NUREG/CR-3145
Vol. 1

Geophysical Investigations of the Western Ohio-Indiana Region

Annual Report
October 1981 - September 1982

Prepared by D. H. Christensen, M. G. Wiedenbeck, P. L. Jackson

University of Michigan

Prepared for
U.S. Nuclear Regulatory
Commission

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Date Published: February 1983

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Prepared for
Division of Health, Siting and Waste Management
Office of Nuclear Regulatory Research
U.S. Nuclear Regulatory Commission
Washington, D.C. 20555
NRC FIN B8080
Under Contract No. NRC 04-81-195-04

ABSTRACT

Earthquake activity in the Western Ohio-Indiana region is monitored with a precision seismograph network: Nine stations clustered about Anna, Ohio, and four stations in Indiana centered about Indianapolis. During this period no earthquakes were detected in the region of the network. This seismic inactivity contrasts with the previous year, during which nine small (unfelt) earthquakes occurred within and adjacent to the Western Ohio portion of the network. Digital triggering and recording capability was added to the analog recording capability. Using the new digital capability, we were able to more precisely locate the focus of some of these small earthquakes. As part of the inception of a modeling investigation, a preliminary location of the Grenville Front was postulated as eastward of the network. Azimuthal changes in travel time residuals of teleseisms were used for this estimate.

SUMMARY

During this period the Western Ohio - Indiana network has been continuously operational as shown in the station reliability chart (Table 2). The nine stations of the Western Ohio portion of the network are recorded with Geospace HS-10, 1 Hz geophones, and the four stations of the Indiana portion with Mark Products L-4C, 1 Hz geophones. Data from the Ohio stations are radioed to Wapakoneta, Ohio, while the Indiana stations are transmitted by telephone to Wapakoneta. Data from all stations are then transmitted by telephone from Wapakoneta Ohio to Ann Arbor Michigan where they are recorded on pen and ink drums in addition to analog magnetic tape and monitored by a PDP 11/23 digital computer with a triggering program to digitally record events of suitable size and characteristics. All 13 stations of the network were operational 88% of the time during this period. Recording of at least 10 stations was virtually continuous. Down times were caused by telephone line disruption and station difficulties aggravated by a severe winter and many summer storms.

No local earthquakes in Western Ohio or Indiana were recorded this year. Last year (July 1980 - May 1981) nine small earthquakes were recorded within or near the Western Ohio array. Not having determined the driving mechanism, we cannot draw conclusions about the significance of this prolonged cessation of activity (the last small earthquake was in May, 1981).

We have, however, been able to more accurately locate the focus of several of the small earthquakes. With new digital facilities we were able to digitize the backup analog tape recording of the drum records, and obtain more precise times with small sampling intervals. This has enabled us to obtain depths and locations with smaller residuals than previously obtained for some events.

The substantial, azimuthally-dependent teleseismic residuals and residual differences across the Western Ohio array may be caused by the Grenville Front. Although the residuals cannot definitely prove the existance of the Grenville Front in western Ohio, the Grenville Front does seem to satisfy the observed residuals. Toward this end two-dimensional digital modeling was utilized. Based on a model of the Grenville Front in Canada (Berry M. J. and K. Fuchs, 1973), a cross-section was derived in which simulated residuals were correlated to observed residuals across the Western Ohio array. The predicted residuals through this cross-section were calculated by digital ray tracing using interactive graphics.
A more exhaustive and updated review of the geology of the Western Ohio region was undertaken. The description is included in this report.

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PREFACE

This is the first annual report under the three-year contract NRC-04-81-195-04, a continuation of effort funded under contract NRC 04-76-192: The maintenance and systematic processing of a 9-station seismic array in Western Ohio initiated in 1976, and the subsequent expansion in 1981 to include a 4-station array in Indiana, in addition to concurrent regional investigations.

We wish to express our appreciation to Scott Baird, for keeping a wide range of instruments and computer peripherals in constant working condition, and for creatively improving and expanding our capabilities, and to Sandy Wirick, Jill Pugh, Jeffrey Anagnostou and Nathanial Usher for their help in successfully operating the seismic network.

Michael Wiedenbeck contributed the section which updates the geologic knowledge of the Western Ohio region.

PREVIOUS REPORTS

Four major reports concerning this investigation were published under the previous contract no. NRC 04-76-192:

Mauk, F. J., D. Coupland, D. Christensen, J. Kimball, P. Ford, 1979, Geophysical investigations of the Anna, Ohio, earthquake zone: Annual Progress Report for Nuclear Regulatory Commission, July 1978-July 1979, NUREG/CR-1065.

Mauk, F. J., S. G. Henry, D. H. Christensen, J. Sauber, C. Lanford, W. Meerschaert, J. K. Kimball, 1980, Geophysical investigations of the Anna, Ohio, earthquake zone: Annual Progress Report for the Nuclear Regulatory Commission, July 1979-1980, NUREG/CR-1649.

Mauk, F. J., and D. H. Christensen, 1980, A probabalistic evaluaton of earthquake detection and location capability for Illinois, Indiana, Kentucky, Ohio, and West Virginia: Report for Nuclear Regulatory Commission, September, 1980, NUREG/CR-1648.

Jackson, P. L., D. H. Christensen, F. J. Mauk, 1981, Geophysical investigations of the Western Ohio - Indiana Region: Final Report for Nuclear Regulatory Commission, November, 1975 - September, 1981, NUREG/CR-2484.

THE WESTERN OHIO - INDIANA SEISMOLOGICAL ARRAY

The Western Ohio-Indiana seismological network consists of thirteen short period vertical (SPZ) local stations, two regional stations (ACM, AAM) and seismoscopes at seven locations. The thirteen local stations are formed by nine original Anna, Ohio stations which have been fully operational since June, 1978, and a subnetwork installed in Feburary 1981 of four stations located in Indiana. Station locations are shown in Figure 1.

The nine west-central Ohio stations are designed as schematically illustrated in Figure 2a, using Geospace HS-10, 1Hz geophones and transmitted to Wapakoneta, Ohio. The four Indiana stations are designed as schematically shown in Figure 2b. These stations consist of Mark Products L-4C, 1Hz geophones and Interproducts VCO packages and are transmitted via telephone link to Wapakoneta, Ohio.

The central multiplexing equipment is schematically illustrated in Figure 2c. The multiplexed data are then transmitted by telephone to the recording facility at the University of Michigan, Ann Arbor, Michigan as schematically illustrated in Figure 2d.

Full system response curves have been experimentally produced for the Ohio network using the calibration coils in the HS-10 1Hz geophones through in-field studies. The response is illustrated in the unity gain curves of Figure 3a. The response curves for the Indiana stations, which were calculated through a combination of experimental and published response characteristics, are shown in Figure 3b. In Figure 3 the curves represent the response of the system using 2Hz, 5Hz, and 12.5 Hz low-pass filters. Although any of the three responses are possible in playback mode from the analog tape, only one can be used for the directly recorded visual records. During the last year we have switched from the 5 Hz low-pass filter to the 12.5 Hz low-pass filter for the visual recorders. The 12.5 Hz filter enables the recording of higher frequency energy, but, due to background noise in the higher frequencies, it requires reduced instrumental gains at some frequencies.

Locations of the individual stations as well as the elevations, gains and other information about the stations are listed in Table 1. Station reliability data for the network are given in Table 2.

Further descriptions of the Anna array instrumentation can be found in previous annual progress reports by Mauk et al. (1979, 1980), and Jackson et al. (1982).

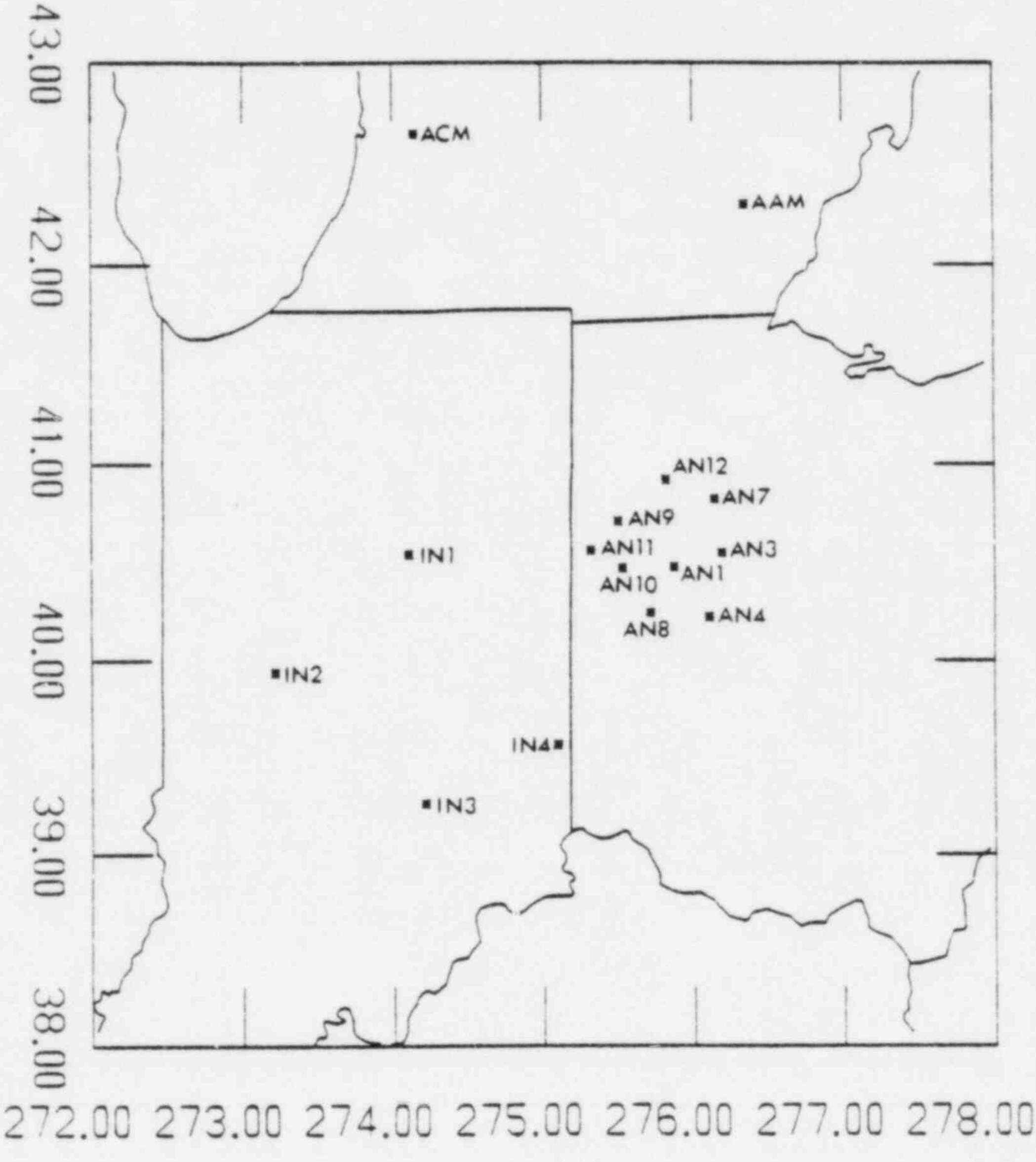


Figure 1. Station Locations for the Ohio-Indiana Seismic Array.

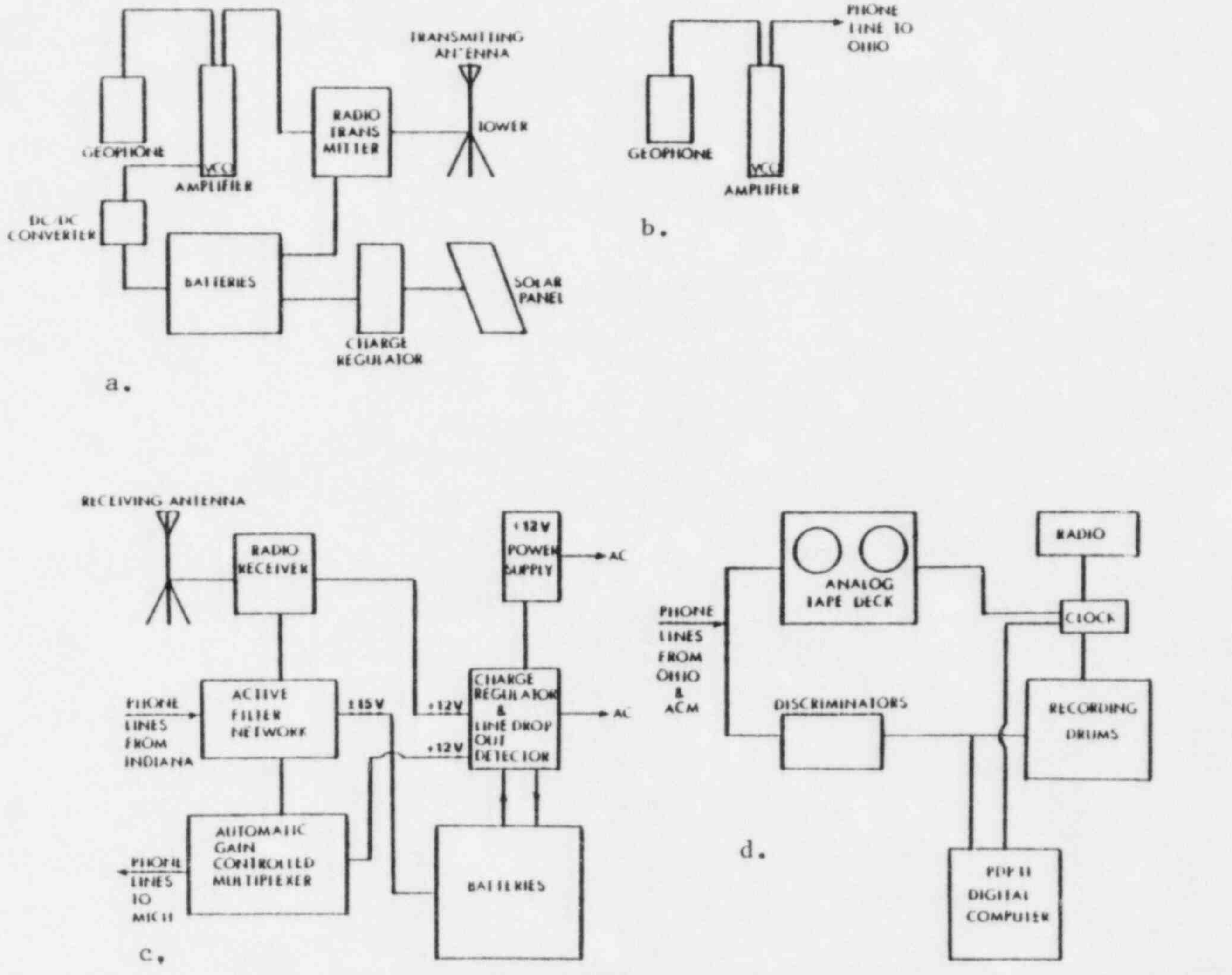


Figure 2. Schematics of Field Installations, Multiplexing, and Recording Facilities.
(See Legend, following page).

a. GEOPHONE - Geospace HS-10-1, 1Hz, .7 critical damping
AMPLIFIER VCO- Interproducts
RADIO TRANSMITTER- Delco Radio Transmitter
TRANSMITTING ANTENNA- Db products 7db gain antenna
TOWER- TRI-X radio tower
BATTERIES- Delco 1150
DC/DC Converter- constructed inhouse
CHARGE REGULATOR - Solarex SR012075AF, 75 watts
SOLAR PANEL- Solarex 6600/12 H. Solar cell system with 66 watts DC peak power output

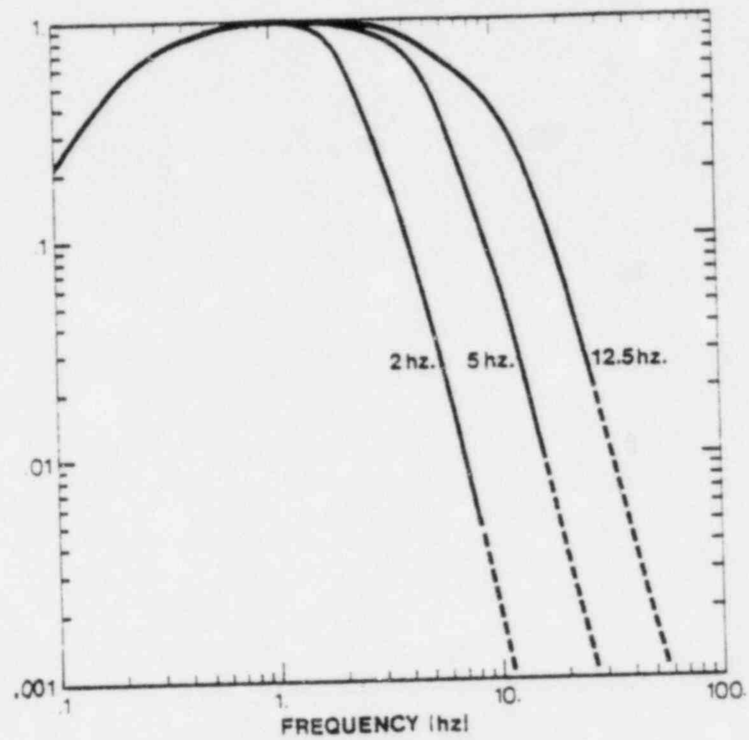
b. GEOPHONE- Mark Products L-4C, 1 Hz, .7 critical damping
AMPLIFIER VCO- Interproducts

c. RECEIVING ANTENNA- 7db gain antennas, mounted on a 300' tower
RADIO RECEIVER- Repco Radio Receiver
ACTIVE FILTER NETWORK
AUTOMATIC GAIN CONTROLLED (AGC)
MULTIPLEXER
POWER SUPPLY- Power Mate PT 15 C.
CHARGE REGULATOR
BATTERIES- MDP5 NICAD

d. ANALOG TAPE DECK- Hewlett-Packard 3964A
DISCRIMINATORS- Teledyne Geotech 46.12
VCO- Manufactured by NEIS from Sonex 'nc. Tex 3075
RADIO- Kinemetrics Model WVTR Mark IV
CLOCK- Teledyne Geotech TG-120
RECORDING DRUMS- Sprengnether, VR-65-3 (3) and VR-55-3 (2)
PDP 11 DIGITAL COMPUTER- DEC PDP-11 Model 23
Minclab digital computer

Figure 2 (Legend)

a.



b.

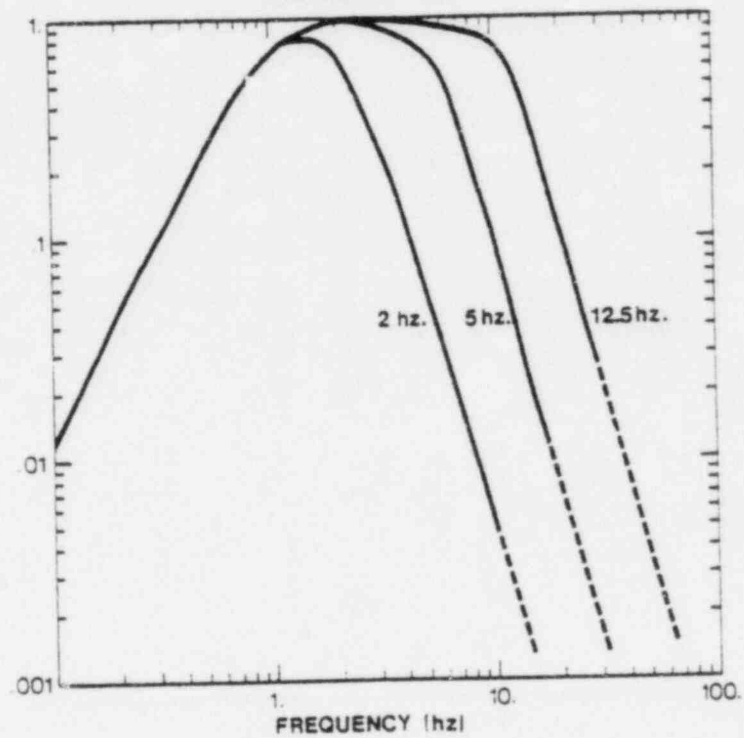


Figure 3. Unity Gain Frequency Responses of the Seismic Network. Upper, Ohio Stations. Lower, Indiana Stations.

TABLE 1

THE OHIO-INDIANA SEISMOGRAPH ARRAY CHARACTERISTICS

Station Code	Latitude	Longitude	Elevation (Feet)	2 H_Z Displacement Gain	Carrier (MHZ)	Subcarrier (HZ)
AN1	40.4792°N	84.1309°W	1003.0	246.7k	164.0093	1700
AN3	40.5489°N	83.8121°W	1070.0	246.7k	165.8093	1400
AN4	40.2222°N	83.8978°W	1134.0	246.7k	173.1940	1400
AN7	40.8235°N	83.8602°W	922.0	493.4k	171.4060	1700
AN8	40.2441°N	84.2860°W	992.0	246.7k	166.4218	680
AN9	40.7118°N	84.4967°W	835.0	246.7k	167.8090	2040
AN10	40.4729°N	84.4700°W	901.0	246.7k	167.1937	1020
AN11	40.5638°N	84.6804°W	895.0	246.7k	166.6565	1020
AN12	40.9217°N	84.1823°W	741.0	493.4k	163.7937	2040
IN1	40.542°N	85.894°W	837.0	84.7k		680
IN2	39.939°N	86.783°W	872.0	84.7k		1020
IN3	39.265°N	85.785°W	722.0	84.7k		1400
IN4	39.570°N	84.903°W	1025.0	84.7k		1700
ACM	42.6475°N	85.8517°W	880.0	42.3k		1700

TABLE 2

STATION RELIABILITY DATA

	AN1	AN3	AN4	AN7	AN8	AN9	AN10	AN11	AN12	IN1	IN2	IN3	IN4	ACM
MONTHLY SUMMARY FOR OCT 1981	100%	100%	96%	83%	99%	100%	80%	100%	100%	99%	99%	99%	100%	0%
MONTHLY SUMMARY FOR NOV 1981	65%	100%	97%	98%	99%	98%	0%	100%	73%	100%	100%	100%	100%	0%
MONTHLY SUMMARY FOR DEC 1981	86%	97%	93%	100%	98%	99%	63%	98%	100%	99%	99%	99%	99%	0%
MONTHLY SUMMARY FOR JAN 1982	99%	93%	98%	100%	94%	100%	100%	100%	100%	98%	100%	100%	61%	0%
MONTHLY SUMMARY FOR FEB 1982	3%	97%	92%	99%	100%	98%	100%	100%	100%	97%	100%	100%	0%	0%
MONTHLY SUMMARY FOR MAR 1982	0%	99%	97%	100%	98%	100%	99%	96%	100%	100%	97%	100%	0%	0%
MONTHLY SUMMARY FOR APR 1982	10%	84%	100%	100%	99%	98%	99%	98%	100%	100%	92%	76%	0%	23%
MONTHLY SUMMARY FOR MAY 1982	96%	57%	88%	88%	97%	75%	98%	97%	64%	93%	83%	94%	74%	95%
MONTHLY SUMMARY FOR JUN 1982	96%	56%	86%	93%	93%	51%	94%	74%	76%	29%	70%	98%	87%	100%
MONTHLY SUMMARY FOR JUL 1982	98%	95%	84%	99%	96%	99%	71%	99%	89%	99%	98%	95%	99%	99%
MONTHLY SUMMARY FOR AUG 1982	[illegible]	97%	63%	37%	95%	97%	22%	99%	67%	99%	99%	99%	100%	100%
MONTHLY SUMMARY FOR SEP 1982	98%	99%	99%	99%	99%	99%	99%	98%	98%	99%	99%	92%	99%	100%
TOTAL FOR REPORT PERIOD	70%	90%	91%	91%	97%	93%	77%	97%	89%	93%	95%	96%	68%	43%

II
EVENT RELOCATION FROM DIGITAL REPLAYS

During the period July 1980 to May 1981 nine very small events occurred in western Ohio (see Fig. 4). These events are well located, particularly the six that are within the array. Depths, on the other hand, were poorly constrained and in the best cases depths between 0 to 12 km gave equally good solutions for the epicenters with similar residuals throughout this depth range.

It has now become possible through the use of a PDP-11 digital computer to relocate several of the small events which were saved on analog tape. The main results from these relocations is not that the epicenters of the events have changed slightly but that the greater accuracy of arrival times on the digital seismograms enabled the reduction of location errors, significantly improving the depth constraints.

The four small events which occurred on January 4, February 7, March 15 and May 19, 1981 were digitized from analog tape at 75 samples/second. The resulting plots were interpreted to an accuracy of about ± .02 seconds. In addition the two largest events (Jan. 4 and Feb. 7, mag = 1.8) had waveforms which were so similar that the phase arrival times could be reevaluated by visual correlation. This allowed far greater confidence in several of the smaller arrivals. Small scale plots of these digitized events are displayed in Figure 5a-d.

Arrival times for the events on Jan. 4 and Feb. 7 were evaluated using the standard HYP071 earthquake location program. In each case the event was located with depth as a free parameter. The station ANI, located about 7 km from the epicenter, was not used in the original location due to the possible adverse effects of small scale velocity structure at that distance. Instead the location was evaluated using the other stations and then the residual calculated for ANI was used to evaluate the resulting depth. In both cases the residual at ANI for a calculated depth of 5 to 7 km, depending on the velocity structure used, is around .05 seconds. When the locations are rerun using ANI the same results are found.

The event on May 19, 1981 is smaller with fewer arrival times but shows both similar residuals and a similar shallow depth of between 2 to 8 km. However, the error is greater. The event on March 15, 1981 is outside the array and thus the location was slightly improved but constraining the depth was impossible.

Parameters for the above four events plus, for completeness, the five other recent events are listed in Table 3. It appears reasonable (at least for the events which we were able to study in detail) that the small events in western Ohio are located no deeper than 10 km and that the two best studied events occurred at about 5 to 7 km. This may mean that the faults in the area which have been described through seismic profiles and bore holes date to exist in the 1 to 2 km thick paleozoic section, may actually extend into the basement and may in fact be due to older features in the basement.

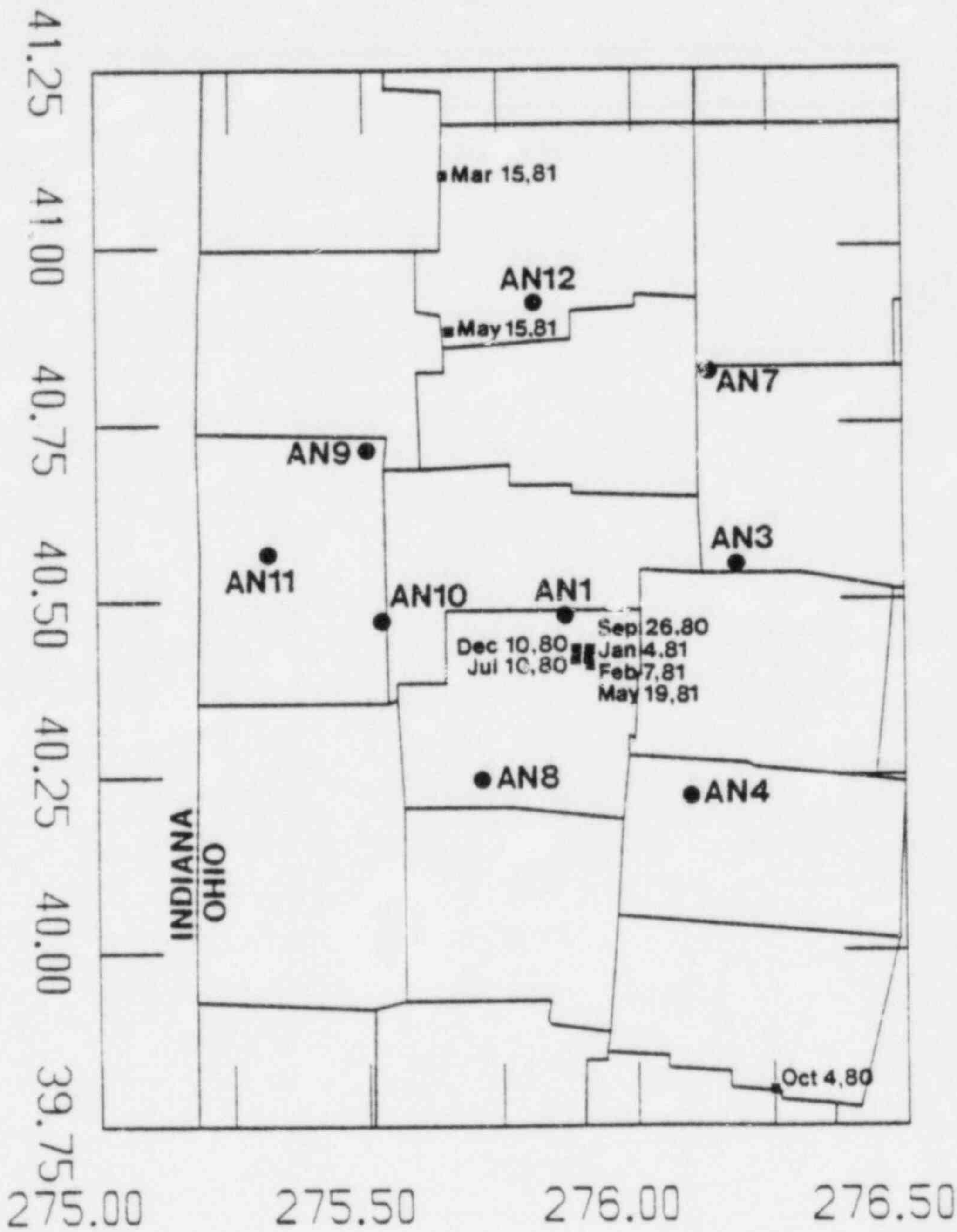


Figure 4. Local Microearthquake Locations from July, 1980, to May, 1981.

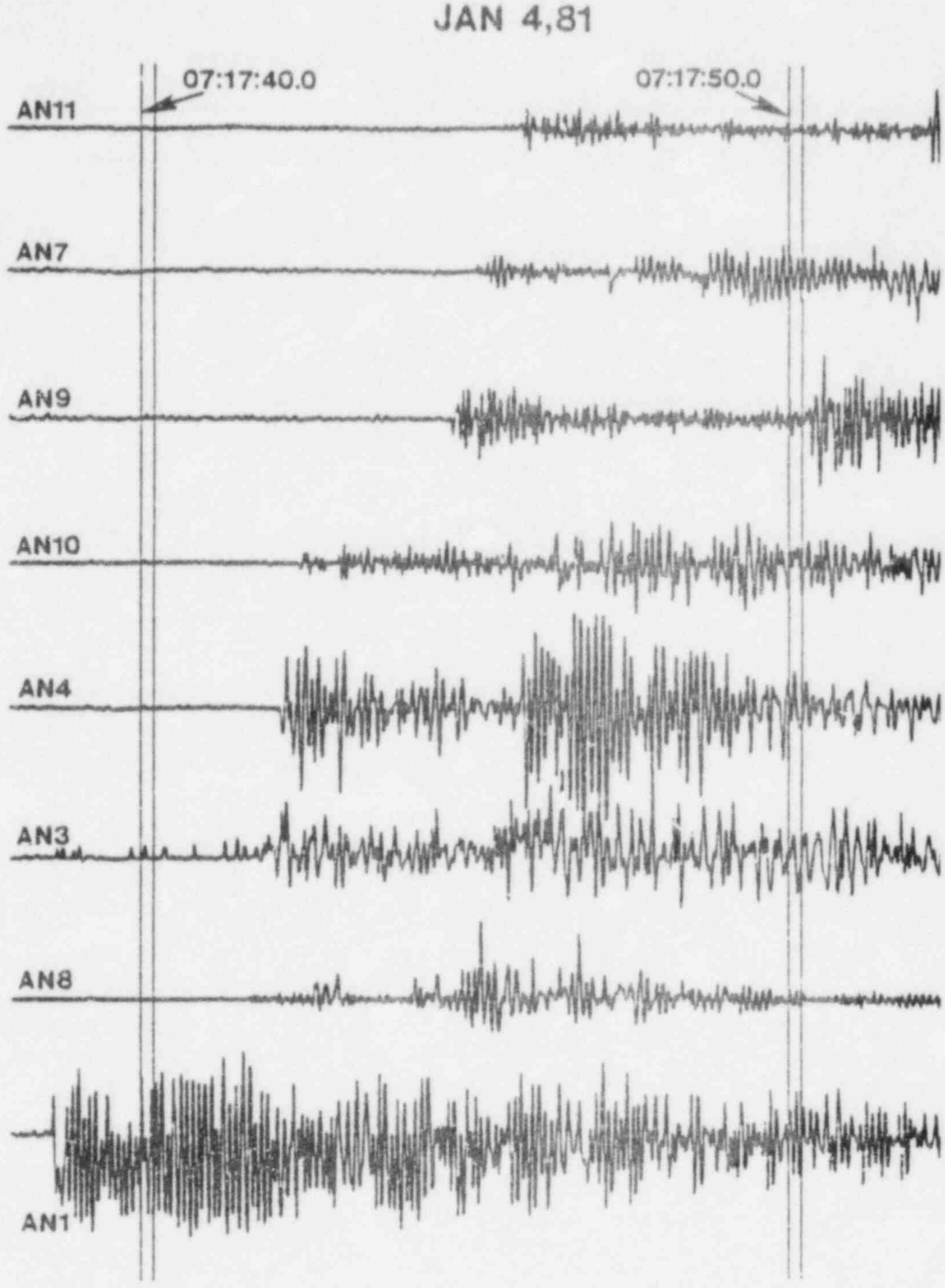


Figure 5a. Digitized Event Recorded by the Ohio-Indiana Array. January 4, 1981.

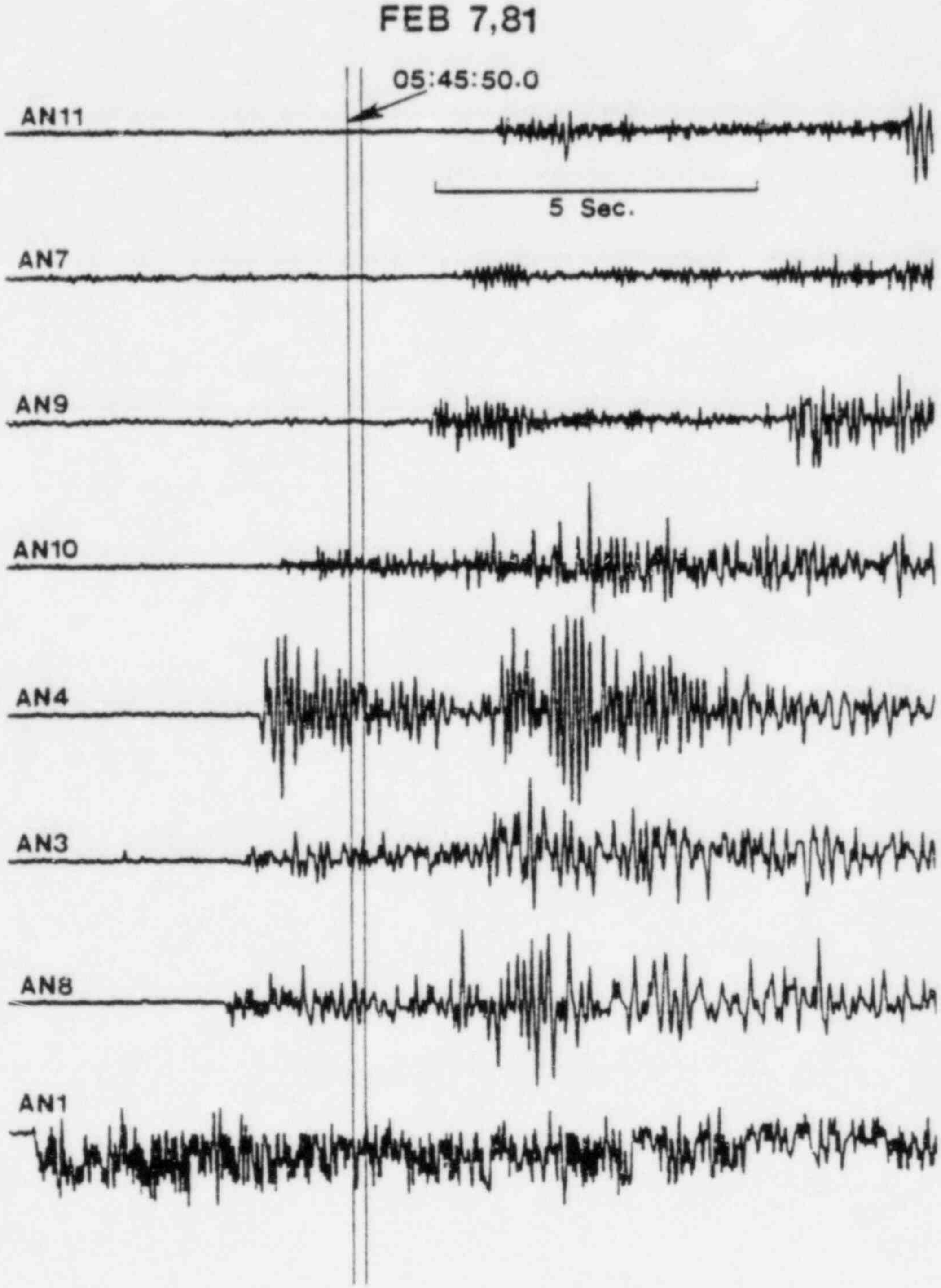


Figure 5b. Digitized Event Recorded by the Ohio-Indiana Array. February 7, 1981.

