NUREG/CR-3021

Regional Tectonics and Seismicity of Southwestern Iowa

Final Report: 1978-1982

Prepared by O. J. Van Eck, R. R. Anderson, C. L. Cumerlato,
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Iowa Geological Survey

Prepared for
U.S. Nuclear Regulatory
Commission

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Manuscript Completed: October 1982
Date Published: November 1982

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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 B6312
Under Contract No. NRC-04-78-228

ABSTRACT

Utilizing gravity and aeromagnetic data, a series of geophysical profiles were constructed across the Midcontinent Geophysical Anomaly (MGA) which extends across the southwestern Iowa study area. By combining the information provided by modeling techniques with limited deep well data, a map of the Precambrian basement was generated. The interpretation that emerged includes a central horst of igneous intrusives and extrusives, extensively faulted, and overlain in some areas by Keweenawan clastics. The horst is flanked by a series of high angle faults, with the majority of the faults displaying vertical displacement along two structural zones, the Thurman-Redfield Structural Zone, along the southeastern margin of the MGA, and the Northern Boundary Fault Zone which flanks the northwestern boundary. The total vertical displacement present along these fault zones is estimated to be a maximum of 9 Km. Two clastic-filled basins flank the horst, one of which has an interpreted depth of 10 Km. Seismic profiling indicates rather extensive folding and faulting of Paleozoic rock units, although the scale of deformation is minor when compared to Precambrian features in the same area. Although the Paleozoic Era was the most tectonically active of the post-Precambrian eras there are indications of post-Cretaceous movement. Recent tectonic activity is suggested by the numerous microearthquakes that were recorded by the monitoring array that was installed for this study.

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INTRODUCTION

In May, 1978 the Iowa Geological Survey began participation in the then on-going tectonic and seismicity study of the Nemaha Ridge being conducted by the Geological Surveys of Kansas, Nebraska, and Oklahoma. The various studies, which were funded by the U.S. Nuclear Regulatory Commission, were designed to obtain information that will provide a better understanding of the regional tectonics and thus better understand the sources and mechanisms of the earthquakes of the region. From this comes an evaluation of the earthquake-risk factor in the siting and designing of nuclear facilities, or any other large structures. The southwestern Iowa study area (Fig. 1) was included in the study because of the close proximity to the juncture of two major tectonic features, the Nemaha Ridge and the Midcontinent Geophysical Anomaly (MGA). The MGA is the term applied to the geophysical anomaly associated with the Keweenawan Mafic Belt where it is buried beneath younger sediments. The location of the MGA was known from aeromagnetic surveys and from widely spaced gravity data.

SCOPE OF STUDY

Earlier workers (Hershey, et al, 1960) mapped a structural feature in the Pennsylvanian rocks that has the form of a series of domes and anticlines, and also possible faulting. The zone was traced from where it enters the south western part of the state near Thurman, Fremont County, past Redfield, Dallas County. The name Thurman-Redfield Structural Zone was applied to the structure. This Structural Zone closely parallels the southeastern boundary of the MGA. Some of the features within the structural zone appear to be reflected in the aeromagnetic maps of the area, which demonstrate that Precambrian structures have at least partially controlled Paleozoic structural movement. Although no information was available to demonstrate the presence of a Paleozoic structural zone along the northwestern boundary of the MGA, it was postulated that such a zone should be present, and the aeromagnetic data did support such a contention.

It was recognized at the outset of this study that great reliance would have to be placed on geophysical methods to obtain the data that would provide a better understanding of the tectonics of the study area. The entire area is covered by glacial drift and loess, which in places reaches a combined thickness of 500 feet. As a result, rock exposures are few and scattered and generally quite limited in lateral extent. To compound the problem, few water wells have been drilled to bedrock. Within the entire study area only 34 oil tests have been drilled. Given this dearth of subsurface information, it was decided that the fastest and most economical method of obtaining information was to use gravity and seismic exploration methods.

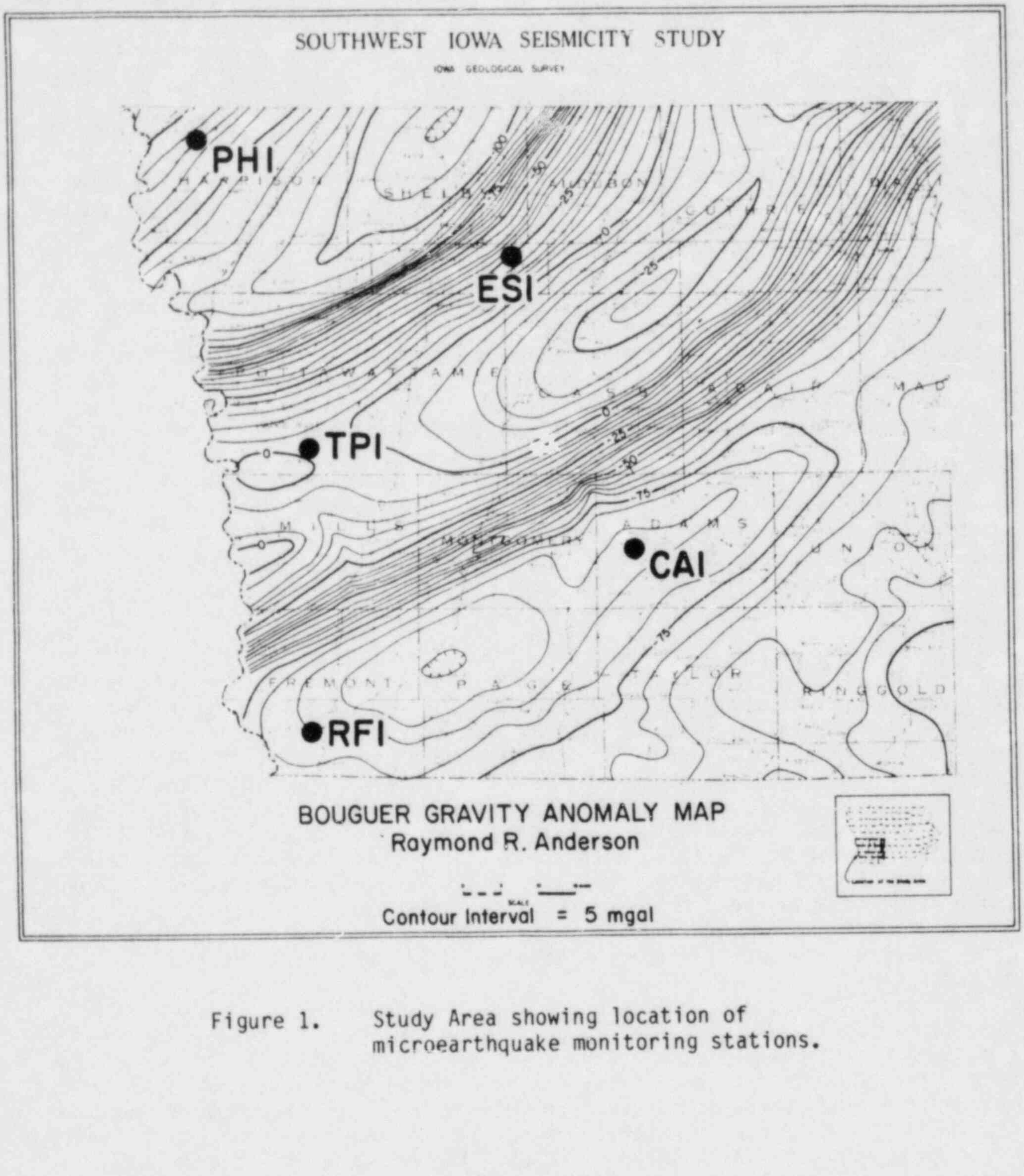


Figure 1. Study Area showing location of microearthquake monitoring stations.

During the study period almost 2,000 gravity stations were established and 18 miles of seismic profiling were completed. Along with establishing new gravity stations, data was compiled from various sources by the National Oceanic and Atmospheric Administration. In addition, every effort was made to locate new subsurface drill information.

A major element of the study was the monitoring of microearthquakes (<3 Richter magnitude). A 5-station network was installed and operated. The location of the stations are shown on Figure 1, which also illustrates the gravity expression of the MGA.

As various aspects of the work were completed, the following maps were completed at the scale of 1:500,000:

Bedrock Topography
Surface Topography for Nemaha Ridge-MGA Study Area
Thickness of Unconsolidated Materials
Structure (Base of Kansas City Group)
Precambrian Geology
Precambrian - Topography of Crystalline Surface
Bouguer Gravity Anomaly
Landsat Linears
Compiled Aeromagnetics
Calculated 4th Degree Regional Gravity Surface
Calculated 4th Degree Residual Gravity Surface

The following maps were then compiled as single sheets for the entire Nemaha Ridge-MGA Study Area at a scale of 1:1,000,000:

Precambrian Configuration
Precambrian Rock Type
Structure (Base of Kansas City Group)
Bedrock Geologic Map
Bouguer Gravity Anomaly
Aeromagnetic
Historic Earthquake Epicenters
Landsat Linears
Shaded Surface Relief
Drainage

These maps, with an accompanying Executive Summary from each state included in the Nemaha Ridge-MGA Study will be furnished to the Nuclear Regulatory Commission.

DATA INTERPRETATION

Along with the preparation of the various maps listed above, it was considered important that the data acquired be carefully interpreted and conclusions be drawn. In previous Annual Reports to the Nuclear Regulatory Commission prepared by the Iowa Geological Survey (NUREG/CR 0955, 1979; NUREG/CR 1876, 1981; NUREG/CR 2548, 1982) interpretations and conclusions, regarding various phases of the study have been discussed in detail. The following is a summary of those interpretations and conclusions along with those that were made during the present reporting period and included in the appendices of this report.

Utilizing the revised Bouguer gravity map that was prepared from all available gravity data and the total-field aeromagnetic map, Anderson and Black constructed a series of eight geophysical profiles across the MGA in the study area. By combining the information that was obtained by the modeling and the limited deep well data, a map of the geology of the Precambrian basement of southwestern Iowa was generated.

The interpretation that emerged includes a central horst of igneous extrusives and intrusives, extensively faulted and overlain in some areas by Keweenawan clastics. The horst is bounded by a series of high-angle faults with the majority of the interpreted vertical displacement along two structural zones, the previously discussed Thurman-Redfield Structural Zone along the southeastern margin, and the other, which has been named the Northern Boundary Fault Zone, on the northwestern margin. Total vertical displacement along these zones is estimated to be locally in excess of 9 km. Two clastic-filled basins flank the horst, one of which has an interpreted depth of 10 km.

While gravity and aeromagnetic data are extremely useful in interpreting Precambrian basement lithology and structure, those data are of small value in interpreting Paleozoic structure in Iowa. The depth to the Precambrian basement is so shallow that any geophysical expression of Paleozoic structure is completely masked by that produced by variations in Precambrian basement lithology and topography.

To overcome this problem the decision was made to use seismic reflection methods. Six detailed traverses, totaling 18 miles, were collected across the MGA. The interpretations and conclusions drawn are discussed by Logel in NUREG/CR 2548 and in Appendix A of this report. Late-Paleozoic folding along the Grant (Montgomery Co.) and Middle River (Adair Co.) traverses, minor post-Silurian faulting along the Stennett (Montgomery Co.) and Harlan (Shelby Co.) traverses, along with several possible periods of faulting and folding along the Malvern (Mills Co.) traverse are interpreted. Although the interpretations indicate that Paleozoic structural features do exist, their displacements are minor when compared to interpreted Precambrian features in the same immediate areas.

Although few seismic epicenters have been located in Iowa, a rather large number have been closely adjacent to Iowa. The importance of this is that the deep-seated dense mafic rocks of the MGA can act as a "channeling" mechanism to transmit seismic energy. This was a consideration in the design of the geometry of the 5-station monitoring network.

The results of the microearthquake monitoring program are discussed by Faller (1981) and in Appendix B of this report, and a catalog of events is presented.

