defining the boundaries of small crustal blocks. Minor readjustments between these blocks are most likely facilitated or triggered by the presence of fluids.

Another characteristic of these events suggesting that they are induced is the tendency of some events to cluster in the time domain. Such tendency has been observed near Ashtabula, OH where the July 13, 1987 sequence, considered induced by Armbruster et Al. (1987) took place. Since then, several other isolated short sequences have occurred there, comprising foreshocks, main shock, and aftershocks. This temporal distribution is usually not observed for small magnitude events that are purely tectonic.

4.3 Other events detected by CEI monitoring.

During the six years of operation, AUTOSTAR triggered several times on small events originating from the Fairport Harbor area near 41.75N and 81.25W, where deep and

shallow injection wells are located. Because of the close proximity, a causal relationship has been suspected; no attempt has been made to obtain daily logs for each of the injection wells and investigate potential temporal correlation.

Several events were located offshore. The largest one, Mc=3.5, occurred just few kilometers north of Euclid, a suburb of Cleveland, on January 26, 1991 and was discussed in Quarterly Report no.17. A small sequence of events (Mc=2.7) was recorded June 1988, just north of Painesville. Three smaller ones were also located north-northeast of Madison-on-the-Lake. The location accuracy of all these offshore events is variable with the distance from the network aperture, size of events, and azimuthal gap; given the small dimensions of the array, the location error may well be in the order of several kilometers at times.

One important fact learned from this local monitoring exercise is the confirmation of offshore seismicity on the basis of instrumental data. The historical record lists several tremors with inland locations along the lake shore, based on felt reports only. Some of these events may have occurred offshore, as suggested in Appendix 2D-D of the USAR. This fact was confirmed by the small earthquake that occurred offshore Euclid, on January 26, 1991. This event, studied in detail by CEI, was located offshore on the basis of instrumental data from the two networks. Yet, on the basis of intensity reports alone collected through a telephone survey, the exact epicentral location was not evident. In fact, without the instrumental data, the event could well have been mislocated inland by several miles. For example, the National Earthquake Information Service reported a maximal intensity V at Brecksville and Broadview Heights, more than twenty miles south of Euclid. The apparent randomness of these small offshore events seems to suggest again stress releases along boundaries of small crustal blocks, as supported by the short wavelength aeromagnetic anomalies. This conceptual model of small crustal blocks was discussed in Quarterly Report no. 13, in reference to a crisscross pattern of seismic lineations observed in the cluster of microearthquakes located east of the injection wells, and probably applies to a large portion of the site region.

Other significant observations include the recording and locationing of small events onshore, e.g. near Aurora, Willoughby, Fostoria, Madison-on-the-Lake, Ashtabula, Ohio, and also south of Erie, PA. Several of these new epicenters confirm historical locations based on felt reports only.

The triggering of AUTOSTAR on a multiplicity of events occurring in the vicinity of an injection well just east of Ashtabula was also enlightening. (See Quarterly Report no.15). Although the distance from the network aperture and the relative short dimensions of the network did not permit the detailed tracking of the spatial migration of the induced seismicity, the detection threshold was low enough to capture the temporal distribution of the events. The periodic pattern of brief seismic episodes provided a useful criterion to distinguish purely tectonic events from induced ones. The best example illustrating the contrast of the two seismic regimes: a Mc=2.8 occurring at Leroy on December 28, 1988 without any aftershock at all versus a Mc=2.8 at Ashtabula on August 1, 1989, followed by at least 12 events with Mc greater than 0.5 over a period of five days (Quarterly Report No. 15).

5.0 CONCLUSIONS

With almost six years of intensive seismic monitoring of the area encompassing the Perry Nuclear Power Plant, two ICI Americas deep injection wells, and the January 31, 1986 Leroy earthquake, with a highly sensitive network, CEI has gathered sufficient information to answer questions raised about the nature of the Leroy event and the local microseismicity.

First, the seismic activity in the Leroy area continued to remain extremely well contained in space around the main shock hypocenter. The aftershock sequence was relatively brief in time, as typical of other similar size tectonic events in the Eastern United States and Canada. In addition, the cluster of activity at Leroy has remained spatially isolated from other seismic events considered as probably induced. The corridor connecting the epicentral area and the two ICI Americas injection wells never developed as a seismic lineament, as hypothetically predicted. It is interesting to note that a long period of observations has corroborated the evaluation made by CEI one month after the main shock, i.e that the Leroy event was a natural tectonic event and not induced by injection. Equally relevant is the fact that Nicholson et al. (1988) of the USGS reached the same conclusion after a detailed study, using similar observations "to argue for a natural origin".

Secondly, the detailed monitoring of an area larger than the corridor revealed that some low level activity exists in the vicinity of the two wells, particularly to the southeast. Certain characteristics of this activity, such as the shallow focal depth, the temporal distribution, and the proximity to the wells suggest strongly a causal relationship, in the same manner

oruster et al.(1987) concluded the seismic activity near an injection well owned by Environmental near Ashtabula to be most probably induced. Injection depth and re near Ashtabula are almost identical to those used by ICI.

rdly, the occurrence of small events near injection wells in the Fairport Harbor area has so been suspected to be induced.

inally, several small earthquakes, some felt locally, have confirmed that low level activity, ossibly associated which minor readjustments of small crustal blocks suggested in the eromagnetic data, exists both onshore and offshore, as suspected in CEI original ssessment of the historical seismicity. (Appendix 2D-D of USAR)

.0 ACKNOWLEDGEMENT

EI and Weston Geophysical are grateful to Rev. W.R. Ott, S.J. of the John Carroll Jniversity Seismological Observatory for contributing data from his network. Considering he small aperture of CEI's network, the additional data are critical to the locationing of everal events.

TABLES

Table 1

AFTERSHOCK PARAMETERS OF THE JANUARY 31, 1986 EARTHQUAKE *

	YEARMODY	HRMISEC	LATITUDE	LONGITUDE	DEPTH	NP	GAP	RMS	ERH	ERZ	Mc
1.	19860201	185449.35	41N38.67	81W 9.17	4.35	20	94	.09	.3	.5	1.5
2.	19860202	32248.67	41 38.72	81 9.55	4.86	37	72	.07	.1	.2	.9
3.	19860203	194719.77	41 38.92	81 9.48	5.83	52	75	.08	.2	.2	2.0
4.	19860205	634 2.47	41 38.90	81 9.27	3.73	31	52	.08	.2	.3	.1
5.	19860206	183622.44	41 38.72	81 9.61	5.[illegible]0	50	47	.07	.1	.2	2.5
6.	19860207	152020.38	41 39.03	81 9.22	3.76	44	42	.07	.1	.3	1.1
7.	19860210	200613.61	41 39.10	81 9.39	4.73	29	70	.06	.1	.4	.8
8.	19860223	32948.50	41 39.18	81 9.09	5.48	22	76	.06	.2	.4	-.1
9.	19860224	1655 6.48	41 38.85	81 9.60	3.25	10	91	.09	.5	2.7	.1
10.	19860228	13934.21	41 39.23	81 9.61	3.91	12	91	.06	.3	.5	-.1
11.	19860308	204249.68	41 38.67	81 9.20	3.12	20	65	.10	.3	.7	-.1
12.	19860324	134241.24	41 38.43	81 9.11	5.30	11	80	.06	.3	.8	1.4
13.	19860410	65805.71	41 38.91	81 9.55	5.11	22	63	.08	.2	.3	-.1
14.	19860617	221633.20	41 38.91	81 9.55	3.40	16	93	.09	.3	.8	.8
15.	19860714	075423.12	41 38.68	81 9.13	4.93	12	99	.08	.3	.8	.3
16.	19870212	011056.67	41 39.10	81 9.11	3.87	13	186	.09	.8	1.0	1.8
17.	19880805	222632.99	41 39.07	81 9.11	4.60	12	170	.04	.2	.3	0.1
18.	19881011	063132.33	41 39.20	81 8.78	5.33	13	147	.04	.2	.3	-.2
19.	19881228	232824.52	41 38.17	81 9.97	5.87	18	90	.05	.1	.2	2.8
20.	19900901	135054.46	41 38.87	81 9.09	4.56	17	82	.05	.2	.3	1.5
21.	19910117	071153.29	41 39.33	81 8.91	6.13	8	159	.02	.1	.2	-.2

Vp1=4.25 km/s Thickness = 2 km
Vp2=6.5 km/s Thickness = 33 km

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Vp/Vs=1.78

* The more recent events may not be true aftershocks

Table 2

MICROEARTHQUAKES INSIDE THE MICRONET APERTURE OR IN THE IMMEDIATE VICINITY
(2/1986-9/1991)

NO.	YEAR	MODY	HRMISEC	LAT.N	LONG.W	D	RMS	EH	EZ	NP	NS	GAP	MC	SD	TR.NO.
1.	1986	0312	085526.6	41.7272	81.1707	2.0	0.06	0.7	0.4	10	6	216	-.3	GS	
2.	1986	0928	103604.2	41.7247	81.1091	2.3	0.04	0.3	0.4	11	6	174	.3	WG	
3.	1986	1020	105944.7	41.7587	81.1453	3.0	0.07	1.7	2.0	6	4	337	-.6	WG	
4.	1986	1027	122555.5	41.7435	81.0944	2.9	0.07	2.7	1.5	6	3	221	-.2	WG	
5.	1986	1103	085449.6	41.7098	81.1292	1.8	0.06	0.5	0.5	7	5	145	.3	WG	
6.	1986	1201	050317.5	41.7120	81.1195	2.1	0.07	0.6	5.8	7	5	188	-.2	WG	
7.	1987	0102	024114.8	41.7472	81.1027	2.0	0.06	0.3	0.5	10	6	174	.6	WG	
8.	1987	0128	235829.8	41.7399	81.0974	2.1	0.03	0.4	0.7	8	5	199	-.7	WG	
9.	1987	0223	114556.4	41.7284	81.1197	2.0	0.03	0.1	0.3	10	7	100	.5	WG	
10.	1987	0228	204644.5	41.7451	81.0932	2.4	0.07	1.0	1.7	7	4	239	-.4	WG	
11.	1987	0501	211332.3	41.7466	81.0872	1.9	0.06	0.3	0.2	7	4	196	-.6	WG	
12.	1987	0501	211352.1	41.7466	81.0921	2.4	0.08	0.2	0.8	15	9	100	1.3	WG	363
13.	1987	0502	183307.7	41.7475	81.0932	2.0	0.02	0.1	3.0	6	4	174	-.6	WG	
14.	1987	0502	202526.5	41.7424	81.0889	2.7	0.08	0.3	0.6	14	8	115	.4	WG	366
15.	1987	0708	034835.2	41.7392	81.1037	2.7	0.07	0.7	1.1	8	5	166	-.2	WG	
16.	1987	0815	052637.7	41.6994	81.1472	2.8	0.06	0.2	1.0	10	6	133	-.1	WG	1061
17.	1987	1010	000610.4	41.7430	81.1030	1.9	0.04	0.3	0.2	7	5	166	-.5	WG	
18.	1987	1014	195924.8	41.7250	81.1318	3.4	0.04	1.6	0.7	6	3	190	-.7	WG	
19.	1987	1122	024918.9	41.6989	81.1447	2.2	0.04	0.2	3.8	9	5	120	-.1	WG	1720
20.	1988	0116	22403.	*41.747	81.098						2		-.6	WG	
21.	1988	0116	223010.	*41.747	81.098						3		-.6	WG	
22.	1988	0116	231704.4	41.7474	81.0981	2.0	0.05	0.5	0.3	9	5	185	1.8	WG	1879
23.	1988	0117	024821.7	41.7467	81.0997	1.9	0.06	0.5	0.3	10	5	180	0.5	WG	1881
24.	1988	0117	092236.	*41.747	81.098						3		-.6	WG	
25.	1986	0117	092400.	*41.747	81.098						2		-.6	WG	
26.	1988	0117	131551.	*41.747	81.098						2		-.6	WG	
27.	1988	0205	155837.0	41.7351	81.0907	2.0	0.04	0.4	0.2	10	5	195	0.5	WG	1971
28.	1988	0820	005423.1	41.7026	81.1121	2.4	0.05	0.2	1.6	8	4	162	-.2	WG	3011
29.	1988	0927	154639.1	41.7716	81.1334	3.2	0.03	0.2	0.3	11	6	292	0.1	WG	3076
30.	1988	1022	201132.9	41.7150	81.0578	2.5	0.06	0.3	0.7	13	7	193	0.1	WG	3136
31.	1988	1031	063428.7	41.7290	81.1035	2.1	0.04	0.2	0.5	10	5	120	.0	WG	3412
32.	1988	1103	190335.4	41.7133	81.1232	2.1	0.05	0.2	7.9	9	5	126	-.2	WG	3437
33.	1988	1205	055514.9	41.7578	81.1538	2.4	0.06	0.5	0.7	7	4	279	0.0	WG	3525
34.	1989	0103	120244.5	41.7287	81.1328	2.1	0.06	0.2	11.0	8	5	226	-.1	WG	3623
35.	1989	0130	032527.0	41.7018	81.1846	2.0	0.04	0.4	18.2	10	6	182	-.2	WG	3661
36.	1989	0130	185020.8	41.7334	81.0983	2.0	0.04	0.2	0.4	11	5	155	-.2	WG	4663
37.	1989	0309	033045.8	41.7105	81.0581	2.0	0.04	0.2	15.1	13	8	187	0.6	WG	5719
38.	1989	0310	165722.4	41.7107	81.0585	1.9	0.04	0.2	0.1	10	6	186	-.2	WG	5725
39.	1989	0312	192349.6	41.7113	81.0596	2.0	0.04	0.2	13.2	13	8	185	0.1	WG	5729
40.	1989	0322	201335.9	41.7269	81.1545	2.1	0.03	0.1	1.4	16	9	119	1.9	WG	5770
41.	1989	0530	142039.6	41.7188	81.1223	2.1	0.04	0.1	3.0	7	4	115	-.4	WG	5953
42.	1989	0719	085451.1	41.7261	81.1542	2.1	0.05	0.1	2.0	16	8	161	.9	WG	4132
43.	1989	1002	071123.5	41.6981	81.1447	2.2	0.04	0.2	4.7	8	5	163	-.3	WG	4415
44.	1990	0331	025526.6	41.7303	81.1001	2.0	0.05	0.3	0.6	9	5	134	-.2	WG	4938
45.	1990	0505	212924.0	41.7111	81.0556	2.1	0.03	0.2	1.5	13	8	194	.2	WG	5086
46.	199C	0519	222828.5	41.6901	81.1269	2.1	0.05	0.2	13.0	8	5	153	-.2	WG	5153
47.	1990	0522	140632.2	41.7026	81.1119	2.2	0.05	0.3	3.9	9	5	162	.3	WG	5159
48.	1990	0526	120735.4	41.7300	81.0774	2.3	0.03	0.2	0.2	10	5	236	.1	WG	5198
49.	1990	0812	102352.0	41.7340	81.0761	2.3	0.02	0.1	0.2	10	5	237	-.2	WG	5480
50.	1990	1021	132813.8	41.7113	81.0552	2.0	0.04	0.1	0.2	13	8	195	.5	WG	5795
51.	1990	1022	122847.5	41.7127	81.0545	2.0	0.04	0.2	3.0	14	9	146	.2	WG	5796
52.	1990	1112	142426.6	41.7125	81.0589	2.3	0.03	0.3	0.9	9	5	250	.3	WG	5919
53.	1991	0424	091108.5	41.7052	81.1254	2.3	.04	0.2	2.9	9	5	137	0.2	WG	7022
54.	1991	0531	210145.3	41.7550	81.0592	2.2	.04	0.2	3.5	12	7	143	1.6	WG	7149
55.	1991	0531	212808.8	41.7562	81.0580	2.1	.04	0.2	9.3	12	7	144	1.3	WG	7150
56.	1991	0604	053615.5	41.7283	81.1315	2.1	.05	0.2	2.5	9	5	120	0.5	WG	7162
57.	1991	0726	214949.9	41.7229	81.0959	2.0	.05	0.3	0.4	10	5	141	0.4	WG	7453
58.	1991	0727	011739.1	41.7227	81.0952	2.0	.05	0.3	0.4	10	5	146	0.2	WG	7454
59.	1991	0731	093948.3	41.7256	81.1227	1.9	.06	0.3	0.2	10	5	100	1.2	WG	7466
60.	1991	0916	152956.3	41.6967	81.1469	2.8	.06	0.2	1.5	8	5	161	-.4	WG	7558
61.	1991	0924	230021.3	41.7579	81.1522	2.2	.06	0.3	0.6	10	5	179	0.1	WG	7564
62.	1991	0927	174549.9	41.7575	81.1525	2.3	.06	0.3	0.5	10	5	179	-.2	WG	7567