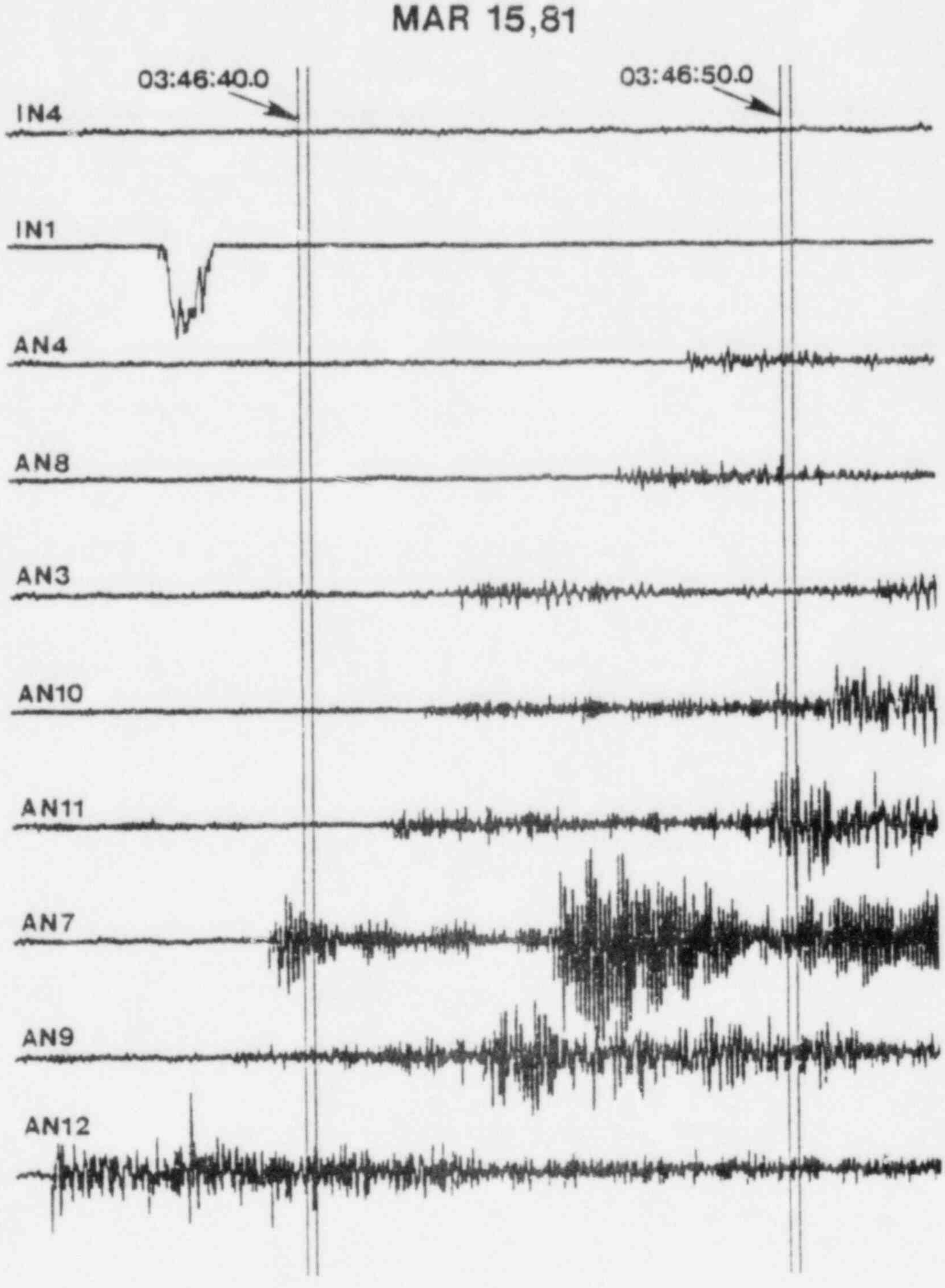


Figure 5c. Digitized Event Recorded by the Ohio-Indiana Array. March 15, 1981.

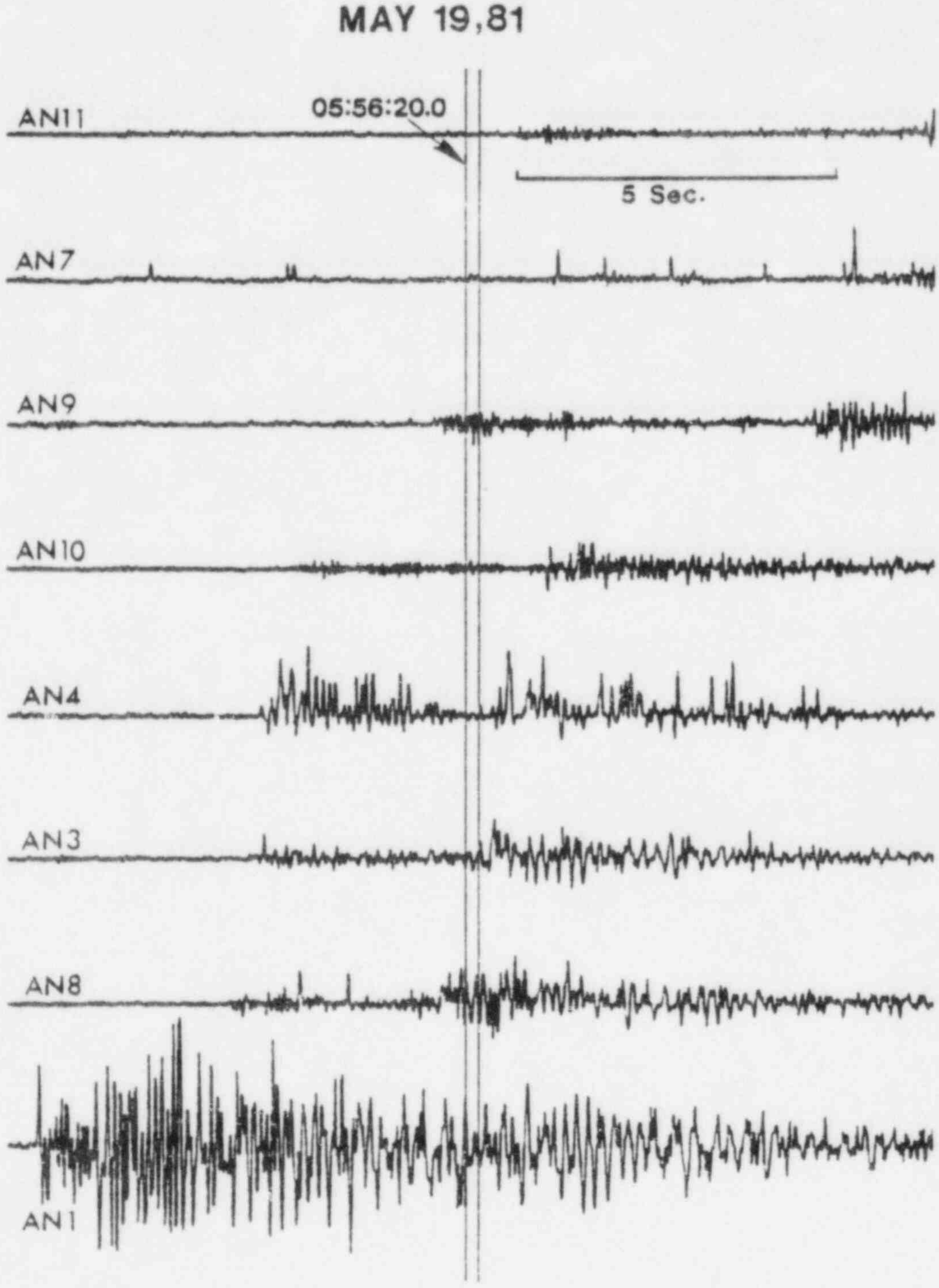


Figure 5d. Digitized Event Recorded by the Ohio-Indiana Array. May 19, 1981.

TABLE 3

LOCAL AND NEAR-REGIONAL EVENTS FROM JUNE 1977
THROUGH SEPT. 1981

Date Yr Mo Day	Origin Time Hr Min Sec	Location Latitude°N	Longitude°W	Magnitude (Duration)	Depth (km)
1977 06 17	15 39 47.3	40.706	84.581	3.3mb	
1980 07 10	11 40 53.3±.1	40.415±.003	84.111±.003	0.9	
1980 08 20	09 34 53.4±.7	41.87±.02	82.99±.02	2.4	
1980 09 26	12 27 25.6±.1	40.43±.007	84.085±.008	0.5	
1980 10 04	11 46 58.0±.6	39.80±.04	83.75±.03	2.0	
1980 12 10	02 30 54.3±.1	40.43±.01	84.11±.01	1.2	
1981 01 04	17 17 37.1±.1	40.418±.005	84.087±.005	1.8	5-7
1981 02 07	05 45 43.0±.1	40.417±.005	84.087±.005	1.8	5-7
1981 03 15	03 46 30.3±.3	41.10±.03	84.35±.03	1.2	
1981 05 15	23 15 14.0±.2	40.88±.01	84.34±.01	0.8	
1981 05 19	05 56 11.7±.1	40.407±.005	84.085±.005	1.2	2-8

III
P-WAVE RESIDUALS AND THE GRENVILLE FRONT

The following is a description of the observed teleseismic P-wave residuals abstracted from Jackson et al. (1982).

P-wave residuals were found to be azimuthally dependent, and to vary in a consistent manner between the nine statons of the Anna subarray. These intra-array residual variations imply gross structural change near the eastern boundary of the array.

P-wave residuals (observed-JB) from the 9 Ohio Stations were calculated for 311 teleseismic events which were recorded by the array between June 1978 and March 1981. The teleseismic phase arrivals for each event are listed in Jackson et al. (1982 , Appendix B). The residuals along with the back azimuth, distance and return angle are listed for each event in Jackson et al. (1982, Appendix C).

The teleseismic phase arrivals recorded by the array between Jan. 1981 and March 1982 are listed in Appendix A. Residuals calculated for this time period are listed in Appendix B for the 9 Ohio stations and Appendix C for the Indiana stations. However, none of these events were used in the P-wave residual plots.

Average residuals were calculated for each station and are listed in Table 4. The average residuals range from - 0.43 seconds at AN7 to -0.63 seconds at AN11 in the Western Ohio array and from -.47 seconds at IN2 to -.87 seconds at IN1 in the Indiana array. These average residuals are biased, however, by the large number of events which occurred to the west and south of the array. The events considered here had epicentral distances between 20° and 105°. Events with residuals greater than 4.0 seconds were not used in the calculations.

The residuals were sorted by azimuth of arrival at ten degree intervals and averaged over the nine Ohio stations. The average residuals at each azimuth are plotted on the histogram in Figure 6. The number associated with each azimuth is the number of individual arrivals that were used in the average. A geographical description of the source regions is also shown in Figure 6. Positive residuals reflect an average slowness of the paths and negative residuals an average fastness. Two major divisions can be seen, a positive region between 30° and 160° azimuth and a negative region between 160° and 330°. Several isolated events from Algeria and the Gulf of California do not reflect the generally observed azimuthal trend. Source characteristics alone cannot explain the azimuthal dependence of the residuals. Regions which are very similar tectonically such as the ocean ridges in the Atlantic and Pacific often have very different residuals. Detailed studies of P-wave residual differences between stations as described below suggest that near-receiver velocity structure is responsible for much of the azimuthal variations of the P-wave residuals.

TABLE 4

AVERAGE P-WAVE RESIDUALS FOR THE OHIO-INDIANA NETWORK (WITH RESPECT TO THE JB TABLES)

Station	Average P-Wave Residual (observed-JB) in sec.	Number of Observations
AN1	-.52	253
AN3	-.46	257
AN4	-.52	243
AN7	-.43	218
AN8	-.46	215
AN9	-.45	254
AN10	-.51	254
AN11	-.63	276
AN12	-.47	267
IN1	-.87	49
IN2	-.47	40
IN3	-.64	45
IN4	-.69	35

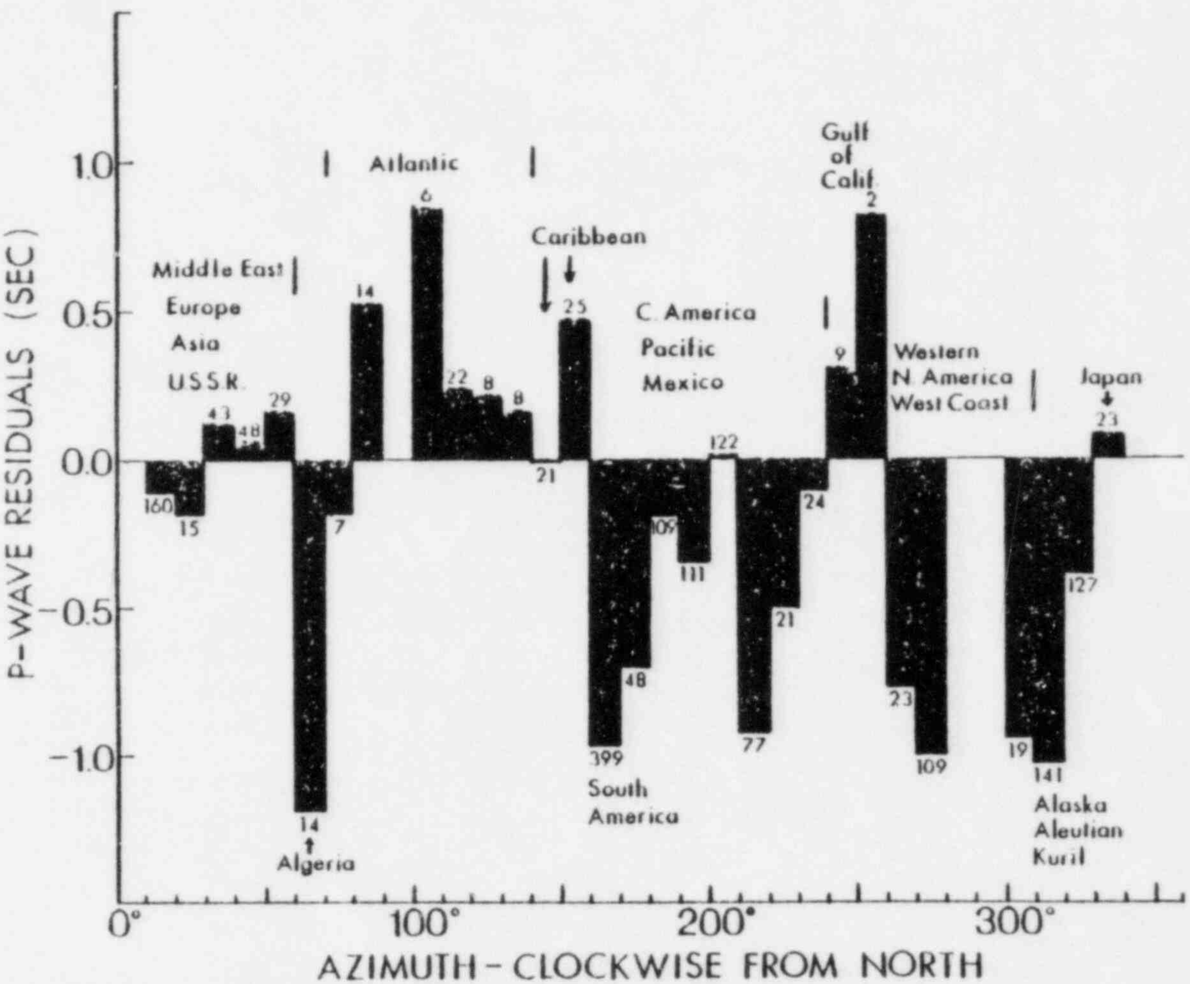


Figure 6. Average P-wave Travel Time Residuals as a Function of Azimuth for the Ohio Seismic Network.

To alleviate the source characterstics from the P-wave residuals it is convenient to look at differences in residuals between stations instead of the absolute residual values. This effectively eliminates the velocity signature from hypocentral mislocations, structure at the source, and path structure since all of the rays travel essentially the same path to the stations, leaving only the structure in the receiving region to account for the differences.

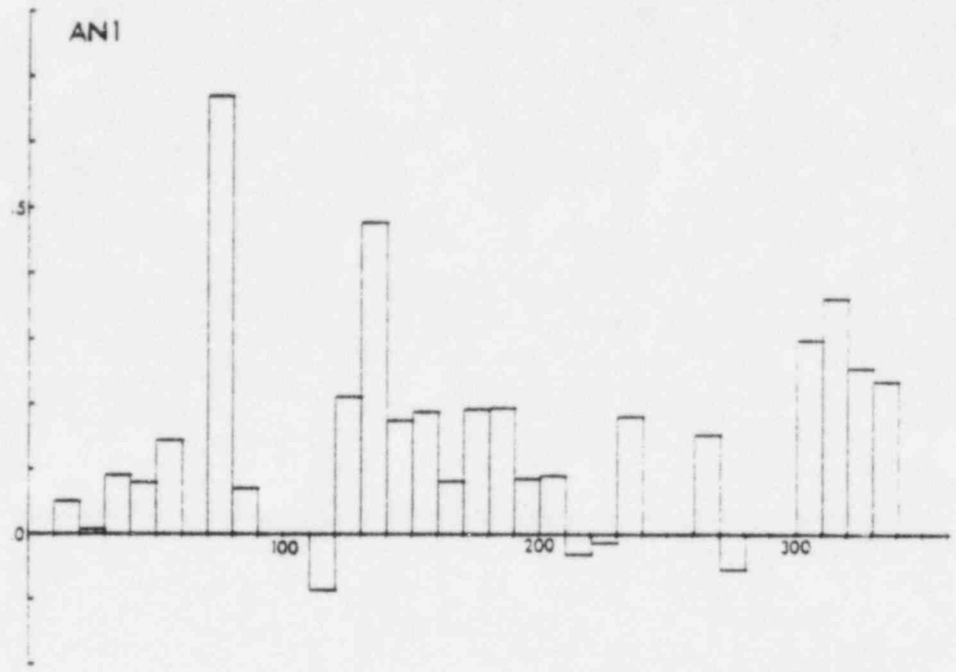
For this type of study it was important to use only well-developed and distinctive P-wave arrivals. Careful review of the available records reduced the number of usable events from 311 to 293.

The westernmost Ohio station, ANII, was arbitrarily chosen to be the standard by which to measure the residual differences. For each station, residual differences were calculated (obseved residual - ANII observed residual). These differences were averaged over ten degree azimuths for each station and plotted in Figure 7 (a-d) which shows the difference in P-wave residuals relative to ANII, plotted against azimuths to events. The histograms in Figure 8 are the same as those shown in Figure 7, but are reduced and arranged to correspond to the spatial distribution of the Ohio array. There are several observations that can be made about these histograms: First, the peaks and troughs of these curves correspond very well, giving us confidence in the general shape. Second, nearly all of the values are positive becoming larger toward the northeast. This means that the apparent velocity across the array changes from fastest in the west to slowest in the northeast. Third, the differences are very dependent on azimuth of arrival, particularly waves that arrive from the east appear to be slowed down more than waves that arrive from the west.

For some azimuths a difference in residuals of up to 0.7 seconds are observed between the eastern and western stations. Residual differences of this size cannot be explained by station elevation differences or small scale velocity changes. There are several possible structures which may explain the observed differences. The Grenville Front which may pass through this region, could be a candidate. In this case younger, possibly slower crust in the eastern portion of the array would slow the seismic waves with respect to the older, possibly faster crust to the west. The Logan-Hardin and Auglaize proposed faults which run N-S in the eastern portion of the array may, if they are sufficiently extensive, slow the arrivals to that area. In addition a thickening of the crust at the eastern flank of the Cincinnati arch could affect the arrival times, or possibly anisotropic effects could slow down or speed-up waves preferentially with azimuth.

Any one or combination of the above speculations could be responsible for the observations. Further studies using both quarry blasts and earthquakes must be made before definite conclusions can be drawn about the observed P-wave residuals.

In this report we explore the possibility that the observed P-wave residual differences may be related to the location of the Grenville Front. Several



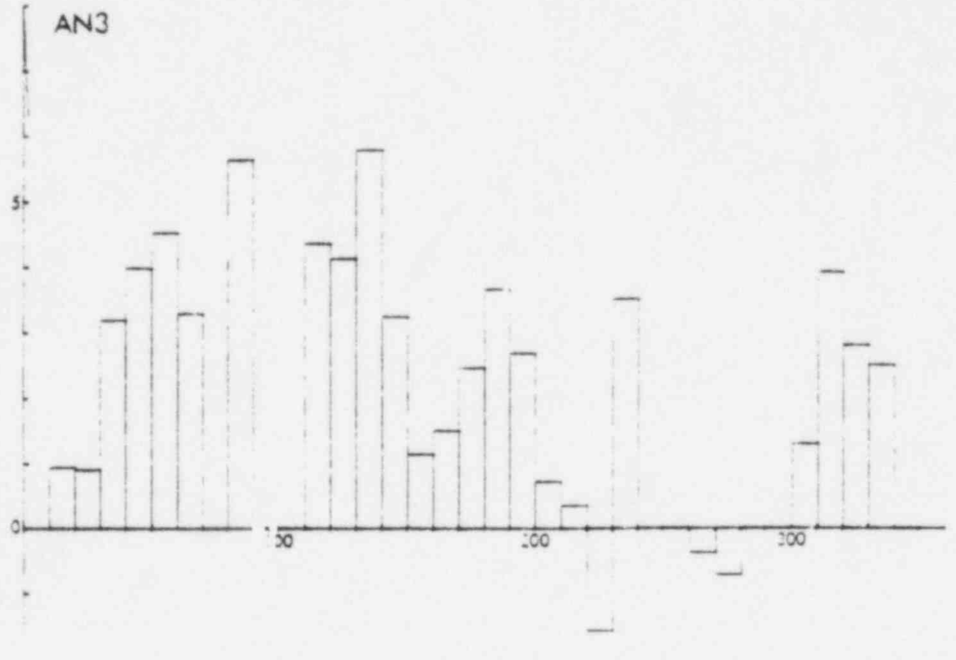
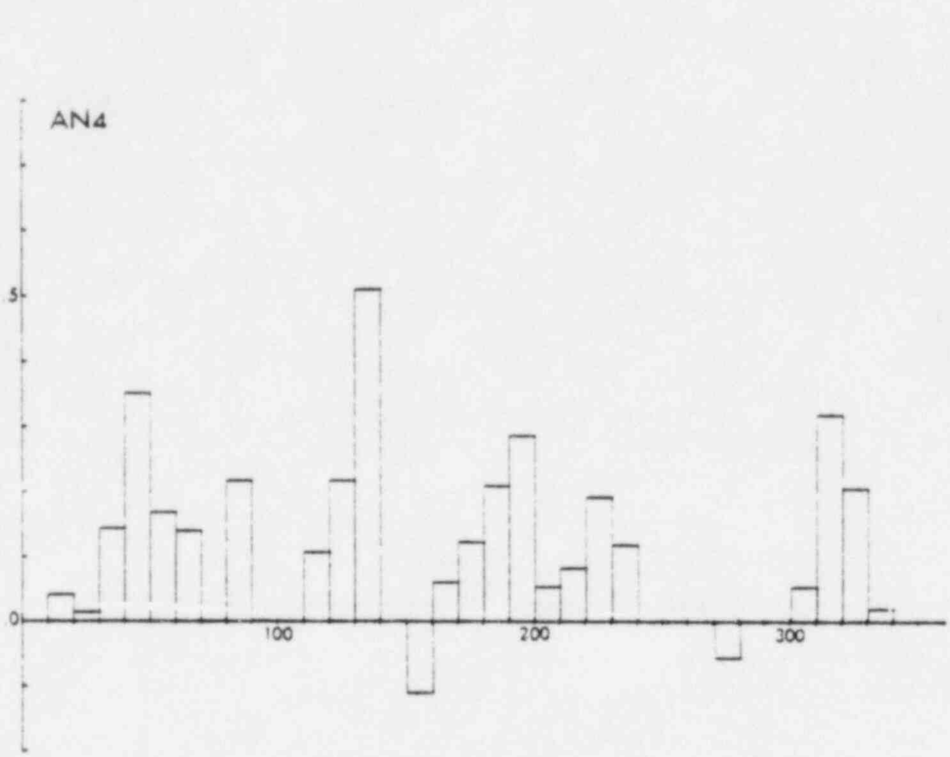


Figure 7a. Differences in P-Wave Residuals between Stations Relative to AN11 vs. Azimuth (Station Residual-AN11 Residual). Stations AN1 and AN3.



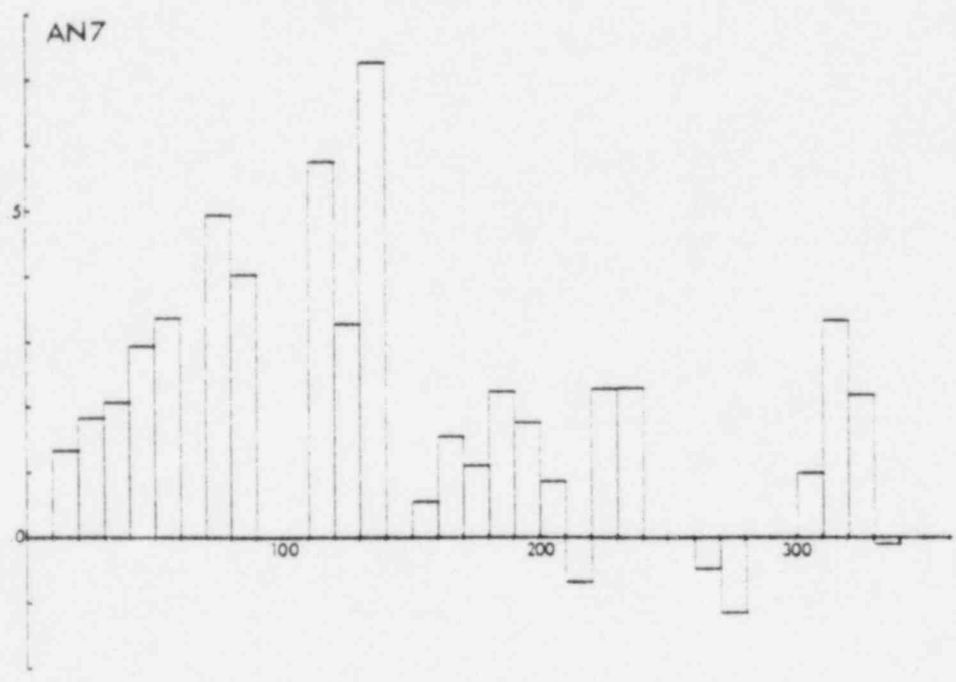
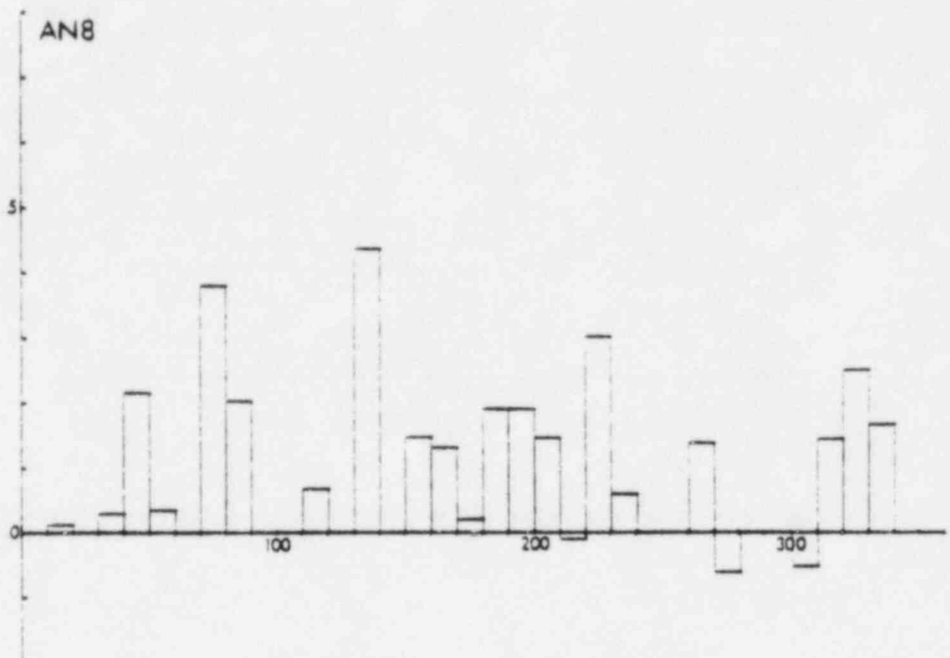


Figure 7b. Differences in P-Wave Residuals between Stations Relative to AN11 vs. Azimuth (Station Residual-AN11 Residual). Stations AN4 and AN7.



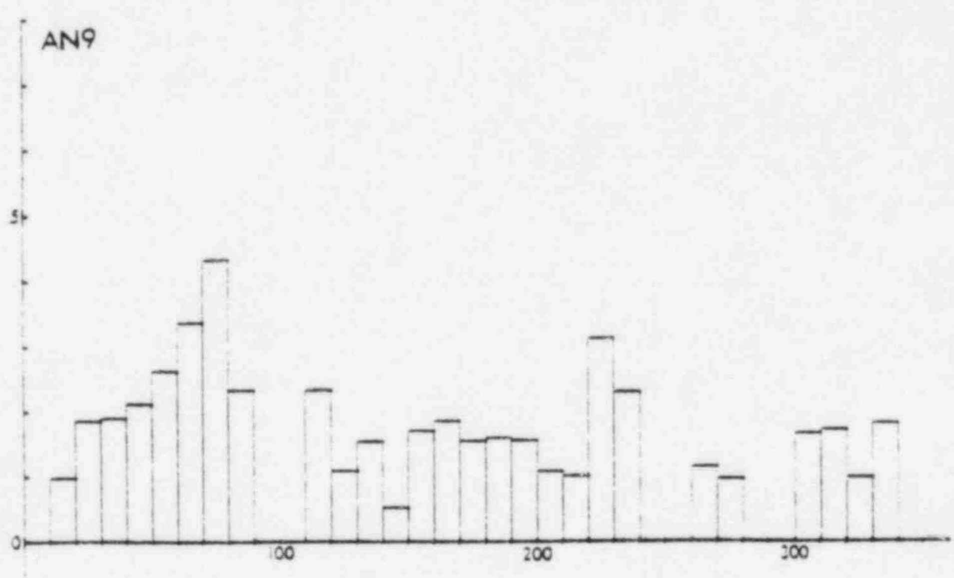
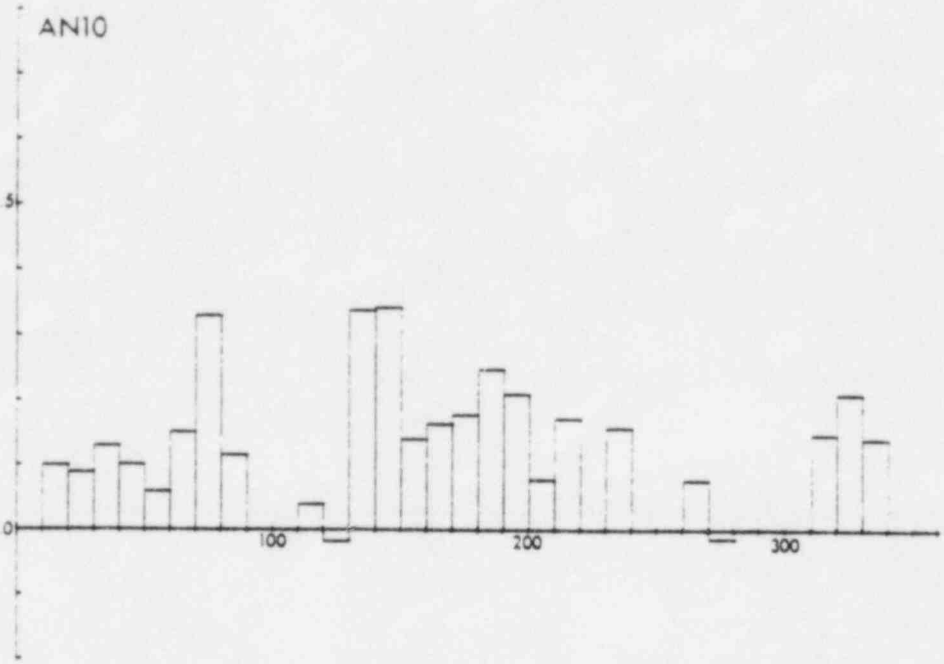


Figure 7c. Differences in P-Wave Residuals between Stations Relative to AN11 vs. Azimuth (Station Residual-AN11 Residual). Stations AN8 and AN9.



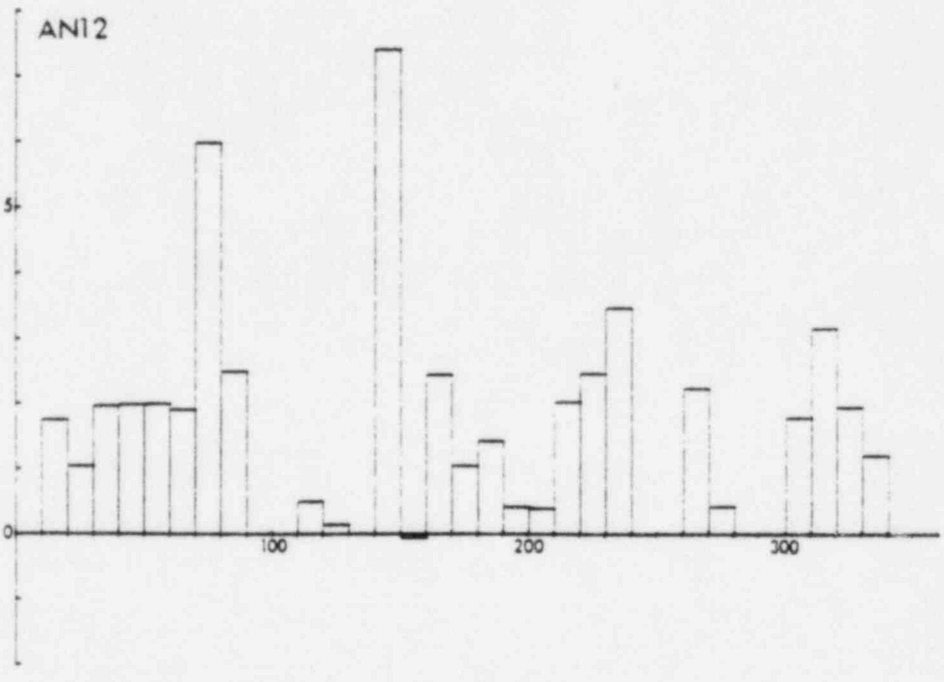


Figure 7d. Differences in P-Wave Residuals between Stations Relative to AN11 vs. Azimuth (Station Residual-AN11 Residual). Stations AN10 and AN12.

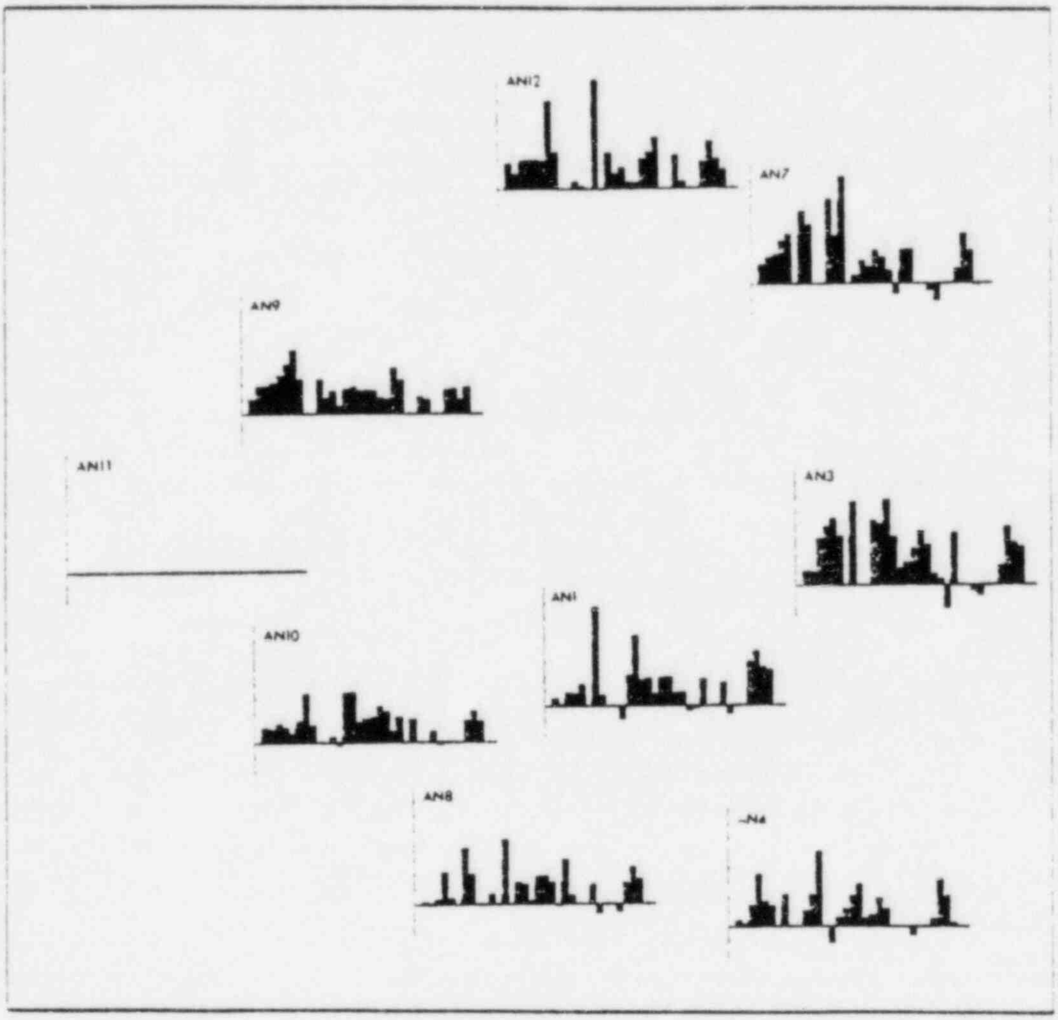


Figure 8. Representation of the Difference in P-Wave Residuals between Stations Relative to AN11 with Azimuth.

investigators have suggested that the Grenville Front passes through the region (Bayley et al., 1968; Bass, 1960; McCormick, 1961; Lidiak et al., 1966). They have based their suggestions on age and petrology of bore hole samples in addition to gravity interpretation. Figure 9 shows one example of the proposed trend of the Grenville Front by Bayley and Muehlberger (1968).

Seismic studies of the Superior and Grenville Precambrian provinces, including the Grenville Front in NE Canada, have shown that the thickness of the crust in the Grenville Front is up to 11 km thicker than in the Superior province, and that this change in thickness may occur over a distance of as little as 50 km. This is roughly the type of structure which could cause the observed P-wave residual differences. In the remainder of this section we will show this in a general way using an interactive two-dimensional seismic ray tracing program (Jackson, 1970; Jackson and Wackerman, 1980).

An idealized cross-section through the Grenville Front in Eastern Canada taken from a study by Berry and Fuchs (1973) is shown in Figure 10. Using this cross-section we calculate P-wave residuals through this model for rays which approach from both directions, and compare these to the observed data. In this simple demonstration we are not trying to match the residuals exactly but only the general trends.