Numerous low-magnitude (<2 Richter) events were recorded. Unfortunately, none of these events were recorded at more than one station at any one time, and thus it was not possible to make epicenter locations. The network was very successful in the recording of regional microseisms (Richter magnitudes 3-2), and provided useful data to other network operators in the Nemaha-MGA study.

As a result of the seismic monitoring program, it must be concluded that southwestern Iowa remains seismically active, with the magnitudes of most of the activity below the threshold of human detection. Since a direct relationship between fault length and earthquake magnitude has been proposed in other regions, it has been suggested that the Thurman-Redfield Structural Zone and the Northern Boundary Fault Zone may be a series of short en-echelon faults. The results of the seismic profiling substantiate this suggestion.

CONCLUSIONS

From the cited and associated investigations, the following conclusions are drawn.

The MGA in Iowa consists of a central horst of igneous extrusives and intrusives, extensively faulted and overlain in some areas by Keweenawan clastics. The horst is bounded by a series of high-angle faults, with the majority of the interpreted vertical displacement along two structural zones -- the Thurman-Redfield Structural Zone and the Northern Boundary Zone. Total Vertical displacement may reach 9 km. Post-Precambrian movement on individual faults may range up to 300 meters or more. The horst is flanked by clastic-filled basins which reach a maximum interpreted depth of 10 km.

Seismic profiling identified faulting and folding in Paleozoic age rocks, although the scale of deformation is much smaller than that inferred to have occurred in Precambrian time.

Although the Paleozoic Era apparently was the most tectonically active post-Precambrian period, post-Cretaceous movements are also strongly suggested by the location of the Cretaceous outliers in the study area. These Cretaceous rocks lie above the central horst and probably represent erosional remnants of units which once covered all of southwest Iowa and were structurally preserved in their present locations by post-depositional subsidence along the crest of the central horst.

Recent tectonic activity is suggested by the frequent recording of microearthquakes by several of the five seismic recording stations installed along the MGA in southwest Iowa. Although microearthquake activity has been identified, vertical movements have been minimal, at least since mid-Pleistocene time.

REFERENCES

Anderson, R.R., Black, R. A., 1982, Geologic Interpretation from Geophysical Models of the Midcontinent Geophysical Anomaly in Southwest Iowa: Nuclear Regulatory Commission, NUREG/CR-2548, Appendix III.

Hershey, H.G., Brown, C.N., Van Eck, O. J and Northup, R.C., 1960, Highway Construction Materials from the Consolidated Rocks of Southwest Iowa: Iowa Highway Research bull., no. 15, 115 p.

APPENDIX

A. Seismic Reflection Studies in Southwest Iowa

B. Final Report of the Southwest Iowa Seismic System

C. Southwest Iowa Gravity Data Collection, Analyses, and Interpretation

D. Result of Geophysical Studies in Southwest Iowa, 1978-1982

APPENDIX A

SEISMIC REFLECTION STUDIES IN SOUTHWEST IOWA

by

John Logel

INTRODUCTION

All of the data used in this study were collected in southwest Iowa (Figure A1), in the area of the mid-continent geophysical anomaly (MGA). The data was used to interpret structure in the Paleozoic strata in this area. Due to limited well data, seismic reflection profiles were an economic option for investigation of the existence and extent of structure, including faulting, in the Paleozoic section.

The Pennsylvanian-Mississippian contact, at a depth of 300 to 400 meters, was the primary target reflector. It was subsequently found that much deeper units could also be resolved. Interval velocity calculations from a sonic log in Montgomery County showed the reflection coeficient for this contact to be 0.59, theoretically a good reflector throughout southwest Iowa.

PURPOSE

This report is a summary of the seismic reflection work completed since the previous reporting. In the previous report (NUREG/CR 2548) three seismic traverses were discussed. They were the grant traverse in Montgomery and Cass Counties, the Middle River traverse in Adair County, and the Stennett traverse in central Montgomery County. During the 1981 field season, three seismic profiles were collected in Southwest Iowa with varying degrees of success. Interpretations of these new profiles, as well as those previously reported, are discussed here in order to produce a series of final conclusions based on all seismic reflection data.

METHOD OF STUDY

The Nimbus engineering seismograph used in this study was purchased by the Iowa Geological Survey under a Nuclear Regulatory Commission contract in April 1980. Its intended use was for subsurface investigation of the Thurman-Redfield Structural Zone. During the summer field season of 1980 it was tested in the field to determine its capabilities and limitations. Both reflection and refraction data were collected and evaluated to determine which method would produce the most useful results. The data were hand reduced and visually interpreted. Several structural features were identified in the data, including monoclinal folding and a doubly-plunging anticline.

In April 1981, the Iowa Geological Survey acquired a digital recorder and an APPLE II microcomputer. This new equipment allowed data to be recorded and processed in the field. With it, the data were manipulated with greater speed and accuracy than could have been done by hand reduction.

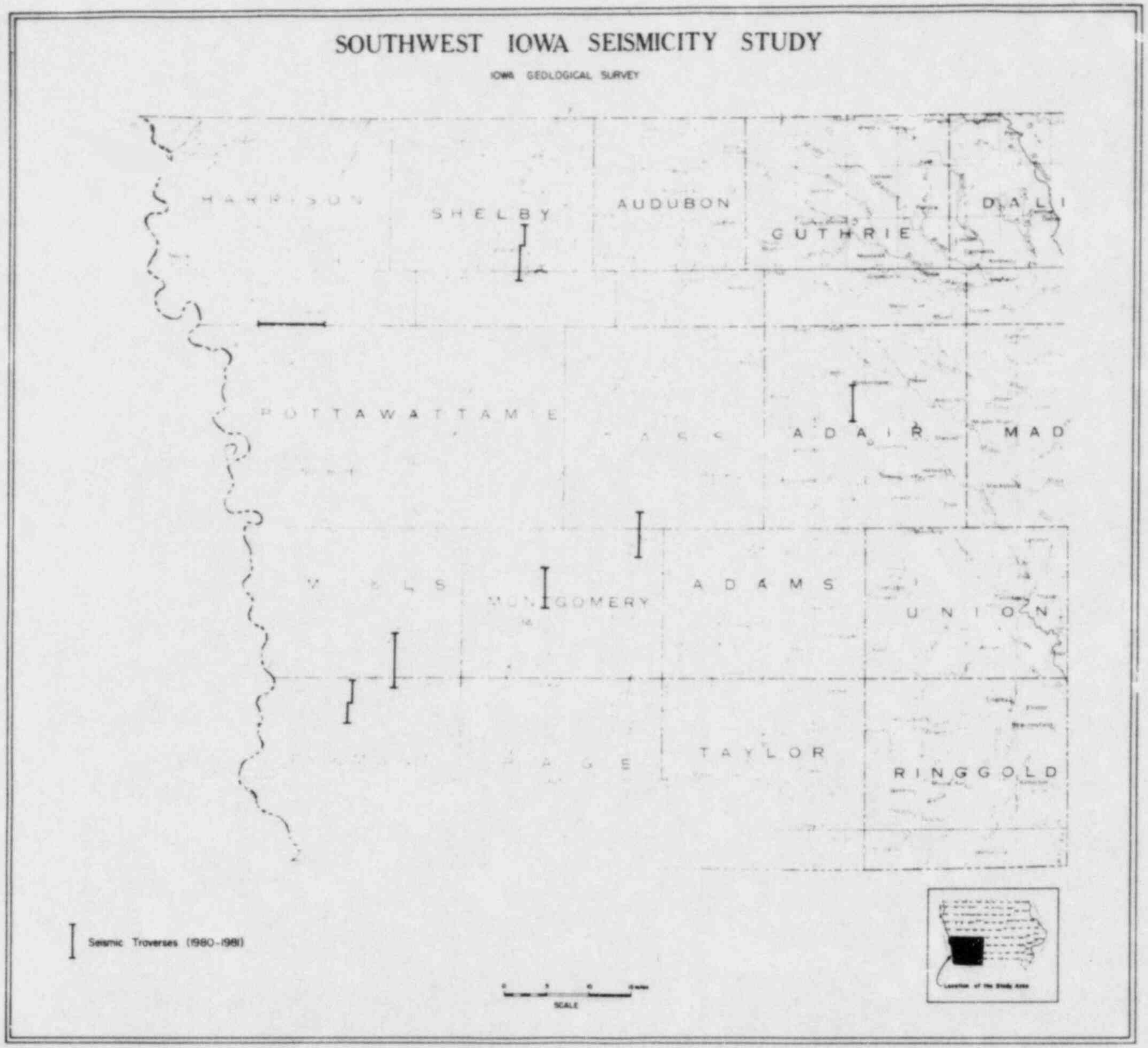


Figure A1. Location of Seismic Reflection Profiles

Data were as collected with varying degrees of resolution. Station spacing varied from 8 meters to 35 meters and sampling intervals ranged from 0.5 milliseconds (ms) to 2 ms. Most of the data were collected with 17 meter station spacing and a 1 ms sample rate. The recording length on most records was one second, giving subsurface coverage up to 900 meters in depth. Primacord was used as the energy source.

DATA PROCESSING

The APPLE computer's compatibility with the seismograph allowed data to be reduced faster and more accurately than was possible by hand. Several software routines for processing the data will be discussed here. Figure A2 shows a generalized flow chart of the processing sequence for the APPLE II as developed by Chris Hall of the Iowa Geological Survey.

The data are read from the tape recorder into the APPLE where they are stored in digital form on floppy discs using a program called NIMTODISK (Hall, 1982). Once the data are read into the APPLE and reside on disk, it can then be manipulated for refinement. The program POINT PICKER (Hall, 1982) plots the data on the screen and allows the movement of the cursor to pick events. Both refraction and reflection data can be picked.

The next step is to perform a normal moveout correction and time-domain bandpass filtering. This is accomplished using NMOF (Hall, 1982). This program will prompt the user for input of filter parameters to build a sine function time domain operator of variable length with a Fejer-weighted window to be convolved with the moved-out data later. The program will then prompt the user for input and output file information and then for time and velocity pairs from the POINT PICKER (Hall, 1982) program.

Once the data have been moved out and filtered, the user has the option to plot the data on the screen using RECORD DISPLAY or to plot a hard copy using SECTION PLOT, or FINPLOT. SECTION PLOT prompts the user for an initial gain, a linear gain adjustment that is time dependent, and a trace gain adjustment that is trace dependent. The program FINPLOT is a plotting routine that plots individual records separately, while SECTION PLOT links all of the records together.

If extensive topographic relief exists along the traverse, an elevation correction is necessary. This is accomplished by calculating two-way travel time differences above or below the assigned elevation datum, for each shot location, using the velocity for the near surface layer derived from the noise test. These travel time differences are then applied to the data.

GEOPHYSICAL INTERPRETATION

Structural interpretations are constrained by the limitations of the seismic reflection method. Several parameters influence the limits of interpretation, including source penetration, frequency content, record quality, processing techniques, velocity control, and surface and near-surface geology (Stander, 1981).