* Indicates location by inference

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Table 3

MICROEARTHQUAKES OUTSIDE THE CEI MICRONET APERTURE
(2/1986-9/1991)

YEARMODY	HRMISEC	LAT.N	LONG.W	D	RMS	EH	EZ	NP	NS	GAP	MC	LOCATION	TR.NO
19861224	093733.9	41.7487	81.2392	1.0	0.04	8.5	6.7	6	3	306	0.3	FAIRPORT H.	
19870228	113833.8	41.6200	81.4400	2.5	0.10	0.5	4.9	13	8	247	1.4	WILLOUGHBY	
19870618	103057.3	41.5146	80.3859	3.0	0.80	1.4	23.	13	7	345	2.7	NW. PA	725
19870713	054917.3	*41.903	80.738								3.6	ASHTABULA	805
19871219	1156	41.903	80.738								2.0	ASHTABULA	1807
19871225	0828	41.903	80.738								2.2	ASHTABULA	1822
19871229	072226.9	41.7485	81.2640								1.2	FAIRPORT H.	1832
19880331	1630	41.3147	81.0479								2.8	NELSON,OH	2599
19880420	165127.9	41.7738	81.3085	3.3	0.05	0.2	2.0	16	10	221	1.4	OFFSHORE	2652
19880627	044631.3	41.8180	81.2293	2.2	0.06	0.2	7.4	22	11	239	2.7	OFFSHORE	2812
19880627	0447	41.8180	81.2293								0.2	OFFSHORE	
19880627	044826.0	41.8180	81.2293								1.7	OFFSHORE	2813
19880627	0655	41.8180	81.2293								-.1	OFFSHORE	
19880627	072940.0	41.8180	81.2293								1.3	OFFSHORE	2814
19880627	082908.0	41.8180	81.2293								0.7	OFFSHORE	2815
19880722	160902.1	41.7575	81.2496	2.1	0.05	0.4	19.	10	5	274	-.1	FAIRPORT H.	2900
19880930	172556.9	41.7500	81.2500	1.9	0.02	2.8	2.2	6	4	306	0.1	FAIRPORT H.	3081
19881225	021124.9	41.8305	81.0296	1.1	0.03	1.0	0.8	13	9	299	2.4	MADISON	3610
19890325	233507.9	41.7468	81.2653	2.2	0.06	0.3	15.	14	9	115	0.3	FAIRPORT H.	3786
19890615	164751.6	41.7475	81.2570	2.0	0.04	0.3	17.	11	6	278	0.4	FAIRPORT H.	4023
19890721	052202.4	41.7485	81.2595	1.7	0.03	0.7	0.5	9	5	280	0.2	FAIRPORT H.	4134
19890801	161248.6	+41.903	80.738								2.8	ASHTABULA	4170
19890811	115354.3	41.8378	81.0192	2.0	0.03	0.3	14.	9	5	320	1.2	MADISON H.	4211
19891019	224300.5	41.7462	81.2612	2.0	0.03	0.2	0.2	13	7	182	0.4	FAIRPORT H.	4458
19891206	123618.3	41.7476	81.2533	2.0	0.05	0.4	24.	10	6	276	0.2	FAIRPORT H.	4522
19891221	153915.4	41.7726	81.2477	2.2	0.04	0.6	20.	6	5	352	0.3	FAIRPORT H.	4600
19900526	095118.9	41.7498	81.2624	2.4	0.04	0.2	3.8	13	8	186	1.3	FAIRPORT H.	5197
19900713	1914	41.903	80.738								1.5	ASHTABULA	5369
19900724	2304	41.903	80.738								2.1	ASHTABULA	5405
19900805	025348.8	41.7590	81.2501	2.6	0.03	0.2	1.9	8	4	307	.2	FAIRPORT H.	5457
19900926	0613	#41.903	80.738								2.3	ASHTABULA	5683
19901004	040303.7	41.7831	81.2123	6.9	0.05	0.6	1.0	9	5	262	-.4	OFFSHORE	5732
19901109	224833.2	41.7472	81.2493	2.5	0.03	0.2	2.4	13	8	268	1.7	FAIRPORT H.	5910
19901207	04/318.6	41.9641	81.0155	3.0	0.03	0.4	3.8	13	9	324	1.3	OFFSHORE	6001
19901217	072248.5	41.9530	80.1220								2.5	ERIE, PA.	
19910126	032124.4	41.5995	81.5983	1.0	.04	7.2	6.2	10	5	337	3.5	OFFSHORE	6173
19910225	011254.3	41.9215	81.1250	1.5	.02	4.9	4.2	10	5	339	0.3	OFFSHORE	6237
19910312	085048.9	41.3468	81.4055	9.4	.14	4.2	12.	9	5	350	2.3	AURORA, OH	6266
19910423	204938.9	41.9560	81.0111	1.0	.05	26.	26.	9	5	347	0.3	OFFSHORE	7021
19910502	1109	41.903	80.738								1.7	ASHTABULA	7051
19910616	095600.6	41.7625	81.2483	2.7	.04	0.4	3.6	10	5	275	0.5	FAIRPORT H.	7252
19910	124451.1	41.964	80.575	2.1	.05	1.2	24.	8	4	344	1.9	E OF AHSTA	7345
19910	125316.8	41.7732	81.3133	2.1	.04	0.3	16.	10	5	303	1.6	OFFSHORE	7428

* This event had more than 50 aftershocks. See Armbruster et al. 1987.
All Ashtabula events are assumed to be at the same location near the injection well.

\+ Thirteen event sequence

\# Five event sequence

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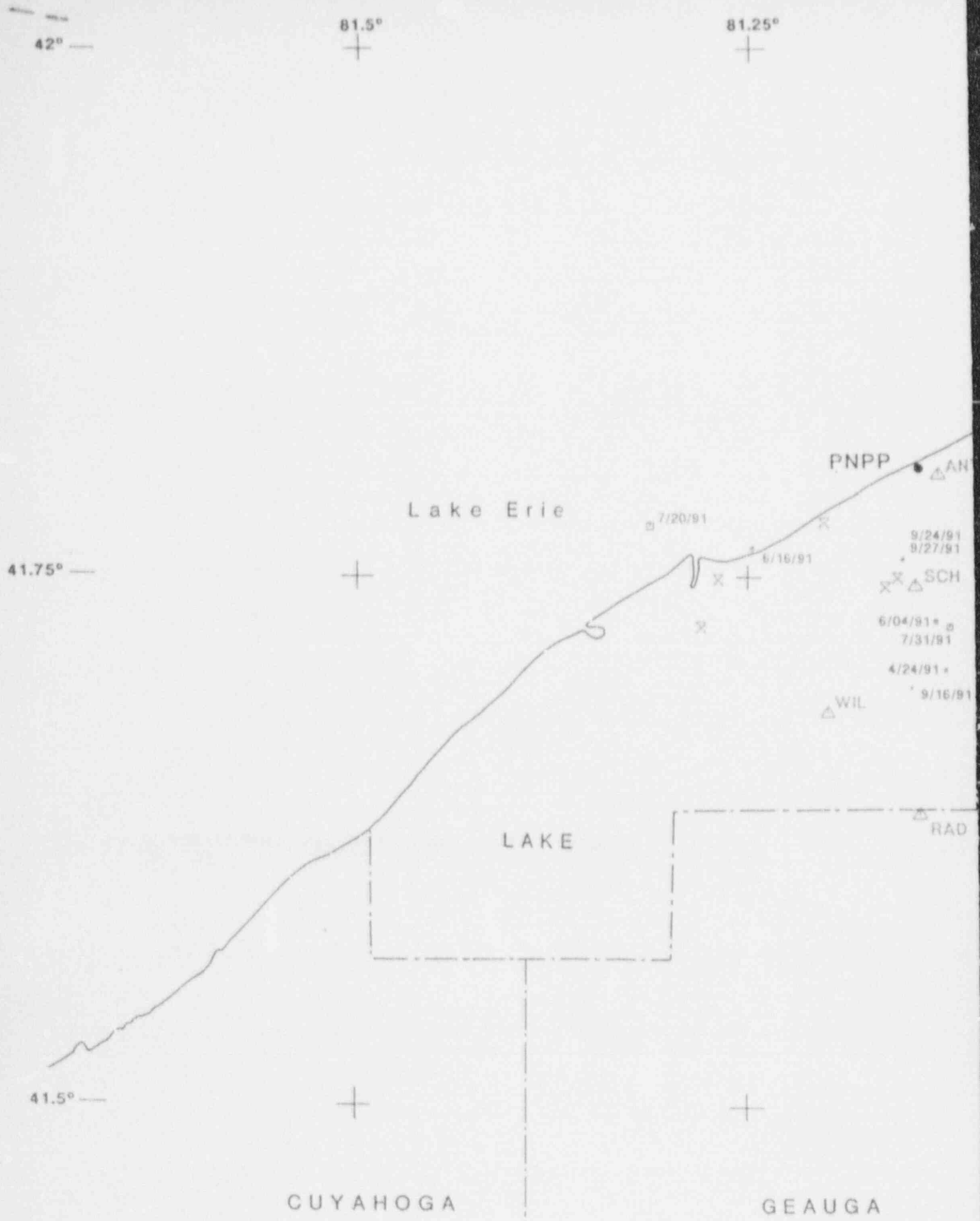
FIGURES

Note:
See Table 1 for identification of events.