The Grenville Front in Canada is characterized by a large negative Bouguer gravity anomaly. For the present experiment we will let the trend of the hypothetical Grenville Front be parallel to the elongated trend of low values in the upper right hand corner of the Bouguer Gravity Anomally map of Western Ohio in Figure 11 (line A-A'). We then set the Grenville Front cross-section perpendicular to this line (B-B'). We can now calculate the minimum distance of each station from the proposed front and then plot the relative residual as a function of distance from this line for different azimuths. Two such plots can be seen in Figures 12a, b.

The values plotted in Figure 12a are averaged from observed rays with back azimuths between 20-40° and return angles of between 10°-20° from vertical. Figure 12b is from observed rays with back azimths between 220°-260° and return angles of between 25°-30°. We can see from these plots that waves arriving from the NE show residuals that increase in a more-or-less constant fashion relative to AN11 as we approach the hypothetical line. Rays arriving from the SW show little or no relative residuals across the array. This is the behavior that we must try to predict using this simple modeling.

The rays used in the model calculation and residual plots are shown in Figure 13a, b. Figure 13a shows rays approaching from the right side of the model (NE) and Figure 13b from the left (SW). The actual data from Figures 12a, b to are also plotted on these plots. The actual data are not expected to fit the predicted values exactly due to the effect of forcing a two dimensional model onto the three dimensional problem. Also the cross-section used is taken directly from Grenville Front studies in Canada and has not been altered to match our data. In this

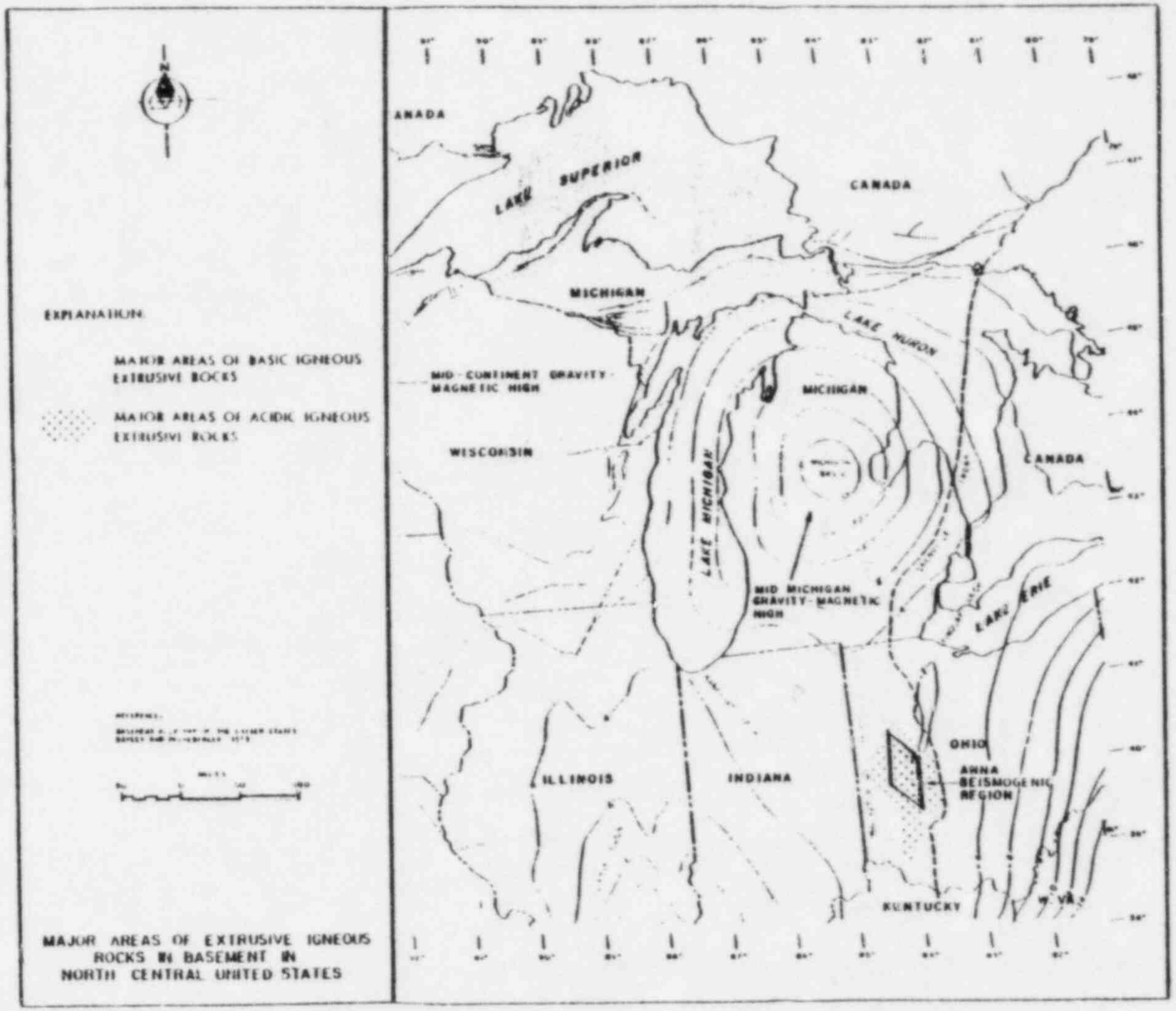
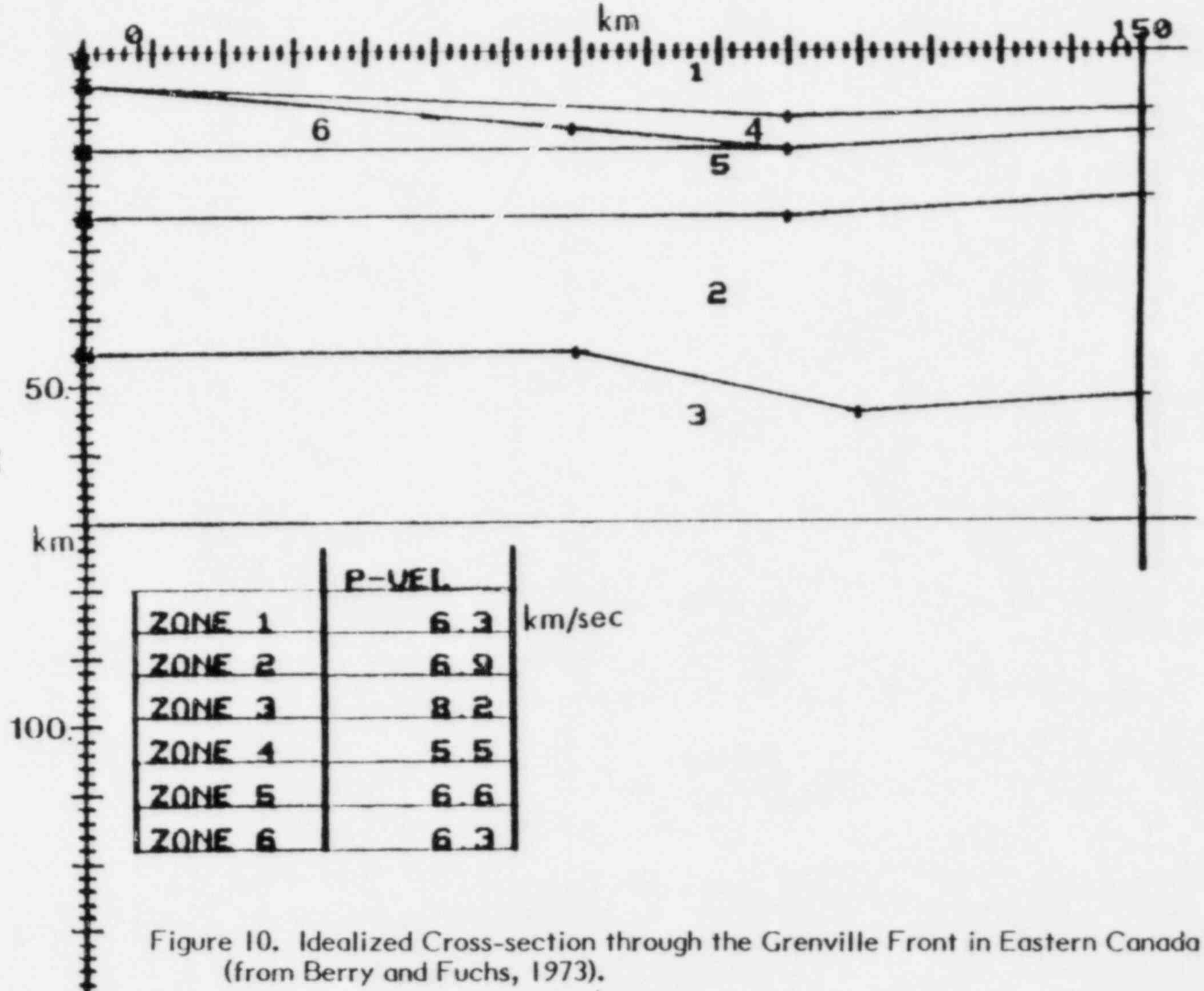


Figure 9. Proposed Location of Grenville Front through Ohio (from Bayley and Muehlberger, 1968).



	P-VEL
ZONE 1	6.3 km/sec
ZONE 2	6.9
ZONE 3	8.2
ZONE 4	5.5
ZONE 5	6.6
ZONE 6	6.3

Figure 10. Idealized Cross-section through the Grenville Front in Eastern Canada (from Berry and Fuchs, 1973).

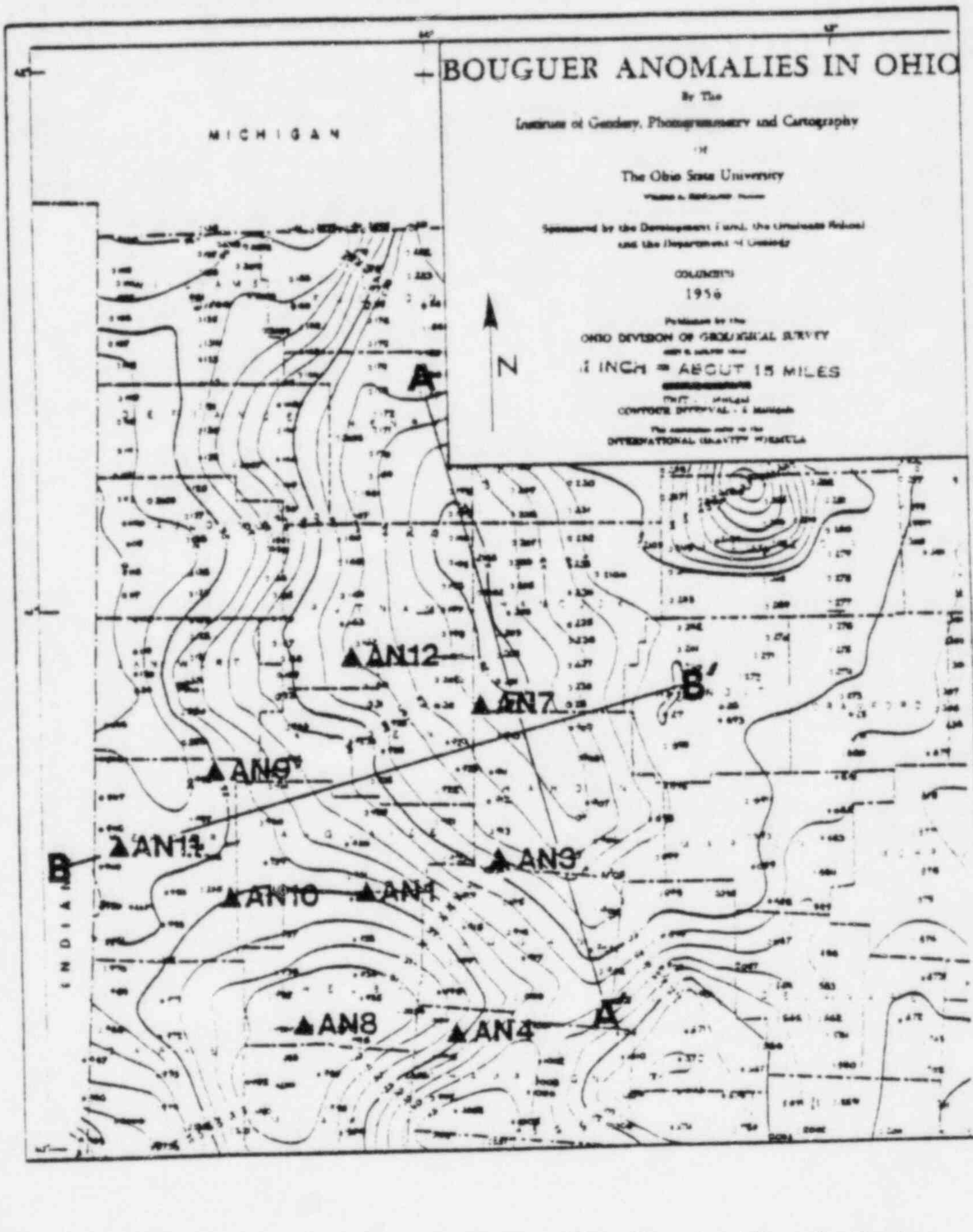


Figure 11. Bouguer Gravity Anomaly Map of Western Ohio Showing Hypothetical Trace of Grenville Front (A-A'), Trace of Cross-Section (B-B'), and Seismograph Stations.

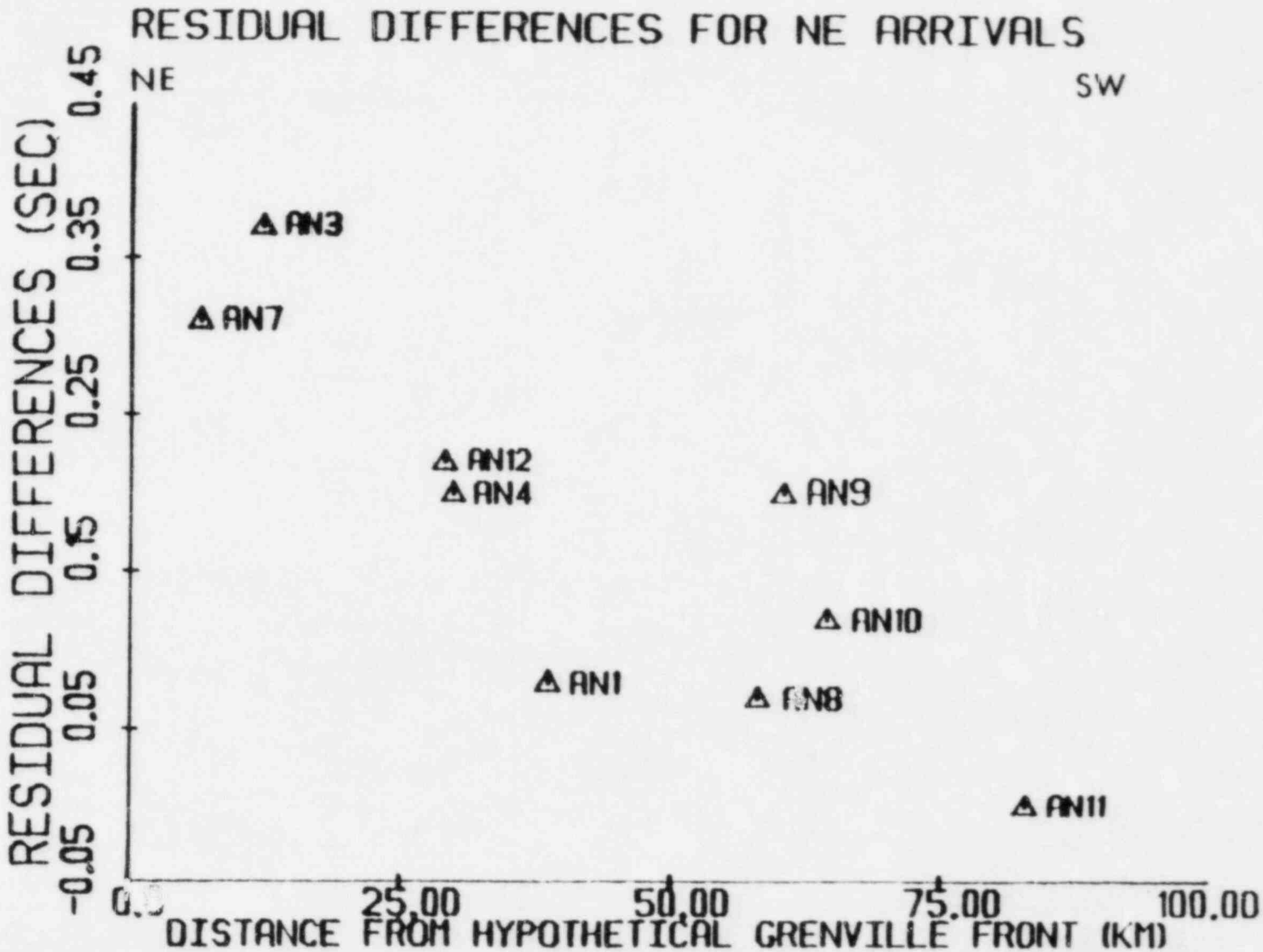


Figure 12a. Residual Differences Plotted with Distance from Hypothetical Grenville Front Line: Rays Arriving from the NE.

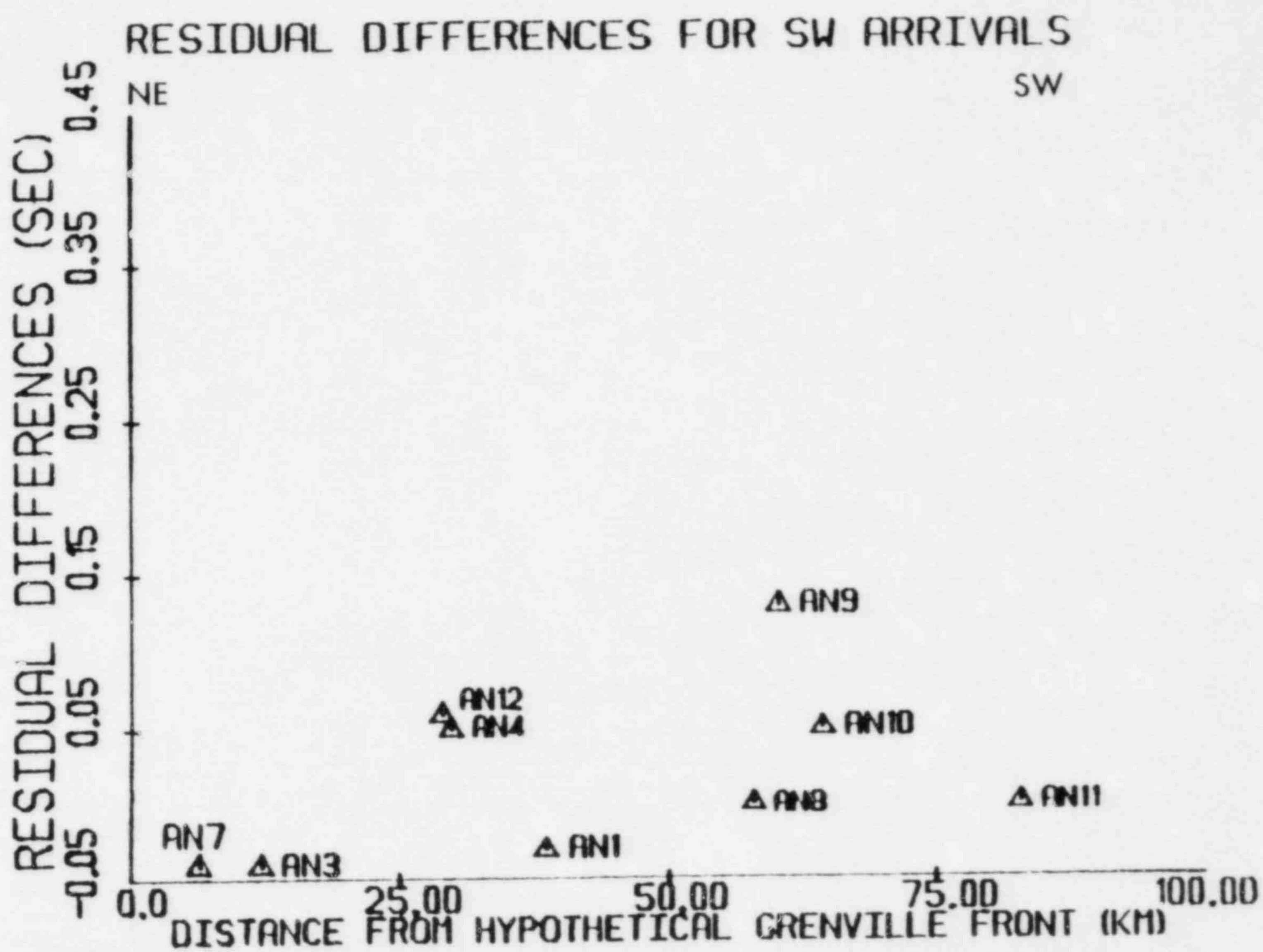


Figure 12b. Residual Differences Plotted with Distance from Hypothetical Grenville Front Line: Rays arriving from the SW.

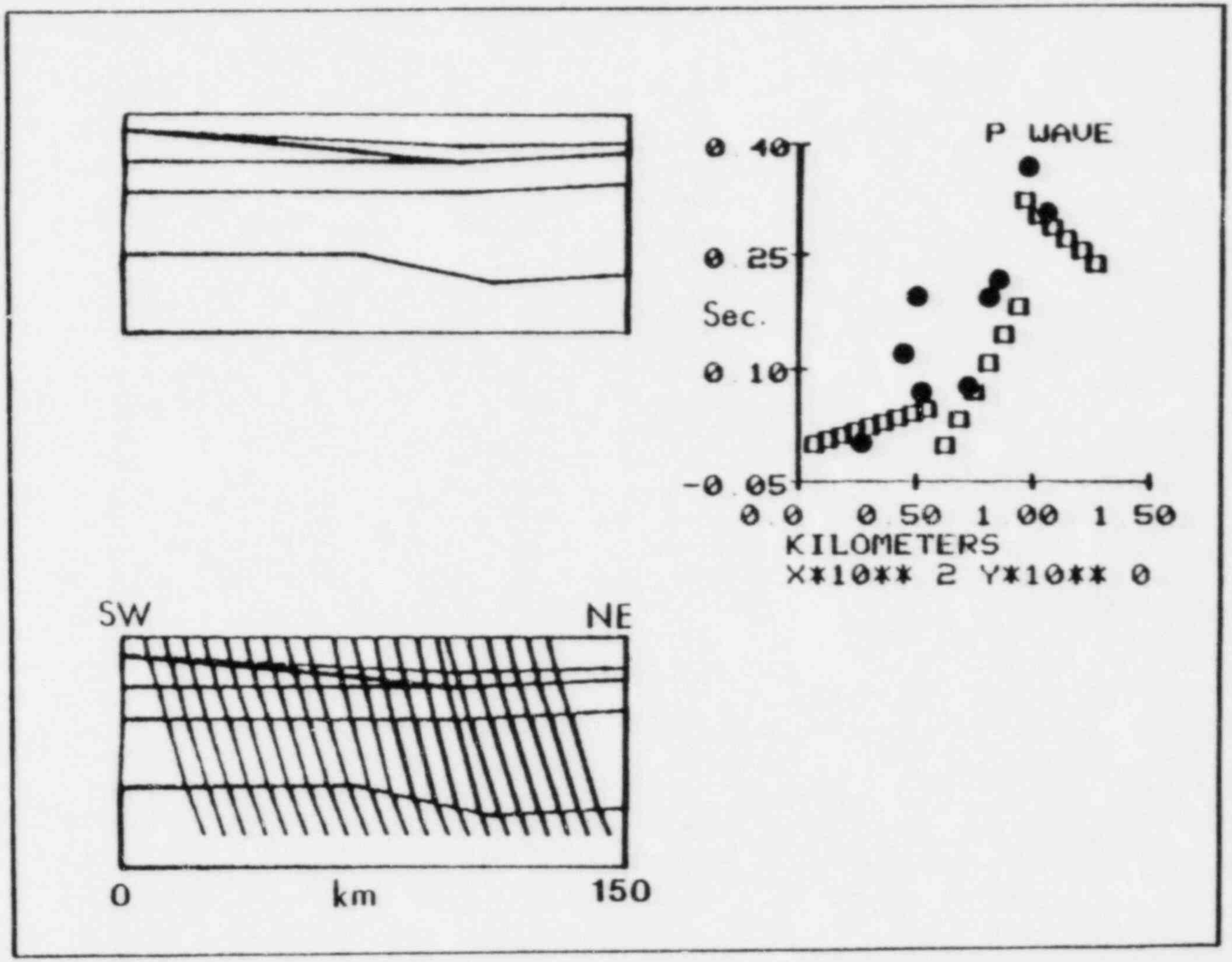


Figure 13a. Calculated Residual Difference Plot for Rays and Structure Shown Along with observed Data Points (dots) from Figure 12. Above for Rays Arriving from the NE.

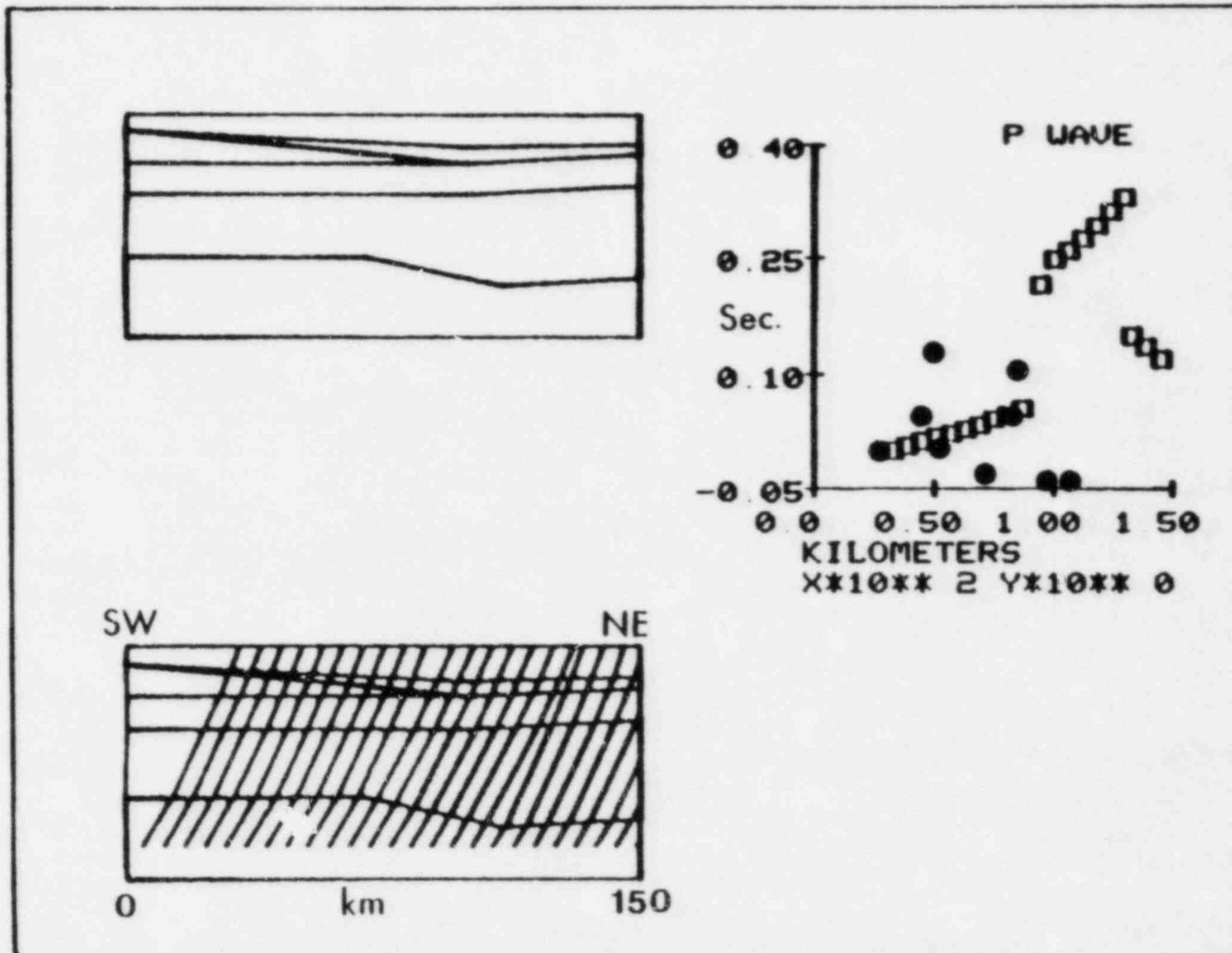


Figure 13b. Calculated Residual Difference Plot for Rays and Structure Shown Along with observed Data Points (dots) from Figure 12. Above for Rays Arriving from the SW.

exercise we are testing the Grenville Front structure for our data. As can be seen the general trends and magnitudes are predicted from this simple model. This obviously doesn't prove that the Grenville Front passes through this region. The P-waves residuals, however, seem to be consistent with this possibility.

If the Grenville Front does pass through this region one could speculate that the historic seismic activity in this area could be related to the reactivation of the Grenville Front which is sometimes seen as a fault. Even though seismicity is not generally asociated with the Grenville Front it may be that its intersection with younger features such as the Cincinnati, Findley, and Kankakee archs or other unknown factors may be sufficient to activate this older feature. We emphasize that this speculation is not an interpretation, but a possibility which merits further study.

IV
THE GEOLOGY OF THE ANNA, OHIO AREA

Introduction

A region of elevated seismic activity is situated in west-central Ohio, centered around the town of Anna. The Anna area experienced twenty-three earthquakes of modified Mercalli intensity III or greater over the time span 1875-1964 (Bradley and Bennett, 1965). Such a level of seismic activity is unique for Ohio, as it represents approximately 50 percent of historic earthquake events for the entire state (McGuire, 1975). This unusually high level of seismic activity has led Kieffer, et al. (1975) to define a region of approximately 4,300 km^2 in western Ohio as the "Anna Seismogenic Region." Although no consensus exists as to the exact boundaries of the Anna area, there is general agreement that the level of seismic activity is abnormally elevated, relative to the regional background seismicity, in the vicinity of Anna.

The state of Ohio is located within the Interior Lowlands province of the north American craton (King, 1977), which extends across the central United States from the Appalachian orogenic belt to the Rocky Mountains. Although characterized by long term structural stability, a number of highly localized concentrations of earthquake epicenters occur within this region. See Figures 14 and 15. Neither the driving forces nor the nature of the faulting are clearly understood for these seismic zones. Intra-plate seismicity appears to fundamentally differ from the more common inter-plate seismicity in having both relatively higher rates of energy release and greater effective stresses for events of comparable "long term magnitudes" (Sbar and Sykes, 1973).

This section is a summary of the geology of the area around Anna, Ohio. To facilitate the interpretation of the various geological phenomena which affect the local elevated levels of earthquake activity, the geomorphological, stratigraphic, structural and geophysical literature for western Ohio are combined into a single source.

Physiography

The town of Anna is located in Dinsmore and Franklin townships of Shelby County, Ohio at 40° 23' 45" N; 84° 07' 15" W, in sections 28 and 33 of T7S R6E in Shelby County. Anna is located within the Central Lowlands physiographic province, the region of Ohio in which bedrock is essentialy flatlying. The Central Lowlands, extending north-south from Lake Erie to Cincinnati and east-west from central Ohio to the Indiana state line, is the area where the pre-glacial bedrock topography was dominated by the processes of stream erosion. Limestones are the dominant surface lithologic units within this region. This area contrasts with the Appalachian Plateau physiographic province in the eastern half of Ohio where the

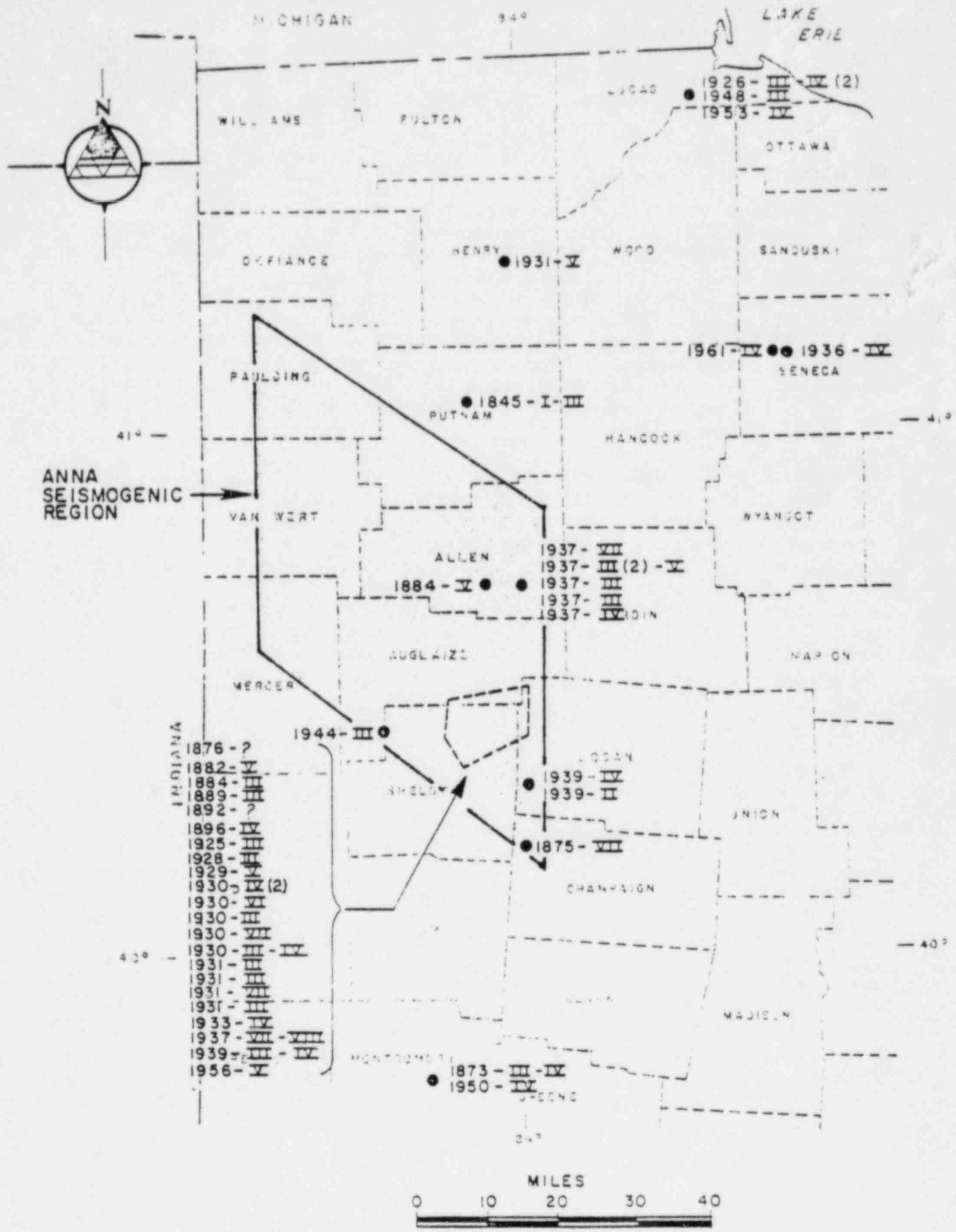
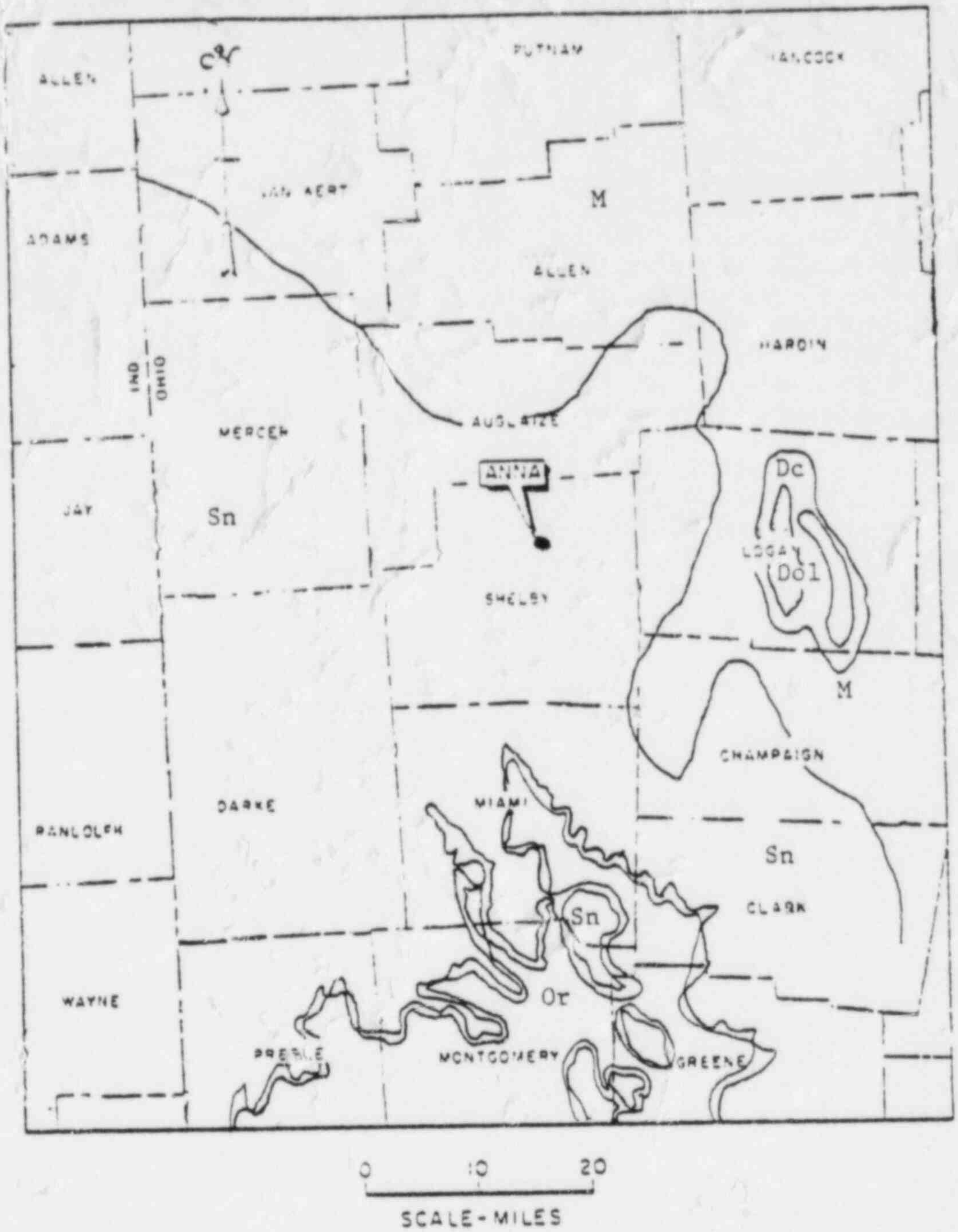


Figure 14. The Location of the Anna Seismogenic Area including the Locations of the Post-1870 earthquakes (Kieffer and Trapp, 1975).