In southwest Iowa the maximum depth penetration, using Primacord as a source in shallow augered holes, was about 1125 meters which represents a two-way travel time of approximately 700 ms. (at 3000 meters/second average

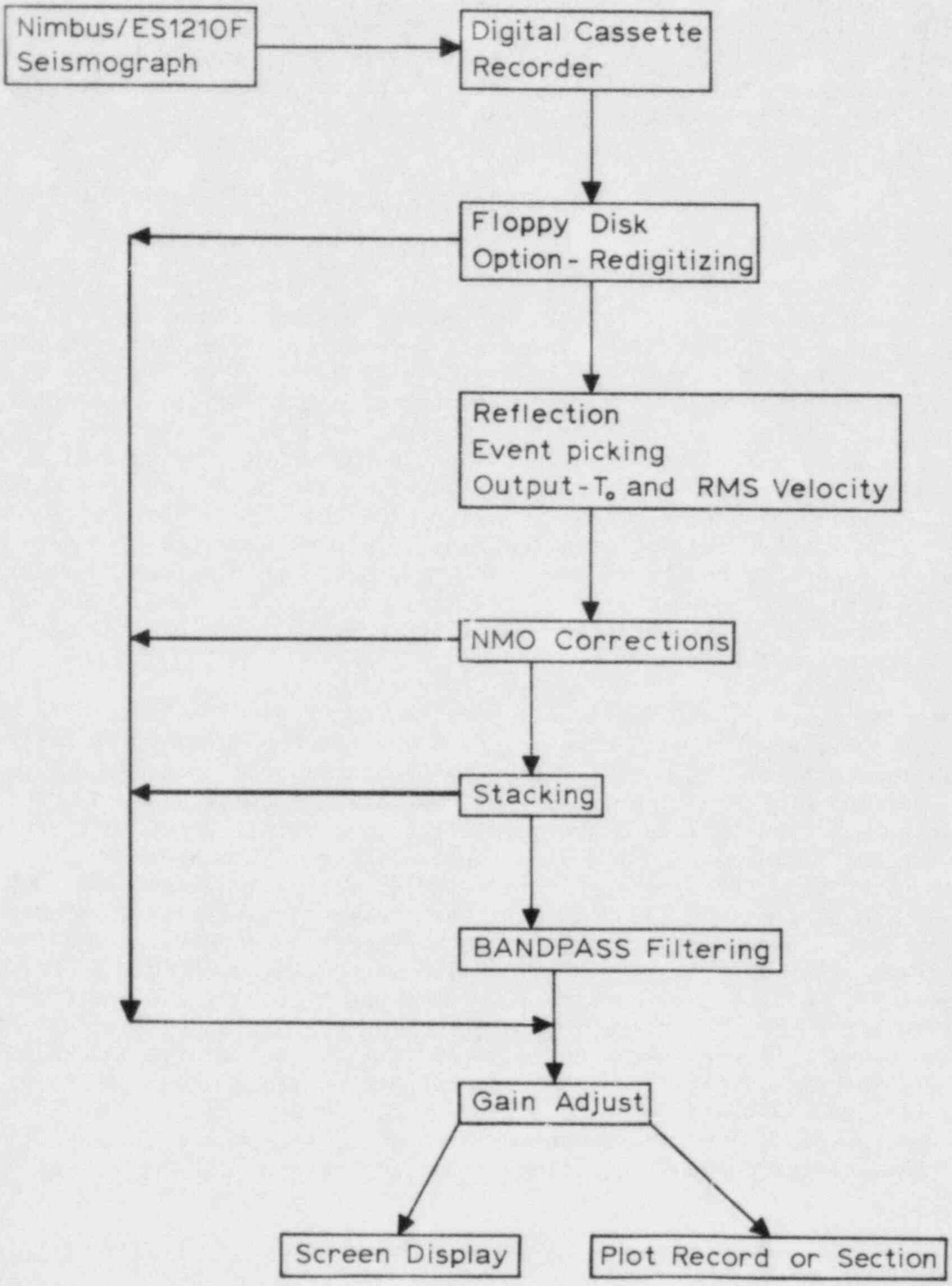


Figure A2. APPLE II Seismic Processing Flow Chart velocity). The highest usable frequency from any of the seismic data was 90 hertz, which corresponds to a wavelength of 33 meters and yields a minimum resolvable thickness for a geologic unit of 20 meters.

Velocity control in southwest Iowa is very sparse with only one sonic log available (Blazer Orstad #1, Grant, Iowa). Velocity data were extrapolated as far as 100 km from the well location.

MODELING PROCEDURE

For each traverse a geologic model was developed from well data, and a one-dimensional synthetic seismograph was generated. Velocities from the sonic log were assigned to specific geologic units or inferred from characteristic velocity tables. Figure A3 shows geologic units, typical lithologies, velocities, and reflection coefficients for southwest Iowa. The geologic model was converted to a reflectivity log using CONLOG2 written by Ross Black of the Iowa Geological Survey. A reflectivity log is a log of reflection coefficients. A reflection coefficient (R) gives the relative amplitude of the reflected wave to the incident wave (Dobrin, 1976). The amount of energy reflected is dependent on the contrast in the product of density and velocity (Dobrin, 1976), but because of the relatively small variation in density among different kinds of rocks, only the velocity contrast is generally calculated. This is expressed as:

$$R=(V2-V1)/(V2+V1)$$

Vertical incidence is assumed when generating the typical reflectivity log using the above expression. However, this was not the case during collection of data in southwest Iowa. The reflectivity log was then convolved with an input wave and plotted using CONSIP2 also written by Black. The synthetic seismogram was used to relate geologic units to distinct reflectors and enabled further refinement of the structural history of the area.

In generating the synthetic seismogram it was assumed that the shot and geophone are at the same location and that the wave travels straight down and straight back. Because of this, a bedrock reflection appears on the synthetic seismogram. In reality an offset of 50-150 meters was used in the field. Consequently, reflections from shallow low velocity layers are sometimes overtaken and masked by arrivals from deeper, higher velocity layers. Figure A4 illustrates this phenomenon on a synthetic field seismogram and helps explain why the Kansas City Group bedrock reflection at 25 meters doesn't appear on the finished sections using an offset of 122 meters.

Average velocities and synthetic seismograms were useful in approximating depth and stratigraphic location, although they are estimations at best.

TRAVERSE LOCATION AND SELECTION

The Malvern Traverse

The Malvern Traverse was located in Mills Co., Iowa. The traverse starts at the approximate common corner of section 2, 3, 10, and 11, of T. 71N., R. 41W., and ends at the approximate common corner of section 34 and 35, T. 71N., R. 41W., and section 2 and 3, T. 70N., R. 41W.

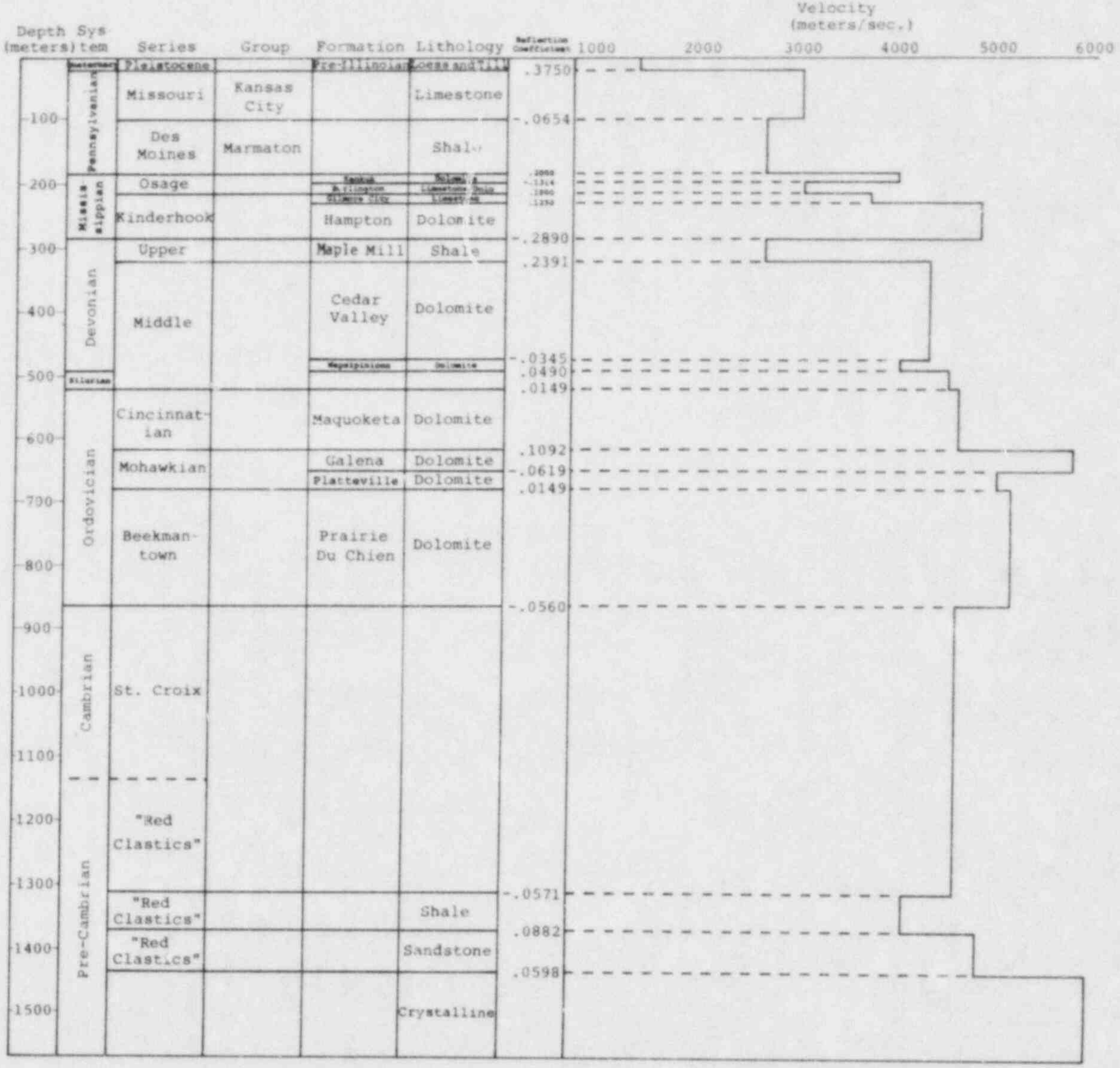


Figure A3. Geologic Units, Lithologies, Velocities and Reflection Coefficients in SW Iowa.

The six-fold, 600% CDP data were collected using a 17 meter station spacing and an off-end offset of 122 meters. The records were stored on digital cassette and written onto nine-track tape in SEGY format using a program called TAPGEN written by Chris Hall of the Iowa Geological Survey. The data was processed using seismic industry standards by Rob Torrey of Seismograph Services Corporation, Tulsa, Oklahoma.

The pre-processing sequence for the data consisted of velocity analysis, bandpass filtering, scaling, normal-moveout, muting, CDP gather, and autocorrelation to determine a predictive deconvolution operator. This was followed by an elevation correction, brute stacking, scaling, predictive deconvolution, bandpass filtering, and a 7 CDP surface and CDP consistent statics correction.

Figures A5 and A6 show the processed section. Figures A7 and A8 show the interpreted record sections (enlarged version in back cover). Several faults, showing a displacement of up to 30 ms., and folded features can be interpreted from the data. A reflectivity log was generated for the Malvern model (Figure 9), and a one-dimensional synthetic seismogram was developed from the data using a 60 hertz McDonal wavelet (McDonal et al., 1958). It shows that a full geologic section, with a Precambrian basement reflector, is present in the data (Figure A10). With this information, distinct reflectors were identified and geologic formation names were assigned.

The Harlan Traverse

The Harlan Traverse was collected near Harlan in Shelby Co., Iowa. The traverse runs from the SW corner of section 5, T. 78N., R. 38W., to the NW corner of section 35, T. 79N., R. 38W.

One-fold data were collected using a 17 meter station spacing and an off-end offset of 122 meters. The records were stored on digital tape and processed on the APPLE II microcomputer in the sequence explained earlier, and then interpreted. Figure A11 shows the interpretation of the Harlan data with the primary reflector at the top of the Silurian System. The faulting in this area was less predominant than in the other areas, suggesting less tectonic activity.

The Beebeetown Traverse

The data from near Beebeetown, in Harrison Co., Iowa, were collected where over 74 meters of Pleistocene loess overlie the bedrock. After the data were collected they were found to have an insufficient signal-to-noise ratio for processing or interpretation. Because of the unconsolidated nature of the loess, shot size increase would only increase the 'blowout' of the shot hole and not greatly improve the signal-to-noise ratio. The only solution to this problem was deeper shot holes which was not an available option at the time of data collection.