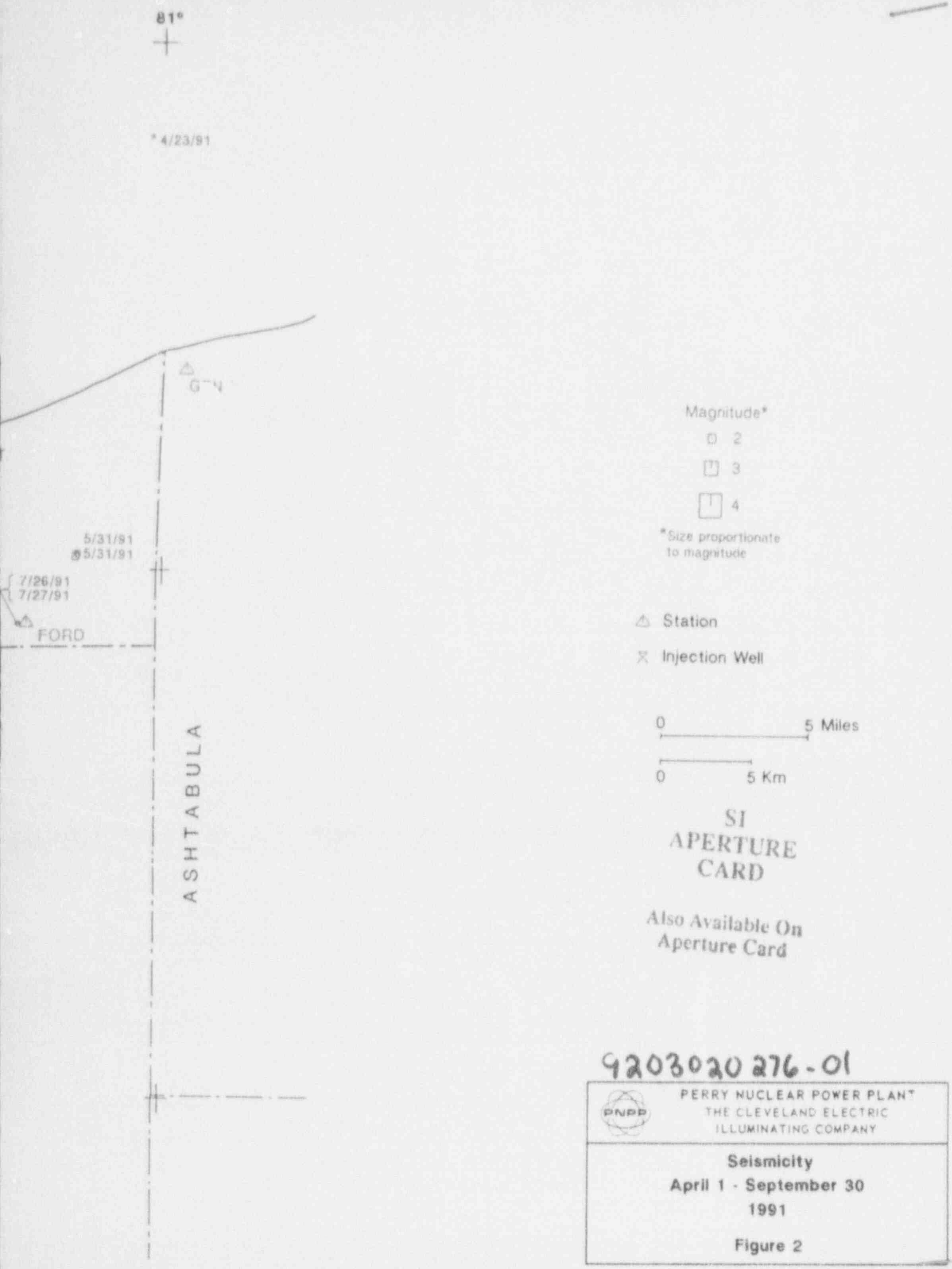
PERRY NUCLEAR POWER PLANT
THE CLEVELAND ELECTRIC
ILLUMINATING COMPANY

January 31, 1986
Aftershock Sequence

Figure 1



42°
81.5°
81.25°
PNPP
AN
Lake Erie
7/20/91
9/24/91
9/27/91
6/16/91
41.75°
SCH
6/04/91
7/31/91
4/24/91
9/16/91
WIL
LAKE
RAD
41.5°
CUYAHOGA
GEAUGA