Devonian	Dol	- Olentangy Shale
	Dc	- Columbus Shale
	M	- Monroe Limestone
Silurian	Sn	- Niagara Limestone
	Sb	- Brassfield Formation
Ordovician	Or	- Richfield Shales and Lmst.

Figure 15. Geologic Map of West Central Ohio (from Brownocker, 1920).

original bedrock relief is influenced by regional uplift modified by extensive stream downcutting. Sandstones and shales dominate the surface lithologies of the Appalachian Plateau (Noble and Korsok, 1975).

The local topography around Anna, Ohio is dominated by low relief ground moraines interspersed with east-west trending Wisconsin age end moraines. Kames, kame terraces and peri-glacial lacustrine deposits also occur in isolated locations in or near Shelby County (Godlthwait, et al., 1961). The modern surface morphology of Shelby and adjoining counties is controlled by Wisconsin age glacial deposits, having been slightly modified by recent fluvial erosion and deposition (Forsyth, 1956). Local elevation varies from 256 meters above sea level in west-central Auglaize County to 396 meters elevation in eastern Logan County. Within Shelby County the total relief is approximately 65 meters of which 24 meters represent downcutting of the Great Miami River channel (Hussey, 1878).

Surface drainage for Shelby and Logan Counties is towards the south through the Great Miami River. The lack of well established end moraines permits the development of both pinnate and dendritic drainage to the south of Anna (U.S. Geological Survey, 1927). Ultimately the Great Miami River drains through a well-established river valley into the Ohio River in extreme south-western Ohio. Auglaize and Hardin Counties, to the north of Anna, drain to the northeast into Lake Erie via the Maumee River. The presence of a series of east-west trending glacial moraines has produced a pinnate drainage system in this region. Portions of Mercer and Karke Counties drain westward into the Wabash River basin. The St. John's End Moraine divides the Great Miami and the Maumee drainage basins except in the locations where stream capture has taken place (Goldthwait, et al., 1961). Erosion due to surface run-off is classified as "little or no erosion" for the majority of the Anna area. Areas of "moderate sheet erosion" and "moderate sheet erosion occasional gullies" are also present (Bennet, et al, 1935).

The soils of the Shelby County region are of predominantly loam and silty loam composition. Clay and clay loam soils are present, though less common. Sandy soils are rare. In a few highly localized areas the soil profile is influenced by surface or near surface bedrock units. Muck soils are often present in topographically low areas. The nearly homogeneous composition of the glacial deposits has resulted in the local slope being the primary source of soil differentiation. Soil drainage varies from moderately well drained to poorly drained. A typical soil profile for the Anna area consists of a subsoil extending to approximately 0.5 meters depth with a total depth of weathering of approximately 1.5 meters (Cunningham, et al., 1981; Lehman, et al., 1980; Waters, et al., 1979; Ritchie and Powell, 1971.

Pleistocene Deposits

The entire Anna area is covered by unconsolidated Pleistocene age glacial tills and outwashes ranging between 10 and 70 meters in thickness. In confined regions and thickness of drift deposits may reach as much as 150 meters due to the bedrock topography beneath the glacial materials (Stout, et al., 1943). Depositional evidence exists within Shelby County to indicate that both Wisconsinan and Illinoisan ice sheets were present in this region. The presence of Kansan aged ground moraines in Hamilton County, Ohio, 100 km to the south, implies that west-central Ohio was affected by Kansan aged glaciation, although no field observations for this event have yet been noted near Anna, Ohio.

The state of Ohio has been divided into five different landform regions (Noble and Korsok, 1975). The boundaries for these regions are based on the overall nature of the glacial deposits (including the total absence of glacial materials) along with the physiographic classification of the local bedrock. The five landform regions of Ohio are:

1. The glaciated Appalachian Plateau is a zone of moderate relief extending from central to northeastern Ohio (see Figures 16 and 17). This region is the result of an area of initially rough topography being modified by glaciation. The Wisconsinan and possibly earlier ice sheets eroded and rounded the hills while flattening and broadening the valleys through deposition of fluvial and/or glacial sediments. The original drainage pattern of the glaciated Appalachian Plateau landform region, though strongly modified, still exerts an influence on the recent surface drainage distribution. Small lakes and poorly drained bottomlands have resulted from glaciation.

2. The unglaciated Appalachian Plateau, occupying the southeastern third of the state, is characterized by heavily eroded hills dissected by deep, steep-sided river valleys. Local relief frequently exceeds 80 meters. Since this landform region has not undergone direct glacial modification the unglaciated Appalachian Plateau is a very mature topographic region. The lack of unconsolidated surface materials has resulted in reduced rates of erosion relative to bordering glaciated areas.

3. The Lexington Plain is the portion of the Central Lowlands physiographic province, centered in Adams County in south-central Ohio, which remained unglaciated throughout the Pleistocene epoch. This region is characterized by broad, well-entrenched stream valleys with relatively gentle flanks, the result of long-term erosion of limestone bedrock. Karst topography is common in this region. Local relief averages approximately 50 meters.

4. The Lake Plains, situated in north and northwestern Ohio, is a region of very low relief, the result of lacustrine deposits which were laid down during the final stages of the Wisconsin glacial episode. With the final retreat of the Pleistocene ice sheet large amounts of melt-water were trapped between the glacier to the north and a series of recessional moraines to the south. The

Figure 16. Map Showing the Physiographic Divisions of the State of Ohio (from Noble and Korsok, 1975).

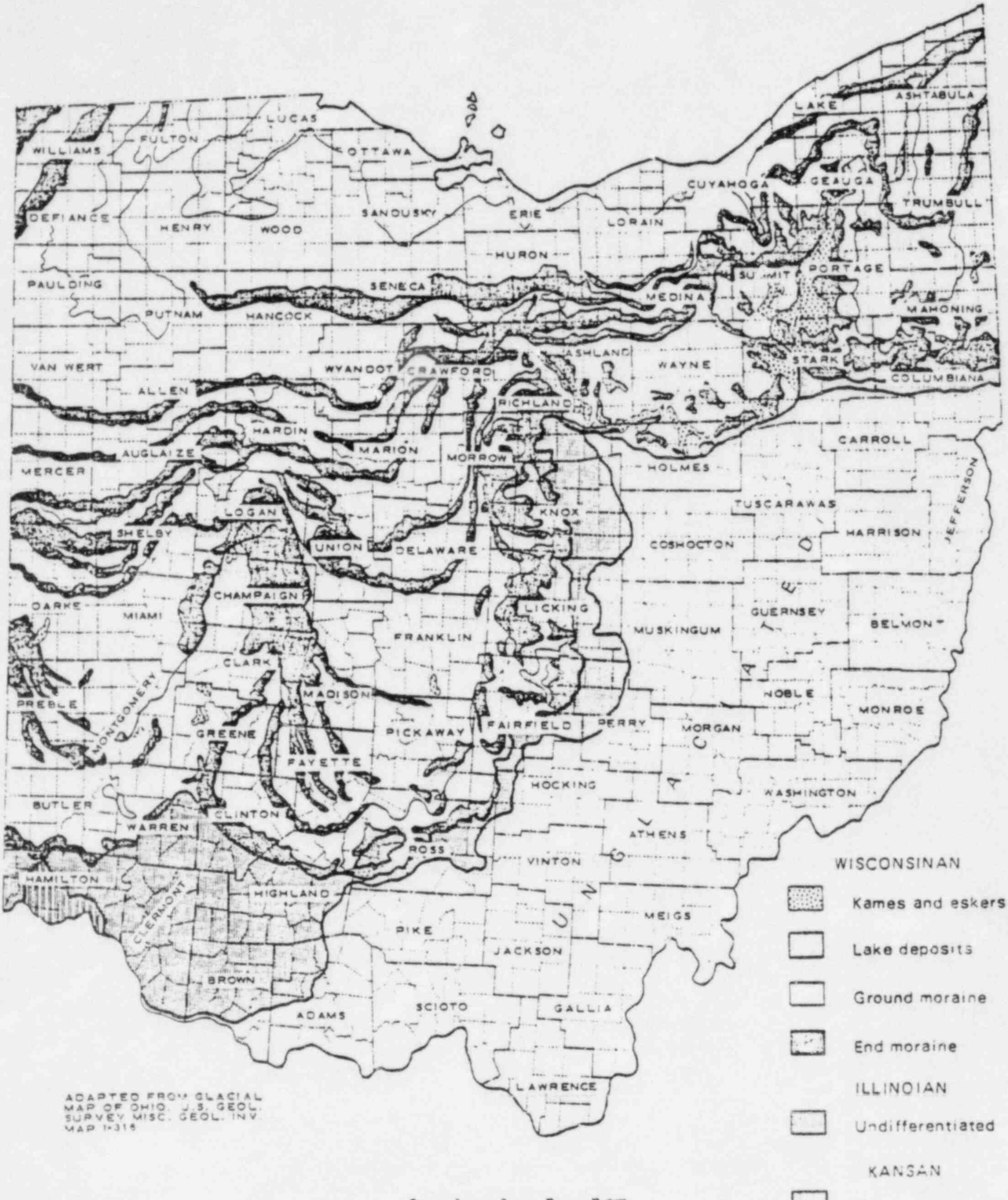


Figure 17. Glacial Deposits of the State of Ohio (Goldthwait, et al., 1961).

direction of lake drainage varied with the position of the ice margin, resulting in a series of changes in lake levels. The deposition of lake silts and clays produced the current topography while obliterating the preexisting ground moraine deposits. Current topography, with local relief not exceeding 10 meters, is the result of fluvial erosion on the initially flat lake beds.

5. The Till Plains extend from central to western Ohio. This landform region was produced by the deposition of Wisconsinan glacial drift within the Central Lowlands physiographic province. The regional topography is the product of Holocene stream dissection of ground and end moraines (Goldthwait, et al., 1961). The region is traversed by a series of arcuate, subparallel, east-west trending end moraines. Local relief within the Till Plains averages approximately 30 meters.

The Anna area is located within the boundaries of the Till Plains landform region. Glacial drift is 10 to 70 meters in thickness. Local bedrock is composed of Niagara dolomites of upper Silurian age (Bownocker, 1920). The bedrock surface, part of the Parker Strath erosion surface, has a maturely developed topography (VerSteeg, 1946), the result of erosion by the Tertiary Teays River system.

Wisconsin Episode Glaciation: Forsyth (1956) undertook an extensive survey of the Pleistocene geology of Shelby and Logan Counties, Ohio. She determined from stratigraphic correlations of buried paleosols and from radiocarbon dating that two distinct glacial substages occurred in west-central Ohio during the Wisconsinan glacial episode. These two events have been given the names "Early" Wisconsin Substage and the "Late" Wisconsin Substage (Figure 18).

The "Early" Wisconsin ice advanced well to the south of the Anna area. During the retreat of the "Early" Wisconsin glacier a period of stagnation of the ice front resulted in the deposition of the Inner Upland moraine in southern Logan County. This moraine contains large amounts of kame deposits, reflecting the irregular nature of topography on which the drift was deposited (Forsyth, 1956). Meltwater flowed south through a now-abandoned channel near the town of Peckrelltown in south-central Logan County. Eventually the ice withdrew northward depositing the West Liberty and, later the Farmersville end moraines. With the retreat of the ice margin a series of outwash materials were deposited at various elevations (Forsyth, 1956). The Miami River esker, a north trending ridge, was also produced during the withdrawal of the "Early" Wisconsin ice.

An inter-glacial period of unknown duration has been identified in the Anna area. The evidence for this is the existence of at least 15 post-"Early" Wisconsin buried soils in Logan and Shelby Counties. As the "Late" Wisconsin ice advanced southward it overrode a series of boreal forests. Radiocarbon dating indicates that the ice margin passed southward through Anna, Ohio, approximtely 23,000 year ago (Forsyth, 1956). Rates of southward advance have been estimated at 33 to 46 meters per year (Forsyth, 1956) or 48 meters per year (Flint, 1955). The maximum advance of the "Late" Wisconsin glacier occurred between 20,000 and 18,000 years ago. During the "Late" Wisconsin glacial maximum portions of the Anna area

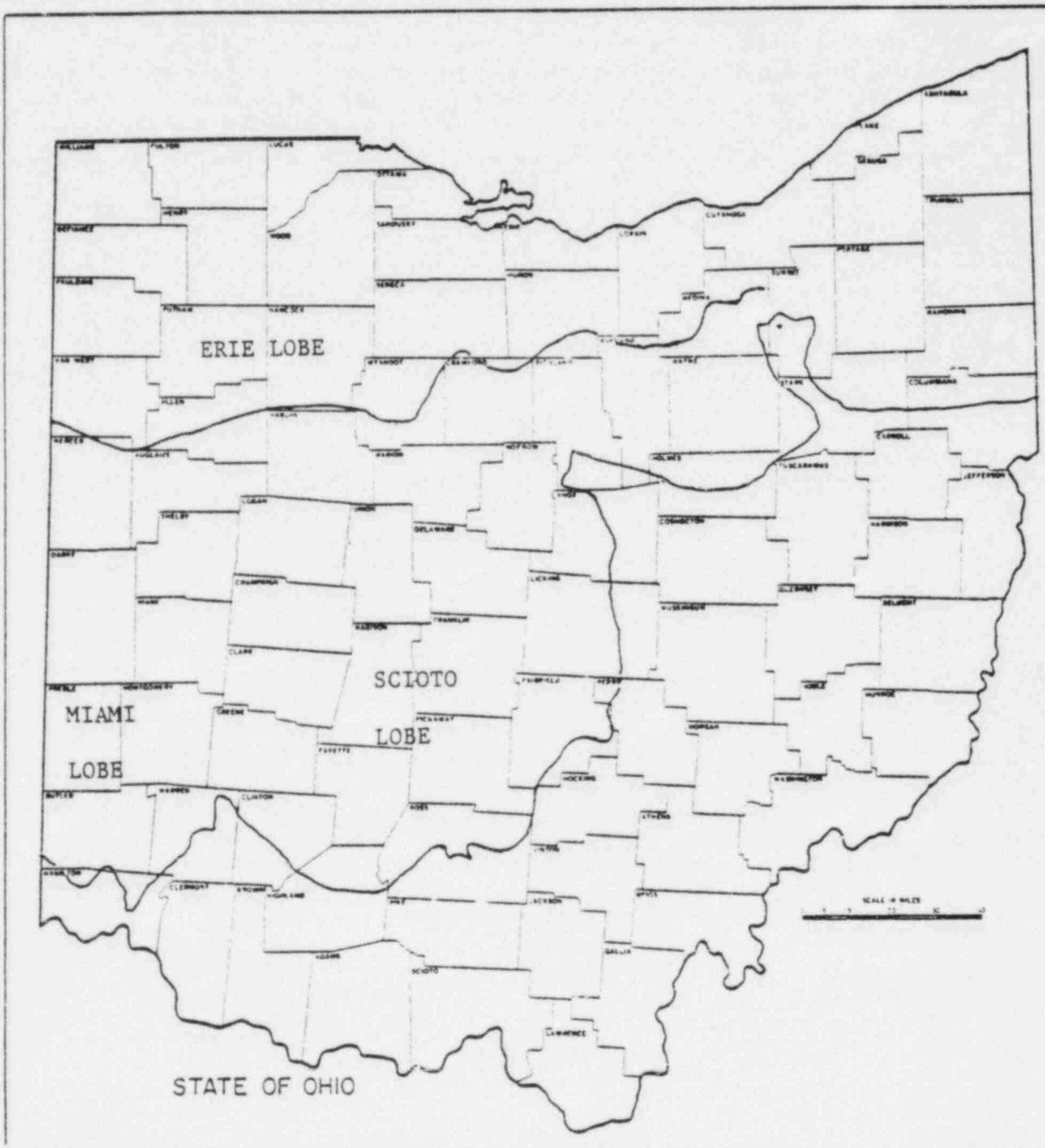


Figure 18. Map Showing the Relative Locations of the Major "Late" Wisconsinan Glacial Lobes in Ohio (from Goldthwait, et al., 1961).

remained ice free, although the majority of the preexisting glacial deposits were overridden.

The retreat of the "Late" Wisconsin ice sheet produced the present topography of the Shelby county region. Meltwater deposited gravel outwash materials. Water flowing along the course of the present-day Mad River began to erode a valley. Oscillations in the position of the ice front produced a series of east-west trending end moraines. A number of glacial lakes were established due to the large amounts of meltwater being produced. As the ice ultimately withdrew from the Anna area the foundations of the modern drainage pattern had been established.

The pre-Wisconsin Pliestocene: No deposits of pre-Wisconsin aged tills have been proven to exist within the surface deposits of Shelby and Logan Counties. One suspected case of Illinoisan till is located in a railroad cut 3 km south of the town of Sidney in Shelby county. It is presumed that drift materials found at great depths, especially within the pre-Pleistocene Teays River valleys, represent glacial deposits from the early Pleistocene ice advances (Forsyth, 1956). The thickness of these early ice masses are unknown.

One of the major effects of the early glacial, Kansan or pre-Kansan ice advances was to disrupt the Tertiary Teays River drainage system. The best established/preserved interglacial drainage system--the Deep Stage--is of post-Kansan or pre-Kansan in age. At this time the ice margin covered pre-existing drainage routes, while clogging many sections of the Teays River with the deposition of the lacustrine Minford silt at an elevation of 256 meters (Stout, 1943). Drainage patterns shifted to the south resulting in the erosion of deep, steep-sided valleys where none had previously existed. Evidence from the town of Wheelersburg in Scioto County in south-central Ohio suggests that a period of regional uplift occurred at Deep Stage times (Stout, 1943). This is indicated by the valley floor of the Teays system being approximately 59 meters higher in elevation than the Cincinnati River, a major river of the Deep Stage drainage system. The existence of this period of uplift has not been confirmed.

The Teays River System: The Tertiary surface of Ohio was composed of rounded hills with low gradient rivers occupying broad valleys. This erosional surface is known as the Teays surface in West Virginia or the equivalent Parker Strath in Ohio. The dendritic drainage system which was present at this time is known as the Teays River. VerSteeg (1946) has interpreted this morphological feature as representing a well developed, mature erosional surface. Evidence exists to suggest that the Teays River Valley in Ohio was the result of two periods of erosion, an inner valley carved within the flood plain of a broader, pre-existing valley (Figure 19). The presence of a well-graded valley floor implies that local base level was stabilized for a significant length of time.

The Tertiary Teays River had its source in the Piedmont plateau in Wautauga county, North Carolina. From there it flowed northward across the majority of the Appalachian Orogenic belt into Virginia, turned westward across West Virginia,

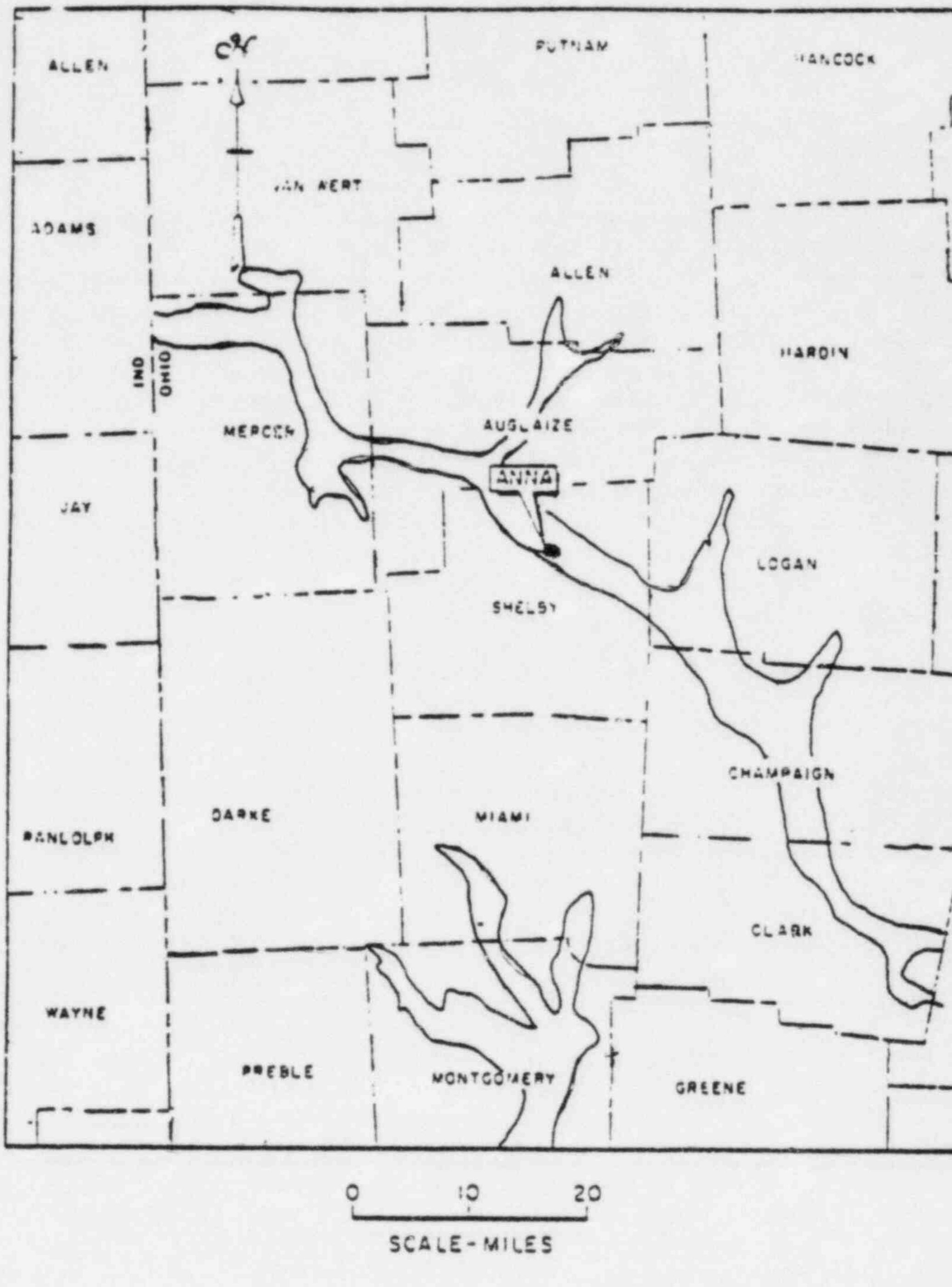


Figure 19. The Location of the Teays River Channels beneath the Anna Area (adapted from Cummins, 1959).

Ohio, and Indiana to ultimately drain into the ancient Mississippi River in central Illinios. This course had a length of approximately 1500 km. In the Anna area the Teays system was ultimately abandoned due to the disruption of flow caused by glacial damming and sedimentation.

Stratigraphy

The nature of the bedrock beneath the Anna area is only poorly understood. Due to the extensive glacial deposits, bedrock outcrops in Shelby County are limited to the valley of the Great Miami River and to the quarries which are present within the region. A significant amount of drilling for both oil and natural gas has taken place in west-central Ohio. A review of the lithologic data from these wells has shown the value of the well logs often to be limited. It is necessary to be selective in using this particular source of information. A small amount of data is also available from a number of domestic water wells which penetrate to bedrock in the Anna area. Again, well records are often inaccurate. The majoirty of the stratigraphic information for the Anna area is based on knowledge gained from the oil drilling logs, including drilling chips collected at a small pecentage of the wells, and lithologic descriptions of rock units which outcrop in other parts of Ohio and in Indiana. A review of the literature produced no published seismic reflection data for Shelby or surrounding counties.

Given accurate oil and gas well logs, describing the nature of the Paleozoic strata near Anna still has a number of problems associated with it. Over time the stratigraphic nomenclature for west-central Ohio has varied greatly. Changes in formation names often cause difficulty in correlating units from wells drilled in different years. Unit names also frequently have more than one meaning, such as "Niagara" to mean formation, group, or series of stratigraphic deposits. Caution must also be observed when using well log data to detemine unit thicknesses. Records from well heads generally imply an accuracy of position for formation contacts of one foot, but drilling chips frequently do not support this high level of confidence. Some well logs appear to use the degree of lithification and changes in the mechanical properties of the rock being drilled, rather than actual changes in lithologies, to locate unit contact at depth.

The following is a brief description of each major stratigraphic formation in the Anna area.

Tymochtee Dolomite: Silurian, 38-53 meters thick; laminated to massive dolomties with low clay content, coarsely crystalline, porous, locally homogeneous, high shell fragment concentrations (Stout, et al., 1943).

Greenfield Dolomite: Silurian, locally 15 meters thick; thin to massive bedded gray to brown dolomite, generally dense and hard (Stout, et al., 1943).

Lockport "Formation": Silurian, 15-40 meters thick; frequently referred to as a formation, although it has been reclassified as a stratigraphic group; fine to medium-crystalline, light-grey to white, vuggy dolomite (Janssens, 1968).

Goat Island Formation: Silurian, 6-12 meters thick; finely crystalline, light-brown to yellowish-brown, silty dolomite, fossiliferous, contains white to gray chert, locally slightly glauconitic (Janssens, 1968, 1977).

Gasport Dolomite: Silurian, 4-9 meters thick; porous, fine to coarsely-crystalline, bluish-gray dolomite, mottled appearance due to the presence of crinoid stem fragments (Janssens, 1968, 1977).

Rochester Shale: Silurian, 8 meters thick; gray to greenish-gray, green or dark-brown shale, argillaceous near the top of the unit, brownish-gray dolomite present, thins towards the west (Janssens, 1968, 1977).

Dayton Formation: Silurian, 3 meters thick; evenly bedded, well lithified light-yellowish-brown dolomite, slightly glauconitic (Janssens, 1968; Stout, et al., 1943).

Cabot Head Shale: Silurian, locally 3 meters thick; grayish-green shale interbedded with slightly hematitic, coarse grained dolomites (Janssens, 1968).

Brassfield Formation: Silurian, 7 meters thick; massive to thin-bedded, fine to coarse grained limestone, fine to coarsely crystalline dolomites, glauconitic, fossiliferous, cherty, shaley partings present in some locations (Janssens, 1968; Stout, 1941).

Queenston Shale: Upper Ordovician, 285-312 meters thick; also goes by the names of Reedsville Shale and the Loraine Formation; bluish shale interbedded with impure limestones, red in color near top of the unit (Lamborn, et al., 1943).

Cynthiana Limestone: Ordovician, 21-43 meters thick; impure limestone, regularly layered (5 to 70 cm) spearated by thin shale partings (Stout, 1941).

Trenton Formation: Ordovician, locally 40-130 meters thick; fine to medium grained, well lithified, thinly bedded to massive bluish-gray limestone, fossiliferous, petroleum rich (Stout, 1941).

Black River Limestone: Ordovician, locally 46-118 meters thick; light bluish-gray, finely-crystalline limestone, massive with some shaley partings, locally cherty and/or oolitic (Stout, 1941).

Glenwood Formation: Middle Ordovician, 15 meters in thickness; equivalent to the Chazy Limestone, green or bluish-green shale containing irregular lenses of dolomite and sandstone, "clay-like in nature and high in plastic properties" (Stout, 1941, p. 26).

Knox Group: Lower Ordovician, 200 meters in thickness; contains the Beekmantown, Trempealeau and Maynardsville dolomites; very light-gray to medium-gray dolomite, microcrystalline though locally fine to medium crystalline, peelitic and oolitic, basal unit (20 meters thick) of glauconitic siltstones interbedded with silty dolomites (Janssens, 1973).

Eau Clair Formation: Cambrian, 94 meters thick; fine to medium grained, glauconitic, fossiliferous sandstones, interbedded with siltstones, shales, argillaceous sands and dolomitic sands, laterally equivalent to the Conosauga Shale and the Rome formation (Janssens, 1973).

Mt. Simon Sandstone: Cambrian, 20-64 meters thick; fine to coarse-grained, clear, pink, poorly cemented sandstone, little to no glauconite, often contains a basal conglomeratic sand, generally poorly sorted though some beds are well sorted, siliceous cement (Janssens, 1973).

An investigation of the Trenton Limestone has led Rooney (1966) to conclude that the region west of Anna was exposed to subaerial erosion while the area to the east of Anna had continuous deposition across the Trenton Limestone--Cynthiana Limestone contact. This conclusion is based on the presence of very sharp unit contacts between the Trenton Limestone and the overlying shales in Indiana, solution pits on the surface of the Trenton Limestone, solution cavities within the Trenton Limestone, high concentrations of pyrite, phosphatic grains, angular chert and brecciated dolomites and limestones within the upper Trenton Limestone and the presence of local relief at the top of the Trenton Limestone. These features are not seen in central Ohio. It has therefore been proposed that a "hinge line", passing through west central Ohio trending north-northeast, may be drawn to divide the region of subaereal exposure to the west from the region of continuous deposition to the east. Assuming an originally horizontal topography for the Trenton Limestone during deposition, this evidence strongly suggests a period of differential uplift during post-Trenton (middle Ordovician) time (Rooney, 1966).

The lack of post-Silurian strata in the Anna area has resulted in the loss of data for this time span. It is known, though, that between Silurian and Quaternary times this region of North America saw a net minimum drop of local sea level of 300 meters (Cummins, 1959), probably partially due to regional uplift of the North American continent. It has been estimated that approximately 1.6 km of sedimentary deposits were eroded during late-Paleozoic and Mesozoic times from the central United States (Hinze, et al., 1977). If this is true, then the amount of apparent post-Silurian drop in local sea level would increase to a total of 1.9 km. The Paleozoic bedrock of western Ohio lies horizontal or dips up to 0.5 degrees to the east (McGuire, 1975) which suggests that the rate of uplift was equal across the area. Data from other sections of North America indicate that rates of regional vertical movement are often oscillatory with time (Hinze et al., 1977), though no evidence has been preserved to justify this conclusion specifically for the Anna area.

Oil wells which have penetrated to the Precambrian in the Anna area have shown that this surface is gently undulating and dissected in nature (Owens, 1967). Such topography implies a well developed erosion surface on which Phanerozoic strata were subsequently deposited. The lapse of time between the final event in the formation of the local basement complex and when the Mt. Simon Sandstone was deposited must, therefore, have been of significant length.

Regional Structure

The majority of both Ohio and Indiana, including the Anna seismic region, is underlain by a well-developed basin and arch structural framework. By comparing lateral variations in the thicknesses of the overlying Paleozoic sedimentary deposits it is possible to determine the dates of the arch development within the basement complex. This technique is only of use for the geologic periods in which regional sedimentation has been preserved until the present day. Therefore, the structural history for the Anna area is only well documented for the early and mid-Paleozoic.

Shelby County is located in the northeastern quadrant of the Indiana-Ohio Platform (Thompson, et al., 1976), a broad, positive structural feature within the basement surface topography of western Ohio and eastern Indiana (see Figure 20). Paleozoic strata which overlie the Indiana-Ohio Platform have been thinned relative to corresponding units in the surrounding basin regions. This implies that the platform formation took place throughout the Paleozoic (Kieffer, et al., 1975). The basement surface has been elevated approximately 3,000 meters relative to the top of the Precambrian in the adjacent basins (Owens, 1967). The platform possesses a roughly circular geometry centered approximately 110 km north of the city of Cincinnati on the Indiana-Ohio state line (Thompson, et al., 1976), with north-south dimensions of 360 km and east-west dimensions of 280 km (Jackson, et al., 1982). Due to the gentle nature of the structure, the boundary positions for the platform are highly subjective, particularly along the southern edge. Oil well data have shown that the maximum elevation of the basement surface for the Indiana-Ohio Platofrm occurs east of Anna in Logan County where a topographic ridge, trending north-south across the entire state, has been located. This ridge, with an elevation of approximately 600 meters below sea level, slopes eastward at a rate of 11.4 meters per kilometer and slopes to the west at 3.8 meters per kilometer (See Figure 21).

Within the Anna area the Indiana-Ohio Platform divides into two distinct arch structures. This bifurcation begins somewhere near Champaign County (Owens, 1967). The Kankakee Arch, a topographic ridge within the basement complex, trends in a northwest direction extending across central Indiana towards northeastern Illinois. The Kankakee Arch, a topographic ridge within the basement complex, trends in a northwest direction extending across central Indiana towards northwestern Illinois. The Kankakee Arch has northwest-southeast dimensions of 400 km and a width of 110 km (Jackson, et al., 1982). Lateral variations of the overlying sediments indicate that the Kankakee Arch developed during Middle

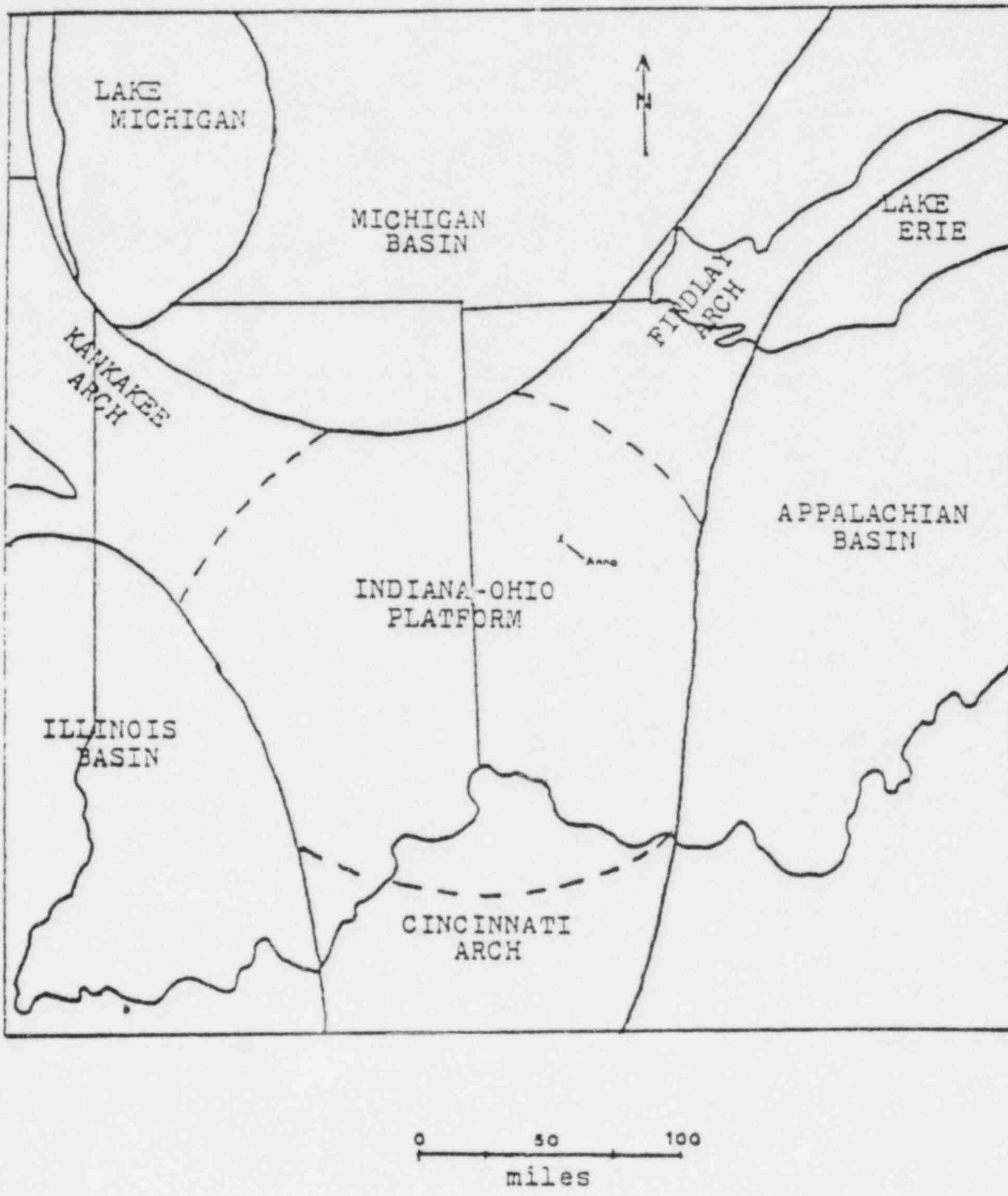


Figure 20. Distribution of the Basin and Arch Structure of the Precambrian Surface of Indiana and Ohio (Heidorn, 1979).

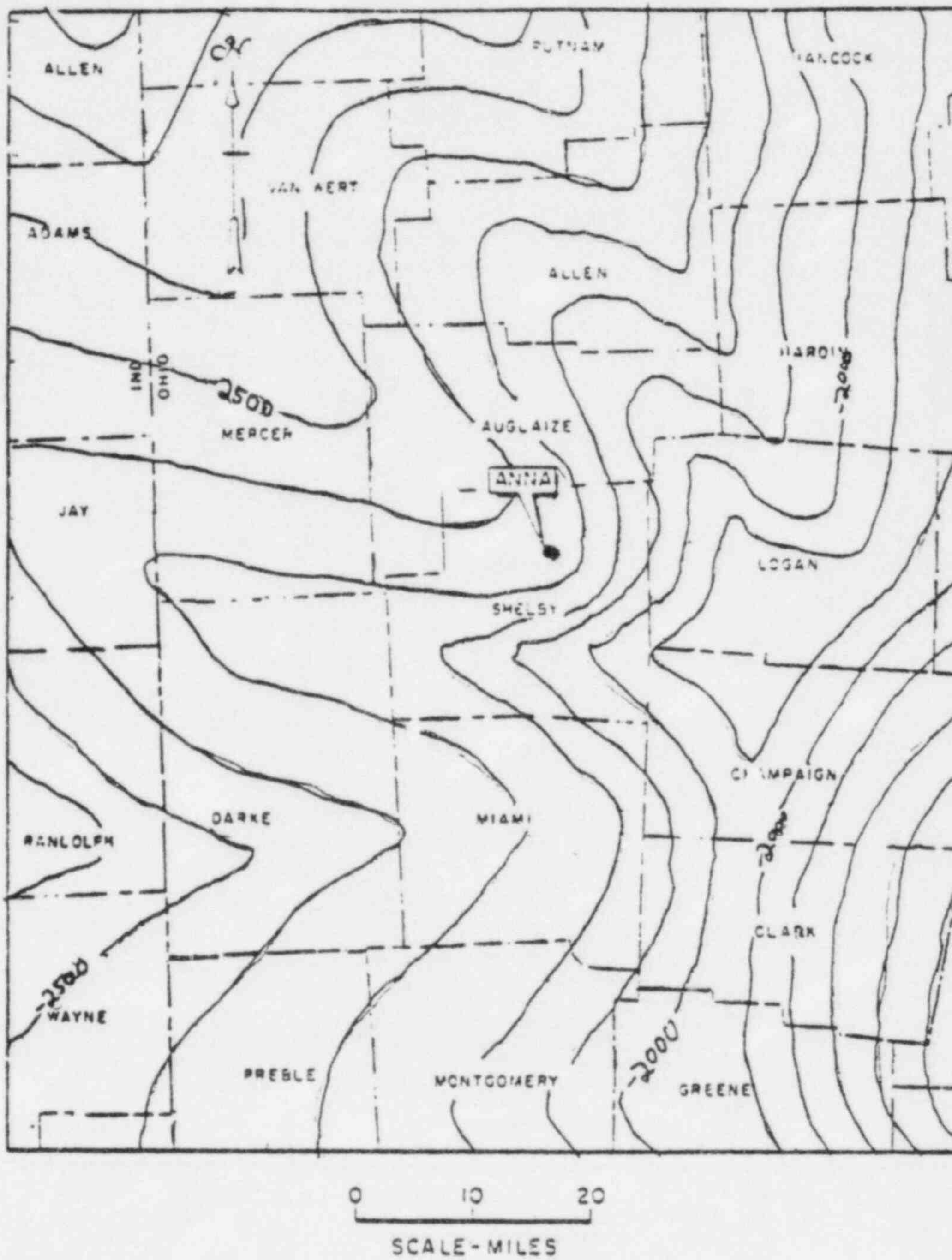


Figure 21. The topography of the Precambrian surface in the Anna area (from Owens, 1967).