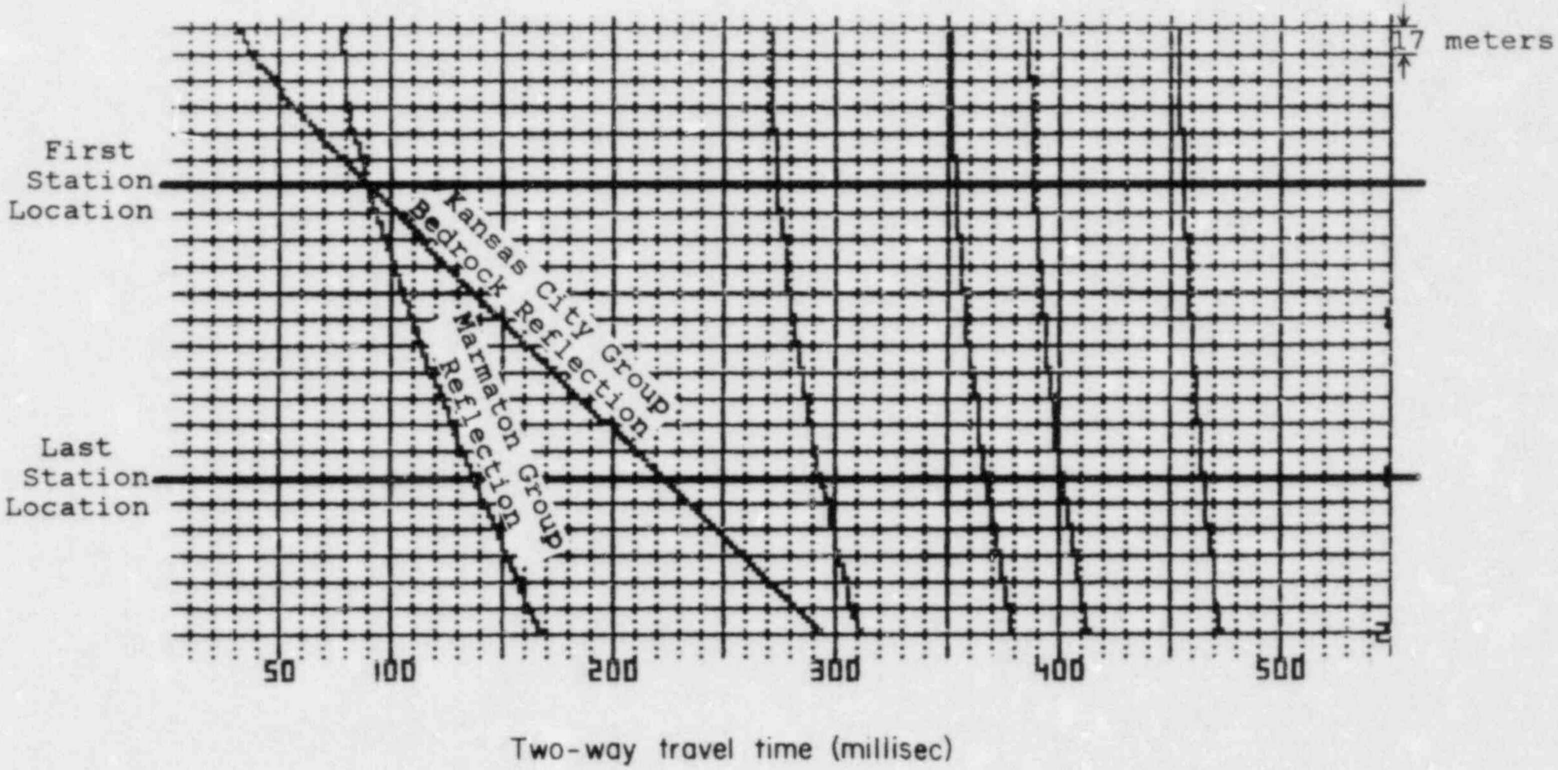


Figure A4. Synthetic Field Seismogram for the Malvern Traverse.

REGIONAL GEOPHYSICAL ANALYSIS

While interpretation of the seismic traverses shows Paleozoic structural features, they are minor structural features when compared with interpreted basement features in the same immediate area. Late Paleozoic folding at the Grant and Middle River locations, minor post-Silurian faulting at Stennett and Harlan, along with several possible periods of faulting and folding at Malvern, are of a much smaller scale than the structural deformation inferred to have occurred in Precambrian time.

These interpretations suggest that the majority of the deformation on the Thurman-Redfield Structural Zone and Northern Boundary Fault Zone occurred prior to the deposition of the Late Mississippian and Pennsylvanian strata. It also suggests that the forces that later deformed these sediments were more localized. The superpositon of some of these Paleozoic structures over larger basement structures suggests reactivation of the older features. When data on the frequency and intensity of recent local microearthquakes (Faller, 1981) and isopach mapping (Bunker, 1981) for southwest Iowa are incorporated with gravity and seismic data, the conclusion is that these structural zones have been periodically active through most of Paleozoic time.

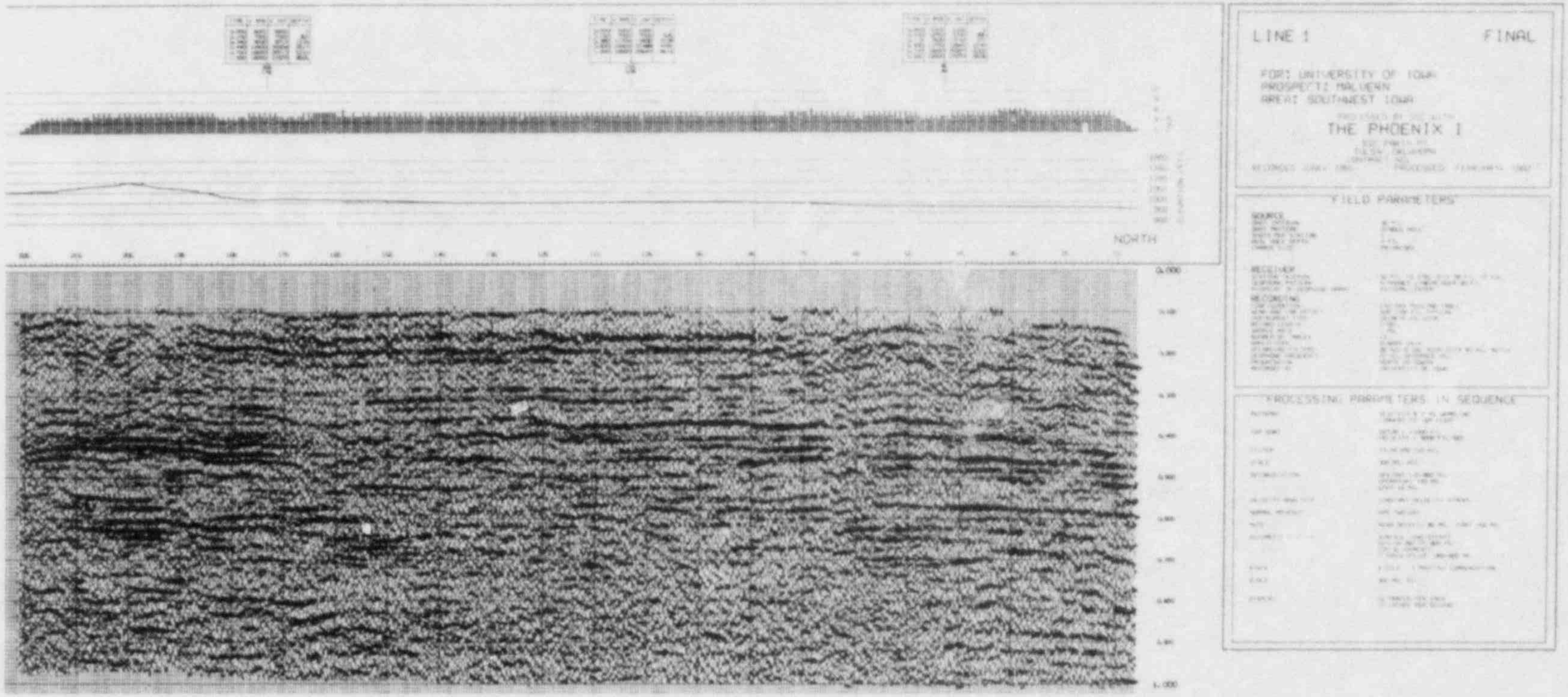


Figure A5. North-half of Processed Data from the Malvern Traverse.

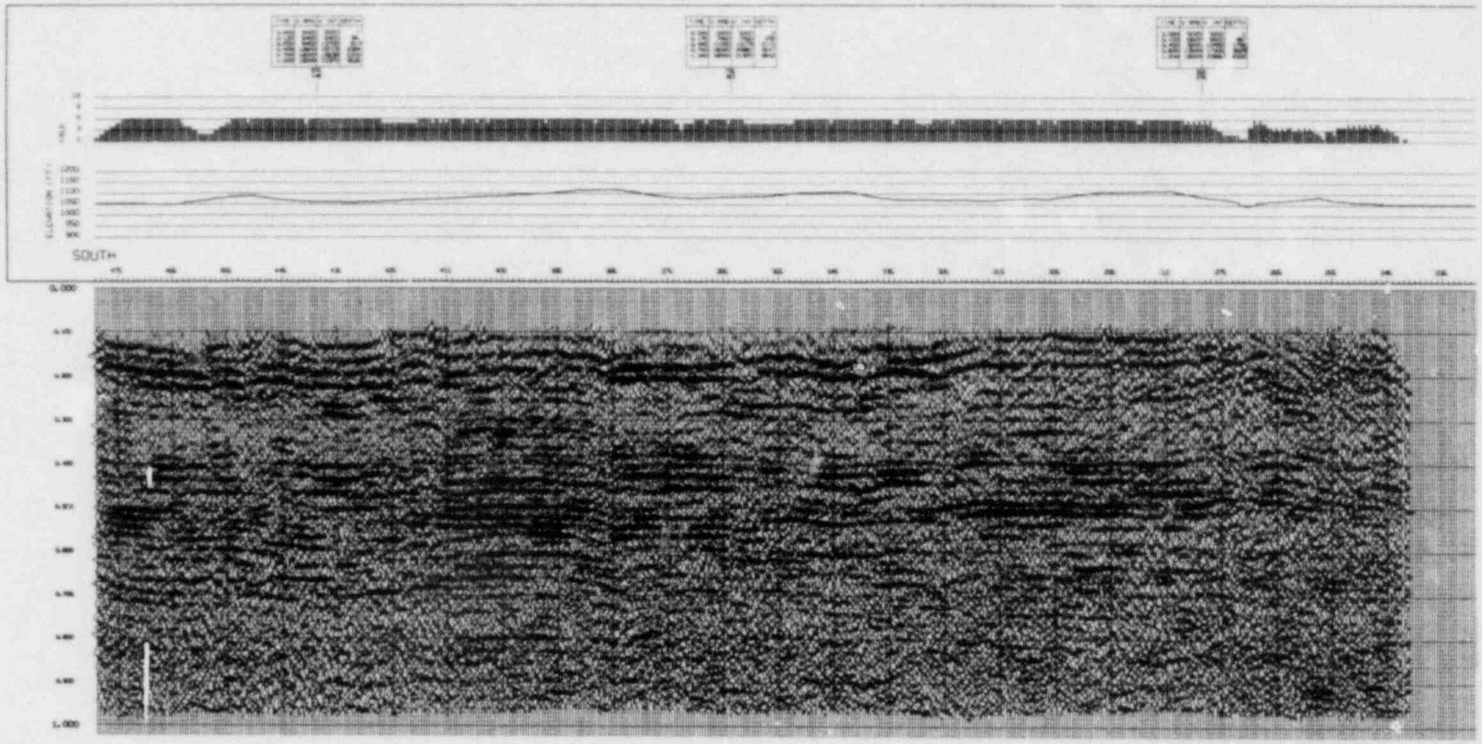


Figure A6. South-half of Processed Data from the Malvern Traverse.