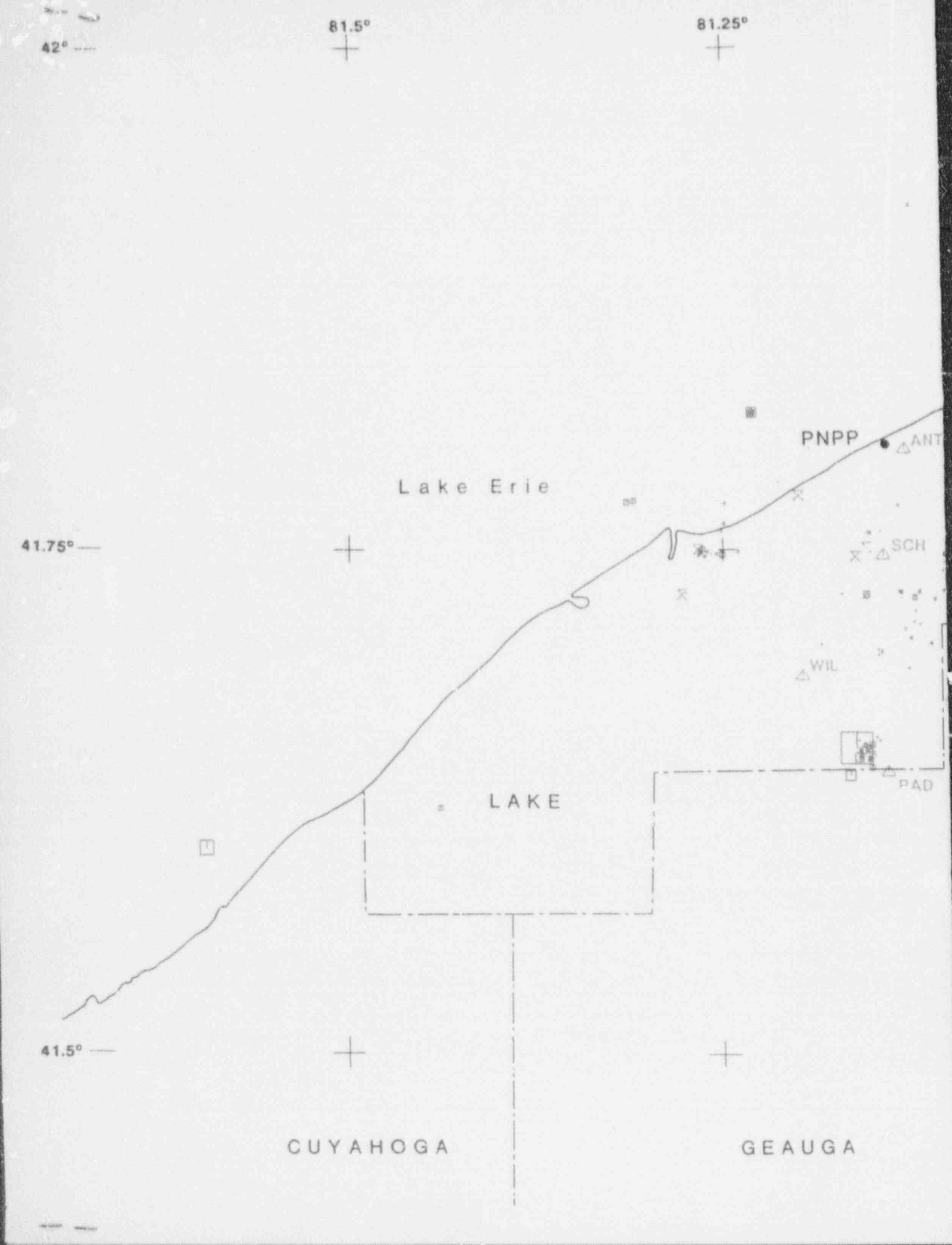


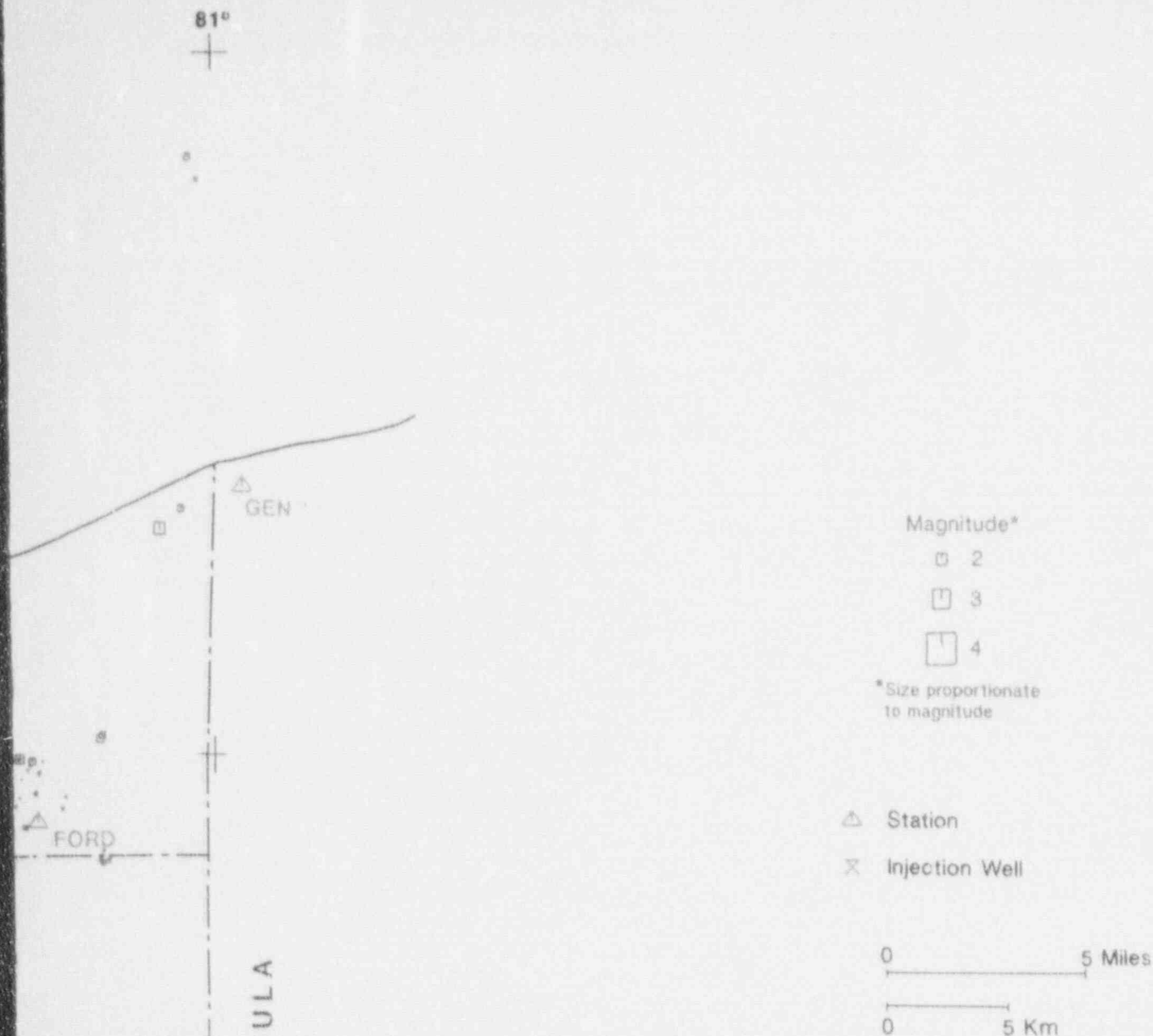
9203020276-01

PERRY NUCLEAR POWER PLANT
THE CLEVELAND ELECTRIC
ILLUMINATING COMPANY

Seismicity
April 1 - September 30
1991

Figure 2


81.5°
81.25°
42°
PNPP
ANT
Lake Erie
41.75°
SCH
WIL
PAD
LAKE
41.5°
CUYAHOGA
GEAUGA

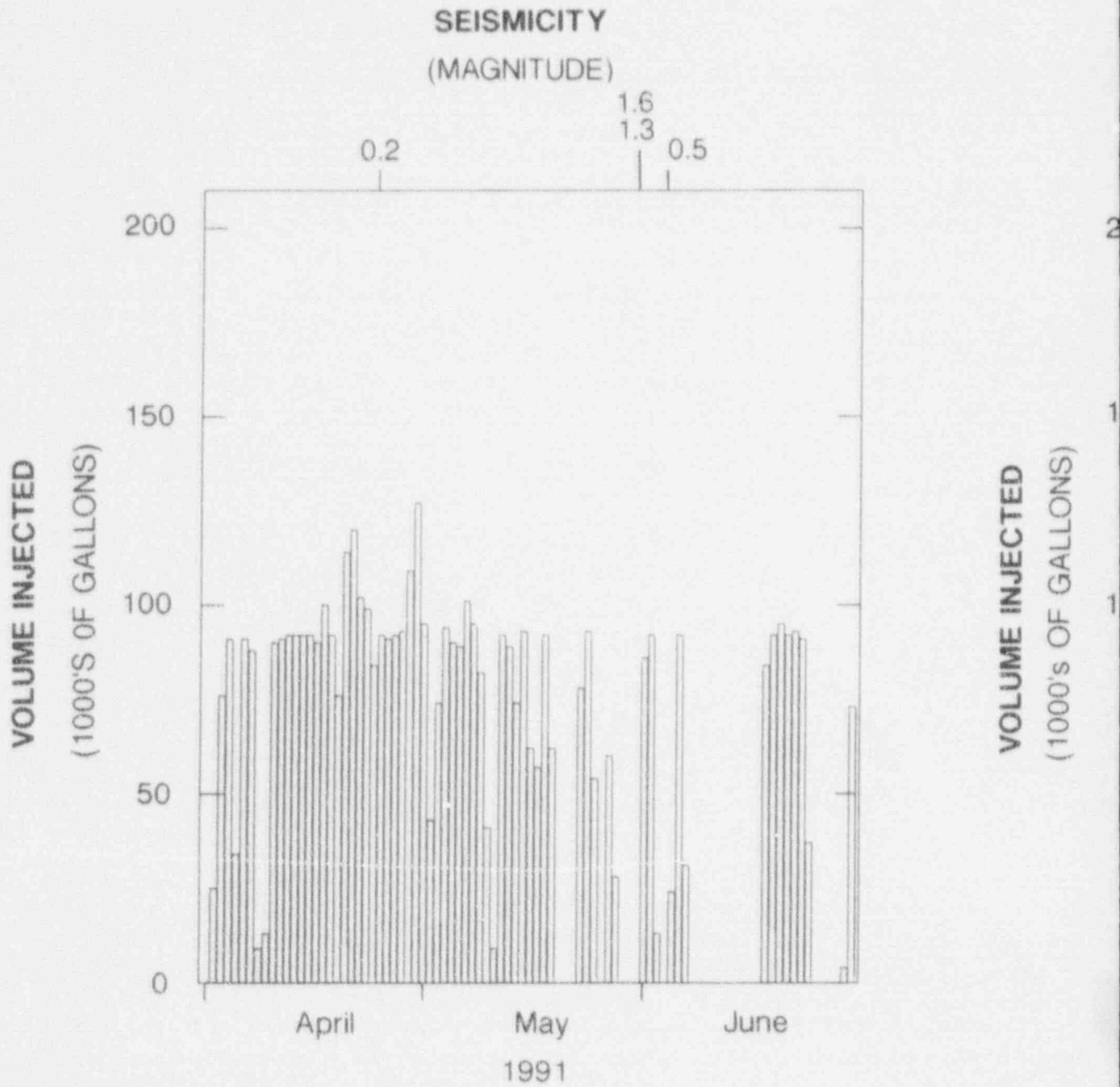


PERRY NUCLEAR POWER PLANT
THE CLEVELAND ELECTRIC
ILLUMINATING COMPANY

Cumulative Seismicity
1/31/86 - 9/30/91

Figure 3

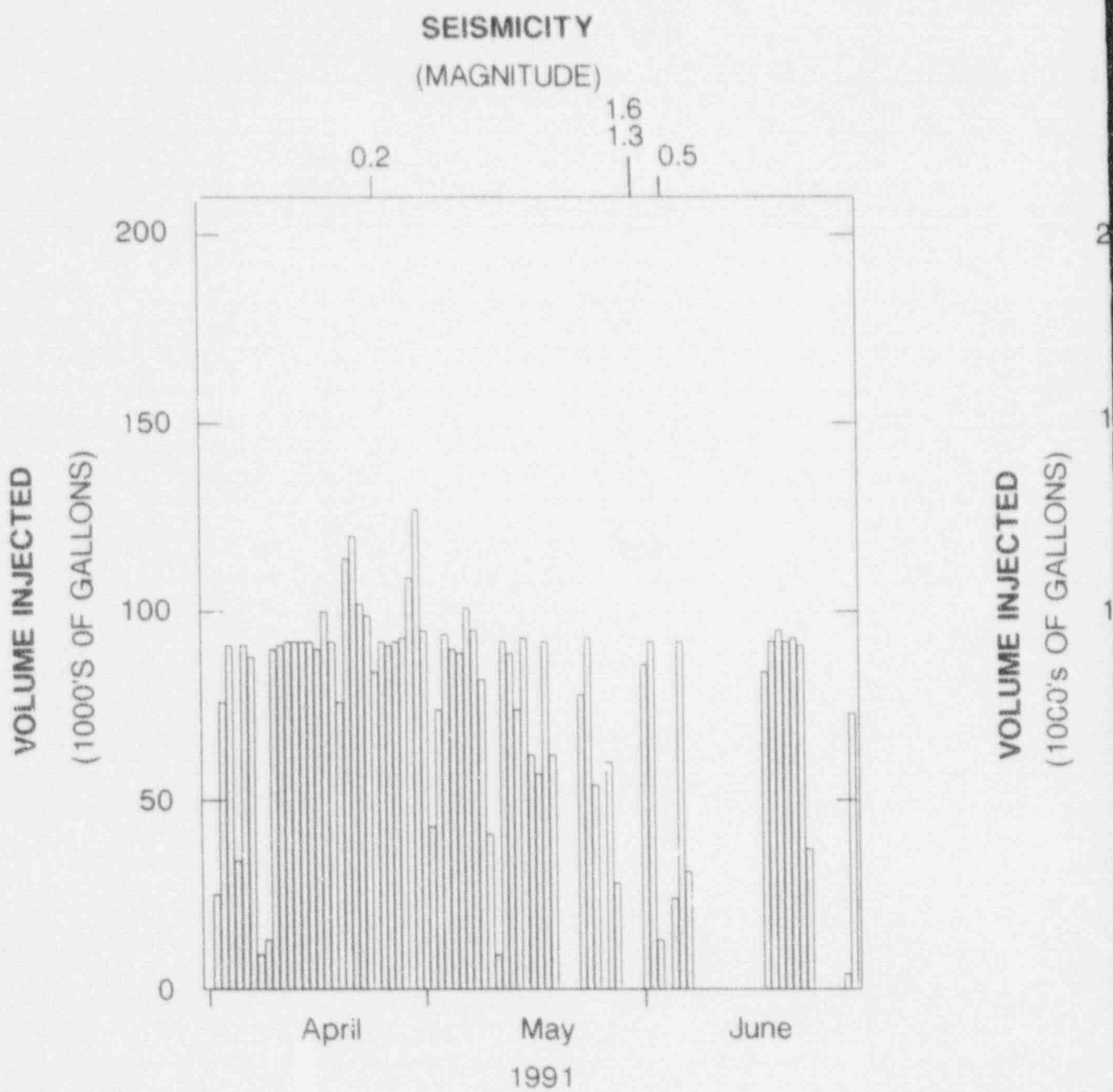
APPENDIX A



Solid lines represent Well #1

Dashed lines represent Well #2

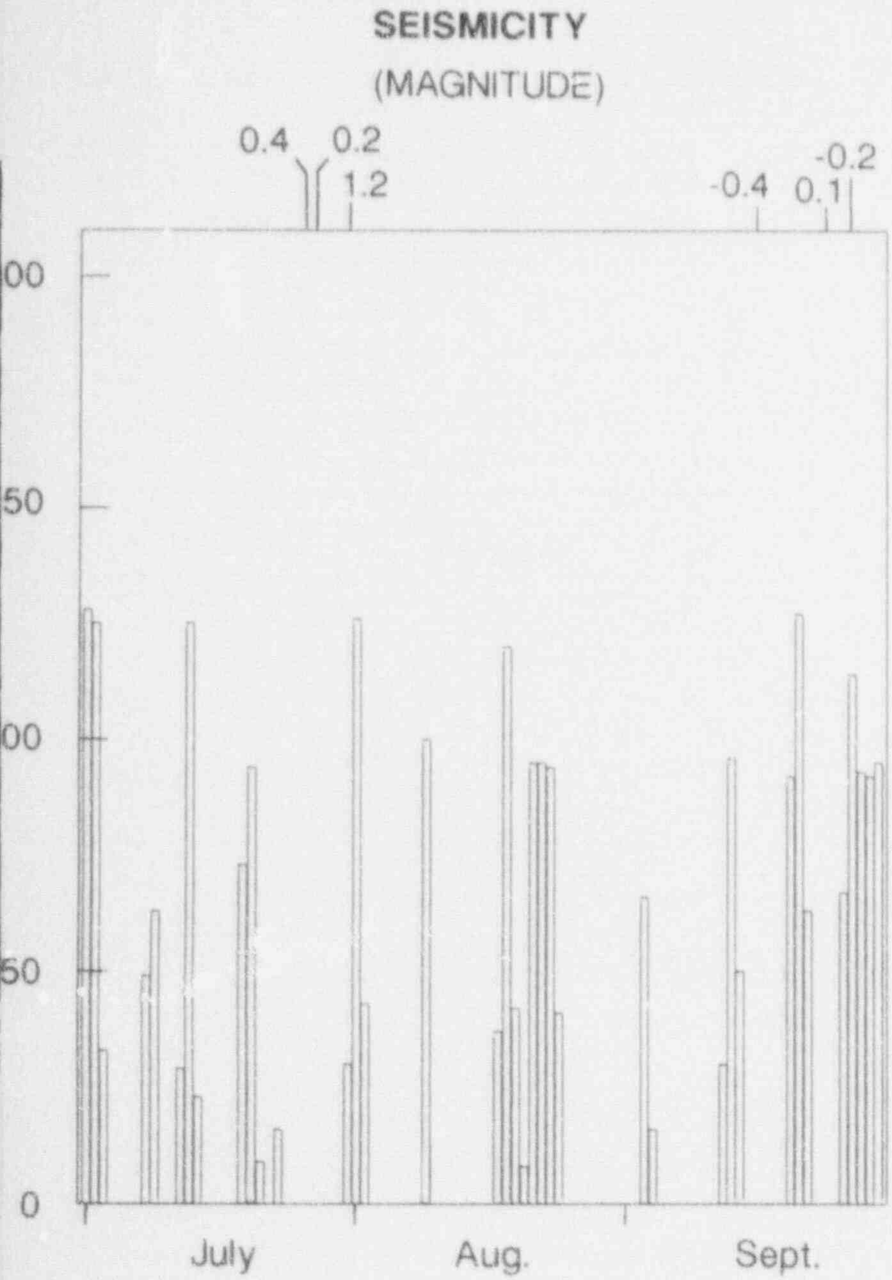
Data provided by ICI Americas, Perry, Ohio



Solid lines represent Well #1

Dashed lines represent Well #2

Data provided by ICI Americas, Perry, Ohio



9203020276-03

PERRY NUCLEAR POWER PLANT
THE CLEVELAND ELECTRIC
ILLUMINATING COMPANY

Daily Injection Volume and
Observed Seismicity
1991

Figure A-1

APPENDIX B

CRUSTAL INVESTIGATIONS IN
LAKE AND GEAUGA COUNTIES, N.E. OHIO

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CRUSTAL INVESTIGATIONS IN LAKE AND GEAUGA COUNTIES, N.E. OHIO

1.0 INTRODUCTION

When Cleveland Electric Illuminating (CEI) assumed the task of monitoring the microseismicity of the corridor between two Calhio injection wells and the epicentral area of the January 31, 1986 earthquake, special efforts were made to obtain high quality data. Starting with the aftershock program, up to 13 portable stations were deployed in the epicentral area and immediate vicinity. Within a year, a permanent digital telemetered network was installed, with three-component borehole sensors placed on rock, and a station distribution symmetrical around the area of interest. Close cooperation with the operator of the John Carroll University seismic network was initiated, thus assuring an optimal pool of arrival times.

For processing the observed aftershocks and other local events, CEI consultant Weston Geophysical (WG) selected the first and simplest crustal model out of three available (Table B1). As pointed out by Nicholson et al. (1988), these models give similar results except for small variations in focal depth estimates. WG's preference was based on sensitivity tests and technical considerations, but still remained subject to further verification.

This appendix briefly summarizes a report on the activities undertaken over the last four years to assess the validity of the crustal model used (Weston Geophysical, September 1991).

2.0 DESCRIPTION OF THE CRUSTAL MODEL INVESTIGATIONS

2.1 Objectives and Approaches

The CEI network aperture is somewhat limited to the corridor between the two deep injection wells and the main shock epicentral area. The John Carroll University (JCU) regional network has a larger aperture. For the local seismicity monitored by the two networks, travel paths of first arrivals never reach the MOHO discontinuity at the base of the crust. For this reason, only velocities of the upper crust needed to be investigated with relatively short refraction profiles. The planned strategy called for very short refraction lines to investigate the near surface rocks, and longer profiles using data from both local quarries and nearby microearthquakes. Portable MEQ recorders were deployed on four

occasions to increase the number of data points collected, but the permanent stations of the two networks provided the bulk of usable data.

Figure B1 shows the locations of the two quarries used, BEST SAND and SIDLEY, and of the SCHneider site where two special explosions were detonated in an attempt to reverse a long profile between BEST SAND and ANTIOCH; it also gives blast dates, and station locations of two networks.

2.2. Difficulties Encountered

The main difficulty encountered regards the insufficient energy released by the quarry blasts and the two CEI explosions at Schneider. The distance between the BEST SAND quarry and ANTioch is about 28 km. Because of the many delays in the firing sequence, arrivals from both quarries were often emergent beyond 10 km. In addition, shot sizes at SCHneider were limited by the presence of nearby pipelines and residences; as a result, the crustal profile between BEST SAND and SCH could not be reversed. The deployment of portable stations at regular close spacing along the profile was abandoned after four attempts in 1988. Only data from the permanent network stations on selected larger quarry blasts were used in 1989 and 1990.