Ordovician through Pennsylvanian times (Kieffer, et al., 1975). The lateral dimensions of the elevated region of basement are approximately 320 km in a direction parallel to the ridge axis and 95 km across the arch (Jackson, et al., 1982). Thinning strata over both the Kankakee and Findlay Arches indicate that both were produced by relatively lower rates of subsidence as compared to the adjacent basin regions (Hinze, et al., 1977).

To the south of Anna the Indiana-Ohio Platform narrows and merges into a series of structural highs which make up the Cincinnati Arch. This broad, discontinuous feature extends southward across central Kentucky and into Tennessee. The primary components of the Cincinnati Arch are the Lexington Dome in north-central Kentucky and the Nashville Dome in central Tennessee (see Figure 22). The axis of the Cincinnati arch turns to the south-southwest in Tennessee, paralleling the trend of Appalachian deformation to the east. The Cincinnati Arch developed primarily during the Late Silurian, as indicated by localized shallow marine deposits over the arch area (Hinze, et al., 1977).

The three structural highs which extend outward from the Indiana-Ohio Platform are separated from each other by Paleozoic basins. These basins are the Michigan Basin between the Kankakee and Findlay Arches, the Appalachian Basin between the Findlay and Cincinnati Arches and the Illinois Basin between the Cincinnati and Kankakee Arches. Stratigraphic analyses of basin deposits have shown that the centers of these basins migrated with time. It has also been determined that the rates of subsidence were equal to the rates of sedimentation for the basins througout the Paleozoic (Hinze, et al., 1977).

The differential rates of subsidence which were responsible for the production of the basin and arch structures of the Anna area also resulted in the formation of a series of reentrant zones--the zone of maximum dip between a basin-arch pair. Structural models indicate that regional stresses would be preferentially concentrated along these reentrant zones during the periods of differential subsidence. Three major reentrant zones converge towards the Ann area:

1. the contact of the Kankakee and Findlay Arches with the Michigan Basin;

2. the contact of the Kankakee Arch and the Indiana-Ohio Platform with the Appalachian Basin (Kieffer, et al., 1975).

The influence of these reentrant zones on post basin and arch deformation events is unknown.

A number of smaller structural features have been identified in Ohio. One of these features is the Bowling Green monocline, a linear structure trending north-south through Lucas, Wood and Hancock Counties in northern Ohio. Several authors have concluded that this structure is actually a high-angle reverse fault (Janssens, 1973), but this has not been firmly established. Structure maps for the top of the Trenton Limestone (Ordovician) suggest an "offset" of between 30 and 55 meters with the "downthrown" side on the east (Janssens, 1973). Hinze, et al. (1977) suggest that

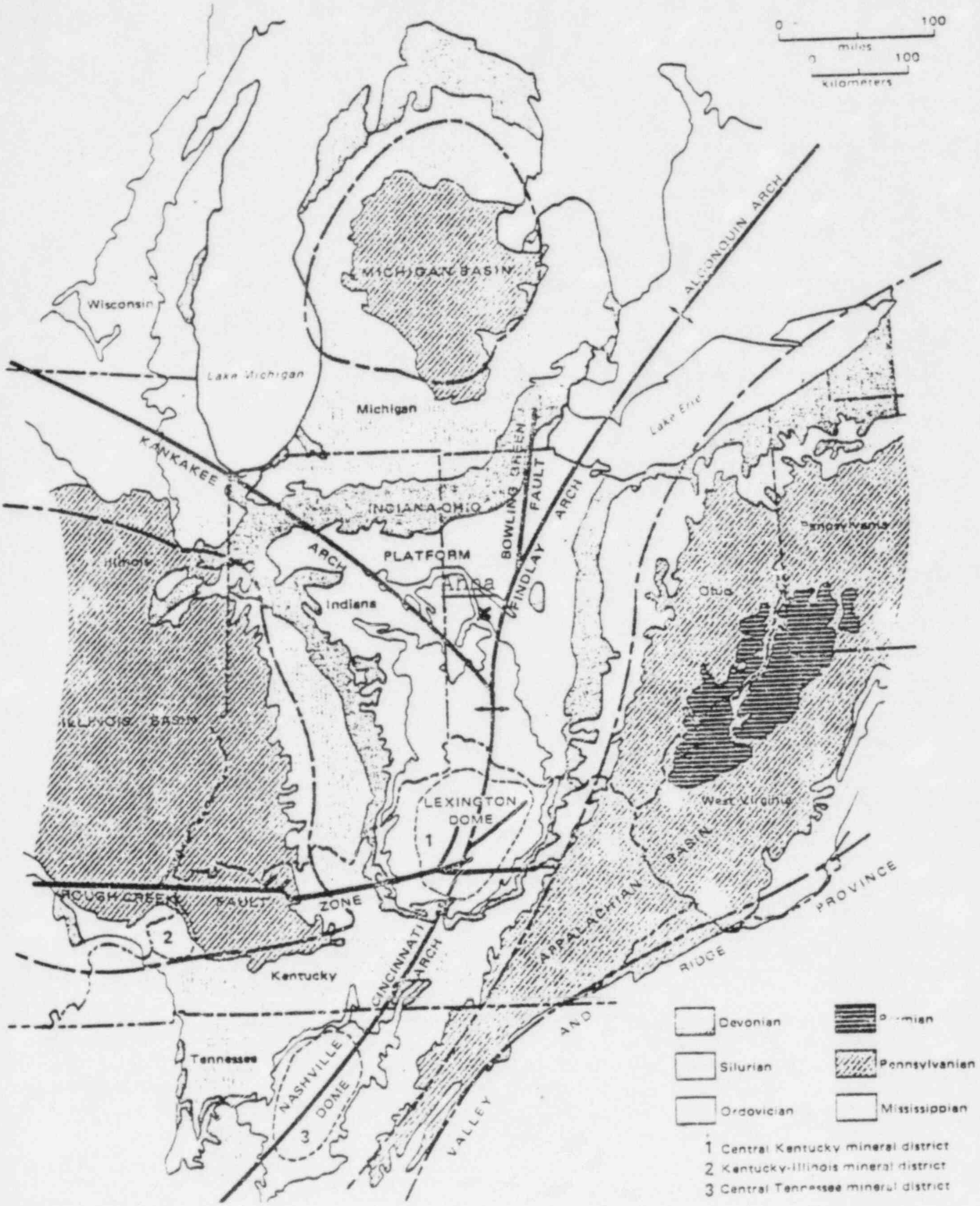


Figure 22. The Basin and Arch structure of the Anna Area including General Geologic Map of the Region (Botoman and Stieglitz, 1978).

the Bowling Green Monocline is related to a minor period of Paleozoic (?) reactivation of Precambrian stress fields.

Another structural feature of significance is the Waverly Arch, a roughly north-south trending structure first identified in the Waverly Oil and Gas #1 well in Pike County in south-central Ohio. The Waverly Arch, as first proposed, was a structural high of approximately 550 km in north-south length and of 95 to 130 km in width within lower Paleozoic strata. Maximum amplitude of the arch was estimated to be 230 meters (Janssens, 1973). Since first proposed in 1961, the existence of the Waverly Arch as a structural entity has not been clearly demonstrated. The primary oil well, which is cited as evidence for the existence of the arch, was poorly logged at the time of drilling in 1909. Drilling chips saved from the well have been poorly cared for, many sample intervals were lost and the remaining samples apparently subjected to contamination (Janssens, 1973). Stratigraphic correlation is also difficult in this region due to the lack of clear marker-bed units within the Knox Group in southern Ohio. The existence of a non-structural "pseudo-arch" has been proposed by Calvert (1974). Calvert postulates that the inference of an arch-like structure was due to a mis-interpretation of the erosional unconformity at the top of the Knox dolomite as an assumed horizontal surface. According to this reasoning, the presence of a paleo-valley within the Knox erosional surface would produce an apparent arch structure without structural deformation.

Within the state of Ohio, excluding the Anna area, there is no clear evidence for brittle deformation. Within the Interior Region of the north American Craton a number of major fault zones have been detected (Hinze, et al., 1977). The relationship between these deformation events, many of which are Precambrian in age, and the recent seismic activity at Anna, Ohio, has not been established.

Regional Stress

In order to fully understand the nature of the seismicity at Anna it will be necessary to describe the nature of the stresses in the area. A small volume of information exists concerning the nature of the current stress rgime as a function of location for North America. The amount and distribution densities of the field data are, in general, not adequate to provide quantitative information for specific small localities. Only qualitative trends over relatively large distances may be defined.

Sbar and Sykes (1973) analyzed stress patterns specifically for eastern and central North America. This work was based on fault plane solutions, in situ stress measurements (overcoring and hydrofracture) and post-Pleistocene geologic features (pop-ups, rock bursts, faulting offset and fracturing). From this investigation it was concluded tht the maximum compressive stress trends ENE and that the minimum compressive stress is near vertical and equal in magnitude to the stress derived from the lithostatic overburden for regions west of the Appalachian Mountains and east of the Rocky Mountains. Sbar and Sykes (1973) believe that this type of information will eventually define the nature of the driving mechanism for plate tectonics. All stresses involved are post-Mesozoic in age. No significant dynamic stresses were observed in the Gulf Coast Region, the maximum principal stress being vertical that is.

Sbar and Sykes (1973) note that no simple relationship exists between the magnitude of the measured stress and the level of seismicity of any given region. They propose that in addition to high stress levels the presence of pre-existing unhealed faults is also necessary to produce earthquake activity. High deviatory stress levels are also believed to be favorable if faulting is to occur. They propose that the faulting in the New Madrid region is derived from the downwarping of the Mississippi embayment.

The extrapolation of results from continental dimensions down to an arc the size of the Anna region cannot be justified by the data provided by Sbar and Sykes (1973). In Ohio there are a total of three data locations, all in the far eastern portion of the state. With specific reference to the Anna area, the only geographically close fault plane stress datum is for southern Illinois. This single value is for a shock with a depth of focus of 25 km. Whether the stresses involved in this single deep shock have any significant relationship to the apparently shallow depth seismic activity at Anna is not known. If one discards the Illinois datum as not being relevant to the seismic activity at Anna, Ohio, then there exists no reported stress information west of Ohio closer than St. Cloud, Minnesota and Carthage, Missouri.

New York state is represented by five geographically well-distributed data locations along with six associated values from adjoining states. The value for Nyack, New York is interesting in that it indicates a tensional environment. Furthermore, normal faulting has been detected 50 km to the west of Nyack at Lake Hopatcong, New Jersey. This locality, which is dominated by an extensional deformation environment, is characterized by low stress values. No mechanism is proposed to explain this isolated region of tensional stress (Sbar and Sykes, 1973).

In general, it must be concluded that the available data on contemporary dynamic stress in eastern North America should not preclude the existence of strike-slip or normal faulting on localized geographic scales. The consistency of large scale trends is substantial, implying the existence of a continent-wide mechanism for stress generation. More data values are needed if meaningful conclusions are to be drawn for areas as small as the Anna earthquake area.

Basement Distribution

Due to the great depth of burial of Precambrian rocks throughout most of the central United States, the properties of the basement complex in the Anna area are not well defined. The main source of information about the crystalline basement of west-central Ohio is from a small number of oil wells which penetrate to the Precambrian surface. Only seven wells penetrate basement within a 50 km radius of the town of Anna (Janssens, 1973). This restricted volume of data results in both the lateral extent and thickness of any given unit being poorly constrained. In addition to data obtained from local petroleum exploration, surface outcrops of Precambrian rocks in the St. Francois Mountains of southeastern Missouri and in the Canadian Shelf of northern Minnesota have been used to extrapolate the regional nature of the basement beneath the midwestern United States (Hinze, et al., 1977). Geophysical studies of regional seismic travel time curves have also provided information about very deep structures within the North American Craton (Herrin, 1969). Considering the nature and extent of these data sources, it must be concluded that our understanding of the basement within the Ohio-Indiana region is not adequate to make precise conclusions about the local basement.

Using drilling chips, Bass (1961) has identified a major lithologic boundary within the basement complex of Ohio. This contact is presumed to represent the southern continuation of the Grenville Front, a Precambrian lithologic/structural contact which outcrops in Quebec and western Ontario. The correlation of the basement feature with the Grenville Orogeny is further supported by Rb/Sr age dates across the lithologic boundary. Dates of 1.0-0.9 by are reported east of the contact (McGuire, 1975) which are contrasted to minimum dates of 1.5-1.2 west of the front (Hinze, et al., 1977). In Fulton County, Indiana a K/Ar age of 1.52 ± 0.04 by has been obtained for a basement granite material (Hinze, et al., 1977). The location of the Grenville Front is based on the transition of the crystalline basement from mica and hornblend schists and genisses, two-feldspar granites and amphibolite grade metamorphics east of the front to rhyolites, trachytes, one-feldspar granites, basalts and Precambrian metasediments west of the front (Hinze, et al., 1977). Due to the small volume of data available, the position and the sharpness of the Grenville boundary are not well defined in Ohio (see figure 20). Based on currently available data, the Grenville Front has been positioned approximately 35 km east of Anna, trending due north through eastern Logan county (Bass, 1961; Janssens, 1973). King (1977) has interpreted the Grenville Front as the contact between older, low grade super-crustal metamorphics of the Superior Province, and younger high grade granitic gneisses of upper amphibolite/granulite facies of the Grenville Province. Precise correlation of the basement west of the Grenville Front has not been possible.

Although the Grenville Front is recognized as being a major Precambrian feature, its origin is not well understood. Thompson, et al. (1976) have proposed the following models for the development of the Grenville Front and its associated orogenic belt:

1. The Grenville Front represents the suture zone of a continental mass which accreted onto the margin of the North American Craton.

2. The Grenville Front represents an area of shortening within the continental crust.

3. The Grenville Front represents a metamorphic transition zone.

Hinze, et al. (1977) have deduced a petrographic history of the Grenville orogenic event which they summarize as:

1300-1000 m.y. High grade metamorphism in the Blue Ridge of the Southern and central Appalachians. Some granitic intrusives.

1000-800 m.y. Schist and gneiss formation in Pennsylvania, Ohio, West Virginia and Michigan, indicating a late stage thermal event probably associated with deep burial and subsequent uplift.

910-820 m.y. Rifting (Catoctin volcanics) in the central and southern Appalachians. Also, the lower part of the Carolina Slate Belt may reflect this event.

A series of pre-Grenville tectonic and/or thermal events has been identified in the Canadian Shield. There is evidence to suggest that these events were present in the Anna area. Presumably any structural deformation which might have occurred during these early times has been annealed by the subsequent Grenvillian aged metamorphism.

Lithologic data collected from deep oil wells indicate that the Anna area is underlain by a laterally variable basement complex. To the northeast and southwest of the town of Anna granitic materials have been observed. To the northwest and southeast of Anna low grade metamorphics have been reported. Directly beneath the town of Anna igneous extrusives dominate the upper basement (Severy, et al., 1975). Due to lack of data, the locations and sharpness of the contacts between these regions are unknown at present. It has been noted by Senery et al. (1975) that;

"...all of the Anna (seismic) events have occurred in the area underlain by acidic extrusive rocks

McGuire (1975) has proposed a model for the formation of a rhyolite sequence at 1.50-1.28 b.y. which was later intruded by granitic magmas. Rhyolites between 1.5-1.4 b.y. in age would correspond to the Elsonian Thermal event, a widespread series of anorogenic plutons and extrusives which were emplaced over the midcontinent during this time. Micrographic granites in eastern Indiana have been given Rb/Sr ages of feldspars of 1.1 b.y., corresponding to Middle Keweenawan igneous activity, a period of continental rifting, with a thermal-plume-induced triple point located in northen Michigan (Hinze, et al., 1977).

Geophysics

In an effort to gain information about midcontinental tectonism, a variety of geophysical investigations have been undertaken within the Interior Region of central North America. These studies have included magnetic and gravity surveys in addition to reviews of the distribution and nature of seismic activities. Field data have successfully been used to define geophysical anomalies on both regional and local scales. At present, though, lack of clear understanding of these anomalies has left their interpretation in dispute.

Investigations of historical seismicity in Ohio have resulted in a less subjective, more quantitative description of recent earthquake activity within the state. Bradley and Bennett (1965) reviewed both scientific and newspaper accounts of earthquake shocks in Ohio between the year of 1776-1964. Due to the imprecise nature of the early records, all references to pre-1900 events should be discounted as being scientifically unreliable. An analysis of the post-1900 data shows that earthquake events within an approximately 30 km radius of Anna represent 50 percent of the detected seismic activity for the state (Pawlowicz, 1974). Data for the Anna area show that earthquake activity has occurred in two distinct episodes of 1925-1933 and 1936-1940 including three modified Mercalli VII events. A least-squares error has been used to determine a linear best fit frequency vs. intensity curve (Pawlowica, 1975). The result for the Anna area is:

$$\log N = 0.04 - 0.25\, I \qquad (\mathrm{II} \quad I \quad \mathrm{VIII})$$

where N equals the number of events per year and I equals the minimum shock intensity. The significance of these calculations is questionable considering the small volume of data which is being dealt with. The February 1981 completion of the thirteen station Ohio-Indiana Seismic Array by the University of Michigan hopefully will improve both the accuracy and detection limits of sesimic events in the Anna area (Jackson, et al., 1982).

A pattern of epicentral locations appears to exist along the margins of the Illinois basin (Wollard, 1969). Similar recent activity has been noted on the flanks of the Missouri uplift. It has been proposed that such seismic activity is due to current differential movement of mobile crustal elements within the craton (Wollard, 1969). Two general models have been proposed for predicting high concentrations of midcontinent earthquake foci (Hinze, et al., 1977):

1. Seismicity is concentrated in regions of high vertical velocities; or

2. seismicity is concentrated in regions of high differential rates of uplift/subsidence.

Which model reflects the nature of the activity at Anna has not been determined. It has been further proposed that the current vertical strain pattern in the north-central United States may have been partially derived from stresses associated with the unloading of the Pleistocene glaciers; heavy overburdens, such as associated with continental glaciation, may inhibit local release of seismic energy (Wollard, 1969). On a localized scale, it is believed that the ratio of Young's Modulus between two adjacent rock bodies of different rheologies defines the stress conditions under which rupture will occur (Hinze, et al., 1977).

Serpentinization reduces the ratio of the Young's Moduli which will, in turn, result in slow creep instead of sudden catastrophic failure. It is believed that within the Anna area the modern stress field would be amplified near the contacts of the differing basement lithologies (Hinze, et al., 1977). The processes involved in the release of seismic energy when rupture does not occur along a preexisting fault plane are not well understood.

Both magnetic and gravity surveys have been conducted throughout the central midcontinent. The major geophysical feature of the Interior Region of the North American Craton is the Midcontinent Gravity High (King, 1976). This feature has been interpreted to represent a Keweenawan aged 1.2-1.0 b.y. rift zone. Large regional surveys indicate that gravity anomalies are arranged in an arcuate patern extending from Iowa trending north-northeast through Minnesota to northern Michigan where the direction of trend changes to the southeast, crossing central Michigan. Thus, the failed arm of the rift system would trend north from central-northern Michigan towards Hudson Bay in Ontario.

Geophysicists are starting to draw relationships between occurrences of earthquakes and the local magnetic and/or gravitational anomalies. Two theories have been proposed which use gravitational anomaly patterns to predict sites of potential seismic activity (Hinze, et al., 1977):

1. Earthquakes tend to occur near positive gravitational anomalies in regions of high gradient; or

2. earthquakes tend to occur in relatively low gradient zones between positive and negative anomaly closures.

Severy, et al. (1975) have suggested that high gravity gradients represent the contact between deformed and undeformed basement terrains. The mechanism for relating gravitational, and even magnetic anomalies to earthquake activity is unclear. Hinze et al., (1977) state that this relationship may be due to:

1. Crustal fractures directly expressing themselves in the surface physical fields; or

2. variations in rock lithology producing both changes in surface fields and passive influences on the local stress field.

The relationship between seismic activity and magnetic anomalies is unclear. Surface magnetic fields depend not only on local structure, but also on the mineral composition of the local bedrock. Field evidence indicates that structural discontinuities tend to occur near aeromagnetic lineaments.

To identify the locations of the fault or faults responsible for the recent seismicity at Anna, McGuire (1975) undertook an extensive geophysical investigation within Shelby, Auglaize, Allen, Hardin, Logan, Champaign and Miami Counties. Both magnetic and gravity surveys were undertaken. The magnitude and extent of residual anomalies indicate that the source of seismicity is within the local basement materials and not within the overlying Paleozoic strata. No clear relationship was found between the magnetic and gravitational anomalies; the residual magnetic anomolies produced greater variations in the data than those obtained from gravity work. Lack of a relationship indicates that the source of the local magnetic anomaly pattern is of equal density to the country rock. Depth to the source of the magnetic anomaly has been calculated at 1.5-5.6 km (McGuire, 1975). Two models have been proposed to explain the source of the local magnetic anomaly pattern (McGuire, 1975):

1. Granitic intrusions of a rhyolite-latite sequence; or

2. rhyolite flows extruded on a crystalized eroded granitic surface.

Both models fulfill the requirement of having two distinct lithologies present within the local basement of the Anna area. The data collected by McGuire (1975) indicated the existence of two parallel faults trending N 40°W within the local basement (Figure 23). The data manipulation methods employed were incapable of further defining the nature of the faulting. No significant conclusions were drawn from the data collected during the gravity survey.

Conclusions about the Faulting

The geophysical survey conducted by McGuire (1975) indicates a series of northwest trending magnetic and gravitational anomalies in the Anna area. These linear features are superimposed on a north-south trending gradient in both the magnetic and gravity field data. This information implies that the seismicity which is seen near Anna is derived from basement faulting within the region. Using computer models for the region, he proposes that two parallel normal faults striking N40°W, named the Anna and the Logan Faults, are present within the basement of the Anna area (McGuire, 1975). Stratigraphic information obtained from oil wells in the area indicate an offset of 10-45 meters within the Cambro-Ordovician Knox Dolomite, which nearly corresponds to McGuire's Anna Fault (Stone and Webster, 1976). This fault, slightly modified in position and renamed the Anna-Champaign Fault, approximates a prominant Landsat lineament (Jackson, et al., 1982). Based on oil well logs and proprietary data from a seismic reflection survey conducted by American Pacific International, Inc., McGuire's Logan Fault has been discounted. Stone and Webster (1976) used these data sources to propose two sub-parallel north-northeast trending faults within local basement which were named the Auglaize Fault and the Logan-Hardin Fault. Gravity and magnetic work by Krupa (1980) north of the Anna area was unable to clearly define the locations of these faults to the north of Anna (Figure 24). An investigation of the structural control of paleo-valley formation in central Auglaize County has revealed an unspecified structural feature approximately aligned with the proposed Auglaize

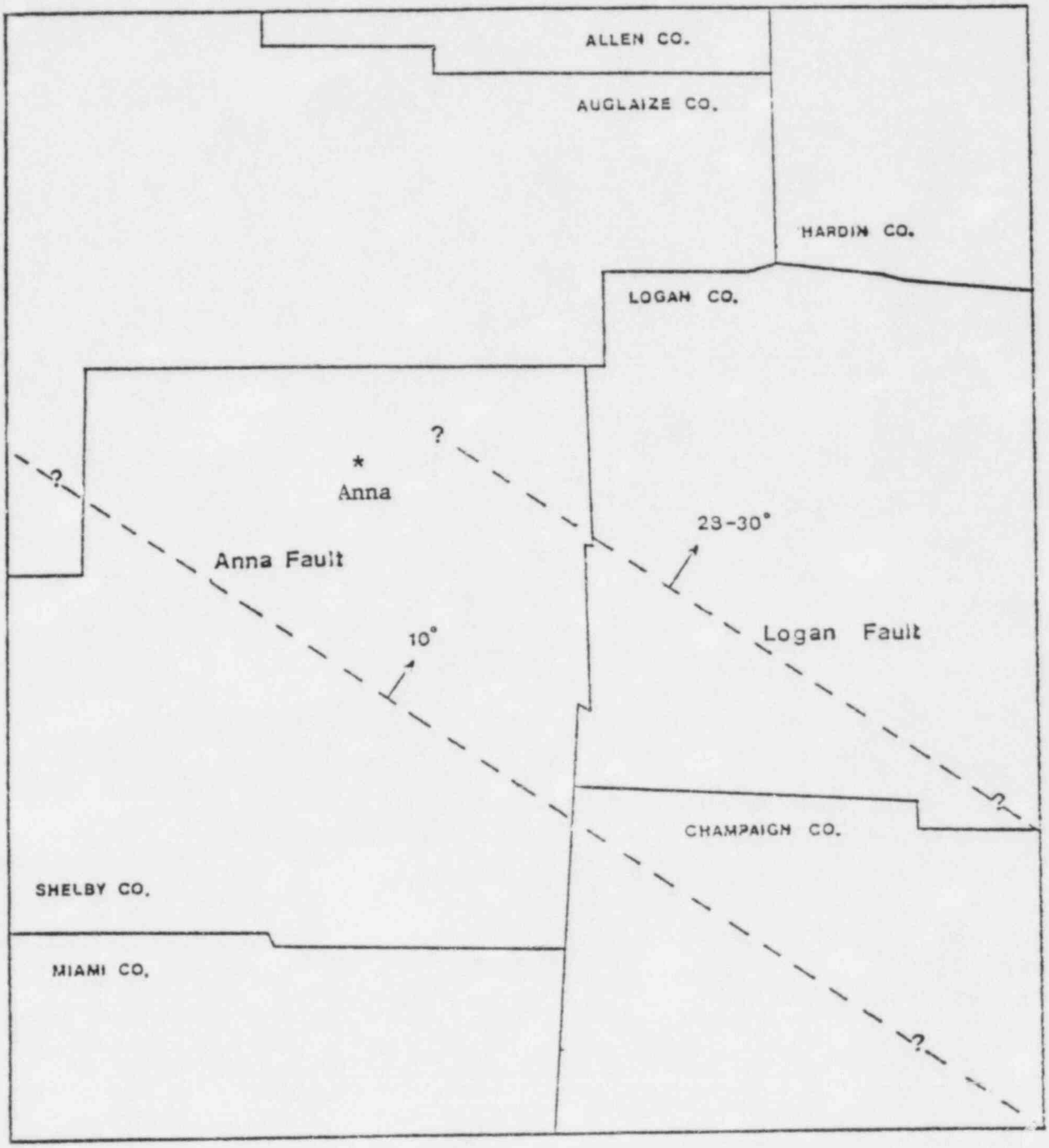


Figure 23. McGuire's Proposed Normal Faults within the Basement of the Anna Area (from McGuire, 1975).

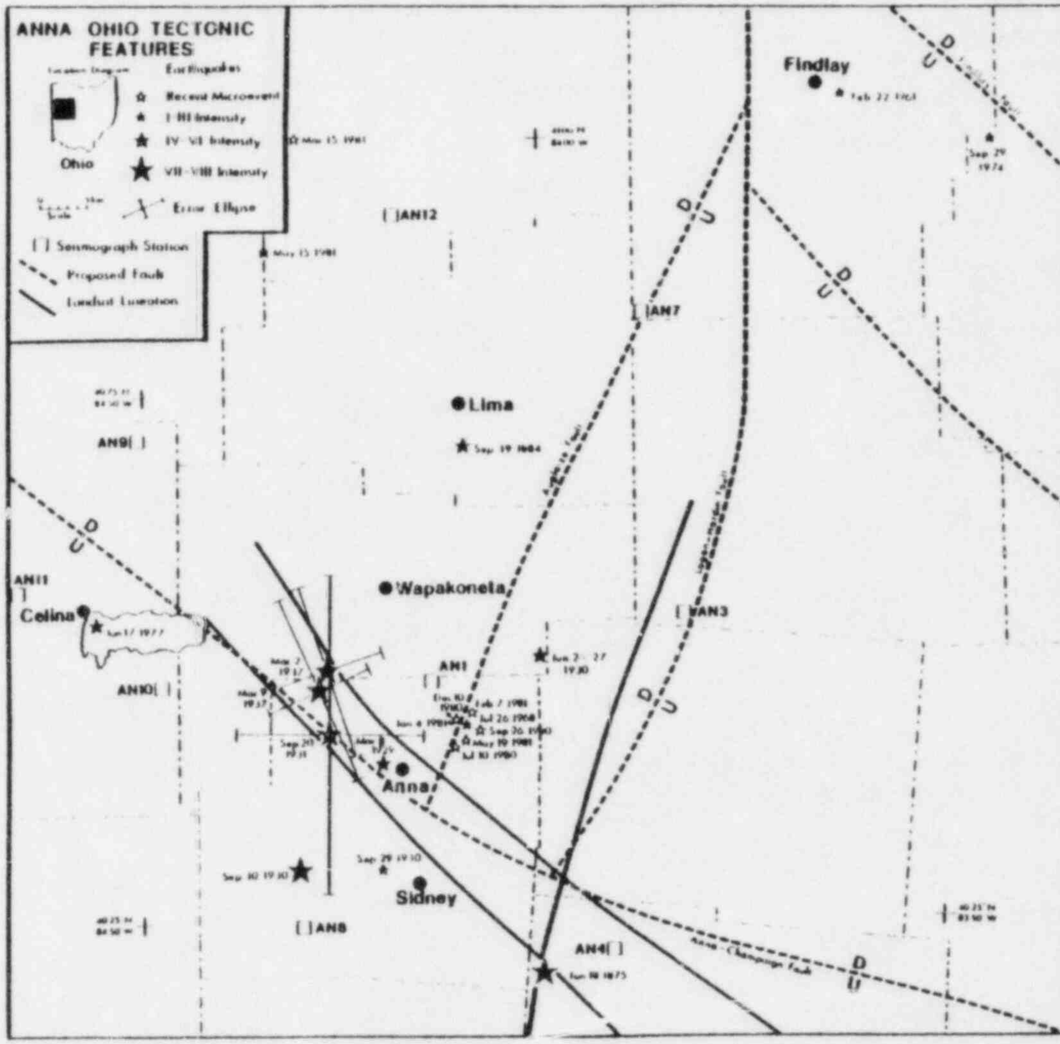


Figure 24. Map showing the relationship between the postulated faults, Landsat Lineations and Earthquake Epicenters including the Recent Microearthquakes (from Jackson, et al., 1982).

Fault (Heidorn, 1979). It has been proposed that both the Auglaize Fault and the Logan-Hardin Fault merge into the Bowling Green Monocline to the north of the Area (Thompson, et al., 1976). There is no evidence to support this claim. The Anna seismic array recorded a series of six micro-earthquakes between July 1980 and September 1981 located approximately 7 km northeast of the town of Anna. The locations of these events, which are precisely known, correspond to the southern limit of the proposed Auglaize Fault.

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APPENDIX A

TELESEISMIC PHASE ARRIVALS
(Janurary 1981-March 1982)

This appendix contains phase arrival information for teleseismic events which are routinely reported to the National Earthquake Information Service and are used in the P-wave residual studies. Because this table is compiled after the PDE monthly reports by NEIS are completed, the time period of the events included do not necessarily correspond to the fiscal year.

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        N  DATE     ORIGIN TIME      LAT.         LONG.     DEPTH  MAG.  LOCATION

       358 25/12/80 23:55: 6.4      8.955 S    112.041 E     63KM 5.6MB SOUTH OF JAVA
AN3   24:14:39.9 EP                                    AN4  24:14:41.1 IPD        0:14:58.6 AP
AN7   24:14:39.5 IPD                                   AN9  24 14:39.3 IPD
AN11  24:14:39.2 IPD
AAM   24:14:34.6 IPD

       359 27/12/80  4: 9: 8.2     50.040 N     79.046 E      0KM 5.9MB EAST KAZAKH (NTS)
AN3    4:22: 9.0 IPC                                   AN4    4:22:10.4 IPC
AN7    4:22: 7.5 IPC                                   AN9    4:22: 8.5 IPC
AN10   4:22: 9.7 IPC                                   AN11   4:22: 9.[illegible] IPC
ACM    4:22: 0.4 IPC
AAM    4:22: 0.5 IPC

       360 29/12/80 22:10:21.7     17.160 N     97.892 W     74KM 5.2MB OAXACA MEXICO
AN4   22:15:55.1 PD                                    AN7  22:15:59.5 P
AN9   22:15:56.4 P                                     AN10 22:15:54.[illegible] P
AN11  22:15:54.7 P                                     ACM  22:16: 7.8 PD
AAM   22:16:11.9 P

       361 31/12/80 10:32:11.0     46.060 N    151.453 E     33KM 6.1MB KURIL IS.
AN3   10:44:26.5 IP                                    AN7  10:44:25.1 IP
AN9   10:44:24.0 IP                                    ACM  10:44:13.5 P

       362 23/ 1/81  4:58:31.5     42.524 N    142.122 E    116KM 6.3MB HOKKAIDO JAPAN
AN3    5:11: 7.5 IPC                                   AN4   5:11: 8.6 IPC
AN7    5:11: 6.2 IPC                                   AN8   5:11: 7.8 IPC
AN9    5:11: 5.4 EPC                                   AN10  5:11: 6.5 EPC
AN11   5:11: 5.5 EPC                                   AN12  5:11: 5.1 EPC
ACM    5:10:54.5 IPC
AAM    5:11: 0.7 P         5:14:25.2 PP       5:21:12.8 S

       363 27/ 1/81  1:53:14.3     11.377 N     86.252 W     74KM 5.1MB COAST OF NICARAGUA
AN3    1:59:10.8 PC        1:59:21.8 AP                AN9   1:59:11.5 IPC
AN11   1:59:10.0 IPC       1:59:21.2 AP                AN12  1:59:13.6 IPC        1:59:24.7 AP

       364 30/ 1/81  8:52:44.1     51.720 N    176.274 E     33KM 6.3MB RAT IS.
AN3    9: 3:20.6 IPC                                   AN4   9: 3:21.8 EPC
AN7    9: 3:19.0 EPC                                   AN8   9: 3:20.1 EPC
AN9    9: 3:17.1 IPC                                   AN10  9: 3:18.5 IPC
AN11   9: 3:17.0 EPC                                   IN1   9: 3:12.7 IPC
IN3    9: 3:19.5 IPC
AAM    9: 3:12.7 IPC       9:11:42.0 S
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N DATE ORIGIN TIME LAT. LONG. DEPTH MAG. LOCATION

365 30/ 1/81 10:29: 9.8 5.608 S 110.209 E 562KM 5.7MB JAVA SEA

AN3 10:47:39.6 IPD | AN4 10:47:40.7 IPD
AN7 10:47:38.7 EPD | AN8 10:47:40.0 IPD
AN9 10:47:38.5 EPD | AN10 10:47:39.2 EPD
AN11 10:47:38.5 EPD | IN1 10:47:37.4 IP
IN2 10:47:38.4 EPD | IN3 10:47:41.3 EPD

366 1/ 2/81 4:35:25.8 11.139 S 117.314 E 33KM 5.6MB S. OF SUMBAWA IS.

AN3 4:55: 2.5 IPD 4:55:17.6 AP | AN4 4:55: 3.4 IPD 4:55:18.2 AP
AN7 4:55: 1.8 IPD 4:55:16.9 AP | AN9 4:55: 1.1 IPD
AN10 4:55: 1.8 IPD | AN11 4:55: 1.0 IPD
AN12 4:55: 0.9 IPD 4:55:16.2 AP | IN1 4:54:58.7 IPD
IN2 4:54:59.0 IPD | IN3 4:55: 2.4 IPD
AAM 4:54:58.1 IPD

367 1/ 2/81 22:43:27.5 53.030 N 162.406 E 33KM 5.9MB COAST OF KAMCHATKA

AN3 22:54:40.9 IPD | AN4 22:54:42.1 IPD
AN7 22:54:39.3 IPD | AN8 22:54:40.9 IPD
AN9 22:54:38.1 IPD | AN11 22:54:38.1 IPD
AN12 22:54:37.6 IPD | ACM 22:54:24.9 IPD
IN3 22:54:41.4 IPD
AAM 22:54:33.3 IPD

368 5/ 2/81 10:52: 2.3 50.167 N 176.273 W 33KM 5.7MB ANDREANOF IS.

ACM 11: 2: 0.1 P
AAM 11: 2:10.4 P

369 6/ 2/81 16:47: 7.4 48.300 N 146.354 E 479KM 5.3MB SEA OF OKHOTSK

AN3 16:58:31.9 IP | AN4 16:58:33.0 IP
AN7 16:58:30.6 IPC | AN8 16:58:32.4 IPC
AN9 16:58:29.7 IP | AN10 16:58:31.0 IPC
AN11 16:58:29.9 P | AN12 16:58:29.4 IPC
ACM 16:58:18.1 IPC | IN1 16:58:27.3 IPC
IN2 16:58:28.2 IPC | IN3 16:58:33.4 IPC
AAM 16:58:24.3 IPC

370 14/ 2/81 1: 8:41.9 16.059 N 96.300 W 39KM 5.0MB OAXACA MEXICO

AN3 1:14:19.3 P | AN4 1:14:16.0 P
AN7 1:14:21.3 P | AN8 1:14:15.5 P
AN11 1:14:16.5 P | IN1 1:14:12.8 P
IN2 1:14: 6.0 P | IN3 1:14: 2.9 P

371 15/ 2/81 14:36:32.2 18.515 N 68.970 W 112KM 5.1MB MONA PASSAGE

AN3 14:41:51.3 EP | AN8 14:41:51.0 EP
AN9 14:41:55.0 EP | AN10 14:41:53.3 EP
AN11 14:41:54.6 EP | ACM 14:42:14.2 PD
IN1 14:41:59.4 EP | IN3 14:41:50.0 EP

N DATE ORIGIN TIME LAT. LONG. DEPTH MAG. LOCATION

372 19/ 2/81 19:36:11.6 44.639 N 149.342 E 33KM 5.9MB KURIL IS.