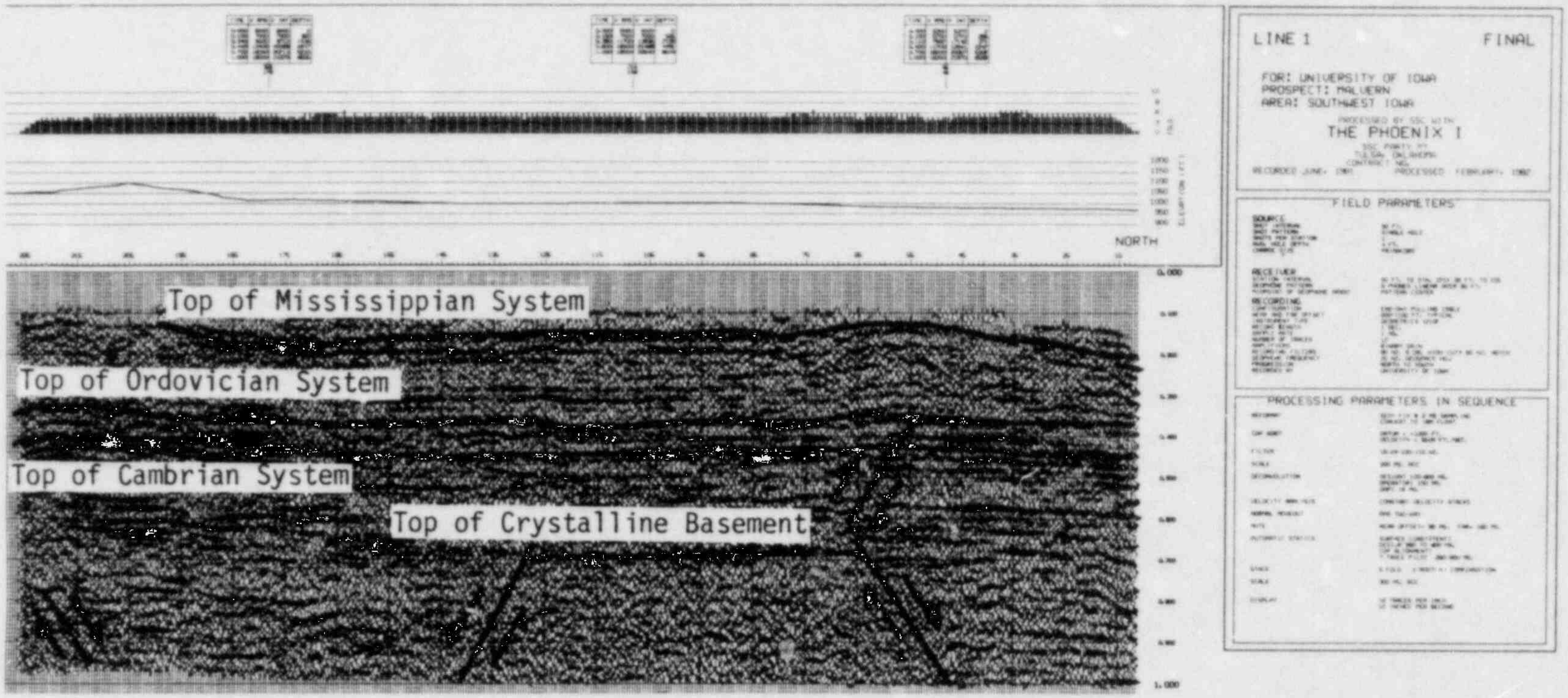


Figure A7. North-half of Interpreted Section from the Malvern Traverse.

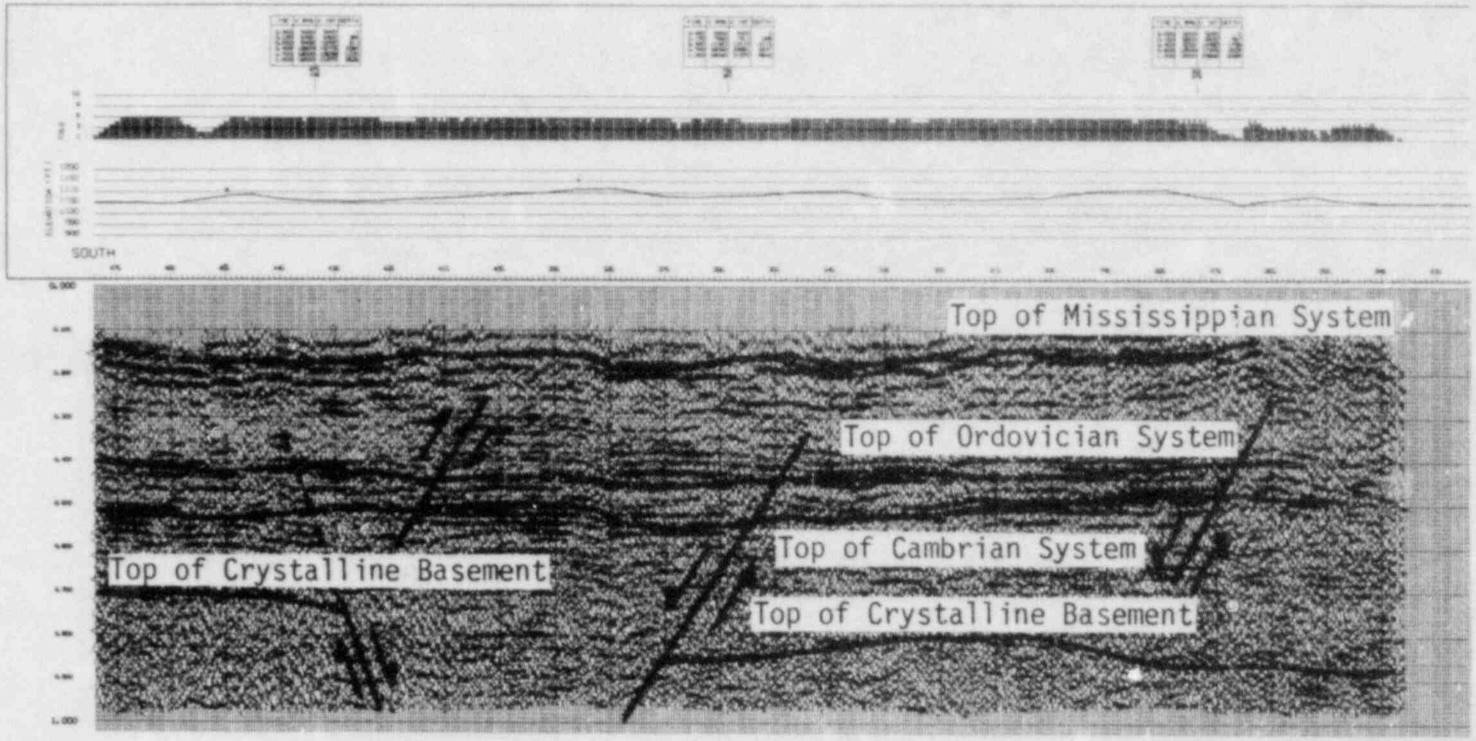


Figure A8. South-half of Interpreted Section from the Malvern Traverse.

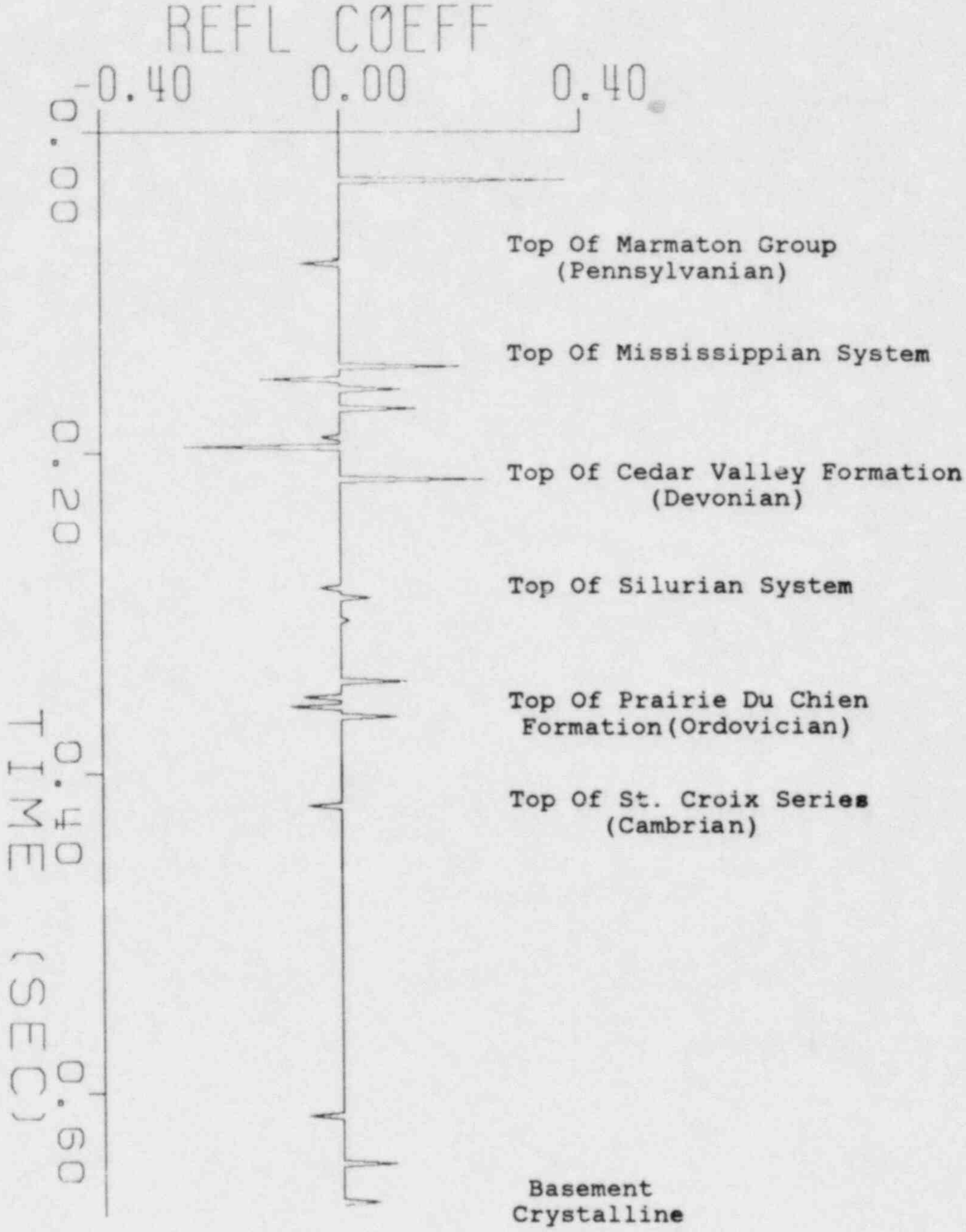


Figure A9. Reflectivity Log from the Malvern Traverse.