A second important difficulty came from the large uncertainty attached to arrival time readings due to the poor resolution offered by analog recorders, either because of drum speed or internal clock limitations. With a possible cumulative error as large as 0.2 sec for individual data points, the calculated velocities on the time-distance plots can have an uncertainty of about 0.2 km/sec. This is one order of magnitude less than what is obtained in formal crustal experiments using one or two thousand pounds of explosives and hundreds of digital recorders along reversed linear profiles.

A third difficulty resulted from the lack of shallow nearby local microearthquakes large enough to be seen at all stations. Deeper events do not give critically refracted arrivals and thus are not suitable for the current objective. Several events were examined but only a few were retained.

3.0 PRESENTATION OF THE RESULTS

3.1 Shallow Refraction Lines

Two short (2500 ft and 1800 ft) reversed profiles were shot on December 12, 1988 on the BEST SAND quarry floor and at SCHneider. Figures B2 and B3 indicate average velocities of 3.5 and 3.7 km/sec, values that agree with local surficial geology. Although thicknesses could not be formally calculated, boring logs suggest that 0.1 to 0.2 km estimates are realistic.

3.2 Long Refraction Lines

Although the long linear profile could not be reversed as originally planned, the apparent velocities of the Paleozoic and upper Precambrian horizons remain informative since the 2 km-thickness of the Paleozoic and the gentle regional dip of the interface to the southeast are already known from borings.

3.2.1 Quarry Blasts and SCH Explosions

Four blasts originating from the BEST SAND quarry were monitored, but only two were retained in last analysis. Figure B4 presents the results of the November 2, 1988 survey. The two velocities seen, 4.72 and 6.17 km/sec, are inferred to represent the Paleozoic and Precambrian rocks respectively. Figure B5 gives the results of the September 20, 1989 blast from which only a 6.25 km/sec velocity was read and assumed to be from the Precambrian horizon.

Two explosions made at the SCHneider site, on December 13 and 14, 1988, with limited explosives, provided information on the Paleozoic rocks only. Figures B6 and B7 present the respective results, 4.76 and 4.81 km/sec.

Only one of the two monitored blasts from the SIDLEY quarry provided usable data. Figure B8 shows the results of the March 26, 1990 blast, with a Paleozoic velocity of 4.67 km/sec.

3.2.2 Data from Local Microearthquakes

In view of the limited seismic energy generated by quarry blasts, several local microearthquake data sets were examined. Those selected had to be considered relatively shallow (about 2 km) and have a very stable solution. All Leroy aftershocks could not be used since they are relatively deeper (about 5 km); other locals within the CEI aperture were not large enough. The Madison-on-the-Lake event of December 25, 1988, with Mc=2.4 was the only one local retained. Figure B9 suggests that observed first arrivals yield a 6.33 km/sec apparent velocity over the distance range related to the Precambrian rocks.

Beyond the two network apertures, one relatively well located source is associated with the Ashtabula activity, considered to be induced by injection (Armbruster, et al. 1987). Three events recorded during the August 1989 sequence, assumed to be at the location and shallow depth determined by Armbruster for the main 1987 sequence, were examined. Figu.e B10 illustrates the relative consistency of three data sets, with a velocity of about 6.17 km/sec.

4.0 DISCUSSION

4.1 Inferred Crustal Model

Given all limitations previously mentioned, the modest experiment is expected to give relatively imprecise velocity estimates, with only a 0.2 km/sec accuracy, but still informative. With the data collected, a three layer model seems indicated, e.g., a thin surficial layer with a 3.5 km/sec velocity, a Paleozoic column of about 1.9 km with a velocity of 4.8 km/sec, and a Precambrian sequence with a velocity of 6.2 km/sec near the top.

To account for the velocity uncertainties, several variations of this basic model were tested to relocate the two quarry locations and the SCH site of two explosions. Tables B2 and B3 summarize a subset of the many tests performed on two recorded blasts from BEST SAND. It is interesting to compare the relocation accuracy obtained with the preferred three-layer model derived from the experiment with that of the two-layer model used since 1986. There is indeed a definite improvement. Similar tests for the SCHneider explosions and the SIDLEY blast confirm the same trend.

In view of the observed improvement in the quarry relocation tests, the preferred three-layer model was then used to relocate all observed microseismicity within or near the network aperture. Table B4 presents all relocation parameters for the Leroy aftershock sequence. This Table B4 should be compared with Table 1 of the present Quarterly Report where the old two-layer model is used. There is little change in the epicentral coordinates, as expected when the station configuration is somewhat symmetrical around the source. On the other hand, the focal depth is systematically increased by an average 0.3 km. This change is not substantial.

The effect of the three-layer model on the relocation of other events recorded by the network, even those sometimes outside the aperture, is similar: a pronounced tendency to increase the focal depth, usually by several tenths of a kilometer, a slight improvement in the RMS residuals and standard errors ERH.

5.0 CONCLUSION

Since the crustal model plays an important role in the hypocentral determination of observed seismic events, CEI has supported a modest experiment to validate the crustal model in use since the January 31, 1986 Leroy earthquake. The effort was spread over the last four years; except for four special deployments of portable MEQ analog recorders, all the data were collected by the permanent network stations recording several local quarry blasts, two especially made explosions, and some local microearthquakes.

The results of these crustal investigations have been very informative. Although several factors contributed to limit the accuracy of the collected data, nonetheless the observations were good enough to suggest that a three-layer model should be preferred to the two-layer model actually in use since 1986. This model separates the Paleozoic column in a thin surficial layer (0.1 km) and a thicker layer (1.9 km) with respective P-velocities of 3.5 and 4.8 km/sec. The Precambrian column is given a velocity of 6.2 km/sec, the same 33 km thickness being retained. Several tens of variations of this observed model were tested systematically in relocating known quarry blasts. The observed basic model consistently gave superior results in terms of location accuracy and RMS residuals.

In a final stage, all observed microseismicity either in the Leroy source area or within the two network apertures was reprocessed with the preferred three-layer model. The epicentral coordinates show only a minimal change, and as expected a systematic increase

in the focal depth estimates, 0.3 km in the average. These results are most encouraging; the epicentral changes are small enough to be negligible, and the systematic increase in focal depth does not appear to be substantial and have new tectonic significance. Consequently, conclusions reached previously need not to be modified.

6.0 REFERENCES

Armbruster, J.G., Seeber, L., and K. Evans (1987): The July 1987 Ashtabula earthquake (mb = 3.6) sequence in Northeastern Ohio and a deep fluid injection well; Abstracts of 59th annual meeting of E.S. of S.S.A.; St. Louis University, October 7-9.

Nicholson, C., Roeloffs, E., and R.L. Wesson (1988): The Northeastern Ohio Earthquake of January 31, 1986: Was it induced?; Bull. Seismol. Soc. America, vol. 78, pp. 188-217.

Weston Geophysical, 1991: Crustal Investigations in Lake and Geauga Counties, N.E. Ohio; prepared for Cleveland Electric Illuminating Co., September, 50 p.

TABLES

Table B-1

Depth (km)	Thickness (km)	*P* Velocity (km/s)	*S* Velocity (km/s)	Vp/Vs	Description*
0.0	2.00	4.25	2.53	1.68	Paleozoic section
2.00	99.00	6.50	3.87	1.68	Granitic basement
0.0	1.00	3.70	2.06	1.80	Upper Sedimentary
1.00	1.00	5.60	3.20	1.75	Lower Sedimentary
2.00	35.00	6.33	3.66	1.73	Granitic crust
37.00	99.00	8.10	4.68	1.73	Mantle
0.0	0.05	1.80	0.60	3.00	Glacial till
0.05	0.45	3.00	1.58	1.90	Devonian shale
0.50	0.50	4.20	2.33	1.80	Silurian dolomite
1.00	0.75	4.50	2.53	1.78	Ordovician limestone and dolomite
1.75	0.35	4.75	2.70	1.76	Cambrian sandstone and dolomite
2.10	17.90	6.15	3.54	1.74	Precambrian granite
20.00	25.00	6.70	3.87	1.73	Lower crust
40.00	99.00	8.15	4.63	1.75	Mantle

after: Wesson and Nicholson, 1986.

Table B-2

MODEL TESTING -- BEST SAND QUARRY

Blast: 11-2-1988

Location: 41.5480N 81.2080W

MODELS		SOLUTIONS							
Velocity km/s	Thickness km	Orig.Time UT	Lat. N	Long. W	RMS sec	NP	Gap 0	Δ Lat. km	ΔLong. km
3.5/4.8/6.2 (1.70/1.70/1.78)	0.1/1.9/33	193754.9	41.5460	81.2088	0.06	12	224	-0.22	0.07
3.5/4.8/6.2 (1.78/1.78/1.78)	0.1/1.9/33	193755.1	41.5513	81.2060	0.06	12	219	0.37	-0.17
3.5/4.8/5.9 (1.78/1.78/1.78)	0.1/1.9/33	193754.9	41.5540	81.2098	0.07	12	217	0.66	0.15
4.8/5.9 (1.78/1.78)	2/33	193755.0	41.5524	81.2136	0.08	12	219	0.49	0.47
4.8/6.2 (1.78/1.78)	2/33	193755.1	41.5508	81.2087	0.06	12	220	0.31	0.06
4.25/6.5 (1.78/1.78)	2/33	193755.0	41.5506	81.2023	0.10	12	219	0.29	-0.48

Table B-3

MODEL TESTING -- BEST SAND QUARRY

Blast: 9-20-1989 Location: 41.5440N 81.2090W

MODELS		SOLUTIONS							
Velocity km/s	Thickness km	Orig.Time UT	Lat. N	Long. W	RMS sec	NP	Gap 0	Δ Lat. km	Δ Long. km
3.5/4.8/6.2 (1.70/1.70/178)	0.1/1.9/33	191241.1	41.5405	81.2107	0.08	10	278	-0.39	0.14
3.5/4.8/6.2 (1.78/1.78/1.78)	0.1/1.9/33	191241.3	41.5471	81.2042	0.08	10	271	0.34	-0.40
3.5/4.8/5.9 (1.78/1.78/1.78)	0.1/1.9/33	191241.2	41.5505	81.2060	0.06	10	270	0.72	-0.25
4.8/5.9 (1.78/1.78)	2/33	191241.2	41.5486	81.2098	0.08	10	273	0.51	0.07
4.8/6.2 (1.78/1.78)	2/33	191241.4	41.5465	81.2040	0.10	10	272	0.28	-0.42
4.25/6.5 (1.78/1.78)	2/33	191241.3	41.5476	81.1949	0.13	10	269	0.40	-1.18