AN9 19:48:31.0 P   AN11 19:48:31.1 P
ACM 19:48:19.0 P   IN1 19:48:27.6 P
IN2 19:48:28.0 P   IN3 19:48:33.4 P
IN4 19:48:34.8 P
AAM 19:48:26.0 P

373 24/ 2/81 20:53:38.4 38.222 N 22.934 E 33KM 5.9MB GREECE

AN4 21: 5:33.2 EP   AN7 21: 5:31.0 EP
AN9 21: 5:33.4 EP   AN11 21: 5:34.3 EP
AN12 21: 5:31.7 EP   ACM 21: 5:31.1 EP
IN1 21: 5:35.7 EP   IN2 21: 5:41.1 EP
IN3 21: 5:40.3 EP   IN4 21: 5:36.0 EP
AAM 21: 5:25.2 P   21: 5:28.0 PCP   21: 8: 9.1 PP   21:10: 1.0 PPP
21:15: 8.0 S   21:20: 0.0 SS   21:28:46.0 LR

374 25/ 2/81 2:35:53.3 38.125 N 23.141 E 33KM 5.6MB GREECE

AAM 2:47:40.0 EP   2:52:16.4 PPP   2:57:24.4 S

375 4/ 3/81 21:58: 5.9 38.209 N 23.288 E 29KM 6.0MB GREECE

AN8 22:10: 1.3 EP   ACM 22: 9:59.1 EP
IN2 22:10:10.4 EP
AAM 22: 9:54.0 EP   22:19:40.0 S

376 6/ 3/81 19:42:59.5 3.893 N 85.915 W 33KM 6.1MB COAST OF CENTRAL AMERICA

AN4 19:50: 0.8 EP   AN7 19:50: 6.0 EP
AN8 19:50: 0.9 EP   AN9 19:50: 4.8 EP
AN10 19:50: 2.8 EP   AN11 19:50: 3.3 EP
AN12 19:50: 6.5 EP   ACM 19:50:20.1 EP
IN1 19:50: 2.4 EP   IN2 19:49:57.9 EP
IN3 19:49:52.2 EP   IN4 19:49:54.6 EP

377 9/ 3/81 22:38:51.9 18.831 N 103.907 W 56KM 5.7MB COAST OF MICHOACAN MEXICO

AN4 22:44:32.0 EP   22:44:23.1 EP   AN7 22:44:37.0 EP
AN11 22:44:30.8 EP   AN12 22:44:35.5 EP
IN1 22:44:25.1 EP   IN2 22:44:17.2 EP
IN3 22:44:17.2 EP
AAM 22:44:47.2 EP

378 12/ 3/81 3:17:14.5 11.251 N 85.773 W 33KM 4.7MB NICARAGUA

AN3 3:23:15.9 EPC   AN4 3:23:12.8 EPC
AN7 3:23:18.1 EPC   AN9 3:23:16.8 EPC
AN10 3:23:14.8 EPC   AN11 3:23:15.5 EPC
AN12 3:23:18.8 EPC   IN1 3:23:14.4 EPC
IN3 3:23: 3.7 EP   IN4 3:23: 6.5 EP

N DATE ORIGIN TIME LAT. LONG. DEPTH MAG. LOCATION

379 13/ 3/81 23:22:35.1 8.759 S 110.428 E 51KM 5.6MB JAVA

AN3	23:42:10.5 EP	AN7	23:42:10.4 EP
AN8	23:42:10.6 EP	AN9	23:42:10.0 EP
AN12	23:42: 9.7 EP	IN1	23:42: 8.7 EP
IN2	23:42: 9.5 EP	IN3	23:42:11.9 EP
IN4	23:42:12.2 EP		

380 21/ 3/81 22:52:39.3 5.450 S 146.715 E 227KM 6.3MB NEW GUINEA REGION

AN3	23: 9:55.6 P	AN7	23: 9:54.0 P
AN9	23: 9:51.8 P	AN10	23: 9:53.4 P
AN11	23: 9:5[illegible].9 P	AN12	23: 9:52.1 P
ACM	23: 9:35.9 P	IN1	23: 9:47.2 P
IN2	23: 9:47.7 P	IN3	23: 9:55.1 P
IN4	23: 9:56.0 P		
AAM	23: 9:47.0 P		

381 26/ 3/81 18: 4:44.7 19.370 S 68.957 W 138KM 5.8MB CHILE-BOLIVIA BORDER

AN3	18:14:45.4 P		AN4	18:14:43.2 P	
AN12	18:14:48.9 P		ACM	18:15: 1.6 P	
IN1	18:14:[illegible].2 P		IN2	18:14:46.1 P	18:15:18.0 AP
IN3	18:14:39.8 P	18:15:12.8 [illegible]P	IN4	18:14:40.5 P	
AAM	18:14:57.5 P	18:23:13.6 S			

382 29/ 3/81 4: 3:50.0 50.008 N 79.023 E 0KM 5.6MB EASTERN KAZAKH SSR

AN3	4:16:46.1 P	AN4	4:16:47.5 P
AN7	4:16:44.7 P	AN12	4:16:44.5 IPC
ACM	4:16:37.6 P	IN1	4:16:47.1 IPC
IN2	4:16:50.7 P	IN3	4:16:53.0 IPC
IN4	4:16:50.9 P		
AAM	4:16:37.0 P		

383 1/ 4/81 18: 3:36.5 27.310 S 63.320 W 554KM 5.9MB ARGENTINA

AN3	18:13:5[illegible].6 P	AN4	18:13:52.1 P
AN7	18:13:55.6 P	AN9	18:13:56.1 IP
AN12	18:13:56.7 IP	ACM	18:14: 8.0 IP
IN1	18:13:56.8 IP	IN2	18:13:54.9 IP
IN3	18:13:49.9 IP	IN4	18:13:49.8 IP
AAM	18:14: 4.7 P		

384 20/ 4/81 5:50:17.4 14.308 N 91.543 W 63KM 5.1MB GUATEMALA

AN1	5:55:53.6 P	AN7	5:55:57.3 P
AN9	5:55:55.0 P	AN10	5:55:53.3 P
AN11	5:55:53.3 P	IN1	5:55:51.1 P
IN2	5:55:45.4 P	IN4	5:55:44.2 P
AAM	5:56:10.0 EP		

385 22/ 4/81 1:17:11.4 49.901 N 78.901 E 0KM 5.9MB EASTERN KAZAKH

AN1	1:30: 8.4 P	AN3	1:30: 8.0 P
AN4	1:30: 9.4 P	AN7	1:30: 6.5 P
AN8	1:30: 9.5 P	AN9	1:30: 7.5 P
AN10	1:30: 8.6 P	AN11	1:30: 8.3 P
AN12	1:30: 6.3 IPC	IN1	1:30: 8.9 IPC
IN2	1:30:12.5 IPC	IN4	1:30:12.6 IP
AAM	1:29:59.8 EP		

N	DATE	ORIGIN TIME	LAT.	LONG.	DEPTH	MAG.	LOCATION
386	24/ 4/81	21:50: 6.0	13.427 S	166.421 E	33KM	6.1MB	VANUATA ISLANDS

AAM 22: 4:49.2 EP 22: 9:30.0 PP 22:19:11.6 S

N	DATE	ORIGIN TIME	LAT.	LONG.	DEPTH	MAG.	LOCATION
387	26/ 4/81	12: 9:28.4	33.133 N	115.650 W	6KM	5.5MB	SOUTHERN CALIFORNIA

AAM 12:15:10.0 EP

N	DATE	ORIGIN TIME	LAT.	LONG.	DEPTH	MAG.	LOCATION
388	30/ 4/81	14:41:41.2	43.233 N	150.222 E	49KM	6.1MB	KURIL ISLANDS REGION

AN1	14:54: 3.9 P	AN11	14:54: 2.2 P
AN12	14:54: 2.0 P	IN1	14:53:57.8 P
AAM	14:53:57.8 P		

N	DATE	ORIGIN TIME	LAT.	LONG.	DEPTH	MAG.	LOCATION
389	1/ 5/81	6:17:25.3	9.953 N	84.857 W	90KM	5.1MB	COSTA RICA

AN1	6:23:30.8 P	AN3	6:23:31.6 P
AN7	6:23:33.8 P	AN8	6:23:28.6 P
AN9	6:23:32.7 P	AN10	6:23:30.6 P
AN11	6:23:31.1 P	AN12	6:23:34.6 P
AAM	6:23:47.0 P		

N	DATE	ORIGIN TIME	LAT.	LONG.	DEPTH	MAG.	LOCATION
390	8/ 5/81	23:34:44.9	42.660 N	139.129 E	200KM	6.0MB	HOKKAIDO JAPAN

AN1	23:47:15.7 P	AN3	23:47:16.1 P
AN4	23:47:17.1 P	AN7	23:47:14.6 P
AN8	23:47:16.2 P	AN9	23:47:14.0 P
AN10	23:47:15.0 P	AN11	23:47:14.0 P
AN12	23:47:13.5 P	IN2	23:47:12.6 P
IN4	23:47:17.6 P		
AAM	23:47: 9.1 P		

N	DATE	ORIGIN TIME	LAT.	LONG.	DEPTH	MAG.	LOCATION
391	13/ 5/81	1:39:54.9	5.829 N	127.008 E	145KM	6.0MB	PHILIPPINE ISLANDS

AN1	1:58:41.8 P	AN3	1:58:42.1 P
AN4	1:58:42.2 P	AN8	1:58:42.0 P
AN9	1:58:41.1 P	AN10	1:58:41.5 P
AN11	1:58:41.0 P	AN12	1:58:41.0 P
IN4	1:58:42.2 P		
AAM	1:58:38.8 P		

N	DATE	ORIGIN TIME	LAT.	LONG.	DEPTH	MAG.	LOCATION
392	25/ 5/81	4:59:57.3	68.205 N	53.656 E	0KM	5.5MB	EUROP USSR NUC EXPL

AN1	5:10:54.0 IPC	AN8	5:10:55.5 P
AN9	5:10:53.0 IP	AN10	5:10:54.4 IPC
AN12	5:10:51.4 IPC	ACM	5:10:43.0 P
IN1	5:10:55.4 IPC	IN2	5:11: 0.0 P
IN3	5:11: 2.6 P	IN4	5:10:59.9 P
AAM	5:10:42.3 PC		

N	DATE	ORIGIN TIME	LAT.	LONG.	DEPTH	MAG.	LOCATION

393 25/ 5/81 5:25:14.4 48.786 S 164.357 E 33KM 6.1MB W.COAST S.IS N.Z.

AN9 5:44:24.8 EP — ACM 5:44:25.0 EP
IN1 5:44:22.5 EP — IN2 5:44:21.3 EP
IN3 5:44:19.2 EP — IN4 5:44:22.9 EP
AAM 5:44:27.0 EP

394 26/ 5/81 6:47:46.9 6.156 N 127.441 E 48KM 5.7MB PHILIPPINE IS. REGION

AN1 7: 6:44.3 P — AN8 7: 6:44.5 P
AN9 7: 6:43.6 P — AN10 7: 6:44.0 P
AN11 7: 6:43.4 P — AN12 7: 6:43.7 P
ACM 7: 6:39.4 P — IN1 7: 6:42.3 P
IN2 7: 6:43.1 P — IN3 7: 6:44.8 P
IN4 7: 6:44.8 P

395 31/ 5/81 1:35:52.5 9.165 S 112.024 E 84KM 4.8MB SOUTH OF JAVA

AN9 1:55:24.3 IPC — AN10 1:55:24.9 IPC
AN11 1:55:24.3 IPC — AN12 1:55:24.0 IPC
IN2 1:55:23.5 IPC — IN3 1:55:26.3 IPC
IN4 1:55:26.8 EP

396 1/ 6/81 19:50:13.3 20.485 S 65.189 W 330KM 5.0MB SOUTHERN BOLIVIA

AN1 20: 0: 6.9 IPD — AN9 20: 0: 9.0 IPD
AN10 20: 0: 7.6 IPD — AN11 20: 0: 8.4 IPD
AN12 20: 0: 9.8 IPD

397 5/ 6/81 19:41:50.6 44.701 N 148.899 E 33KM 5.9MB KURILISLANDS

AN1 19:54:12.6 IPC — AN8 19:54:13.0 IPC
AN10 19:54:11.7 IPC — AN11 19:54:10.8 IPC
AN12 19:54:10.5 IPC — ACM 19:53:58.9 IPC
IN2 19:54: 8.6 IPC — IN3 19:54:13.8 IPC
IN4 19:54:14.2 IPC
AAM 19:54: 6.0 IPC

398 6/ 6/81 18: 0: 0.0 37.303 N 116.326 W 0KM 5.5MB SOUTHERN NEVADA

AN1 18: 5:27.4 P — AN9 18: 5:24.9 PC
AN12 18: 5:26.8 PC — IN2 18: 5: 9.9 PC
IN3 18: 5:17.1 IPC — IN4 18: 5:22.7 IPC

399 11/ 6/81 18:34:20.6 16.722 N 86.110 W 20KM 5.2MB CARIBBEAN SEA

AN1 18:39:34.0 EP — AN8 18:39:31.9 EP
AN10 18:39:33.9 EP — AN12 18:39:38.0 EP
IN1 18:39:33.4 EP — IN4 18:39:23.7 EP
AAM 18:39:51.2 EP 18:44:18.0 S

N DATE ORIGIN TIME LAT. LONG. DEPTH MAG. LOCATION

400 4/ 7/81 5:30:50.7 17.814 N 96.642 W 73KM 4.8MB OAXAC MEXICO

IN1 5:36: 3.5 EP IN2 5:35:56.5 EP
IN3 5:35:53.5 EP IN4 5:35:59.2 EP

401 18/ 7/81 11:15:18.1 22 677 S 66.238 W 246KM 5.0MB JUJUY ARGENTINA

AN1 11:25:32.7 IPD AN4 11:25:30.6 IPD
AN7 11:25:34.4 IPD AN8 11:25:31.3 IPD
AN9 11:25:34.6 IPD AN12 11:25:35.5 IPD
ACM 11:25:47.8 IPD IN2 11:25:33.3 IPD
IN3 11:25:27.7 IPD IN4 11:25:27.8 IPD

402 21/ 7/81 9:14:18.6 16.282 N 98.373 W 25KM 5.1MB GUERRERO MEXICO

IN1 9:19:55.7 EP
AAM 9:20:16.8 EP 9:25:14.8 ES

403 21/ 7/81 10:22:54.7 16.508 N 98.408 W 53KM 5.2MB GUERRERO MEXICO

IN1 10:28:26.9 EP
AAM 10:28:48.0 10:33:46.4 ES

404 26/ 7/81 5:14:22.6 18.216 N 101.890 W 29KM 5.4MB GUERRERO MEXICO

AAM 5:20:16.9 IPC

405 1/ 8/81 1:42:16.4 60.136 N 153.185 W 114KM 5.2MB SOUTHERN ALASKA

AN1 1:50:28.1 P AN4 1:50:30.4 P
AN10 1:50:26.6 P IN1 1:50:20.4 PD
IN3 1:50:28.5 IPD

406 4/ 8/81 22: 0:15.1 16.824 N 61.4?7 W 50KM 5.3MB LEEWARD ISLANDS

IN1 22: 6:36.0 EPC IN3 22: 6:28.3 EPC
IN4 22: 6:25.4 EPC
AAM 22: 6:36.8 EPC

N	DATE	ORIGIN TIME	LAT.	LONG.	DEPTH	MAG.	LOCATION
407	5/ 8/81	12:58:27.4	3.895 N	76.409 W	58KM	5.0MB	COLUMBIA

AN10 13: 5:34.5 IPD
IN3 13: 5:26.7 IPD

N	DATE	ORIGIN TIME	LAT.	LONG.	DEPTH	MAG.	LOCATION
410	15/ 8/81	10:30:56.9	56.400 N	156.680 W	53KM	5.1MB	ALASKA PENINSULA

IN1 10:39:26.0 IP

N	DATE	ORIGIN TIME	LAT.	LONG.	DEPTH	MAG.	LOCATION
411	17/ 8/81	2:18:58.7	14.422 N	93.784 W	35KM	5.6MB	COAST CHIAPAS MEXICO

AAM 2:24:55.6 P

N	DATE	ORIGIN TIME	LAT.	LONG.	DEPTH	MAG.	LOCATION
412	23/ 8/81	12: 0:26.5	48.718 N	157.390 E	40KM	6.0MB	KURIL ISLANDS REGION

AN1 12:12: 9.9 EPC
AN3 12:12:10.2 EPC
AN4 12:12:11.4 EPC
AN7 12:12: 8.8 EPC
AN8 12:12:10.4 EPC
AN9 12:12: 7.7 EPC
AN10 12:12: 8.9 EPC
AN11 12:12: 7.8 EPC
AN12 12:12: 7.6 EPC
IN1 12:12: 4.3 EPC
IN4 12:12:11.5 EPC
AAM 12:12: 2.8 EPC

N	DATE	ORIGIN TIME	LAT.	LONG.	DEPTH	MAG.	LOCATION
413	24/ 8/81	15:46:27.6	51.508 N	178.355 W	56KM	5.2MB	ALEUTIAN ISLANDS

AN1 15:56:43.6 EP
AN3 15:56:44.3 IPC
AN4 15:56:45.6 EP
AN7 15:56:42.8 EP
AN11 15:56:40.6 EP
AN12 15:56:41.1 EP
IN1 15:56:36.1 IP
IN3 15:56:42.8 IPC
IN4 15:56:44.4 EP

N	DATE	ORIGIN TIME	LAT.	LONG.	DEPTH	MAG.	LOCATION
414	28/ 8/81	9: 4:24.7	61.738 N	150.452 W	71KM	5.1MB	SOUTHERN ALASKA

AN1	9:12:29.1 IPD	AN3	9:12:29.8 IPD
AN7	9:12:28.0 IPD	AN8	9:12:29.7 IPD
AN9	9:12:26.0 IPD	AN10	9:12:27.6 IPD
AN11	9:12:26.1 IPD	AN12	9:12:26.2 IPD
IN1	9:12:21.5 IPD	IN3	9:12:2[illegible].8 IPD
IN4	9:12:30.9 IPD		
AAM	9:12:20.0 IPD		

N	DATE	ORIGIN TIME	LAT.	LONG.	DEPTH	MAG.	LOCATION
415	1/ 9/81	9:29:31.5	14.360 S	173.085 W	25KM	7.0MB	SAMOA ISLANDS REGION

AAM	9:43:13.6 IPD

N	DATE	ORIGIN TIME	LAT.	LONG.	DEPTH	MAG.	LOCATION
416	3/ 9/81	5:35:44.8	43.621 N	147.031 E	45KM	6.6MB	KURIL ISLANDS

AN1	5:48:13.7 EPC	AN3	5:48:14.0 EPC
AN4	5:48:15.1 EPC	AN7	5:48:12.9 EPC
AN8	5:48:14.5 EPC	AN9	5:48:11.8 EPC
AN10	5:48:12.8 EPC	AN11	5:48:11.8 EPC
AN12	5:48:11.9 EPC	IN1	5:48: 9.3 EPC
IN3	5:48:15.2 EPC	IN4	5:48:15.5 EPC
AAM	5:48: 7.2 IPC 5:51:20.8 PP	5:58:22.8 IS	

N	DATE	ORIGIN TIME	LAT.	LONG.	DEPTH	MAG.	LOCATION
417	8/ 9/81	7: 1:16.9	51.468 N	178.368 W	55KM	4.9MB	ALEUTIAN ISLANDS

AN1	7:11:33.0 IP	AN3	7:11:33.9 IP
AN4	7:11:35.0 IP	AN7	7:11:32.2 IP
AN8	7:11:33.3 IP	IN1	7:11:25.5 IPC
IN3	7:11:32.1 IPC	IN4	7:11:33.9 IP

N	DATE	ORIGIN TIME	LAT.	LONG.	DEPTH	MAG.	LOCATION
418	13/ 9/81	2:17:18.2	49.897 N	78.983 E	OKM	6.0MB	EASTERN KAZAKH SSR

AN1	2:30:15.2 IPC	AN3	2:30:14.6 IPC
AN4	2:30:16.2 IPC	AN7	2:30:13.4 IPC
AN8	2:30:16.2 IPC	AN9	2:30:14.4 IPC
AN10	2:30:15.4 IPC	AN11	2:30:15.0 IPC
AN12	2:30:13.2 IPC	IN1	2:30:15.8 IPC
IN2	2:30:19.4 IPC	IN4	2:30:19.5 IPC

N	DATE	ORIGIN TIME	LAT.	LONG.	DEPTH	MAG.	LOCATION
419	13/ 9/81	9:19:30.9	24.866 N	46.301 W	10KM	5.8MB	NORTH ATLANTIC RIDGE

AAM	9:26:29.0 EP 9:32: 2.8 S

N	DATE	ORIGIN TIME	LAT.	LONG.	DEPTH	MAG.	LOCATION
420	14/ 9/81	12:44:29.8	18.320 N	68.891 W	170KM	5.9MB	MONA PASSAGE

AN9	12:49:48.4 EPC	AN10	12:49:46.6 EPC
AN11	12:49:48.0 EPC	IN1	12:49:52.5 IPC
IN2	12:49:52.9 IPC	IN3	12:49:43.6 IPC
IN4	12:49:41.4 IPC		
AAM	12:49:57.6 IP 12:50:34.0 PP	12:54:24.8 S	

N	DATE	ORIGIN TIME	LAT.	LONG.	DEPTH	MAG.	LOCATION
422	1/10/81	12:14:56.8	73.317 N	54.812 E	OKM	5.9MB	NOVAYA ZEMLYA

AN1	12:25:27.1 IPC	AN4	12:25:28.4 IPC
AN7	12:25:24.5 IPC	AN8	12:25:28.5 IPC
AN10	12:25:27.5 IPC	AN11	12:25:27.1 IPC
AN12	12:25:24.3 IPC	IN1	12:25:27.3 IPC
IN2	12:25:32.8 IPC	IN3	12:25:35.9 IPC
IN4	12:25:33.0 IPC		

N	DATE	ORIGIN TIME	LAT.	LONG.	DEPTH	MAG.	LOCATION
423	4/10/81	20: 3:53.0	1.550 S	77.364 W	203KM	5.2MB	EQUADOR

AN1	20:11:26.9 EPC	AN3	20:11:27.1 IPC
AN4	20:11:24.5 IPC	AN7	20:11:29.1 EPC
AN8	20:11:24.9 IPC	AN10	20:11:26.9 IPC
AN11	20:11:27.8 IPC	AN12	20:11:30.2 IPC
IN1	20:11:28.7 IPC	IN2	20:11:25.3 IPC
IN3	20:11:18.9 IPC		
AAM	20:11:40.6 EPC		

N	DATE	ORIGIN TIME	LAT.	LONG.	DEPTH	MAG.	LOCATION
424	7/10/81	8:32:55.1	6.402 S	154.899 E	41KM	5.3MB	SOLOMON ISLANDS

AN1	8:51:37.6 PC	AN3	8:51:38.0 PC
AN8	8:51:37.4 PC	AN9	8:51:37.0 PC
AN10	8:51:37.1 PC	AN11	8:51:36.8 PC
AN12	8:51:37.4 PC	IN1	8:51:34.7 PC
IN2	8:51:34.2 PC	IN3	8:51:35.7 PC
IN4	8:51:36.6 PC		

N	DATE	ORIGIN TIME	LAT.	LONG.	DEPTH	MAG.	LOCATION
425	8/10/81	22:25:53.0	17.124 S	70.051 W	147KM	5.0MB	NEAR COAST OF PERU

AN10	22:35:36.7 EPC	AN11	22:35:37.5 EPC	22:35:37.5 EPC
AN12	22:35:39.5 IPC	IN1	22:35:39.0 IPC	
IN2	22:35:36.6 IPC	IN3	22:35:30.7 IPC	
IN4	22:35:30.9 IPC			
AAM	22:35:47.5 EP			

N	DATE	ORIGIN TIME	LAT.	LONG.	DEPTH	MAG.	LOCATION
426	15/10/81	1:47:52.9	40.229 N	142.287 E	47KM	6.0MB	COAST HONSHO JAPAN

AN1	2: 0:45.1 EPC	AN3	2: 0:45.5 EPC
AN4	2: 0:46.7 EPC	AN7	2: 0:44.2 EPC
AN8	2: 0:45.8 EPC	AN9	2: 0:43.5 EPC
AN10	2: 0:44.5 EPC	AN11	2: 0:43.6 EPC
AN12	2: 0:43.2 EPC	IN1	2: 0:41.0 EPC
IN2	2: 0:41.6 EPC	IN3	2: 0:46.5 EPC
IN4	2: 0:46.8 EPC		
AAM	2: 0:38.9 EPC		

N	DATE	ORIGIN TIME	LAT.	LONG.	DEPTH	MAG.	LOCATION
427	16/10/81	3:25:42.2	33.134 S	73.074 W	33KM	6.2MB	COAST OF CENTRAL CHILE

AAM	3:37:24.4 EPC	3:47: 2.3 ES

N	DATE	ORIGIN TIME	LAT.	LONG.	DEPTH	MAG.	LOCATION
428	18/10/81	3:57: 2.6	49.886 N	78.898 E	OKM	6.0MB	EASTERN KAZAKH SSR

AN1	4: 9:59.4 IPC	AN3	4: 9:58.9 IPC
AN8	4:10: 0.6 IPC	AN9	4: 9:58.7 IPC
AN11	4: 9:59.4 IPC	AN12	4: 9:57.5 IPC
IN1	4:10: 0.3 IPC	IN2	4:10: 3.6 IPC
IN3	4:10: 5.9 IPC	IN4	4:10: 3.8 IPC

N	DATE	ORIGIN TIME	LAT.	LONG.	DEPTH	MAG.	LOCATION
429	18/10/81	4:31: 2.7	8.117 N	72.527 W	54KM	5.4MB	VENEZUELA

IN2	4:37:44.7 EP	IN4	4:37:36.1 EP

N	DATE	ORIGIN TIME	LAT.	LONG.	DEPTH	MAG.	LOCATION
430	25/10/81	3:22:15.5	18.048 N	102.108 W	33KM	6.2MB	MICHOACAN MEXICO

AAM	3:28:10.0 IPC

N	DATE	ORIGIN TIME	LAT.	LONG.	DEPTH	MAG.	LOCATION
431	3/11/81	7: 2:36.8	1.782 S	78.482 W	129KM	5.8MB	ECUADOR

IN1	7:10:22.0 IPC
AAM	7:10:35.1 EPC

N	DATE	ORIGIN TIME	LAT.	LONG.	DEPTH	MAG.	LOCATION
432	3/11/81	13:47:34.1	43.542 N	127.706 W	10KM	6.2MB	COAST OF OREGON

AAM	13:54: 3.2 IP	13:59:17.6 S

N	DATE	ORIGIN TIME	LAT.	LONG.	DEPTH	MAG.	LOCATION
433	7/11/81	3:29:51.0	32.199 S	71.336 W	65KM	6.2MB	COAST CENTRAL CHILE

AN1	3:41:15.8 EP		AN3	3:41:16.2 EP
AN4	3:41:14.3 EP		AN7	3:41:17.7 EP
AN8	3:41:14.6 EP		AN9	3:41:17.5 EP
AN11	3:41:16.6 EP		AN12	3:41:18.5 EP
IN1	3:41:17.1 EP		IN2	3:41:14.8 EP
IN3	3:41:10.5 EP		IN4	3:41:10.6 EP
AAM	3:41:26.0 EP	3:50:55.2 ES		

N	DATE	ORIGIN TIME	LAT.	LONG.	DEPTH	MAG.	LOCATION
434	7/11/81	22: 2:49.0	14.595 N	90.416 W	200KM	5.3MB	GUATEMALA

AN1	22: 8: 9.0 IPC	AN4	22: 8: 7.2 IPC
AN7	22: 8:12.4 IPC	AN8	22: 8: 6.7 IPC
AN9	22: 8:10.0 IPC	AN11	22: 8: 8.7 IPC
AN12	22: 8:12.5 IPC	IN1	22: 8: 6.5 IPC
IN2	22: 8: 0.7 IPC	IN3	22: 7:56.0 IPC
IN4	22: 7:59.4 IPC		
AAM	22: 8:25.2 EPC		

N	DATE	ORIGIN TIME	LAT.	LONG.	DEPTH	MAG.	LOCATION
435	8/11/81	13:41:20.0	6.169 S	112.154 E	633KM	5.8MB	JAVA

AN1	13:59:43.0 IPD	AN3	13:59:43.0 IPD
AN4	13:59:44.0 IPD	AN7	13:59:41.9 IPD
AN8	13:59:43.3 IPD	AN9	13:59:41.5 IPD
AN11	13:59:41.7 IPD	AN12	13:59:41.4 IPD
N1	13:59:40.0 IPD	IN2	13:59:40.8 IPD
[illegible]	13:59:44.2 IPD	IN4	13:59:44.3 IPD

N	DATE	ORIGIN TIME	LAT.	LONG.	DEPTH	MAG.	LOCATION
436	27/11/81	17:21:45.8	42.913 N	131.076 E	543KM	5.8MB	E.USSR N.E.CHINA BORDER

AN3	17:33:53.7 IPC	AN4	17:33:55.0 IPC
AN7	17:33:52.5 IPC	AN8	17:33:54.3 IPC
AN9	17:33:52.1 IPC	AN11	17:33:52.3 EPC
AN12	17:33:51.7 IPC	IN1	17:33:50.5 IPC
IN2	17:33:51.8 IPC	IN3	17:33:56.0 IPC
IN4	17:33:55.9 IPC		

N	DATE	ORIGIN TIME	LAT.	LONG.	DEPTH	MAG.	LOCATION
437	29/11/81	3:35: 8.6	49.860 N	78.857 E	0KM	5.6MB	EASTERN KAZAKH SSR

AN3	3:48: 5.1 EPC	AN4	3:48: 6.6 IPC
AN7	3:48: 3.9 IPC	AN8	3:48: 6.8 IPC
AN9	3:48: 4.7 IPC	AN11	3:48: 5.5 IPC
AN12	3:48: 3.6 IPC	IN1	3:48: 6.0 IPC
IN2	3:48:10.0 EPC	IN3	3:48:12.1 IPC
IN4	3:48:10.1 EPC		

N	DATE	ORIGIN TIME	LAT.	LONG.	DEPTH	MAG.	LOCATION
438	2/12/81	6:24:42.8	40.907 N	142.515 E	59KM	5.9MB	COAST HONSHU JAPAN

AN3	6:37:30.6 IPD	AN4	6:37:31.8 EPD
AN7	6:37:29.3 EPD	AN8	6:37:30.7 IPD
AN9	6:37:28.2 EPD	AN11	6:37:28.4 EPD
AN12	6:37:28.2 EPD	IN2	6:37:26.7 IPD
IN3	6:37:31.4 IPD	IN4	6:37:31.8 IPD

N	DATE	ORIGIN TIME	LAT.	LONG.	DEPTH	MAG.	LOCATION
439	6/12/81	14:54:29.4	8.001 N	38.411 W	10KM	5.5MB	CEN MID ATLANTIC RIDGE

AAM	15: 3:46.0 IP

N	DATE	ORIGIN TIME	LAT.	LONG.	DEPTH	MAG.	LOCATION
440	13/12/81	20:35:56.6	9.348 S	111.761 E	83KM	5.7MB	SOUTH OF JAVA

AAM	20:55:25.0 IP

N	DATE	ORIGIN TIME	LAT.	LONG.	DEPTH	MAG.	LOCATION
441	13/12/81	21:40:36.1	6.750 N	72.978 W	159KM	5.3MB	NORTHERN COLUMBIA

AAM	21:47:29.7 EPD

	N	DATE	ORIGIN TIME	LAT.	LONG.	DEPTH	MAG.	LOCATION
	442	21/12/81	10:32:11.8	14.818 N	92.306 W	73KM	5.3MB	COAST CHIAPAS MEXICO
AAM	10:38: 1.1 IPD							
	443	27/12/81	3:43:14.1	49.909 N	78.873 E	0KM	6.2MB	EASTERN KAZAKH SSR
AN1	3:56:10.9 IPC				AN3	3:56:10.4 IPC		
AN4	3:56:11.9 IPC				AN7	3:56: 9.2 IPC		
AN8	3:56:12.0 IPC				AN9	3:56:10.2 IPC		
AN10	3:56:11.1 IPC				AN11	3:56:10.8 IPC		
AN12	3:56: 9.0 IPC				IN1	3:56:11.6 IPC		
IN2	3:56:15.1 IPC				IN3	3:56:17.4 IPC		
IN4	3:56:15.1 IPC							
AAM	3:56: 2.0 IPC							
	444	3/ 1/82	14: 9:50.4	0.972 S	21.870 W	10KM	5.8MB	CEN MID ATLANT RIDGE
AAM	14:21: 5.5 IP							
	447	18/ 1/82	19:27:24.4	40.004 N	24.319 E	10KM	5.8MB	AEGEAN SEA
AAM	19.39:13.8 IP							

N DATE ORIGIN TIME LAT. LONG. DEPTH MAG. LOCATION

449 20/ 1/82 7: 9:17.4 7.119 N 93.944 E 27KM 5.7MB NICOBAR ISLANDS REGION

AN3 7:31:55.2 EPD | AN7 7:31:54.1 EPD
AN8 7:31:56.7 EPD | AN10 7:31:55.5 EPD
AN12 7:31:54.0 EPD | IN1 7:31:55.0 EPD
IN2 7:31:57.5 EPD | IN3 7:31:59.3 EPD
IN4 7:31:58.0 EPD

450 25/ 1/82 5:29:33.5 53.222 N 165.719 W 60KM 6.1MB FOX-ALEUTIAN ISLANDS

AN3 5:38:54.6 EPC | AN4 5:38:55.8 IPC
AN7 5:38:52.9 EPC | AN8 5:38:53.8 EPC
AN9 5:38:50.7 EPC | AN10 5:38:51.8 EPC
AN11 5:38:50.4 EPC | AN12 5:38:51.1 EPC
IN1 5:38:45.6 IPC | IN2 5:38:45.5 IPC
IN3 5:38:52.4 IPC
AAM 5:38:46.7 IPC

451 28/ 1/82 16: 0: 0.1 37.091 N 116.051 W 0KM 5.9MB SOUTHERN NEVADA

AAM 16: 5:28.9 IP

452 29/ 1/82 22:32: 5.9 25.509 N 45.288 W 10KM 5.7MB NORTH ATLANTIC RIDGE

AAM 22:39: 6.9 IP 22:44:47.6 IS

453 30/ 1/82 2:35:10.6 16.737 N 61.430 W 63KM 6.0MB LEEWARD ISLANDS

AN4 2:41:19.3 EPC | AN7 2:41:23.0 EPC
AN8 2:41:21.3 EPC | AN10 2:41:23.4 EPC
AN12 2:41:24.6 EPC | IN1 2:41:30.7 EPC
IN2 2:41:32.4 EPC | IN3 2:41:23.2 EPC
AAM 2:41:31.2 IPC

454 7/ 2/82 6: 7:13.2 51.779 N 176.871 W 60KM 5.3MB ANDREANOF-ALEUTIAN IS

AN3 6:17:22.8 IPC | AN4 6:17:23.7 IPC
AN7 6:17:21.0 IPC | AN12 6:17:19.2 IPC
IN1 6:17:14.2 IPC | IN2 6:17:14.4 IPC
IN3 6:17:21.0 IPC

455 10/ 2/82 20:38: 1.0 22.648 S 66.466 W 196KM 5.9MB JUJUY PROV ARGENTINA

AAM 20:48:30.3 IP 20:57: 0.0 IS

N	DATE	ORIGIN TIME	LAT.	LONG.	DEPTH	MAG.	LOCATION
456	12/ 2/82	14:55: 0.0	37.224 N	116.463 W	OKM	5.4MB	SOUTHERN NEVADA

AN12 15: 0:27.8 EPC — IN1 15: 0:16.4 IPC
IN2 15: 0:10.7 IPC — IN3 15: 0:18.4 IPC
AAM 15: 0:31.5 EPC

N	DATE	ORIGIN TIME	LAT.	LONG.	DEPTH	MAG.	LOCATION
457	12/ 2/82	15:25: 0.0	37.348 N	116.316 W	OKM	5.6MB	SOUTHERN NEVADA

AN12 15:30:26.5 EPC — IN1 15:30:14.9 IPC
IN2 15:30: 9.5 IPC — IN3 15:30:16.9 IPC
AAM 15:30:30.1 EPC

N	DATE	ORIGIN TIME	LAT.	LONG.	DEPTH	MAG.	LOCATION
458	28/ 2/82	17:52:19.2	11.348 S	117.260 E	17KM	5.6MB	SOUTH OF SUMBAWA ISLANF

AN3 18:11:58.9 IPD — AN4 18:11:59.6 IPD
AN7 18:11:57.9 IPD — AN8 18:11:58.7 IPD
AN9 18:11:57.3 IPD — AN10 18:11:58.0 IPD
AN11 18:11:57.5 IPD — AN12 18:11:57.2 IPD
IN1 18:11:55.1 IPD — IN2 18:11:55.4 IPD
IN3 18:11:58.6 IPD
AAM 18:11:54.5 IPD

N	DATE	ORIGIN TIME	LAT.	LONG.	DEPTH	MAG.	LOCATION
459	11/ 3/82	10:32:27.1	9.265 S	118.479 E	33KM	6.1MB	SUMBAWA ISLAND REGION

AAM 10:51:53.1 EP

N	DATE	ORIGIN TIME	LAT.	LONG.	DEPTH	MAG.	LOCATION
460	21/ 3/82	2:32: 6.3	42.168 N	142.479 E	44KM	6.4MB	HOKKAIDO JAPAN

AN3 2:44:52.8 EPC — AN7 2:44:51.5 EPC
AN8 2:44:53.0 EPC — AN9 2:44:50.7 EPC
AN11 2:44:50.8 EPC — AN12 2:44:50.4 EPC
IN1 2:44:48.3 EPC — IN2 2:44:49.2 EPC
IN3 2:44:53.9 EPC
AAM 2:44:46.2 IPC 2:55: 8.8 IS

N	DATE	ORIGIN TIME	LAT.	LONG.	DEPTH	MAG.	LOCATION
461	22/ 3/82	21:44: 9.3	19.880 S	68.743 W	126KM	5.1MB	CHILE-BOLIVIA BORDER

AN12 21:54:18.1 IPD — IN1 21:54:17.6 IPD
IN2 21:54:15.3 EPD — IN3 21:54: 9.6 EPD

N	DATE	ORIGIN TIME	LAT.	LONG.	DEPTH	MAG.	LOCATION
462	28/ 3/82	23:24:50.7	12.769 S	76.090 W	95KM	6.1MB	NEAR COAST OF PERU

AN3 23:34: 1.7 IPD — AN4 23:33:59.5 IPD
AN7 23:34: 3.4 IPD — AN8 23:33:59.9 IPD
AN9 23:34: 3.4 IPD — AN10 23:34: 1.8 IPD
AN11 23:34: 2.4 IPD — AN12 23:34: 4.7 IPD
IN1 23:34: 3.3 IPD — IN2 23:34: 0.2 IPD
IN3 23:33:54.6 IPD
AAM 23:34:14.1 IPD 23:41:49.2 IS

APPENDIX B

P-WAVE RESIDUALS FROM TELESEISMIC EVENTS WITH RESPECT TO J-B TABLES FOR OHIO STATIONS PLUS ACM, AAM (JAN 1981-MAR 1982)

The information presented in this appendix is a compilation of P-wave travel time residuals with respect to the J-B tables. Event locations are taken from the National Earthquake Information Service PDE monthly reports. Because these reports are published with a time lapse of about six months, we have included only events up to the latest issue (March 1982). Other information included:

STAT# Name of reporting station

RESID P-wave travel time residual in seconds (observed-JB table predicted) ***** indicates that clear arrivals were not recorded.