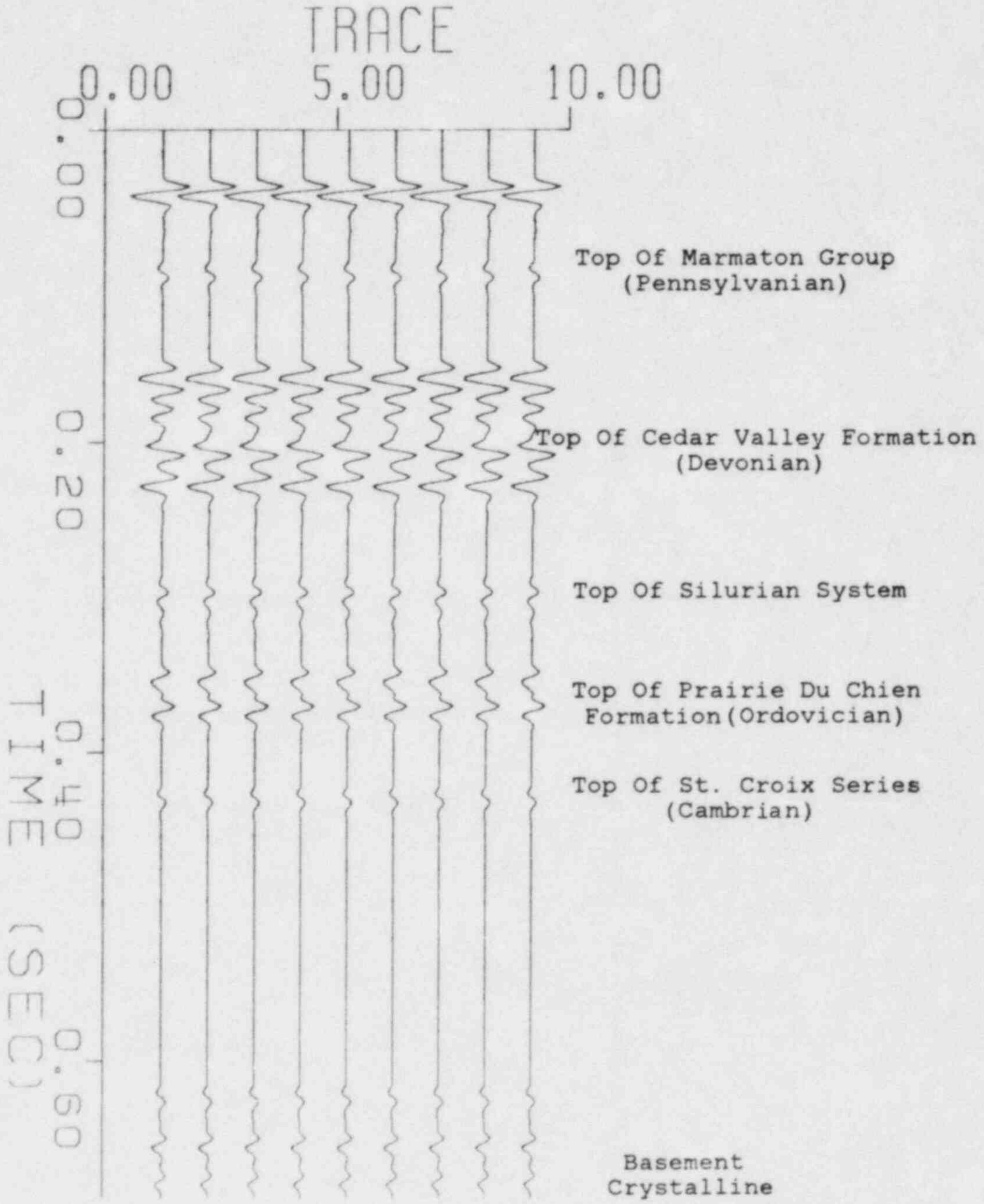


Figure A10. One-Dimensional Synthetic Seismogram from the Malvern Traverse.

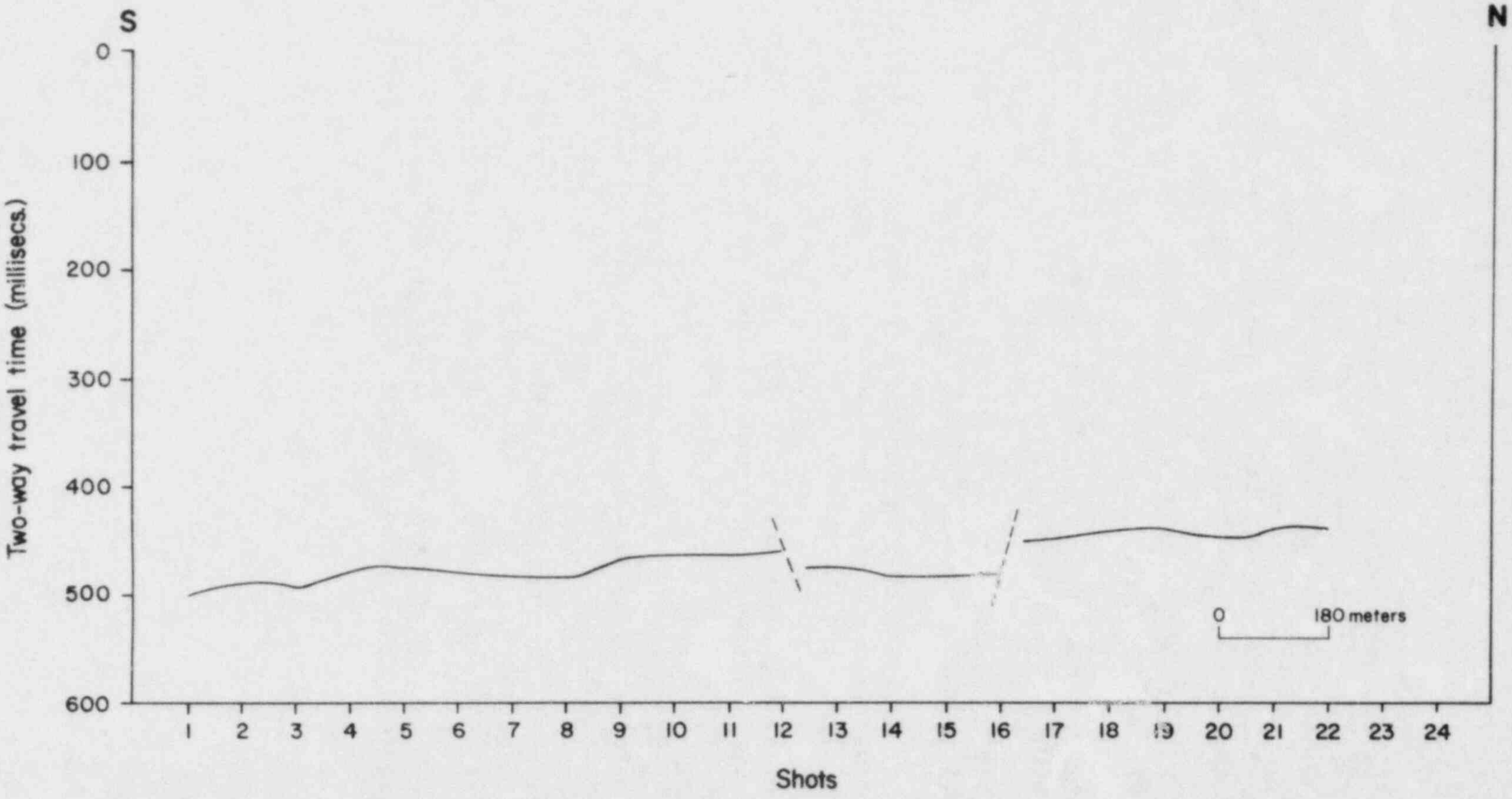


Figure A11. Structural Interpretation of Harlan Traverse.

REFERENCES

Bunker, B. J., 1981, Phanerozoic Structural Development in the Area of the Forest City Basin, Southwestern Iowa (A Brief Overview): U.S. Nuclear Regulatory Commission NUREG/CR-2548, p. 42.

Daut, S. W., 1980, Gravity Study of the Thurman-Redfield Structural Zone in Southwest Iowa: M.S. thesis, University of Iowa, 118 p.

Dobrin, M. B., 1976, Introduction to Geophysical Prospecting, 3rd Edition: McGraw-Hill, 630 p.

E. G. and C. Geometrics, 1979, Operating Manual, ES 1210F engineering seismograph: Sunnyvale, Ca., 21 p.

Faller, T. H., 1981, Seismic Activity in Southwest Iowa: U.S. Nuclear Regulatory Commission NUREG/CR-2548, p. 62.

Hunter, J. A., 1980, Mating the digital engineering seismograph with the small computer--some useful techniques: Society of Exploration Geophysicists Annual Meeting, 18 p.

Lankston, R. W., and Lankston, M. M., 1981, An Introduction to the Utilization of the Shallow or Engineering Seismic Reflection Method: Geo-Compu-Graph Inc., Spokane, Wa., 27 p.

Logel, J. D., 1981, Interpretation of Seismic Profiles Across the Thurman-Redfield Structural Zone: U.S. Nuclear Regulatory Commission NUREG/CR-2548, p. 12.

McDonal, F. J., Angona, F. A., Mills, R. L., Sengbush, R. L., Van Nostrand, R. G., and White, J. E., 1958, Attenuation of Shear and Compressional Waves in Pierre Shale: Journal of Geophysics, v. 23, p. 421-439.

Stander, T. W,. 1980, Structural Nature of the Humboldt Fault Zone in Northeastern Nemaha County, Kansas: M.S. thesis, University of Kansas, 53 p.

APPENDIX B

FINAL REPORT ON THE SOUTHWEST IOWA SEISMIC SYSTEM

by

Thomas H. Faller

Monitoring of seismic activity in and around southwest Iowa began December 1979, when the station near Carbon, Iowa (CAI) became operational. Three more stations were installed by August of the following year, with the last station coming on line in October. The stations straddle the Midcontinent Geophysical Anomaly (MGA) and two major fault zones, the Thurman-Redfield Structural Zone and the Northern Boundary Fault Zone. Exact station locations are given in Figure B1 and Table B1. Station siting procedure was discussed in NUREG/CR-1876 by S. Daut, who made the site determinations. Although siting procedure will not be reviewed here, it is important to note that despite similar siting requirements, terrain and soil type vary from location to location, giving each station a unique signature with regard to seismic activity and background noise.

Station instrumentation and data transmission were discussed in NUREG/CR-2548 by T. Faller; the types and characteristics of observed seismic events were also explained. A listing of regional microseisms current through 5/15/82 is given in Table B2.

The number of local microseisms, including identified quarry blasts has decreased slightly during this report period (August 1981 - June 1982). No reason for this decrease is known.

SYSTEM DOWN TIME

During the past year drastic station problems have reduced the quantity of usable data collected from the seismic monitoring system. A breakdown of the causes of data loss, along with estimates of the chances of a particular station having problems are presented in Table B3 and Table B4. The figures are given for the three-year operating period, as well as for the 1981-82 study year, beginning June 1, 1981.

Note that the figures are averages for all stations, and do not reflect particular problems at a station. For instance, CAI and ESI had repeated water damage, which accounts for most of the percentage given in the table under that category. Other stations had only minor water damage. Also, station repair took much longer than usual this year because of unusually severe winter weather conditions.