Table B-4

AFTERSHOCK PARAMETERS OF THE JANUARY 31, 1986 EARTHQUAKE *

USING THREE-LAYER MODEL

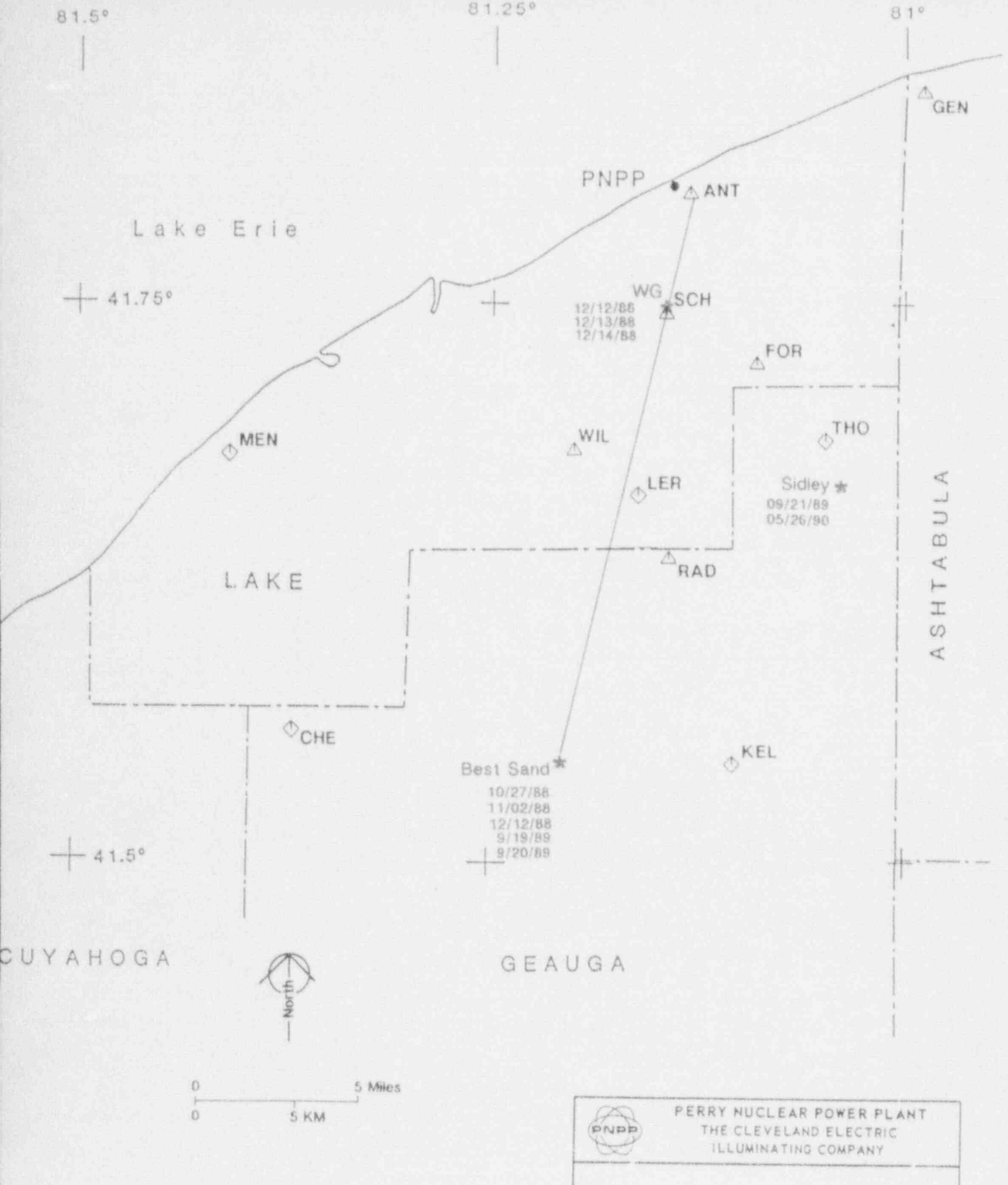
	YEARMODY	HRMISEC	LATITUDE	LONGITUDE	DEPTH	NP	GAP	RMS	ERH	ERZ	Mc
1.	19860201	185449.33	41N38.72	81W 9.22	4.65	20	95	.09	.3	.5	1.5
2.	19860202	32248.64	41 38.73	81 9.56	5.19	37	72	.07	.1	.2	.9
3.	19860203	194719.77	41 38.92	81 9.49	6.28	52	75	.08	.2	.2	2.0
4.	19860205	634 2.46	41 38.89	81 9.29	4.10	31	52	.09	.2	.3	.1
5.	19860206	183622.39	41 38.72	81 9.60	5.89	50	47	.07	.1	.2	2.5
6.	19860207	152020.34	41 39.02	81 9.21	4.42	44	42	.06	.1	.3	1.1
7.	19860210	200613.58	41 39.08	81 9.40	5.20	29	70	.07	.2	.4	.8
8.	19860223	32949.47	41 39.15	81 9.10	5.74	22	76	.06	.2	.4	-.1
9.	19860224	1655 6.50	41 38.84	81 9.62	3.55	10	91	.10	.5	2.1	.1
10.	19860228	13934.22	41 39.20	81 9.65	4.04	12	91	.06	.3	.5	-.1
11.	19860308	204249.64	41 38.66	81 9.20	3.81	20	55	.09	.2	.5	-.1
12.	19860324	134241.20	41 38.40	81 8.97	5.46	11	81	.08	.3	1.0	1.4
13.	19860410	65805.70	41 38.78	81 9.53	5.04	22	53	.07	.2	.3	-.1
14.	19860617	221633.16	41 38.83	81 9.58	3.70	16	93	.10	.3	.8	.8
15.	19860714	075423.06	41 38.61	81 [illegible].22	5.40	12	98	.10	.4	9	.3
16.	19870712	011056.68	41 39.22	81 9.38	3.60	13	201	.10	.8	1.1	1.8
17.	19880805	222632.96	41 39.08	81 9.03	4.80	12	166	.04	.2	.3	0.1
18.	19881011	063132.30	41 39.22	81 8.69	5.40	13	142	.05	.3	.4	-.2
19.	19881228	232824.42	41 38.17	81 10.05	6.30	18	91	.08	.2	.4	2.8
20.	19900901	135054.38	41 38.81	81 9.20	5.00	17	83	.07	.2	.4	1.5
21.	19910117	071153.29	41 39.40	81 8.84	6.10	8	153	.02	.1	.2	-.2

Vp1=3.5 km/s thickness = .1 km
Vp2=4.8 km/s Thickness = 1.9 km
Vp2=6.2 km/s Thickness = 33 km