BACK AZ Azimuth of wavefront approach to the station (clockwise from north in degrees)

DIST Epicentral distance (in degrees)

RET ANG The angle from downward vertical at which the wavefront approaches the station (in degrees).

Time, Date & Location	ANNA NETWORK P-Wave Residuals University of Michigan Seismological Observatory											
15/12/80	STAT #	(AN 1)	(AN 3)	(AN 4)	(AN 7)	(AN 8)	(AN 9)	(AN10)	(AN11)	(AN12)	(AAM)	(ACM)
10: 9:33.0	RESID	*****	0.3	0.2	-0.1	*****	-0.2	0.1	-0.1	-0.2	*****	-1.5
11.494° N	BACK AZ	******	184.84	184.71	184.70	******	183.44	183.52	183.08	184.04	******	180.67
86.204° W	DIST	******	29.02	28.69	29.23	******	29.14	28.90	28.99	29.37	******	31.04
	RET ANG	******	26.71	26.98	26.71	******	26.71	26.98	26.98	26.71	******	26.18
20/12/80	STAT #	(AN 1)	(AN 3)	(AN 4)	(AN 7)	(AN 8)	(AN 9)	(AN10)	(AN11)	(AN12)	(AAM)	(ACM)
20:26:47.2	RESID	*****	*****	-1.5	-1.2	*****	-1.2	-1.1	-1.3	*****	*****	-1.5
24.373° S	BACK AZ	******	******	159.72	159.85	******	159.23	159.22	159.04	******	******	158.24
63.417° W	DIST	******	******	67.04	67.59	******	67.66	67.43	67.57	******	******	69.83
	RET ANG	******	******	17.89	17.89	******	17.89	17.89	17.89	******	******	17.44
22/12/80	STAT #	(AN 1)	(AN 3)	(AN 4)	(AN 7)	(AN 8)	(AN 9)	(AN10)	(AN11)	(AN12)	(AAM)	(ACM)
20:31:45.3	RESID	*****	-0.1	-0.2	-0.3	*****	-0.2	-0.1	-0.3	-0.3	-0.0	-0.5
48.169° N	BACK AZ	******	328.73	328.71	328.68	******	328.34	328.38	328.25	328.50	328.56	327.41
146.208° E	DIST	******	81.18	81.43	80.93	******	80.77	80.98	80.82	80.[illegible]2	79.[illegible]	78.59
	RET ANG	******	14.96	14.96	15.17	******	15.17	15.17	15.17	15.17	15.41	15.62
27/12/80	STAT #	(AN 1)	(AN 3)	(AN 4)	(AN 7)	(AN 8)	(AN 9)	(AN10)	(AN11)	(AN12)	(AAM)	(ACM)
4: 9: 8.2	RESID	*****	5.0	4.8	4.8	*****	4.8	4.9	4.7	*****	4.9	5.0
50. 40° N	BACK AZ	******	10.96	10.90	10.93	******	10.53	10.54	10.41	******	11.07	9.69
79. 46° E	DIST	******	88.54	88.87	88.28	******	88.48	88.71	88.65	******	86.80	86.75
	RET ANG	******	13.99	13.99	13.99	******	13.99	13.99	13.99	******	14.36	14.36
29/12/80	STAT #	(AN 1)	(AN 3)	(AN 4)	(AN 7)	(AN 8)	(AN 9)	(AN10)	(AN11)	(AN12)	(AAM)	(ACM)
22:10:21.7	RESID	*****	*****	5.9	5.4	*****	5.5	5.7	5.6	*****	5.5	5.6
17.160° N	BACK AZ	******	******	211.85	211.28	******	210.15	210.45	209.93	******	210.21	205.68
97.892° W	DIST	******	******	25.98	26.51	******	26.17	25.97	25.97	******	27.86	27.40
	RET ANG	******	******	28.48	28.04	******	28.04	28.48	28.48	******	27.39	27.39
31/12/80	STAT #	(AN 1)	(AN 3)	(AN 4)	(AN 7)	(AN 8)	(AN 9)	(AN10)	(AN11)	(AN12)	(AAM)	(ACM)
10:32:11.0	RESID	*****	4.5	*****	4.4	*****	4.3	*****	*****	*****	*****	5.5
46. 60° N	BACK AZ	******	324.55	******	324.50	******	324.17	******	******	******	******	323.20
151.453° E	DIST	******	80.65	******	80.41	******	80.21	******	******	******	******	78.05
	RET ANG	******	15.63	******	15.63	******	15.63	******	******	******	******	16.16
23/ 1/81	STAT #	(AN 1)	(AN 3)	(AN 4)	(AN 7)	(AN 8)	(AN 9)	(AN10)	(AN11)	(AN12)	(AAM)	(ACM)
4:58:31.5	RESID	*****	0.5	0.4	0.4	0.5	0.4	0.5	0.2	0.3	0.6	0.1
42.524° N	BACK AZ	******	327.88	327.83	327.84	327.59	327.45	327.48	327.34	327.64	327.92	326.54
142.122° E	DIST	******	87.46	87.70	87.21	87.52	87.04	87.26	87.09	86.99	86.04	84.87
	RET ANG	******	14.04	14.04	14.04	14.04	14.04	14.04	14.04	14.26	14.26	14.58
27/ 1/81	STAT #	(AN 1)	(AN 3)	(AN 4)	(AN 7)	(AN 8)	(AN 9)	(AN10)	(AN11)	(AN12)	(AAM)	(ACM)
1:53:14.3	RESID	*****	0.4	*****	*****	*****	0.0	*****	-0.1	0.1	*****	*****
11.377° N	BACK AZ	******	184.92	******	******	******	183.52	******	183.17	184.13	******	******
86.252° W	DIST	******	29.14	******	******	******	29.26	******	29.10	29.48	******	******
	RET ANG	******	26.74	******	******	******	26.74	******	26.74	26.74	******	******

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Time, Date & Location												
30/ 1/81	STAT #	(AN 1)	(AN 3)	(AN 4)	(AN 7)	(AN 8)	(AN 9)	(AN10)	(AN11)	(AN12)	(AAM)	(ACM)
8:52:44.1	RESID	*****	-1.2	-1.3	-1.4	-1.6	-1.7	-1.5	-1.9	*****	-1.3	*****
51.720° N	BACK AZ	******	317.38	317.45	317.28	317.30	317.07	317.16	317.05	******	316.87	******
176.274° E	DIST	******	64.82	65.02	64.60	64.80	64.35	64.54	64.36	******	63.62	******
	RET ANG	******	19.18	18.88	19.18	19.18	19.18	19.18	19.18	******	19.41	******
1/ 2/81	STAT #	(AN 1)	(AN 3)	(AN 4)	(AN 7)	(AN 8)	(AN 9)	(AN10)	(AN11)	(AN12)	(AAM)	(ACM)
22:43:27.5	RESID	*****	-1.1	-1.2	-1.2	-1.3	-1.2	*****	-1.4	-1.5	-0.5	-1.1
53. 30° N	BACK AZ	******	324.15	324.18	324.08	324.01	323.83	******	323.78	323.92	323.85	322.80
162.406° E	DIST	******	70.70	70.93	70.46	70.73	70.26	******	70.30	70.23	69.35	68.10
	RET ANG	******	17.82	17.82	17.82	17.82	17.82	******	17.82	17.82	18.12	18.27
5/ 2/81	STAT #	(AN 1)	(AN 3)	(AN 4)	(AN 7)	(AN 8)	(AN 9)	(AN10)	(AN11)	(AN12)	(AAM)	(ACM)
10:52: 2.3	RESID	*****	*****	*****	*****	*****	*****	*****	*****	*****	-1.3	-1.7
50.167° N	BACK AZ	******	******	******	******	******	******	******	******	******	312.46	311.46
176.273° W	DIST	******	******	******	******	******	******	******	******	******	60.55	59.11
	RET ANG	******	******	******	******	******	******	******	******	******	20.18	20.41
6/ 2/81	STAT #	(AN 1)	(AN 3)	(AN 4)	(AN 7)	(AN 8)	(AN 9)	(AN10)	(AN11)	(AN12)	(AAM)	(ACM)
16:47: 7.4	RESID	*****	-0.4	-0.5	-0.4	-0.2	-0.4	-0.3	-0.5	-0.5	-0.5	-0.7
48.300° N	BACK AZ	******	328.73	328.71	328.68	328.50	328.34	328.38	328.25	328.49	328.66	327.41
146.354° E	DIST	******	81.02	81.26	80.76	81.09	80.61	80.82	80.66	80.55	79.58	78.43
	RET ANG	******	14.96	14.96	15.18	14.96	15.18	15.18	15.18	15.18	15.41	15.63
14/ 2/81	STAT #	(AN 1)	(AN 3)	(AN 4)	(AN 7)	(AN 8)	(AN 9)	(AN10)	(AN11)	(AN12)	(AAM)	(ACM)
1: 8:41.9	RESID	*****	-0.1	-0.5	-0.2	0.1	*****	*****	-0.3	*****	*****	*****
16. 59° N	BACK AZ	******	207.56	207.69	207.21	206.88	******	******	205.80	******	******	******
96.300° W	DIST	******	26.70	26.38	26.93	26.27	******	******	26.42	******	******	******
	RET ANG	******	28.08	28.08	28.08	28.08	******	******	28.08	******	******	******
15/ 2/81	STAT #	(AN 1)	(AN 3)	(AN 4)	(AN 7)	(AN 8)	(AN 9)	(AN10)	(AN11)	(AN12)	(AAM)	(ACM)
14:36:32.2	RESID	*****	0.6	*****	*****	0.7	0.3	0.5	0.2	*****	*****	-0.3
18.515° N	BACK AZ	******	145.48	******	******	144.19	144.35	144.11	143.81	******	******	144.06
68.970° W	DIST	******	25.40	******	******	25.36	25.83	25.63	25.80	******	******	28.00
	RET ANG	******	28.34	******	******	28.34	28.34	28.34	28.34	******	******	27.34
19/ 2/81	STAT #	(AN 1)	(AN 3)	(AN 4)	(AN 7)	(AN 8)	(AN 9)	(AN10)	(AN11)	(AN12)	(AAM)	(ACM)
19:36:11.6	RESID	*****	*****	*****	*****	*****	-0.0	*****	-0.1	*****	-0.2	-0.7
44.639° N	BACK AZ	******	******	******	******	******	324.43	******	324.34	******	324.78	323.48
149.342° E	DIST	******	******	******	******	******	82.26	******	82.29	******	81.33	80.09
	RET ANG	******	******	******	******	******	15.11	******	15.11	******	15.33	15.63
24/ 2/81	STAT #	(AN 1)	(AN 3)	(AN 4)	(AN 7)	(AN 8)	(AN 9)	(AN10)	(AN11)	(AN12)	(AAM)	(ACM)
20:53:38.4	RESID	*****	*****	2.5	2.6	*****	2.5	*****	2.3	2.6	2.8	2.8
38.222° N	BACK AZ	******	******	50.64	50.76	******	50.40	******	50.28	50.61	51.15	50.00
22.934° E	DIST	******	******	77.19	76.79	******	77.23	******	77.44	76.92	75.74	76.78
	RET ANG	******	******	16.38	16.61	******	16.38	******	16.38	16.61	16.83	16.61

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& Location

25/ 2/81	STAT #	(AN 1)	(AN 3)	(AN 4)	(AN 7)	(AN 8)	(AN 9)	(AN10)	(AN11)	(AN12)	(AAM)	(ACM)
2:35:53.3	RESID	*****	*****	*****	*****	*****	*****	*****	*****	*****	1.6	*****
38.125° N	BACK AZ	******	******	******	******	******	******	******	******	******	51.11	******
23.141° E	DIST	******	******	******	******	******	******	******	******	******	75.93	******
	RET ANG	******	******	******	******	******	******	******	******	******	16.83	******
4/ 3/81	STAT #	(AN 1)	(AN 3)	(AN 4)	(AN 7)	(AN 8)	(AN 9)	(AN10)	(AN11)	(AN12)	(AAM)	(ACM)
21:58: 5.9	RESID	*****	*****	*****	*****	0.1	*****	*****	*****	*****	2.2	1.5
38.209° N	BACK AZ	******	******	******	******	50.25	******	******	******	******	50.97	49.80
23.288° E	DIST	******	******	******	******	77.62	******	******	******	******	75.95	76.98
	RET ANG	******	******	******	******	16.37	******	******	******	******	16.82	16.60
6/ 3/81	STAT #	(AN 1)	(AN 3)	(AN 4)	(AN 7)	(AN 8)	(AN 9)	(AN10)	(AN11)	(AN12)	(AAM)	(ACM)
19:42:59.5	RESID	*****	*****	-0.3	-0.1	-0.2	-0.2	-0.2	-0.4	-0.3	*****	-0.9
3.893° N	BACK AZ	******	******	183.41	183.42	182.75	182.37	182.43	182.07	182.88	******	180.10
85.915° W	DIST	******	******	36.21	36.81	36.22	36.68	36.44	36.52	36.90	******	38.59
	RET ANG	******	******	25.27	25.27	25.27	25.27	25.27	25.27	25.27	******	24.87
9/ 3/81	STAT #	(AN 1)	(AN 3)	(AN 4)	(AN 7)	(AN 8)	(AN 9)	(AN10)	(AN11)	(AN12)	(AAM)	(ACM)
22:38:51.9	RESID	*****	*****	-2.1	-1.2	*****	*****	*****	-1.8	-1.8	-1.6	*****
18.831° N	BACK AZ	******	******	224.76	224.02	******	******	******	222.96	223.35	222.50	******
103.907° W	DIST	******	******	27.40	27.85	******	******	******	27.23	27.75	29.03	******
	RET ANG	******	******	27.41	27.41	******	******	******	27.41	27.41	26.76	******
12/ 3/81	STAT #	(AN 1)	(AN 3)	(AN 4)	(AN 7)	(AN 8)	(AN 9)	(AN10)	(AN11)	(AN12)	(AAM)	(ACM)
3:17:14.5	RESID	*****	0.5	0.4	0.3	*****	0.2	0.4	0.3	0.3	*****	*****
11.251° N	BACK AZ	******	183.94	183.81	183.81	******	182.55	182.63	182.20	183.16	******	******
85.773° W	DIST	******	29.23	28.90	29.50	******	29.37	29.13	29.21	29.53	******	******
	RET ANG	******	26.79	27.03	26.79	******	26.79	26.79	26.79	26.79	******	******
26/ 3/81	STAT #	(AN 1)	(AN 3)	(AN 4)	(AN 7)	(AN 8)	(AN 9)	(AN10)	(AN11)	(AN12)	(AAM)	(ACM)
18: 4:44.7	RESID	*****	-1.6	-1.8	*****	*****	*****	*****	*****	-1.1	-0.5	-1.7
19.370° S	BACK AZ	******	163.97	163.82	******	******	******	******	******	163.63	164.38	162.17
68.957° W	DIST	******	61.19	60.90	******	******	******	******	******	61.63	62.84	63.64
	RET ANG	******	19.85	20.10	******	******	******	******	******	19.85	19.59	19.36
29/ 3/81	STAT #	(AN 1)	(AN 3)	(AN 4)	(AN 7)	(AN 8)	(AN 9)	(AN10)	(AN11)	(AN12)	(AAM)	(ACM)
4: 3:50.0	RESID	*****	0.2	-0.0	0.0	*****	*****	*****	*****	0.1	-0.6	0.3
50. 8° N	BACK AZ	******	10.98	10.93	10.9[illegible]	******	******	******	******	10.75	11.09	9.71
79. 23° E	DIST	******	88.57	88.90	88.31	******	******	******	******	88.26	86.83	86.78
	RET ANG	******	13.99	13.99	13.99	******	******	******	******	13.99	14.36	14.36
1/ 4/81	STAT #	(AN 1)	(AN 3)	(AN 4)	(AN 7)	(AN 8)	(AN 9)	(AN10)	(AN11)	(AN12)	(AAM)	(ACM)
18: 3:36.5	RESID	*****	-1.4	-1.2	-0.9	*****	-0.8	*****	*****	-0.9	0.3	-1.4
27.3[illegible]0° S	BACK AZ	******	160.66	160.54	160.65	******	160.06	******	******	160.37	161.00	159.07
63.320° W	DIST	******	70.15	69.86	70.42	******	70.48	******	******	70.59	71.76	72.64
	RET ANG	******	17.27	17.48	17.27	******	17.27	******	******	17.27	17.04	16.82

Time, Date & Location	ANNA NETWORK P-Wave Residuals University of Michigan Seismological Observatory											
20/ 4/81	STAT #	(AN 1)	(AN 3)	(AN 4)	(AN 7)	(AN 8)	(AN 9)	(AN10)	(AN11)	(AN12)	(AAM)	(ACM)
5:50:17.4	RESID	-0.5	*****	*****	-0.3	*****	-0.5	-0.1	-0.5	*****	-0.8	*****
14.308° N	BACK AZ	196.06	******	******	196.44	******	195.18	195.36	194.87	******	196.07	******
91.543° W	DIST	26.87	******	******	27.26	******	27.02	26.79	26.84	******	28.71	******
	RET ANG	28.05	******	******	27.40	******	27.40	28.05	28.05	******	27.03	******
22/ 4/81	STAT #	(AN 1)	(AN 3)	(AN 4)	(AN 7)	(AN 8)	(AN 9)	(AN10)	(AN11)	(AN12)	(AAM)	(ACM)
1:17:1[illegible] 4	RESID	0.1	0.3	0.1	0.0	-0.0	0.1	0.0	0.0	0.1	0.4	*****
49.901° [illegible]	BACK AZ	10.88	11.08	11.03	11.05	10.78	10.65	10.67	10.53	10.85	11.19	******
78.901° E	DIST	88.77	88.65	88.99	88.39	89.02	88.59	88.82	88.[illegible]	88.34	8[illegible].92	******
	RET ANG	13.99	13.99	13.99	13.99	13.77	13.99	13.99	13.99	13.99	14.36	******
26/ 4/81	STAT #	(AN 1)	(AN 3)	(AN 4)	(AN 7)	(AN 8)	(AN 9)	(AN10)	(AN11)	(AN12)	(AAM)	(ACM)
12: 9:28.4	RESID	*****	*****	*****	*****	*****	[illegible]	*****	*****	*****	-1.0	*****
33.133° N	BACK AZ	******	******	******	******	******	******	******	******	******	260.60	******
115.650° W	DIST	******	******	******	******	******	******	******	******	******	26.78	******
	RET ANG	******	******	******	******	******	[illegible]	******	******	******	28.09	******
30/ 4/81	STAT #	(AN 1)	(AN 3)	(AN 4)	(AN 7)	(AN 8)	(AN 9)	(AN10)	(AN11)	(AN12)	(AAM)	(ACM)
14:41:41.2	RESID	-0.2	*****	*****	*****	*****	*****	*****	-0.3	-0.2	0.0	*****
43.233° N	BACK AZ	323.27	******	******	******	******	******	******	322.95	323.21	323.41	******
150.222° E	DIST	83.31	******	******	******	******	******	******	82.99	82.94	82.07	******
	RET ANG	14.86	******	******	******	******	******	******	15.09	15.09	15.09	******
1/ 5/81	STAT #	(AN 1)	(AN 3)	(AN 4)	(AN 7)	(AN 8)	(AN 9)	(AN10)	(AN11)	(AN12)	(AAM)	(ACM)
6:17:25.3	RESID	-0.3	-0.[illegible]	*****	-0.4	-0.4	-0.4	-0.4	-0.7	-0.4	-0.1	*****
9.953° N	BACK AZ	181.41	182.03	******	181.92	181.12	180.70	180.75	180.34	181.30	182.22	******
84.857° W	DIST	30.41	30.49	******	30.76	30.17	30.64	30.40	30.49	30.85	3[illegible].24	******
	RET ANG	26.40	26.40	******	26.40	26.40	26.40	26.40	[illegible].40	26.40	26.00	******
8/ 5/81	STAT #	(AN 1)	(AN 3)	(AN 4)	(AN 7)	(AN 8)	(AN 9)	(AN10)	(AN11)	(AN12)	(AAM)	(ACM)
23:34:44.9	RESID	0.2	0.3	0.1	0.0	0.0	0.1	0.1	-0.2	-0.1	0.2	*****
42.660° N	BACK AZ	329.62	329.82	329.77	329.79	329.53	329.39	329.41	329.28	329.58	329.89	******
139.129° E	DIST	88.46	88.52	88.77	88.27	88.60	88.12	88.34	88.18	88.06	87.07	******
	RET ANG	13.79	13.79	13.79	13.79	13.79	13.79	13.79	13.79	13.79	13.94	******
25/ 5/81	STAT #	(AN 1)	(AN 3)	(AN 4)	(AN 7)	(AN 8)	(AN 9)	(AN10)	(AN11)	(AN12)	(AAM)	(ACM)
4:59:57.3	RESID	-0.8	*****	*****	*****	-1.0	-0.9	-0.9	*****	-0.8	-0.7	-0.7
68.205° N	BACK AZ	15.80	******	******	******	15.73	15.71	15.69	******	15.84	16.19	15.47
53.656° E	DIST	67.11	******	******	******	67.37	66.97	67.19	******	66.70	65.27	65.38
	RET ANG	18.57	******	******	******	18.57	18.80	18.57	******	18.80	19.03	19.03
1/ 6/81	STAT #	(AN 1)	(AN 3)	(AN 4)	(AN 7)	(AN 8)	(AN 9)	(AN10)	(AN11)	(AN12)	(AAM)	(ACM)
19:50:13.3	RESID	-1.6	*****	*****	*****	*****	-1.5	-1.4	-1.5	-1.5	*****	*****
20.485° S	BACK AZ	160.06	******	******	******	******	159.73	159.72	159.52	160.08	******	******
65.189° W	DIST	63.16	******	******	******	******	63.48	63.25	63.39	63.59	******	******
	RET ANG	19.06	******	******	******	******	19.06	19.06	19.06	19.06	******	******

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Time, Date & Location	STAT #	(AN 1)	(AN 3)	(AN 4)	(AN 7)	(AN 8)	(AN 9)	(AN10)	(AN11)	(AN12)	(AAM)	(ACM)
5/ 6/81	RESID	0.1	*****	*****	*****	-0.2	*****	-0.1	-0.2	-0.1	0.1	-0.6
19:41:50.6	BACK AZ	324.95	******	******	******	324.87	******	324.75	324.63	324.88	325.07	323.78
44.701° N	DIST	82.75	******	******	******	82.88	******	82.61	82.44	82.37	81.47	80.24
148.899° E	RET ANG	15.11	******	******	******	15.11	******	15.11	15.11	15.11	15.33	15.63
6/ 6/81	RESID	-1.1	*****	*****	*****	*****	-0.9	*****	*****	-1.2	*****	*****
18: 0: 0.0	BACK AZ	273.23	******	******	******	******	272.52	******	******	272.26	******	******
37.303° N	DIST	25.18	******	******	******	******	24.89	******	******	25.12	******	******
116.326° W	RET ANG	28.58	******	******	******	******	29.16	******	******	28.58	******	******
11/ 6/81	RESID	1.7	*****	*****	*****	1.9	*****	1.8	*****	1.4	1.1	*****
18:34:20.6	BACK AZ	184.72	******	******	******	184.39	******	183.91	******	184.51	185.45	******
16.722° N	DIST	23.74	******	******	******	23.49	******	23.71	******	24.17	25.58	******
86.110° W	RET ANG	29.69	******	******	******	29.69	******	29.69	******	29.16	28.58	******
18/ 7/81	RESID	-1.0	*****	-1.2	-1.0	-1.2	-1.1	*****	*****	-1.0	*****	-1.5
11:15:18.1	BACK AZ	161.75	******	161.95	162.07	161.57	161.43	******	******	161.77	******	160.39
22.677° S	DIST	65.00	******	64.70	65.27	64.82	65.31	******	******	65.44	******	67.47
66.238° W	RET ANG	18.78	******	18.98	18.78	18.98	18.78	******	******	18.78	******	18.32
21/ 7/81	RESID	*****	*****	*****	*****	*****	*****	*****	*****	*****	-0.3	*****
9:14:18.6	BACK AZ	******	******	******	******	******	******	******	******	******	210.38	******
16.282° N	DIST	******	******	******	******	******	******	******	******	******	28.84	******
98.373° W	RET ANG	******	******	******	******	******	******	******	******	******	27.07	******
21/ 7/81	RESID	*****	*****	*****	*****	*****	*****	*****	*****	*****	-0.4	*****
10:22:54.7	BACK AZ	******	******	******	******	******	******	******	******	******	210.63	******
16.508° N	DIST	******	******	******	******	******	******	******	******	******	28.65	******
98.408° W	RET ANG	******	******	******	******	******	******	******	******	******	27.03	******
26/ 7/81	RESID	*****	*****	*****	*****	*****	*****	*****	*****	*****	-1.4	*****
5:14:22.6	BACK AZ	******	******	******	******	******	******	******	******	******	218.43	******
18.216° N	DIST	******	******	******	******	******	******	******	******	******	28.59	******
101.890° W	RET ANG	******	******	******	******	******	******	******	******	******	27.05	******
1/ 8/81	RESID	-0.8	*****	-0.9	*****	*****	*****	-1.0	*****	*****	*****	*****
1:42:16.4	BACK AZ	319.37	******	319.55	******	******	******	319.34	******	******	******	******
60.136° N	DIST	45.87	******	46.18	******	******	******	45.70	******	******	******	******
153.185° W	RET ANG	23.64	******	23.42	******	******	******	23.64	******	******	******	******

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4/ 8/81	STAT #	(AN 1)	(AN 3)	(AN 4)	(AN 7)	(AN 8)	(AN 9)	(AN10)	(AN11)	(AN12)	(AAM)	(ACM)
22: 0:15.1	RESID	*****	*****	*****	*****	*****	*****	*****	*****	*****	0.6	*****
16.824° N	BACK AZ	******	******	******	******	******	******	******	******	******	136.51	******
61.467° W	DIST	******	******	******	******	******	******	******	******	******	31.70	******
	RET ANG	******	******	******	******	******	******	******	******	******	26.34	******
5/ 8/81	STAT #	(AN 1)	(AN 3)	(AN 4)	(AN 7)	(AN 8)	(AN 9)	(AN10)	(AN11)	(AN12)	(AAM)	(ACM)
12:58:27.4	RESID	*****	*****	*****	*****	*****	*****	0.3	*****	*****	*****	*****
3.895° N	BACK AZ	******	******	******	******	******	******	166.60	******	******	******	******
76.409° W	DIST	******	******	******	******	******	******	37.13	******	******	******	******
	RET ANG	******	******	******	******	******	******	25.00	******	******	******	******
17/ 8/81	STAT #	(AN 1)	(AN 3)	(AN 4)	(AN 7)	(AN 8)	(AN 9)	(AN10)	(AN11)	(AN12)	(AAM)	(ACM)
2:18:58.7	RESID	*****	*****	*****	*****	*****	*****	*****	*****	*****	-2.8	*****
14.422° N	BACK AZ	******	******	******	******	******	******	******	******	******	200.49	******
93.784° W	DIST	******	******	******	******	******	******	******	******	******	29.13	******
	RET ANG	******	******	******	******	******	******	******	******	******	26.79	******
23/ 8/81	STAT #	(AN 1)	(AN 3)	(AN 4)	(AN 7)	(AN 8)	(AN 9)	(AN10)	(AN11)	(AN12)	(AAM)	(ACM)
12: 0:26.5	RESID	-0.7	-0.9	-1.0	-1.0	-0.9	-0.9	-0.9	-1.0	-0.9	-0.7	*****
48.718° N	BACK AZ	323.12	323.26	323.27	323.20	323.07	322.90	322.95	322.83	323.02	323.07	******
157.390° E	DIST	75.90	75.99	76.21	75.75	76.02	73.55	75.75	75.58	75.52	74.66	******
	RET ANG	16.82	16.82	16.59	16.82	16.59	16.82	16.82	16.82	16.82	17.04	******
24/ 8/81	STAT #	(AN 1)	(AN 3)	(AN 4)	(AN 7)	(AN 8)	(AN 9)	(AN10)	(AN11)	(AN12)	(AAM)	(ACM)
15:46:27.6	RESID	-0.6	-0.7	-0.6	-0.7	*****	*****	*****	-1.2	-0.8	*****	*****
51.508° N	BACK AZ	315.09	315.18	315.27	315.06	******	******	******	314.86	314.90	******	******
178.355° W	DIST	61.99	62.11	62.29	61.89	******	******	******	61.63	61.65	******	******
	RET ANG	19.95	19.64	19.64	19.95	******	******	******	19.95	19.95	******	******
28/ 8/81	STAT #	(AN 1)	(AN 3)	(AN 4)	(AN 7)	(AN 8)	(AN 9)	(AN10)	(AN11)	(AN12)	(AAM)	(ACM)
9: 4:24.7	RESID	-0.8	-0.9	*****	-0.8	-1.1	-1.1	-1.1	-1.2	-0.8	-0.4	*****
61.738° N	BACK AZ	321.46	321.43	******	321.25	321.60	321.30	321.45	321.39	321.17	320.29	******
150.452° W	DIST	44.40	44.49	******	44.26	44.51	44.04	44.24	44.07	44.03	43.21	******
	RET ANG	23.95	23.95	******	23.95	23.95	23.95	23.95	23.95	23.95	24.15	******
1/ 9/81	STAT #	(AN 1)	(AN 3)	(AN 4)	(AN 7)	(AN 8)	(AN 9)	(AN10)	(AN11)	(AN12)	(AAM)	(ACM)
9:29:31.5	RESID	*****	*****	*****	*****	*****	*****	*****	*****	*****	0.1	*****
14.960° S	BACK AZ	******	******	******	******	******	******	******	******	******	258.49	******
173. 85° W	DIST	******	******	******	******	******	******	******	******	******	99.49	******
	RET ANG	******	******	******	******	******	******	******	******	******	13.17	******
3/ 9/81	STAT #	(AN 1)	(AN 3)	(AN 4)	(AN 7)	(AN 8)	(AN 9)	(AN10)	(AN11)	(AN12)	(AAM)	(ACM)
5:35:44.8	RESID	-0.1	-0.2	-0.3	-0.1	0.1	-0.3	-0.3	-0.5	0.0	-0.1	*****
43.621° N	BACK AZ	325.36	325.55	325.51	325.50	325.29	325.14	325.17	325.04	325.31	325.53	******
147. 31° E	DIST	84.43	84.51	84.74	84.26	84.55	84.08	84.28	84.12	84.04	83.13	******
	RET ANG	14.65	14.65	14.65	14.65	14.65	14.65	14.65	14.65	14.65	14.87	******

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8/ 9/81	STAT #	(AN 1)	(AN 3)	(AN 4)	(AN 7)	(AN 8)	(AN 9)	(AN10)	(AN11)	(AN12)	(AAM)	(ACM)
7: 1:16.9	RESID	-0.8	-0.7	-0.8	-0.9	-1.0	*****	*****	*****	*****	*****	*****
51.468° N	BACK AZ	315.06	315.15	315.24	315.02	315.09	******	******	******	******	******	******
178.368° W	DIST	62.01	62.14	62.32	61.92	62.10	******	******	******	******	******	******
	RET ANG	19.64	19.64	19.64	19.95	19.64	******	******	******	******	******	******
13/ 9/81	STAT #	(AN 1)	(AN 3)	(AN 4)	(AN 7)	(AN 8)	(AN 9)	(AN10)	(AN11)	(AN12)	(AAM)	(ACM)
2:17:18.2	RESID	0.0	-0.0	-0.0	0.0	-0.2	0.1	-0.0	-0.1	0.1	*****	*****
49.897° N	BACK AZ	10.83	11.03	10.98	11.00	10.73	10.60	10.62	10.48	10.80	******	******
78.983° E	DIST	88.78	88.67	89.00	88.41	89.04	88.61	88.84	88.78	88.36	******	******
	RET ANG	13.99	13.99	13.77	13.99	13.77	13.99	13.99	13.99	13.99	******	******
13/ 9/81	STAT #	(AN 1)	(AN 3)	(AN 4)	(AN 7)	(AN 8)	(AN 9)	(AN10)	(AN11)	(AN12)	(AAM)	(ACM)
9:19:30.9	RESID	*****	*****	*****	*****	*****	*****	*****	*****	*****	0.9	*****
24.866° N	BACK AZ	******	******	******	******	******	******	******	******	******	107.51	******
46.301° W	DIST	******	******	******	******	******	******	******	******	******	35.31	******
	RET ANG	******	******	******	******	******	******	******	******	******	25.48	******
14/ 9/81	STAT #	(AN 1)	(AN 3)	(AN 4)	(AN 7)	(AN 8)	(AN 9)	(AN10)	(AN11)	(AN12)	(AAM)	(ACM)
12:44:29.8	RESID	*****	*****	*****	*****	*****	-0.6	-0.5	-0.6	*****	-0.1	*****
18.320° N	BACK AZ	******	******	******	******	******	144.40	144.17	143.87	******	147.78	******
68.891° W	DIST	******	******	******	******	******	26.04	25.84	26.00	******	27.01	******
	RET ANG	******	******	******	******	******	27.64	28.04	27.64	******	27.25	******
1/10/81	STAT #	(AN 1)	(AN 3)	(AN 4)	(AN 7)	(AN 8)	(AN 9)	(AN10)	(AN11)	(AN12)	(AAM)	(ACM)
12:14:56.8	RESID	-1.0	*****	-1.2	-1.1	-1.3	*****	-1.0	-1.1	-1.0	*****	*****
73.317° N	BACK AZ	12.29	******	12.32	12.40	12.22	******	12.19	12.15	12.32	******	******
54.812° E	DIST	63.07	******	63.28	62.69	63.32	******	63.13	63.07	62.64	******	******
	RET ANG	19.49	******	19.49	19.72	19.49	******	19.49	19.49	19.72	******	******
4/10/81	STAT #	(AN 1)	(AN 3)	(AN 4)	(AN 7)	(AN 8)	(AN 9)	(AN10)	(AN11)	(AN12)	(AAM)	(ACM)
20: 3:53.0	RESID	-1.1	-1.2	-1.2	-1.4	-1.4	*****	-1.5	-1.5	-1.4	-1.4	*****
1.550° S	BACK AZ	169.92	170.40	170.21	170.38	169.64	******	169.42	169.13	169.93	170.93	******
77.364° W	DIST	42.28	42.31	42.00	42.59	42.07	******	42.32	42.44	42.73	44.02	******
	RET ANG	24.10	24.10	24.26	24.10	24.10	******	24.10	24.10	24.10	23.71	******
8/10/81	STAT #	(AN 1)	(AN 3)	(AN 4)	(AN 7)	(AN 8)	(AN 9)	(AN10)	(AN11)	(AN12)	(AAM)	(ACM)
22:25:53.0	RESID	*****	*****	*****	*****	*****	*****	-1.7	-1.8	-1.5	-1.8	*****
17.124° S	BACK AZ	******	******	******	******	******	******	163.85	163.63	164.23	165.01	******
70. 51° W	DIST	******	******	******	******	******	******	58.85	58.98	59.22	60.44	******
	RET ANG	******	******	******	******	******	******	20.50	20.50	20.33	20.10	******
15/10/81	STAT #	(AN 1)	(AN 3)	(AN 4)	(AN 7)	(AN 8)	(AN 9)	(AN10)	(AN11)	(AN12)	(AAM)	(ACM)
1:47:52.9	RESID	0.1	0.1	0.2	-0.0	0.2	0.1	0.1	0.0	0.0	0.2	*****
40.229° N	BACK AZ	326.31	326.52	326.46	326.48	326.22	326.08	326.10	325.96	326.28	326.59	******
142.287° E	DIST	89.23	89.31	89.54	89.06	89.36	88.88	89.09	88.93	88.84	87.91	******
	RET ANG	13.82	13.82	13.82	13.82	13.82	13.97	13.82	13.97	13.97	14.12	******