EQUIPMENT FAILURE

Nearly every piece of equipment, in the field and in the office, needed mechanical or electrical repair over the three year study period. Some re-

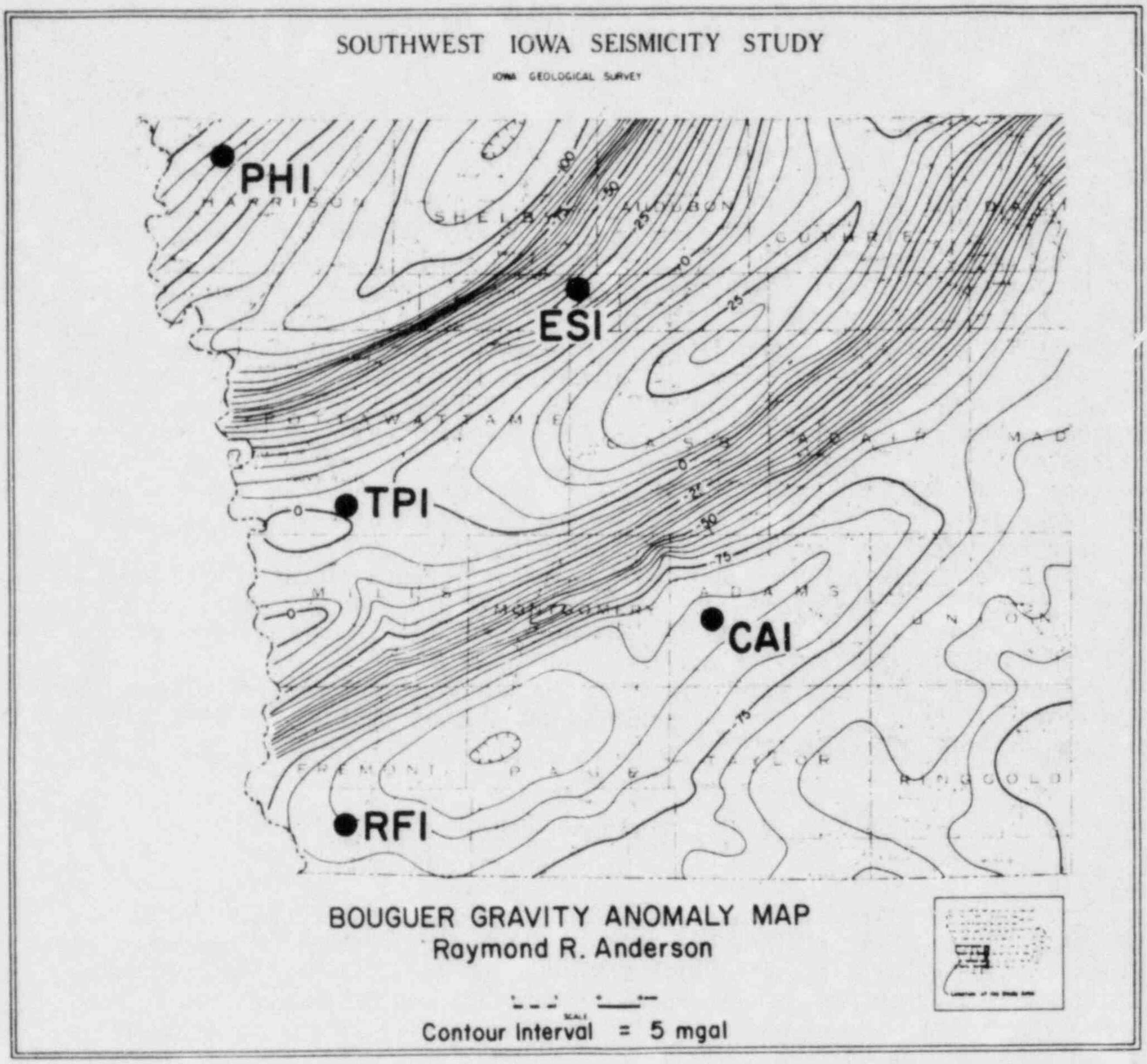


Figure B1. Earthquake Monitoring Stations.

Table B1. Iowa Geological Survey - Earthquake Network

Identification	Town and County	Latitude (W)	Longitude (N)	Elevation (meters)	Beginning Operational Date
CAI	Carbon, Adams	41.034133	94.818166	355	Dec. 19, 1979
ESI	Elkhorn, Shelby	41.579443	95.150277	376	May 5, 1980
PHI	Pisgah, Harrison	41.826943	95.845833	384	Aug. 18, 1980
TPI	Treynor, Pottawattamie	41.234444	95.534999	351	Aug. 21, 1980
RFI	Riverton, Fremont	40.689166	95.566111	308	Aug. 21, 1980

Table B2. Regional Microseisms

Date	Origin Time (UMT)	Magnitude	Latitude*	Longitude*	# of stations reporting
10/29/80	23:23:	1.5	40° 15' N	95° 30' W	4
11/2/80	10:03:33.5	3.0	36° 15'	96°	5
4/20/80	18:18:13.5	2.5	41°	98° 15'	4
5/30/81	9:07:11.4	1.9	39° 30'	94° 30'	5
6/26/81	18:55:02.3	2.6	41° 45'	97° 45'	5
10/9/81	21:54:28	2.8	41°	99°	4
2/2/82	9:28:22	aftershock from New Madrid 1/20			3
3/1/82	00:13:55	aftershock from New Madrid 1/20			2

pairs were minor, or infrequent, such as replacement of printed circuit board relays or drum recorder motors. Other repairs were minor, but constituted a major cause of data loss, for example: problems with drum recorder pens and paper. The original pens and paper supplied with the system interacted to produce frequent clogging and exaggerated pen wear. The system was very sensitive to ink chemistry as reflected by color; green or blue were the least likely to clog, red was unreliable, and black ink was unusable. A change to a lighter, thinner paper reduced pen wear, and a new, tapered pen style greatly reduced clogging problems.

Although the use of a voltage-controlled oscillator to convert seismic signals to a telemetered FM signal resulted in clearer signals than could be obtained by AM telemetry, the VCO module was our most fragile piece of electronic equipment, and in 1982, has been our major cause of data loss.

The VCO unit is sensitive to low voltage conditions. It operates on a +12V, and with less than about +10V supplied, it shuts down. Voltage imbalances between the amplifier circuits and the VCO circuits can destroy the module. The unit is described as waterproof, but damp exterior conditions result in interior corrosion. When malfunctioning, the unit has a tendency to "slop" into nearby frequency bands, affecting the data signals of stations with noise or spurious voltage surges.

On the positive side, the Geotech S-13 seismometer did not malfunction, even though submerged in corrosive liquid for weeks. Lightning surge protectors worked well, although a self-resetting circuit breaker would have been more efficient, as the blown fuses had to be replaced.

The DR-100 digital event recorder originally scheduled to record microseisms for later analysis was never used because the noise content of daily records was generally higher than the amplitude of observed microseisms. Filtering would have removed some of the frequency characteristics of microseisms useful in analysis. Although various schemes were proposed to allow digital recording and computer analysis of microseisms, the noise content of records and the infrequent occurrence of microseisms made them infeasible.

RECOMMENDATIONS

If this project continues with renewed funding, or if similar projects are begun, several suggestions for improvement of efficiency and data quality can be made. It is felt that if these suggestions are taken, system down time may be reduced to 5-10% overall, few significant microseisms will be missed due to recording medium failure, and preventive maintenance will replace repair as the technician's greatest concern.

The first recommendation is re-siting of seismometers to bedrock. This could be accomplished by using a smaller seismometer, or an accelerometer, and placing it at the bottom of a cased drill hole. This would increase signal-to-noise ratio so that an amplitude-triggered digital recorder could be used to record microseisms, eliminating dependence on paper-recorded signals. Drum recorders would probably still be used for verification, however.

Moving the other equipment above ground would reduce the problems of access and re-sealing the enclosure. However, the problems of vandalism and exposure to above-ground temperature and weather conditions could result. One solution is to build a sturdy enclosure inside county maintenance department yards. This would also simplify getting telemetry cables to the site. Some

Table B3

Sources of System Down-Time

Probability of 1, 2, 3, or more of the 5 station array being out of order at any given time

1 station	30%
2 stations	20%
3 stations	10%
more than 3 stations	2%

Causes of Data Interruption

(As a percent of total down-time)

1979-82	1981-82	
30%	5%	Telemetry line problems
40%	35%	Drum recorder problems
0.9%	0.9%	Drum Recorder Pen Problems
0.1%	0.1%	mechanical or electrical
1%	1%	Power failure in Iowa City
2%	2%	Base-station problems (clock, power supply, discriminator)
25%	7%	Station failure (see Table 4)
3%	7%	Miscellaneous

Table B4

Sources of Station Failure
(As a percent of total station-failure time-see Table 3)

1979-82	1981-82	
2%	10%	Loss of solar power
5%	0%	Blown fuses in lightning projector
10%	20%	Battery freezing
15%	30%	Station flooding
10%	2%	Data cables cut or loose
40%	20%	Insufficient voltage *
0	0	Seismometer failure
0	0	Lightning damage to instruments
18%	18%	Miscellaneous (includes station shutdown during repair)

*May affect data channels from other stations due to intermittent noise overload.

type of electrical temperature regulating system could be designed, using locally available power, instead of relying on a self-contained system.

It is felt that an FM signal is still the best for data transmission, but alternate means of telemetry, such as microwave or UHF transmission of data is feasible. Lastly, several portable stations would aid in station siting, and location of very local events.

CONCLUSIONS

The Southwest Iowa Seismic Monitoring System has gathered useful seismic data, showing low-level seismic activity, and fulfilling original study objectives, despite a number of problems with equipment and telemetry lines. Many of these problems can be reduced or eliminated by modifying the present equipment configuration.

REFERENCES

Anderson, R. R., 1980, Bouguer Gravity Anomaly Map of Iowa: Misc. Map Series 7, Iowa Geological Survey.

Van Eck, O. J, Daut, S. W., Anderson, R. R., 1981, Regional Tectonics and Seismicity of Southwestern Iowa, Technical Progress Report NUREG/CR-1876, Iowa Geological Survey.

Van Eck, O. J, 1982, Regional Tectonics and Seismicity of Southwestern Iowa, Technical Progress Report NUREG/CR-2548, Iowa Geological Survey.

APPENDIX C

SOUTHWEST IOWA GRAVITY DATA COLLECTION ANALYSES AND INTERPRETATIONS

by

Calvin Cumerlato

INTRODUCTION

Measurements of the Earth's gravitational and magnetic fields have proven particulary useful in interpreting the geologic configurations of subsurface features. Lateral variations in the Earth's gravitational field can be related to variations in densities, depths, attitudes and other structural features of the Earth's crust. Magnetic field data provide, among other things, information concerning lithologic variations and depths to the sources of anomalies, most often associated with igneous basement materials. Combined with existing direct information from drill holes and outcrops, and more recently with seismic reflection data, potential field data may be used in extrapolative or interpolative fashion to produce models of the subsurface where the costs and difficulties of obtaining direct information are prohibitive.

This report serves as a final summary of all gravity field work completed to date in southwest Iowa by the Iowa Geological Survey under the U.S. Nuclear Regulatory Commission Contract number NRC-0478-228, and describes 5 detailed gravimeter traverses conducted during June through August, 1981. All data were obtained using the Worden Prospector Model 112 gravimeter number 751 owned by the Iowa Geological Survey, which is sensitive to ±.01 milligals and accurate to ±.05 milligals. Methods of data collection, analysis and interpretation, including types and locations of gravity stations established as well as the quantitative and qualitative analytical techniques employed in generating subsurface models, are presented.

INITIAL WORK

During June and July, 1979, 309 stations were added to the gravity network in southwest Iowa by Steven Daut (Daut, 1980). A regional grid which consisted of 194 township-center stations spaced at ~9.6 km (6 miles) was established by a series of loops referenced to the airport gravity base station network previously established by Hase, et al (1969). In addition, a series of 5 detailed traverses were conducted across the Thurman-Redfield Structural Zone consisting of 115 stations spaced at 305 m (1000 ft.) Figure

C1. The results of Daut's work, including computer generated subsurface models from the detailed gravity data, are presented in NUREG/CR1876, "Regional Tectonics and Seismicity of Southwestern Iowa," and will not be repeated here. Further use of Daut's work was made by Anderson (1981) in compiling a Bouguer Gravity Anomaly Map of Iowa.

SUBSEQUENT WORK

In the spring of 1980, it was determined that additional gravity work over the northern flank of the Midcontinent Geophysical Anomaly (MGA) in southwest Iowa would provide useful information necessary for a better assessment of regional gravity trends and for modeling of Precambrian features in that portion of the study area. Consequently, during May through August, 1980, the author established 1340 supplementary gravity stations or reference points (Cumerlato, 1982). These supplementary stations, included on a continuous 106 Km (66 miles) north-south traverse across the entire MGA, were spaced at ~1.6 Km (1 mile) and are considered accurate to ± 1.75 milligals (Figure C1).

PRELIMINARY ANALYSES AND TRAVERSE SELECTION

Program GRAVSUR developed by Kwon, et al (1977) and modified by Susan Daut for use on the Perkin-Elmer 3220 minicomputer at the Iowa Geological Survey, was used to reduce the gravimeter readings to simple Bouguer anomaly values. For calculation of Bouguer values at the supplementary regional stations, a standard 2.67 gm/cm^3 density was assumed for the materials from the surface to a sea level datum.