rev. Aug. 1991

Vp/Vs=1.78
* The more recent events may not be true aftershocks

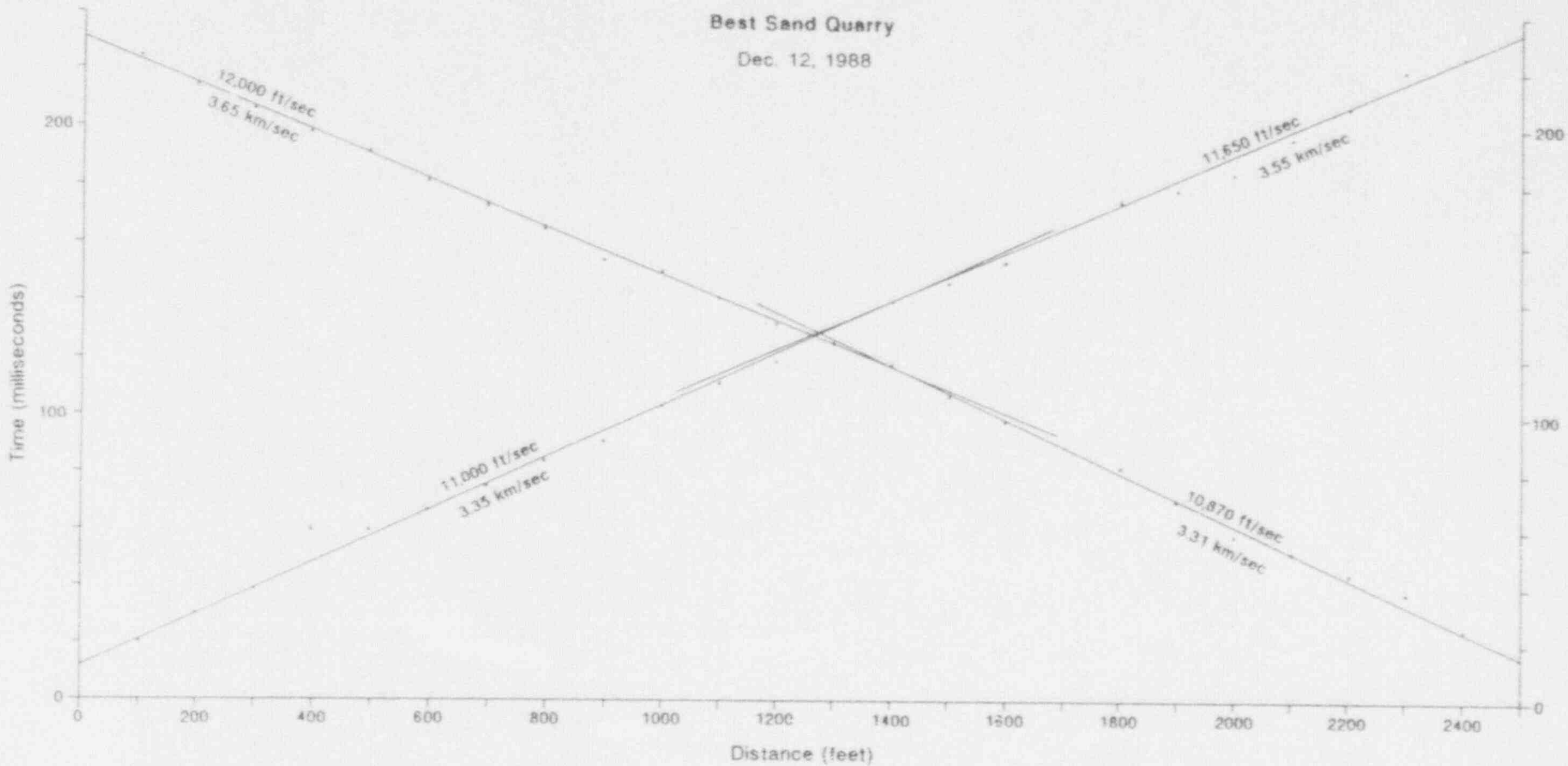
FIGURES



PERRY NUCLEAR POWER PLANT
THE CLEVELAND ELECTRIC
ILLUMINATING COMPANY

Blast Locations and Dates

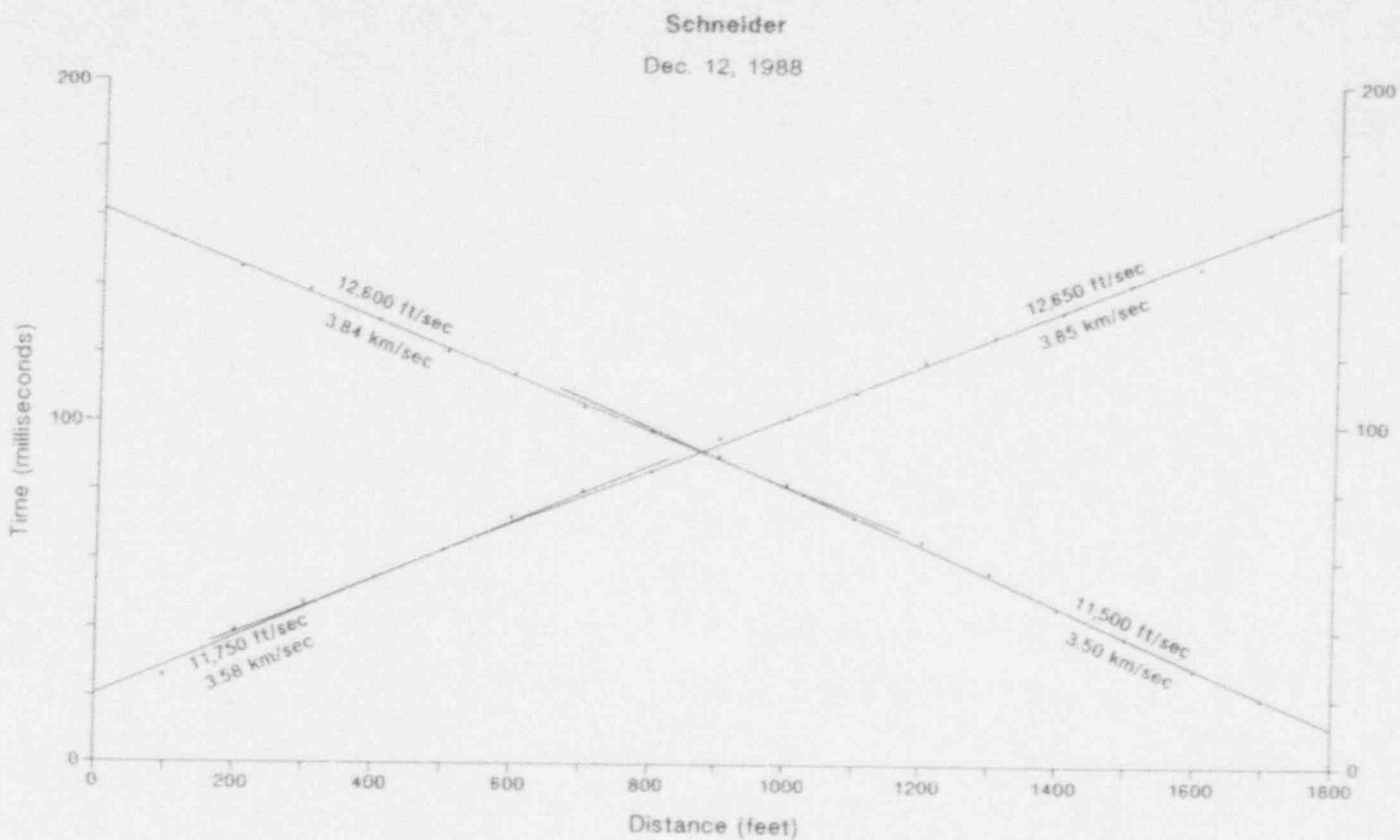
Figure B-1



PERRY NUCLEAR POWER PLANT
THE CLEVELAND ELECTRIC
ILLUMINATING COMPANY

Shallow Refraction
Travel Time Plot
Dec.12,1988
Best Sand Quarry

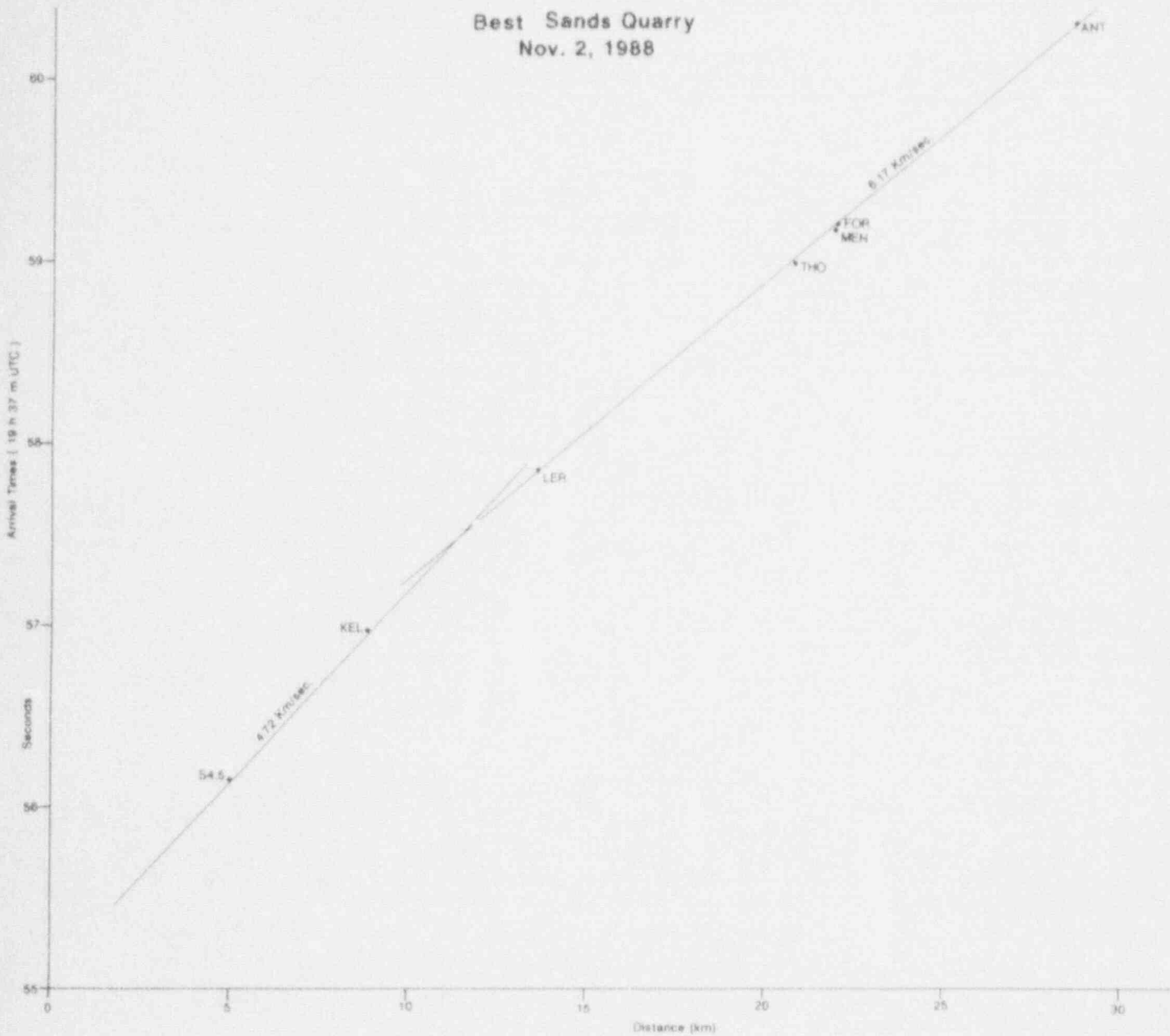
Figure B-2



PERRY NUCLEAR POWER PLANT
THE CLEVELAND ELECTRIC
ILLUMINATING COMPANY

Shallow Refraction
Travel Time Plot
Dec. 12, 1988
Schneider

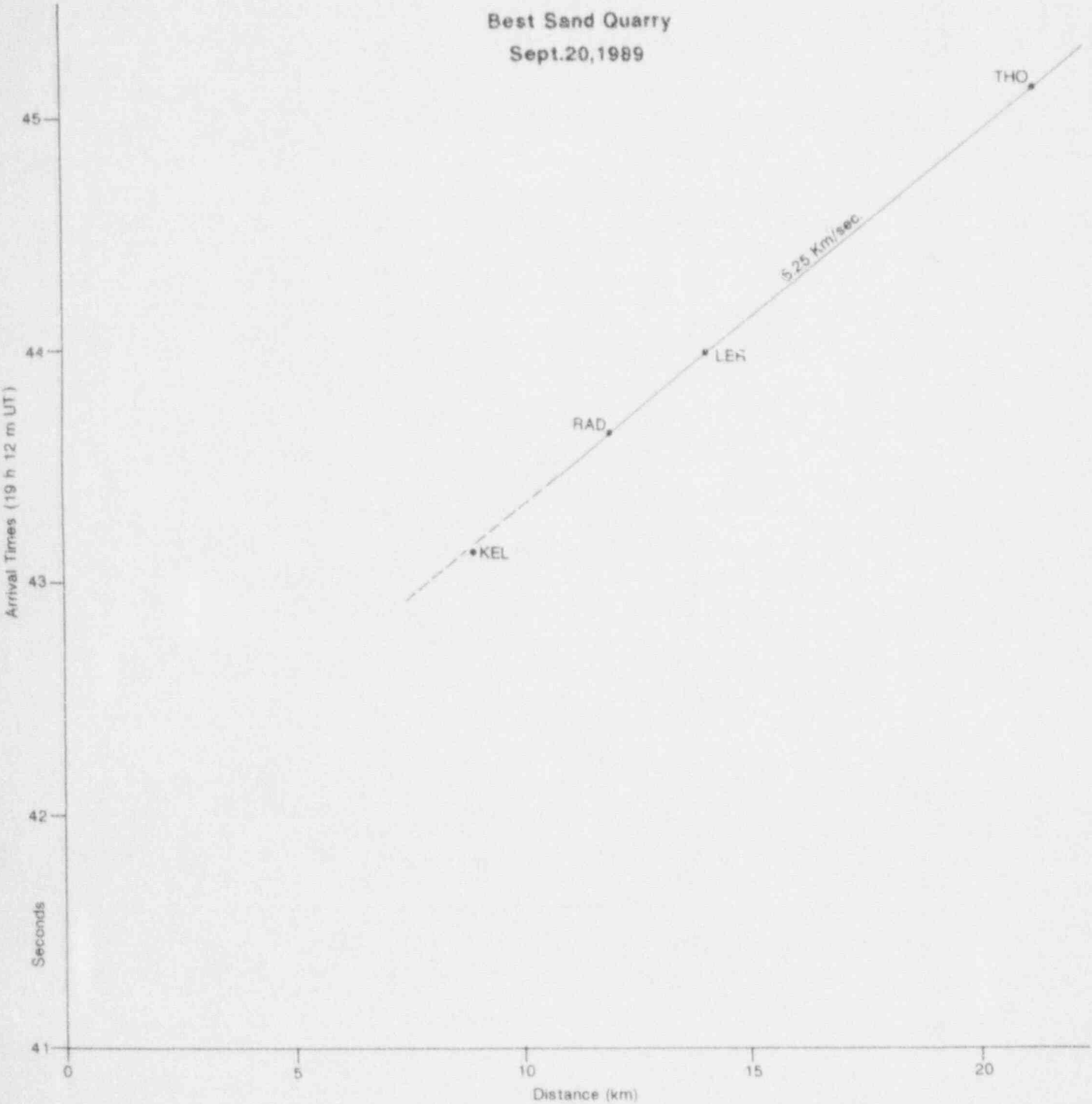
Figure B-3



PERRY NUCLEAR POWER PLANT
THE CLEVELAND ELECTRIC
ILLUMINATING COMPANY

Travel Time Plot
Nov. 2, 1988
Best Sand Quarry

Figure B-4

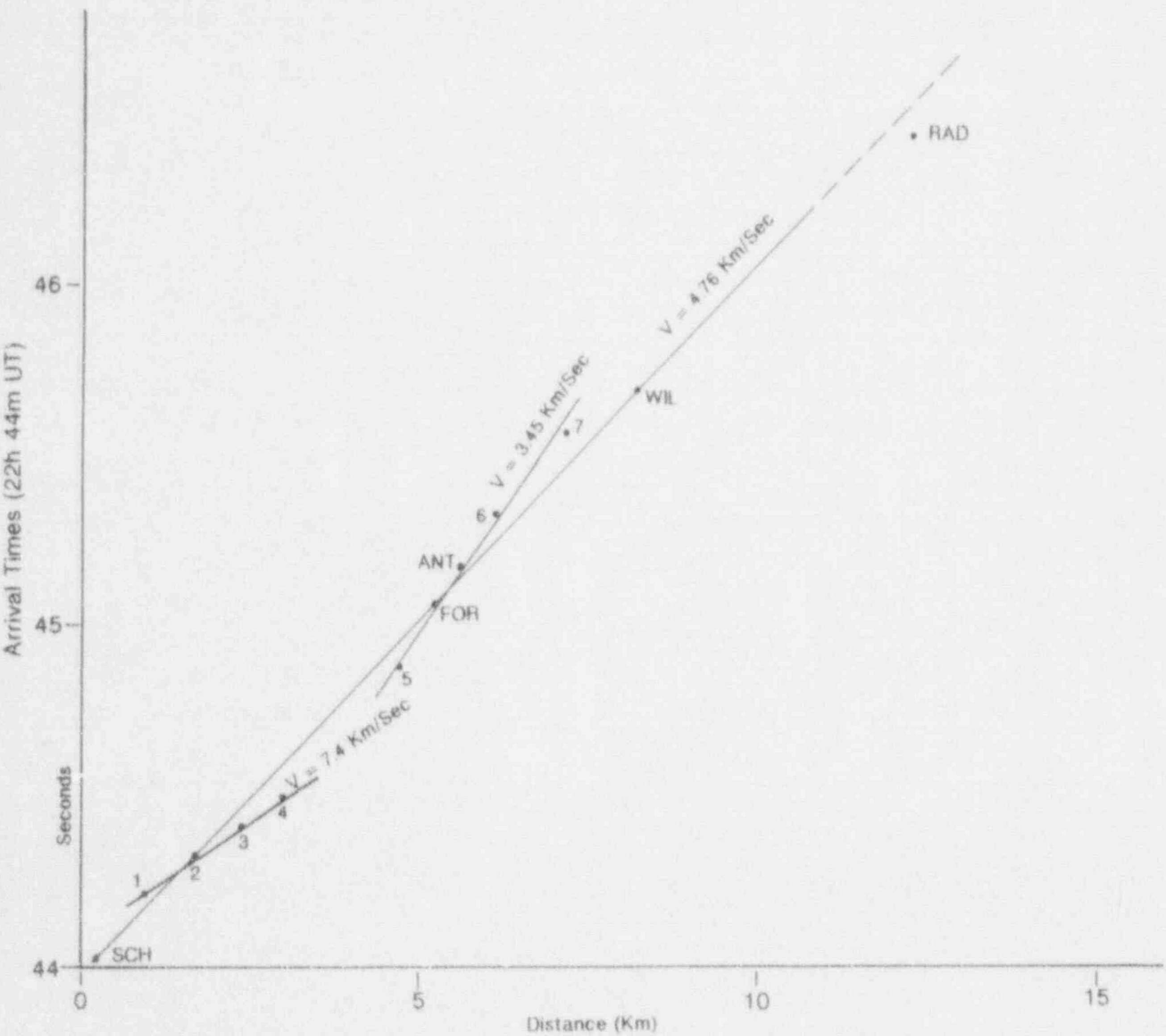


PERRY NUCLEAR POWER PLANT
THE CLEVELAND ELECTRIC
ILLUMINATING COMPANY