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16/10/81	STAT #	(AN 1)	(AN 3)	(AN 4)	(AN 7)	(AN 8)	(AN 9)	(AN10)	(AN11)	(AN12)	(AAM)	(ACM)
3:25:42.2	RESID	*****	*****	*****	*****	*****	*****	*****	*****	*****	-1.6	*****
33.134° S	BACK AZ	******	******	******	******	******	******	******	******	******	170.85	******
73. 74° W	DIST	******	******	******	******	******	******	******	******	******	75.69	******
	RET ANG	******	******	******	******	******	******	******	******	******	16.83	******
18/10/81	STAT #	(AN 1)	(AN 3)	(AN 4)	(AN 7)	(AN 8)	(AN 9)	(AN10)	(AN11)	(AN12)	(AAM)	(ACM)
3:57: 2.6	RESID	-0.2	-0.1	*****	*****	-0.2	-0.0	*****	-0.1	-0.0	*****	*****
49.886° N	BACK AZ	10.89	11.09	******	******	10.79	10.66	******	10.54	10.86	******	******
78.898° E	DIST	88.78	88.67	******	******	89.04	88.61	******	88.78	88.36	******	******
	RET ANG	13.99	13.99	******	******	13.77	13.99	******	13.99	13.99	******	******
25/10/81	STAT #	(AN 1)	(AN 3)	(AN 4)	(AN 7)	(AN 8)	(AN 9)	(AN10)	(AN11)	(AN12)	(AAM)	(ACM)
3:22:15.5	RESID	*****	*****	*****	*****	*****	*****	*****	*****	*****	-2.8	*****
18. 48° N	BACK AZ	******	******	******	******	******	******	******	******	******	218.64	******
102.108° W	DIST	******	******	******	******	******	******	******	******	******	28.83	******
	RET ANG	******	******	******	******	******	******	******	******	******	27.03	******
3/11/81	STAT #	(AN 1)	(AN 3)	(AN 4)	(AN 7)	(AN 8)	(AN 9)	(AN10)	(AN11)	(AN12)	(AAM)	(ACM)
7: 2:36.8	RESID	*****	*****	*****	*****	*****	*****	*****	*****	*****	1.2	*****
1.782° S	BACK AZ	******	******	******	******	******	******	******	******	******	172.56	******
78.482° W	DIST	******	******	******	******	******	******	******	******	******	44.13	******
	RET ANG	******	******	******	******	******	******	******	******	******	23.84	******
3/11/81	STAT #	(AN 1)	(AN 3)	(AN 4)	(AN 7)	(AN 8)	(AN 9)	(AN10)	(AN11)	(AN12)	(AAM)	(ACM)
13:47:34.1	RESID	*****	*****	*****	*****	*****	*****	*****	*****	*****	0.4	*****
43.542° N	BACK AZ	******	******	******	******	******	******	******	******	******	287.44	******
127.706° W	DIST	******	******	******	******	******	******	******	******	******	32.00	******
	RET ANG	******	******	******	******	******	******	******	******	******	26.15	******
7/11/81	STAT #	(AN 1)	(AN 3)	(AN 4)	(AN 7)	(AN 8)	(AN 9)	(AN10)	(AN11)	(AN12)	(AAM)	(ACM)
3:29:51.0	RESID	-1.3	-1.1	-1.2	-1.2	-1.3	-1.3	*****	-1.5	-1.2	-1.1	*****
32.199° S	BACK AZ	168.69	168.98	168.88	168.95	168.54	168.39	******	168.22	168.68	169.21	******
71.336° W	DIST	73.28	73.30	72.99	73.58	73.07	73.56	******	73.44	73.72	74.99	******
	RET ANG	17.17	17.17	17.40	17.17	17.17	17.17	******	17.17	17.17	16.98	******
7/11/81	STAT #	(AN 1)	(AN 3)	(AN 4)	(AN 7)	(AN 8)	(AN 9)	(AN10)	(AN11)	(AN12)	(AAM)	(ACM)
22: 2:49.0	RESID	0.5	*****	0.6	0.4	0.6	0.0	*****	0.3	0.2	-0.0	*****
14.595° N	BACK AZ	193.81	******	194.43	194.22	193.59	192.92	******	192.59	193.49	193.95	******
90.416° W	DIST	26.37	******	26.16	26.75	26.11	26.53	******	26.35	26.79	28.22	******
	RET ANG	27.53	******	27.53	27.53	27.53	27.53	******	27.53	27.53	26.85	******
27/11/81	STAT #	(AN 1)	(AN 3)	(AN 4)	(AN 7)	N 8)	(AN 9)	(AN10)	(AN11)	(AN12)	(AAM)	(ACM)
17:21:45.8	RESID	*****	0.2	0.3	0.2	0.3	0.3	*****	0.2	0.3	*****	*****
42.913° N	BACK AZ	******	335.15	335.09	335.12	334.83	334.70	******	334.57	334.90	******	******
131. 76° E	DIST	******	91.14	91.41	90.87	91.26	90.77	******	90.84	90.68	******	******
	RET ANG	******	13.39	13.39	13.47	13.39	13.47	******	13.47	13.47	******	******

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Time, Date & Location												
29/11/81	STAT #	(AN 1)	(AN 3)	(AN 4)	(AN 7)	(AN 8)	(AN 9)	(AN10)	(AN11)	(AN12)	(AAM)	(ACM)
3:35: 8.6	RESID	*****	-0.0	-0.1	0.1	-0.1	-0.1	*****	-0.1	-0.0	*****	*****
49.860° N	BACK AZ	******	11.12	11.06	11.09	10.82	10.69	******	10.57	10.89	******	******
78.857° E	DIST	******	88.69	89.02	88.43	89.06	88.63	******	88.80	88.38	******	******
	RET ANG	******	13.99	13.77	13.99	13.77	13.99	******	13.99	13.99	******	******
2/12/81	STAT #	(AN 1)	(AN 3)	(AN 4)	(AN 7)	(AN 8)	(AN 9)	(AN10)	(AN11)	(AN12)	(AAM)	(ACM)
6:24:42.8	RESID	*****	-0.1	-0.0	-0.2	-0.3	-0.5	*****	-0.5	-0.3	*****	*****
40.907° N	BACK AZ	******	326.74	326.69	326.71	326.45	326.31	******	326.20	326.50	******	******
142.515° E	DIST	******	88.65	88.88	88.40	88.70	88.22	******	88.27	88.18	******	******
	RET ANG	******	13.96	13.96	13.96	13.96	13.96	******	13.96	13.96	******	******
6/12/81	STAT #	(AN 1)	(AN 3)	(AN 4)	(AN 7)	(AN 8)	(AN 9)	(AN10)	(AN11)	(AN12)	(AAM)	(ACM)
14:54:29.4	RESID	*****	*****	*****	*****	*****	*****	*****	*****	*****	1.9	*****
8. 1° N	BACK AZ	******	******	******	******	******	******	******	******	******	117.43	******
38.411° W	DIST	******	******	******	******	******	******	******	******	******	52.41	******
	RET ANG	******	******	******	******	******	******	******	******	******	22.19	******
13/12/81	STAT #	(AN 1)	(AN 3)	(AN 4)	(AN 7)	(AN 8)	(AN 9)	(AN10)	(AN11)	(AN12)	(AAM)	(ACM)
21:40:36.1	RESID	*****	*****	*****	*****	*****	*****	*****	*****	*****	0.9	*****
6.750° N	BACK AZ	******	******	******	******	******	******	******	******	******	162.04	******
72.978° W	DIST	******	******	******	******	******	******	******	******	******	36.65	******
	RET ANG	******	******	******	******	******	******	******	******	******	25.11	******
21/12/81	STAT #	(AN 1)	(AN 3)	(AN 4)	(AN 7)	(AN 8)	(AN 9)	(AN10)	(AN11)	(AN12)	(AAM)	(ACM)
10:32:11.8	RESID	*****	*****	*****	*****	*****	*****	*****	*****	*****	-0.2	*****
14.818° N	BACK AZ	******	******	******	******	******	******	******	******	******	197.82	******
92.306° W	DIST	******	******	******	******	******	******	******	******	******	28.38	******
	RET ANG	******	******	******	******	******	******	******	******	******	27.03	******
27/12/81	STAT #	(AN 1)	(AN 3)	(AN 4)	(AN 7)	(AN 8)	(AN 9)	(AN10)	(AN11)	(AN12)	(AAM)	(ACM)
3:43:14.1	RESID	-0.0	0.0	-0.1	0.1	-0.1	0.1	-0.1	-0.1	0.1	-0.0	*****
49.909° N	BACK AZ	10.90	11.10	11.04	11.07	10.80	10.67	10.68	10.55	10.87	11.21	******
78.873° E	DIST	88.76	88.64	88.98	88.38	89.01	88.58	88.81	88.75	88.33	86.90	******
	RET ANG	13.99	13.99	13.99	13.99	13.77	13.99	13.99	13.99	13.99	14.36	******
3/ 1/82	STAT #	(AN 1)	(AN 3)	(AN 4)	(AN 7)	(AN 8)	(AN 9)	(AN10)	(AN11)	(AN12)	(AAM)	(ACM)
14: 9:50.4	RESID	*****	*****	*****	*****	*****	*****	*****	*****	*****	0.3	*****
0.972° S	BACK AZ	******	******	******	******	******	******	******	******	******	110.50	******
21.870° W	DIST	******	******	******	******	******	******	******	******	******	70.16	******
	RET ANG	******	******	******	******	******	******	******	******	******	17.87	******
18/ 1/82	STAT #	(AN 1)	(AN 3)	(AN 4)	(AN 7)	(AN 8)	(AN 9)	(AN10)	(AN11)	(AN12)	(AAM)	(ACM)
19:27:24.4	RESID	*****	*****	*****	*****	*****	*****	*****	*****	*****	4.2	*****
40. 4° N	BACK AZ	******	******	******	******	******	******	******	******	******	49.05	******
24.319° E	DIST	******	******	******	******	******	******	******	******	******	75.32	******
	RET ANG	******	******	******	******	******	******	******	******	******	16.78	******

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25/ 1/82	STAT #	(AN 1)	(AN 3)	(AN 4)	(AN 7)	(AN 8)	(AN 9)	(AN10)	(AN11)	(AN12)	(AAM)	(ACM)
5:29:33.5	RESID	*****	-2.1	-2.2	-2.3	-2.5	-2.4	-2.6	-2.7	-2.3	-2.0	*****
53.222° N	BACK AZ	******	312.94	313.09	312.79	312.97	312.67	312.80	312.70	312.64	312.05	******
165.719° W	DIST	******	54.41	54.59	54.20	54.36	53.92	54.10	53.92	53.95	53.32	******
	RET ANG	******	21.69	21.69	21.69	21.69	21.93	21.69	21.93	21.93	21.93	******
28/ 1/82	STAT #	(AN 1)	(AN 3)	(AN 4)	(AN 7)	(AN 8)	(AN 9)	(AN10)	(AN11)	(AN12)	(AAM)	(ACM)
16: 0: 0.1	RESID	*****	*****	*****	*****	*****	*****	*****	*****	*****	-1.5	*****
37. 91° N	BACK AZ	******	******	******	******	******	******	******	******	******	269.03	******
116. 51° W	DIST	******	******	******	******	******	******	******	******	******	25.37	******
	RET ANG	******	******	******	******	******	******	******	******	******	28.58	******
29/ 1/82	STAT #	(AN 1)	(AN 3)	(AN 4)	(AN 7)	(AN 8)	(AN 9)	(AN10)	(AN11)	(AN12)	(AAM)	(ACM)
22:32: 5.9	RESID	*****	*****	*****	*****	*****	*****	*****	*****	*****	1.0	*****
25.509° N	BACK AZ	******	******	******	******	******	******	******	******	******	105.67	******
45.288° W	DIST	******	******	******	******	******	******	******	******	******	35.63	******
	RET ANG	******	******	******	******	******	******	******	******	******	25.48	******
30/ 1/82	STAT #	(AN 1)	(AN 3)	(AN 4)	(AN 7)	(AN 8)	(AN 9)	(AN10)	(AN11)	(AN12)	(AAM)	(ACM)
2:35:10.6	RESID	*****	*****	-0.1	0.1	-0.2	*****	-0.3	*****	-0.5	-0.0	*****
16.737° N	BACK AZ	******	******	133.74	134.52	133.17	******	133.17	******	134.15	136.54	******
61.430° W	DIST	******	******	30.45	30.85	30.68	******	30.94	******	31.09	31.79	******
	RET ANG	******	******	26.47	26.47	26.47	******	26.47	******	26.31	26.31	******
7/ 2/82	STAT #	(AN 1)	(AN 3)	(AN 4)	(AN 7)	(AN 8)	(AN 9)	(AN10)	(AN11)	(AN12)	(AAM)	(ACM)
6: 7:13.2	RESID	*****	-1.1	-1.4	-1.4	*****	*****	*****	*****	-1.5	*****	*****
51.779° N	BACK AZ	******	314.92	315.01	314.79	******	******	******	******	314.64	******	******
176.871° W	DIST	******	61.17	61.36	60.95	******	******	******	******	60.71	******	******
	RET ANG	******	19.95	19.95	20.15	******	******	******	******	20.15	******	******
10/ 2/82	STAT #	(AN 1)	(AN 3)	(AN 4)	(AN 7)	(AN 8)	(AN 9)	(AN10)	(AN11)	(AN12)	(AAM)	(ACM)
20:38: 1.0	RESID	*****	*****	*****	*****	*****	*****	*****	*****	*****	-1.5	*****
22.648° S	BACK AZ	******	******	******	******	******	******	******	******	******	162.69	******
66.466° W	DIST	******	******	******	******	******	******	******	******	******	66.55	******
	RET ANG	******	******	******	******	******	******	******	******	******	18.61	******
12/ 2/82	STAT #	(AN 1)	(AN 3)	(AN 4)	(AN 7)	(AN 8)	(AN 9)	(AN10)	(AN11)	(AN12)	(AAM)	(ACM)
14:55: 0.0	RESID	*****	*****	*****	*****	*****	*****	*****	*****	-1.4	-1.2	*****
37.224° N	BACK AZ	******	******	******	******	******	******	******	******	272.16	269.60	******
116.463° W	DIST	******	******	******	******	******	******	******	******	25.25	25.63	******
	RET ANG	******	******	******	******	******	******	******	******	28.58	28.58	******
12/ 2/82	STAT #	(AN 1)	(AN 3)	(AN 4)	(AN 7)	(AN 8)	(AN 9)	(AN10)	(AN11)	(AN12)	(AAM)	(ACM)
15:25: 0.0	RESID	*****	*****	*****	*****	*****	*****	*****	*****	-1.3	-1.1	*****
37.348° N	BACK AZ	******	******	******	******	******	******	******	******	272.35	269.77	******
116.316° W	DIST	******	******	******	******	******	******	******	******	25.10	25.47	******
	RET ANG	******	******	******	******	******	******	******	******	28.58	28.58	******

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21/ 3/82	STAT #	(AN 1)	(AN 3)	(AN 4)	(AN 7)	(AN 8)	(AN 9)	(AN10)	(AN11)	(AN12)	(AAM)	(ACM)
2:32: 6.3	RESID	*****	1.8	*****	1.7	1.7	1.7	*****	1.5	1.6	2.0	*****
42.168° N	BACK AZ	******	327.46	******	327.43	327.18	327.03	******	326.92	327.22	327.51	******
142.479° E	DIST	******	87.61	******	87.36	87.67	87.19	******	87.24	87.15	86.20	******
	RET ANG	******	14.12	******	14.12	14.12	14.12	******	14.12	14.12	14.29	******
22/ 3/82	STAT #	(AN 1)	(AN 3)	(AN 4)	(AN 7)	(AN 8)	(AN 9)	(AN10)	(AN11)	(AN12)	(AAM)	(ACM)
21:44: 9.3	RESID	*****	*****	*****	*****	*****	*****	*****	*****	-1.3	*****	*****
19.880° S	BACK AZ	******	******	******	******	******	******	******	******	163.54	******	******
68.743° W	DIST	******	******	******	******	******	******	******	******	62.17	******	******
	RET ANG	******	******	******	******	******	******	******	******	19.61	******	******
28/ 3/82	STAT #	(AN 1)	(AN 3)	(AN 4)	(AN 7)	(AN 8)	(AN 9)	(AN10)	(AN11)	(AN12)	(AAM)	(ACM)
23:24:50.7	RESID	*****	-2.0	-1.9	-2.3	-2.0	-2.1	-2.0	-2.2	-2.0	-2.0	*****
12.769° S	BACK AZ	******	170.62	170.47	170.59	170.01	169.82	169.82	169.58	170.22	171.00	******
76. 90° W	DIST	******	53.53	53.22	53.80	53.29	53.78	53.54	53.66	53.94	55.24	******
	RET ANG	******	21.88	21.88	21.88	21.88	21.88	21.88	21.88	21.88	21.34	******

APPENDIX C

P-WAVE RESIDUALS FROM TELESEISMIC EVENTS WITH RESPECT TO J-B TABLES FOR INDIANA STATIONS (JAN 1981 - MAR 1982)

The information presented in this appendix is a compilation of P-wave travel time residuals with respect to the J-B tables. Event locations are taken from the National Earthquake Information Service PDE monthly reports. Because these reports are published with a time lapse of about six months, we have included only events up to the latest issue (March 1982).
Other information included:

STAT# Name of reporting station

RESID P-wave travel time residual in seconds (observed -JB table predicted) ***** indicates that clear arrivals were not recorded.

BACK AZ Azimuth of wavefront approach to the station (clockwise from north in degrees)

DIST Epicentral distance (in degrees)

RET ANG The angle from downward vertical at which the wavefront approaches the station (in degrees).

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Time, Date & Location					
30/ 1/81	STAT #	(IN1)	(IN2)	(IN3)	(IN4)
8:52:44.1	RESID	-2.1	*****	-1.8	*****
51.720° N	BACK AZ	316.59	******	317.06	******
176.274° E	DIST	63.75	******	64.73	******
	RET ANG	19.41	******	19.18	******
1/ 2/81	STAT #	(IN1)	(IN2)	(IN3)	(IN4)
22:43:27.5	RESID	*****	*****	-1.4	*****
53. 30° N	BACK AZ	******	******	323.58	******
162.406° E	DIST	******	******	70.84	******
	RET ANG	******	******	17.82	******
6/ 2/81	STAT #	(IN1)	(IN2)	(IN3)	(IN4)
16:47: 7.4	RESID	-0.7	-0.5	-0.4	*****
48.300° N	BACK AZ	327.60	327.18	327.77	******
146.354° E	DIST	80.19	80.33	81.31	******
	RET ANG	15.18	15.18	14.96	******
14/ 2/81	STAT #	(IN1)	(IN2)	(IN3)	(IN4)
1: 8:41.9	RESID	-0.3	0.6	0.5	*****
16. 59° N	BACK AZ	203.32	201.92	204.64	******
96.300° W	DIST	26.02	25.20	24.89	******
	RET ANG	28.08	28.57	29.13	******
15/ 2/81	STAT #	(IN1)	(IN2)	(IN3)	(IN4)
14:36:32.2	RESID	0.0	*****	0.2	*****
18.515° N	BACK AZ	141.50	******	140.03	******
68.970° W	DIST	26.34	******	25.30	******
	RET ANG	27.93	******	28.34	******
19/ 2/81	STAT #	(IN1)	(IN2)	(IN3)	(IN4)
19:36:11.6	RESID	-0.9	-0.9	-0.6	-0.0
44.639° N	BACK AZ	323.66	323.22	323.82	324.29
149.342° E	DIST	81.77	81.85	82.85	83.00
	RET ANG	15.33	15.33	15.11	14.88
24/ 2/81	STAT #	(IN1)	(IN2)	(IN3)	(IN4)
20:53:38.4	RESID	-0.3	0.1	0.1	-0.2
38.222° N	BACK AZ	49.61	49.04	49.48	49.99
22.934° E	DIST	78.16	79.07	78.92	78.20
	RET ANG	16.16	15.86	16.16	16.16
4/ 3/81	STAT #	(IN1)	(IN2)	(IN3)	(IN4)
21:58: 5.9	RESID	*****	0.2	*****	*****
38.209° N	BACK AZ	******	48.86	******	******
23.288° E	DIST	******	79.28	******	******
	RET ANG	******	15.86	******	******

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6/ 3/81	STAT #	(IN1)	(IN2)	(IN3)	(IN4)
19:42:59.5	RESID	-1.0	-0.5	-0.4	-0.7
3.893° N	BACK AZ	180.04	178.52	180.22	181.74
85.915° W	DIST	36.48	35.89	35.21	35.53
	RET ANG	25.27	25.43	25.43	25.43
9/ 3/81	STAT #	(IN1)	(IN2)	(IN3)	(IN4)
22:38:51.9	RESID	-1.7	-1.3	-1.3	*****
18.831° N	BACK AZ	220.85	220.02	222.78	******
103.907° W	DIST	26.60	25.70	25.71	******
	RET ANG	28.06	28.52	28.52	******
12/ 3/81	STAT #	(IN1)	(IN2)	(IN3)	(IN4)
3:17:14.5	RESID	-0.5	*****	0.2	0.2
11.251° N	BACK AZ	179.76	******	179.97	181.81
85.773° W	DIST	29.17	******	27.90	28.21
	RET ANG	26.79	******	27.44	27.03
26/ 3/81	STAT #	(IN1)	(IN2)	(IN3)	(IN4)
18: 4:44.7	RESID	-1.9	-1.7	-2.0	-1.8
19.370° S	BACK AZ	161.79	160.76	161.68	162.66
68.957° W	DIST	61.65	61.30	60.42	60.50
	RET ANG	19.85	19.85	20.10	20.10
29/ 3/81	STAT #	(IN1)	(IN2)	(IN3)	(IN4)
4: 3:50.0	RESID	-0.2	0.0	-0.2	-0.3
50. 8° N	BACK AZ	9.67	9.10	9.73	10.29
79. 23° E	DIST	88.86	89.56	90.10	89.68
	RET ANG	13.99	13.77	13.62	13.77
1/ 4/81	STAT #	(IN1)	(IN2)	(IN3)	(IN4)
18: 3:36.5	RESID	-1.3	-1.4	-1.1	-1.4
27.310° S	BACK AZ	158.78	157.91	158.71	159.55
63.320° W	DIST	70.69	70.38	69.47	69.51
	RET ANG	17.27	17.27	17.48	17.48
20/ 4/81	STAT #	(IN1)	(IN2)	(IN3)	(IN4)
5:50:17.4	RESID	-0.5	0.5	*****	-0.4
14.308° N	BACK AZ	192.30	190.62	******	194.91
91.543° W	DIST	26.60	25.87	******	25.83
	RET ANG	28.05	28.51	******	28.51
22/ 4/81	STAT #	(IN1)	(IN2)	(IN3)	(IN4)
1:17:11.4	RESID	-0.3	0.0	*****	-0.4
49.901° N	BACK AZ	9.77	9.20	******	10.39
78.901° E	DIST	88.95	89.65	******	89.77
	RET ANG	13.99	13.77	******	13.77

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Time, Date & Location	STAT #	(IN1)	(IN2)	(IN3)	(IN4)
30/ 4/81	RESID	-1.9	*****	*****	*****
14:41:41.2	BACK AZ	322.26	******	******	******
43.233° N	DIST	82.45	******	******	******
150.222° E	RET ANG	15.09	******	******	******
8/ 5/81	STAT #	(IN1)	(IN2)	(IN3)	(IN4)
23:34:44.9	RESID	*****	-0.1	*****	-0.2
42.660° N	BACK AZ	******	327.98	******	329.15
139.129° E	DIST	******	87.87	******	88.94
	RET ANG	******	13.94	******	13.79
25/ 5/81	STAT #	(IN1)	(IN2)	(IN3)	(IN4)
4:59:57.3	RESID	-1.3	-1.5	-1.7	-1.4
68.205° N	BACK AZ	15.21	14.85	15.12	15.44
53.656° E	DIST	67.41	68.17	68.62	68.15
	RET ANG	18.57	18.35	18.35	18.35
5/ 6/81	STAT #	(IN1)	(IN2)	(IN3)	(IN4)
19:41:50.6	RESID	*****	-0.1	-0.0	-0.4
44.701° N	BACK AZ	******	323.50	324.11	324.58
148.899° E	DIST	******	82.00	83.00	83.15
	RET ANG	******	15.11	14.88	14.88
6/ 6/81	STAT #	(IN1)	(IN2)	(IN3)	(IN4)
18: 0: 0.0	RESID	*****	0.7	-0.0	-0.8
37.303° N	BACK AZ	******	272.97	275.01	274.77
116.326° W	DIST	******	23.19	24.00	24.66
	RET ANG	******	29.74	29.16	29.16
11/ 6/81	STAT #	(IN1)	(IN2)	(IN3)	(IN4)
18:34:20.6	RESID	1.0	*****	*****	0.6
16.722° N	BACK AZ	180.51	******	******	182.99
86.110° W	DIST	23.74	******	******	22.79
	RET ANG	29.69	******	******	30.27
4/ 7/81	STAT #	(IN1)	(IN2)	(IN3)	(IN4)
5:30:50.7	RESID	-0.5	0.5	0.2	0.2
17.814° N	BACK AZ	205.39	204.00	206.90	208.51
96.642° W	DIST	24.48	23.64	23.37	23.95
	RET ANG	28.95	29.45	29.45	29.45
18/ 7/81	STAT #	(IN1)	(IN2)	(IN3)	(IN4)
11:15:18.1	RESID	*****	-1.5	-1.3	-1.6
22.677° S	BACK AZ	******	159.08	159.94	160.86
66.238° W	DIST	******	65.18	64.28	64.33
	RET ANG	******	18.78	18.98	18.98

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Time, Date & Location	STAT #	(IN1)	(IN2)	(IN3)	(IN4)
21/ 7/81					
9:14:18.6	RESID	-0.1	*****	*****	*****
16.282° N	BACK AZ	207.73	******	******	******
98.373° W	DIST	26.49	******	******	******
	RET ANG	28.09	******	******	******
21/ 7/81	STAT #	(IN1)	(IN2)	(IN3)	(IN4)
10:22:54.7	RESID	-0.2	*****	*****	*****
16.508° N	BACK AZ	207.99	******	******	******
98.408° W	DIST	26.29	******	******	******
	RET ANG	28.07	******	******	******
1/ 8/81	STAT #	(IN1)	(IN2)	(IN3)	(IN4)
1:42:16.4	RESID	-1.2	*****	-1.2	*****
60.136° N	BACK AZ	319.19	******	320.01	******
153.185° W	DIST	44.94	******	45.97	******
	RET ANG	23.87	******	23.64	******
4/ 8/81	STAT #	(IN1)	(IN2)	(IN3)	(IN4)
22: 0:15.1	RESID	-0.2	*****	-0.1	-0.1
16.824° N	BACK AZ	131.09	******	129.65	131.35
61.467° W	DIST	31.70	******	30.81	30.49
	RET ANG	26.34	******	26.51	26.51
5/ 8/81	STAT #	(IN1)	(IN2)	(IN3)	(IN4)
12:58:27.4	RESID	*****	*****	0.2	*****
3.895° N	BACK AZ	******	******	164.03	******
76.409° W	DIST	******	******	36.22	******
	RET ANG	******	******	25.20	******
15/ 8/81	STAT #	(IN1)	(IN2)	(IN3)	(IN4)
10:30:56.9	RESID	-1.3	*****	*****	*****
56.400° N	BACK AZ	314.45	******	******	******
156.680° W	DIST	47.34	******	******	******
	RET ANG	23.26	******	******	******
23/ 8/81	STAT #	(IN1)	(IN2)	(IN3)	(IN4)
12: 0:26.5	RESID	-1.4	*****	*****	-1.2
48.718° N	BACK AZ	322.24	******	******	322.87
157.390° E	DIST	75.03	******	******	76.27
	RET ANG	16.82	******	******	16.59
24/ 8/81	STAT #	(IN1)	(IN2)	(IN3)	(IN4)
15:46:27.6	RESID	-1.4	*****	-1.1	-1.3
51.508° N	BACK AZ	314.44	******	314.97	315.16
178.355° W	DIST	60.99	******	61.94	62.21
	RET ANG	20.15	******	19.95	19.64

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28/ 8/81	STAT #	(IN1)	(IN2)	(IN3)	(IN4)
9: 4:24.7	RESID	-1.3	*****	-1.4	-1.8
61.738° N	BACK AZ	321.37	******	322.19	322.01
150.452° W	DIST	43.51	******	44.56	44.74
	RET ANG	24.15	******	23.95	23.95
3/ 9/81	STAT #	(IN1)	(IN2)	(IN3)	(IN4)
5:35:44.8	RESID	-0.3	*****	0.1	-0.3
43.621° N	BACK AZ	324.33	******	324.47	324.96
147. 31° E	DIST	83.60	******	84.69	84.83
	RET ANG	14.87	******	14.65	14.65
8/ 9/81	STAT #	(IN1)	(IN2)	(IN3)	(IN4)
7: 1:16.9	RESID	-1.6	*****	-1.4	-1.4
51.468° N	BACK AZ	314.40	******	314.93	315.12
178.368° W	DIST	61.01	******	61.97	62.24
	RET ANG	19.95	******	19.95	19.64
13/ 9/81	STAT #	(IN1)	(IN2)	(IN3)	(IN4)
2:17:18.2	RESID	-0.2	0.1	*****	-0.4
49.897° N	BACK AZ	9.71	9.15	******	10.34
78.983° E	DIST	88.96	89.67	******	89.79
	RET ANG	13.99	13.77	******	13.77
14/ 9/81	STAT #	(IN1)	(IN2)	(IN3)	(IN4)
12:44:29.8	RESID	-1.1	-0.4	-0.4	-0.8
18.320° N	BACK AZ	141.57	139.18	140.12	142.20
68.891° W	DIST	26.55	26.52	25.50	25.31
	RET ANG	27.64	27.64	28.04	28.04
1/10/81	STAT #	(IN1)	(IN2)	(IN3)	(IN4)
12:14:56.8	RESID	-2.3	-1.6	-1.8	-1.8
73.317° N	BACK AZ	11.82	11.51	11.72	11.99
54.812° E	DIST	63.29	64.01	64.52	64.08
	RET ANG	19.49	19.18	19.18	19.18
4/10/81	STAT #	(IN1)	(IN2)	(IN3)	(IN4)
20: 3:53.0	RESID	-2.0	-1.9	-1.5	*****
1.550° S	BACK AZ	167.35	165.90	167.20	******
77.364° W	DIST	42.61	42.18	41.35	******
	RET ANG	24.10	24.10	24.26	******
8/10/81	STAT #	(IN1)	(IN2)	(IN3)	(IN4)
22:25:53.0	RESID	-2.0	-2.0	-1.7	-2.1
17.124° S	BACK AZ	162.31	161.24	162.19	163.22
70. 51° W	DIST	59.23	58.87	57.99	58.08
	RET ANG	20.33	20.50	20.80	20.50

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15/10/81	STAT #	(IN1)	(IN2)	(IN3)	(IN4)
1:47:52.9	RESID	-0.2	-0.1	0.1	-0.2
40.229° N	BACK AZ	325.20	324.65	326.28	325.83
142.287° E	DIST	88.42	88.53	89.52	89.66
	RET ANG	13.97	13.97	13.82	13.82
18/10/81	STAT #	(IN1)	(IN2)	(IN3)	(IN4)
3:57: 2.6	RESID	-0.1	-0.1	-0.3	-0.5
49.886° N	BACK AZ	9.77	9.21	9.84	10.40
78.898° E	DIST	88.96	89.67	90.21	89.79
	RET ANG	13.99	13.77	13.62	13.77
18/10/81	STAT #	(IN1)	(IN2)	(IN3)	(IN4)
4:31: 2.7	RESID	*****	0.0	*****	-0.6
8.117° N	BACK AZ	******	154.26	******	157.21
72.527° W	DIST	******	34.16	******	33.23
	RET ANG	******	25.64	******	25.85
3/11/81	STAT #	(IN1)	(IN2)	(IN3)	(IN4)
7: 2:36.8	RESID	-0.1	*****	*****	*****
1.782° S	BACK AZ	169.03	******	******	******
78.482° W	DIST	42.66	******	******	******
	RET ANG	24.23	******	******	******
7/11/81	STAT #	(IN1)	(IN2)	(IN3)	(IN4)
3:29:51.0	RESID	-2.0	-1.8	-1.2	-2.0
32.199° S	BACK AZ	167.17	166.36	167.17	167.96
71.336° W	DIST	73.62	73.19	72.36	72.51
	RET ANG	17.17	17.17	17.40	17.40
7/11/81	STAT #	(IN1)	(IN2)	(IN3)	(IN4)
22: 2:49.0	RESID	-0.0	0.6	0.9	0.3
14.595° N	BACK AZ	189.97	188.21	190.69	192.55
90.416° W	DIST	26.15	25.45	24.91	25.35
	RET ANG	27.53	27.88	28.38	27.88
27/11/81	STAT #	(IN1)	(IN2)	(IN3)	(IN4)
17:21:45.8	RESID	0.1	0.4	0.2	-0.0
42.913° N	BACK AZ	333.78	333.20	333.84	334.42
131. 76° E	DIST	90.46	90.70	91.64	91.67
	RET ANG	13.47	13.47	13.39	13.39
29/11/81	STAT #	(IN1)	(IN2)	(IN3)	(IN4)
3:35: 8.6	RESID	-0.5	0.2	-0.2	-0.3
49.860° N	BACK AZ	9.80	9.24	9.87	10.43
78.857° E	DIST	88.98	89.69	90.23	89.80
	RET ANG	13.99	13.77	13.62	13.77

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2/12/81	STAT #	(IN1)	(IN2)	(IN3)	(IN4)
6:24:42.8	RESID	*****	-0.3	-0.3	-0.6
40.907° N	BACK AZ	******	324.90	325.53	326.07
142.515° E	DIST	******	87.87	88.87	89.00
	RET ANG	******	14.11	13.96	13.96
27/12/81	STAT #	(IN1)	(IN2)	(IN3)	(IN4)
3:43:14.1	RESID	-0.2	-0.0	-0.2	-0.6
49.909° N	BACK AZ	9.78	9.22	9.85	10.41
78.873° E	DIST	88.94	89.64	90.18	89.76
	RET ANG	13.99	13.77	13.62	13.77
25/ 1/82	STAT #	(IN1)	(IN2)	(IN3)	(IN4)
5:29:33.5	RESID	-2.6	-2.0	-2.6	*****
53.222° N	BACK AZ	312.39	312.49	313.10	******
165.719° W	DIST	53.25	53.16	54.18	******
	RET ANG	21.93	21.93	21.69	******
30/ 1/82	STAT #	(IN1)	(IN2)	(IN3)	(IN4)
2:35:10.6	RESID	-0.5	0.0	-0.2	*****
16.737° N	BACK AZ	131.14	129.12	129.70	******
61.430° W	DIST	31.79	31.92	30.90	******
	RET ANG	26.31	26.31	26.47	******
7/ 2/82	STAT #	(IN1)	(IN2)	(IN3)	(IN4)
6: 7:13.2	RESID	-2.0	-1.4	-1.7	*****
51.779° N	BACK AZ	314.20	314.15	314.75	******
176.871° W	DIST	60.05	59.98	61.00	******
	RET ANG	20.15	20.38	20.15	******
12/ 2/82	STAT #	(IN1)	(IN2)	(IN3)	(IN4)
14:55: 0.0	RESID	-0.4	0.3	0.1	*****
37.224° N	BACK AZ	271.98	272.85	274.89	******
116.463° W	DIST	23.97	23.31	24.13	******
	RET ANG	29.74	29.74	29.16	******
12/ 2/82	STAT #	(IN1)	(IN2)	(IN3)	(IN4)
15:25: 0.0	RESID	-0.4	0.5	-0.0	*****
37.348° N	BACK AZ	272.19	273.07	275.12	******
116.316° W	DIST	23.82	23.17	23.98	******
	RET ANG	29.74	29.74	29.74	******
21/ 3/82	STAT #	(IN1)	(IN2)	(IN3)	(IN4)
2:32: 6.3	RESID	1.4	1.8	1.7	*****
42.168° N	BACK AZ	326.18	325.66	326.28	******
142.479° E	DIST	86.75	86.87	87.86	******
	RET ANG	14.29	14.29	14.12	******

Time, Date & Location	ANNA NETWORK P-Wave Residuals UNIVERSITY OF MICHIGAN SEISMOLOGICAL OBSERVATORY				
22/ 3/82	STAT #	(IN1)	(IN2)	(IN3)	(IN4)
21:44: 9.3	RESID	-2.0	-2.0	-1.7	*****
19.880° S	BACK AZ	161.71	160.70	161.61	******
68.743° W	DIST	62.20	61.84	60.96	******
	RET ANG	19.61	19.88	20.10	******
28/ 3/82	STAT #	(IN1)	(IN2)	(IN3)	(IN4)
23:24:50.7	RESID	-2.5	-2.4	-1.9	*****
12.769° S	BACK AZ	168.12	166.96	168.06	******
76. 90° W	DIST	53.81	53.37	52.55	******
	RET ANG	21.88	21.88	22.12	******

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BIBLIOGRAPHIC DATA SHEET

1. REPORT NUMBER (Assigned by DDC)	NUREG/CR-3145 Vol. 1
4. TITLE AND SUBTITLE (Add Volume No., if appropriate)	Geophysical Investigations of the Western Ohio-Indiana Region Annual Report (October 1981-September 1982 Vol. 1
2. (Leave blank)	
3. RECIPIENT'S ACCESSION NO.	
7. AUTHOR(S)	D. H. Christensen, M. G. Wiedenbeck, P. L. Jackson
5. DATE REPORT COMPLETED	MONTH: January YEAR: 1983
9. PERFORMING ORGANIZATION NAME AND MAILING ADDRESS (Include Zip Code)	Dept. of Geological Sciences University of Michigan Ann Arbor, Michigan 48109
DATE REPORT ISSUED	MONTH: February YEAR: 1983
6. (Leave blank)	
8. (Leave blank)	
12. SPONSORING ORGANIZATION NAME AND MAILING ADDRESS (Include Zip Code)	Division of Health, Siting, and Waste Management Office of Nuclear Regulatory Research U.S. Nuclear Regulatory Commission Washington, D.C. 20555
10. PROJECT/TASK/WORK UNIT NO.	
11. FIN NO.	B8080
13. TYPE OF REPORT	Annual Progress Report
PERIOD COVERED (Inclusive dates)	October 1981-September 1982
15. SUPPLEMENTARY NOTES	
14. (Leave blank)	

16. ABSTRACT (200 words or less)

Earthquake activity in the Western Ohio-Indiana region is monitored with a precision seismograph network: Nine stations clustered about Anna, Ohio, and four stations in Indiana centered about Indianapolis. During this period no earthquakes were detected in the region of the network. This seismic inactivity contrasts with the previous year, during which nine small (unfelt) earthquakes occurred within and adjacent to the Western Ohio portion of the network. Digital triggering and recording capability was added to the analog recording capability. Using the new digital capability, we were able to more precisely locate the focus of some of these small earthquakes. As part of the inception of a modeling investigation, a preliminary location of the Grenville Front was postulated as eastward of the network. Azimuthal changes in travel time residuals of teleseisms were used for this estimate.

17. KEY WORDS AND DOCUMENT ANALYSIS 17a. DESCRIPTORS

Seismicity
Ohio
Indiana
Velocity structure
P-wave residuals

17b. IDENTIFIERS/OPEN-ENDED TERMS

18. AVAILABILITY STATEMENT	Unlimited
19. SECURITY CLASS (This report)	Unclassified
21. NO. OF PAGES	
20. SECURITY CLASS (This page)	Unclassified
22. PRICE	S

NRC FORM 335 (11 81)

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WASHINGTON, D.C. 20555

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