Travel Time Plot
Sept. 20, 1989
Best Sand Quarry

Figure B-5

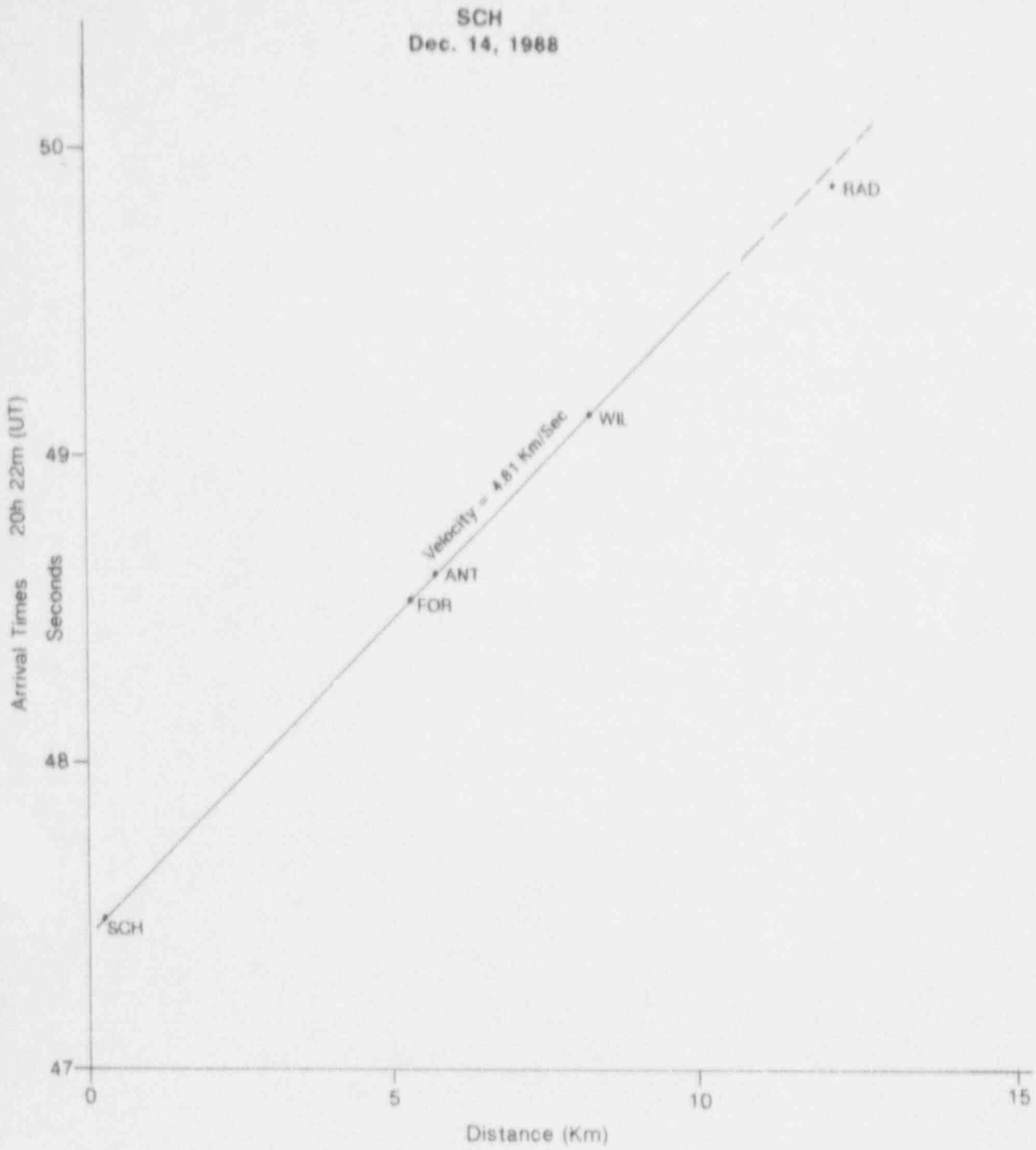
SCH
Dec. 13, 1988



PERRY NUCLEAR POWER PLANT
THE CLEVELAND ELECTRIC ILLUMINATING COMPANY

Travel Time Plot
Dec. 13, 1988
SCH

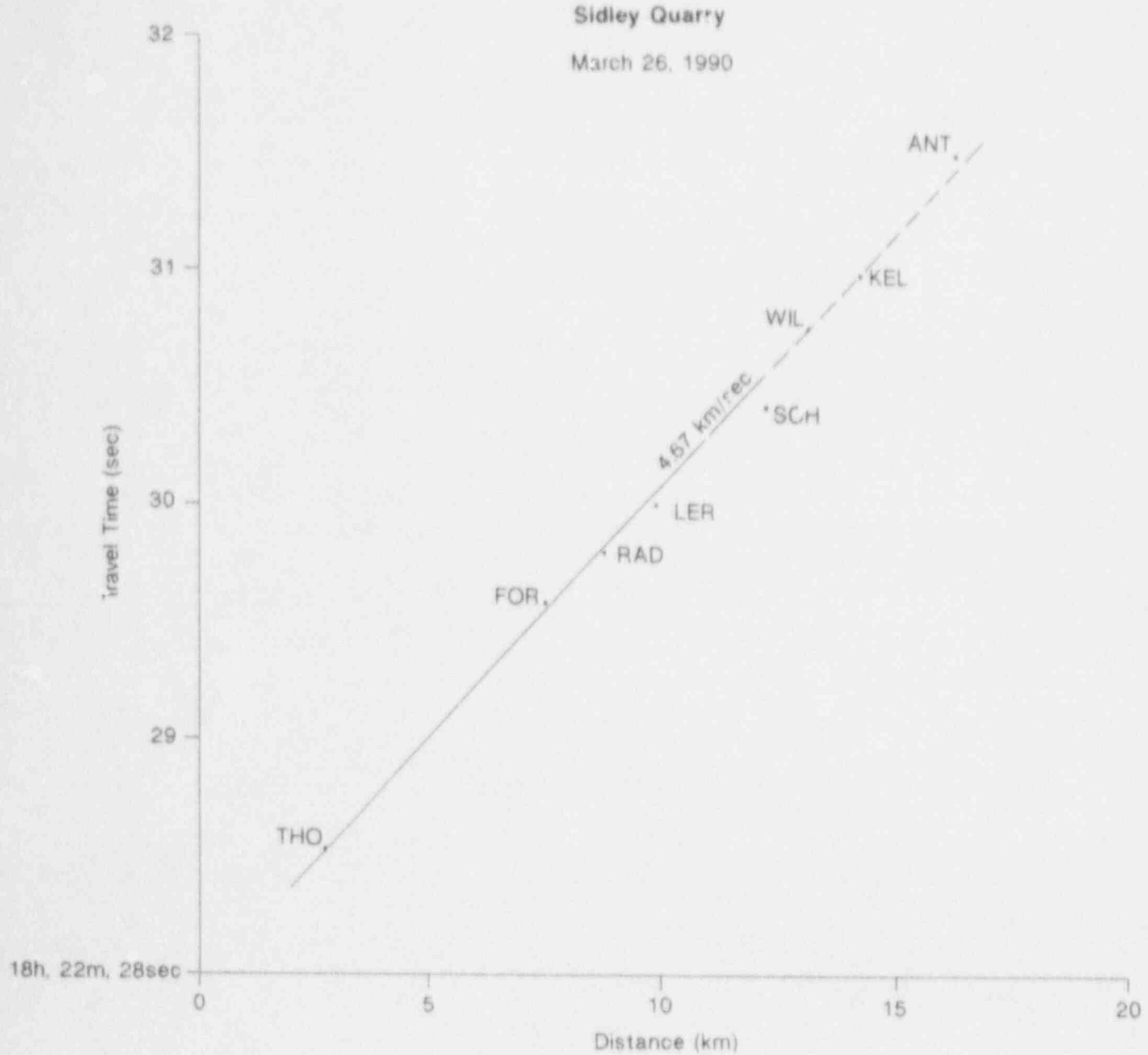
Figure B-6



PERRY NUCLEAR POWER PLANT
THE CLEVELAND ELECTRIC
ILLUMINATING COMPANY

Travel Time Plot
Dec. 14, 1988
SCH

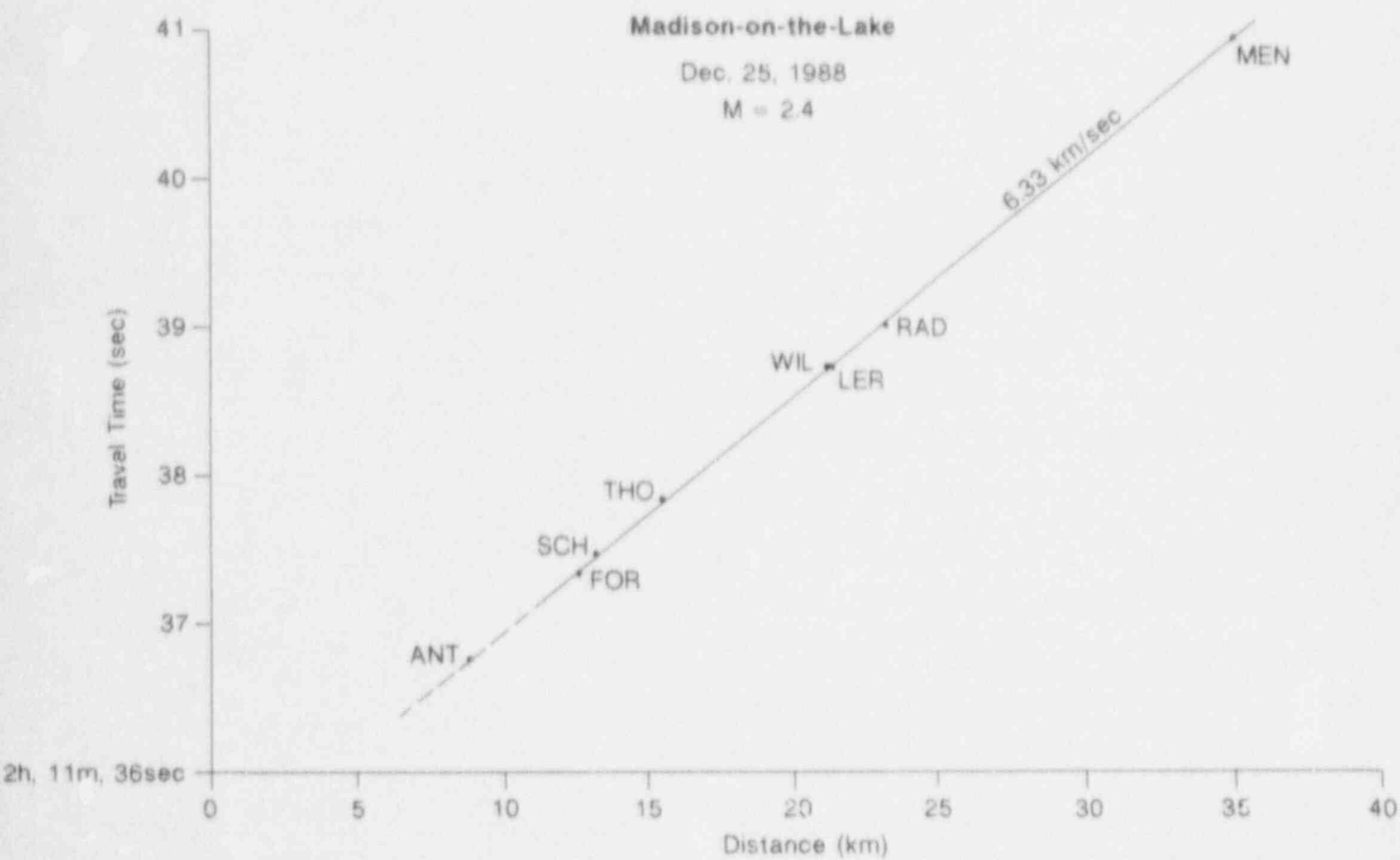
Figure B-7



PERRY NUCLEAR POWER PLANT
THE CLEVELAND ELECTRIC
ILLUMINATING COMPANY

Travel Time Plot
March 26, 1990
Sidley Quarry

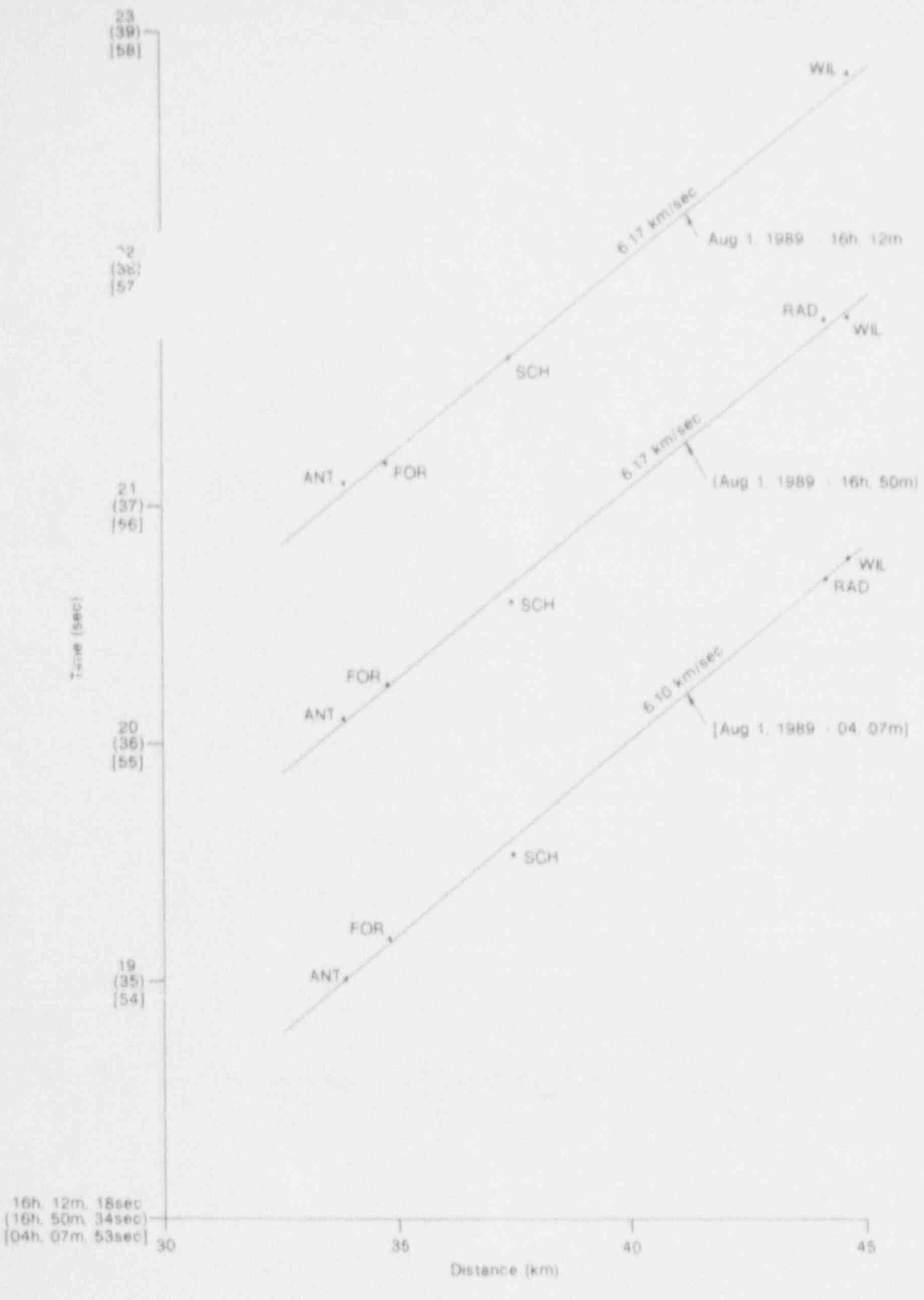
Figure B-8



PERRY NUCLEAR POWER PLANT
THE CLEVELAND ELECTRIC
ILLUMINATING COMPANY

Travel Time Plot
Dec. 25, 1988
Madison-on-the-Lake

Figure B-9



PERRY NUCLEAR POWER PLANT
THE CLEVELAND ELECTRIC
ILLUMINATING COMPANY

Travel Time Plots
Ashtabula Earthquakes
August 1, 1989

Figure B-10