As suggested by Daut (1980), further detailed gravity work along the northern flank of the MGA in southwest Iowa would be expected to determine the presence of faulting in that region. This was the objective in selecting locations for the detailed traverses to be discussed in this report.

As a first step in this process all available Bouguer gravity anomaly data for southwest Iowa, including data collected by Daut, Cumerlato, and data compiled by the National Oceanographic and Atmospheric Administration (NOAA), were used to assess regional gravity trends in the study area. This was accomplished by the use of a computer program developed by Coons (1966), and modified by Ross Black and the author for use on the Perkin-Elmer. The program uses a least squares surface fitting method capable of calculating regional and residual surfaces up to the 14th degree from randomly spaced geophysical data.

Keeping in mind the level of accuracy of the regional data and the purposes for which the gravity work was conducted, an examination of the Bouguer Gravity Anomaly Map of Southwest Iowa (Anderson, 1981) led to the choice of a 4th degree surface as most accurately defining the long wavelength features of the Bouguer anomaly field in the entire study area. Removal of the 4th degree regional surface (Figure 2C) from the total Bouguer gravity anomaly values yielded a 4th degree residual surface (Figure 3C). The residual gravity map was then analyzed to select locations for more detailed gravity traverses with the idea of accurately locating faults along the northern flank of the MGA.

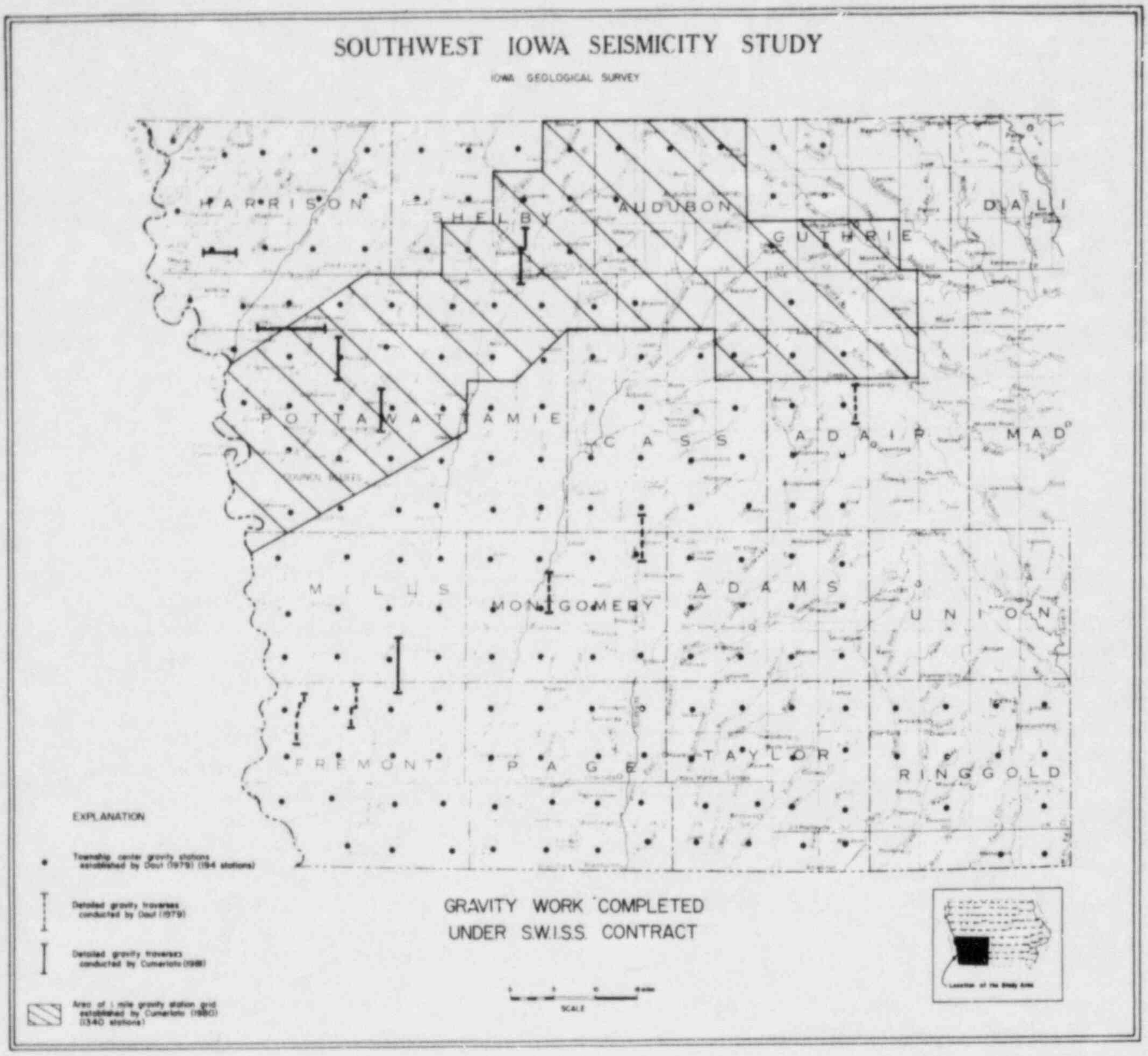


Figure C1. Types and locations of all gravity stations established.

As shown in Figure 3C, three north-south traverses crossing the northern flank of the MGA were selected near the towns of Harlan, Bentley and Underwood, Iowa. One additional north-south traverse site, near the town of Malvern, Iowa, crossing the southern flank of the MGA was also selected to be conducted in conjunction with shallow seismic investigations discussed by Logel in this volume.

Finally, two east-west traverse sites were selected north of the MGA in Harrison County near Logan and Beebeetown, Iowa. These traverses were chosen to investigate the possible extension into Iowa of the Humboldt Fault System, known from deep well data in eastern Nebraska (Burchett and Carlson, 1966 and Carlson, 1967).

DETAILED GRAVITY DATA COLLECTION AND REDUCTION

These six (6) detailed gravity traverses were conducted during June through August, 1981 with the gravity stations, spaced at about 402 m (.25 miles), located at road intersections and along road shoulders between intersections. Latitudes and longitudes accurate to ±1 second of arc were digitized from dimensionly stable Iowa Department of Transportation county highway maps using a Tektronix digitizing table and graphics terminal at the Iowa Survey. Since elevation and density errors are usually the sources of greatest errors in reduced gravity values, station elevations were obtained by electronic leveling accurate to ±.03 (.1 ft.) A separate datum for each traverse was selected at, or slightly below bedrock, and carefully integrated density values for materials down to each datum were calculated for each station using data from the Iowa Geological Survey well log files.

Standard corrections made to the field data in this study included conversion of instrument units to milligals, an adjustment for diurnal variation in gravity due to the effect of solid earth tides, a latitude correction, an instrument drift correction and the free air and Bouguer corrections down to datum (See Dobrin, 1976). All corrections were calculated using program GRAVSUR (Kwon, et al, 1977) and final gravity values are assumed to be accurate to ±.25 milligals, which is the level of accuracy necessary to resolve the estimated ±.50 milligal anomalies caused by faulted basement blocks in the study area.

DATA ANALYSIS

Before subsurface modeling was undertaken, it was necessary to remove a regional trend from the corrected Bouguer gravity data for each traverse. This is the standard analytical technique used to isolate the shorter wavelength features in the gravity data caused by local anomalous subsurface structures. It was also assumed that any regional isostatic anomalies resulting from the area being isostatically over/under-compensated, would be removed.

Regional data collected by Daut, Cumerlato and that compiled by NOAA were available, and data "windows" 10 to 20 times the size of the smallest feature to be mapped were chosen for each traverse. Bouguer gravity data, reduced to sea level using a 2.67 gm/cm^3 Bouguer density, were plotted and contoured for each window. Once again utilizing the least squares surface fitting program, the regional data for the Malvern, Harlan, Underwood, and Bentley traverses were fit

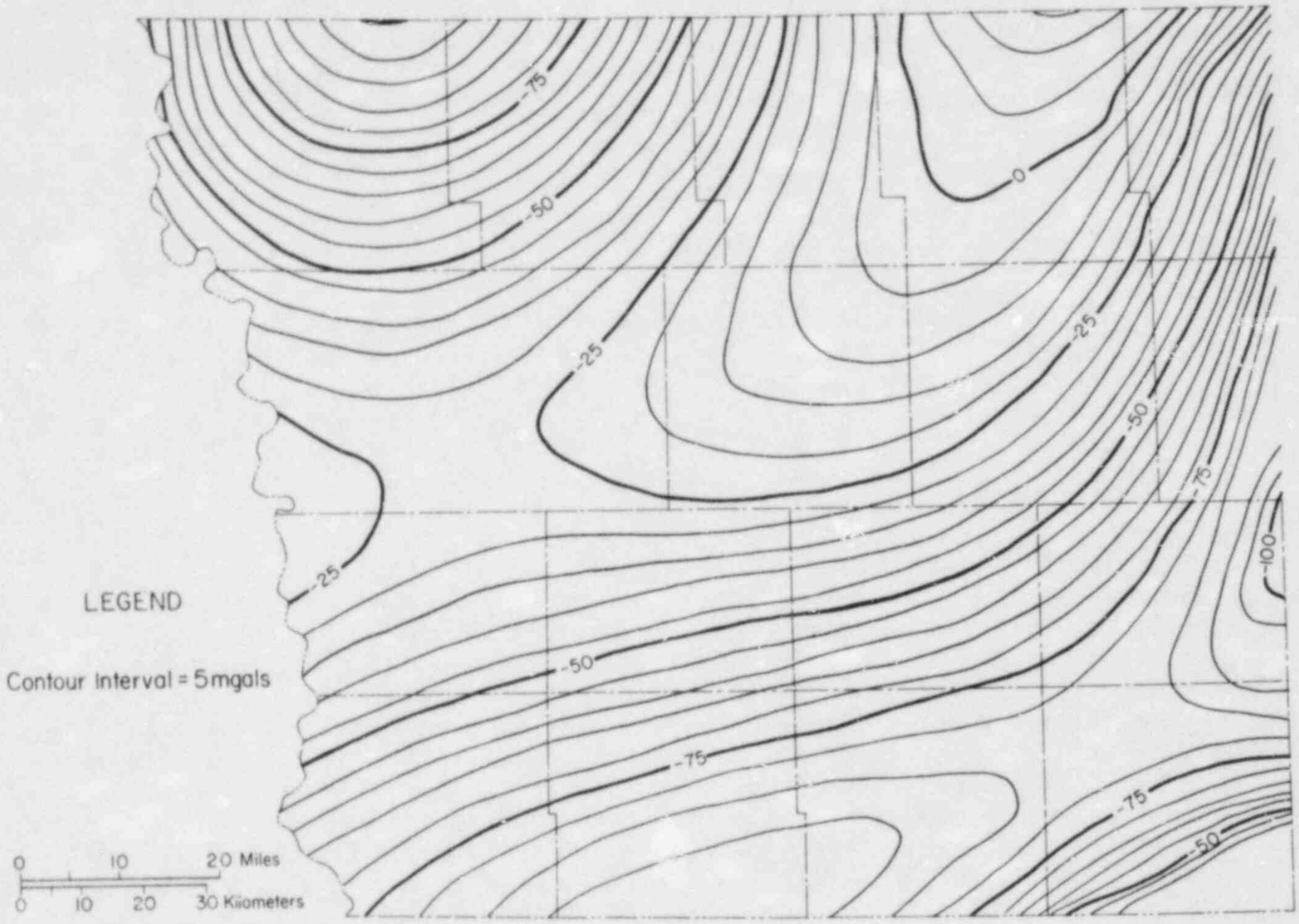


Figure C2. Calculated 4th degree regional gravity surface.

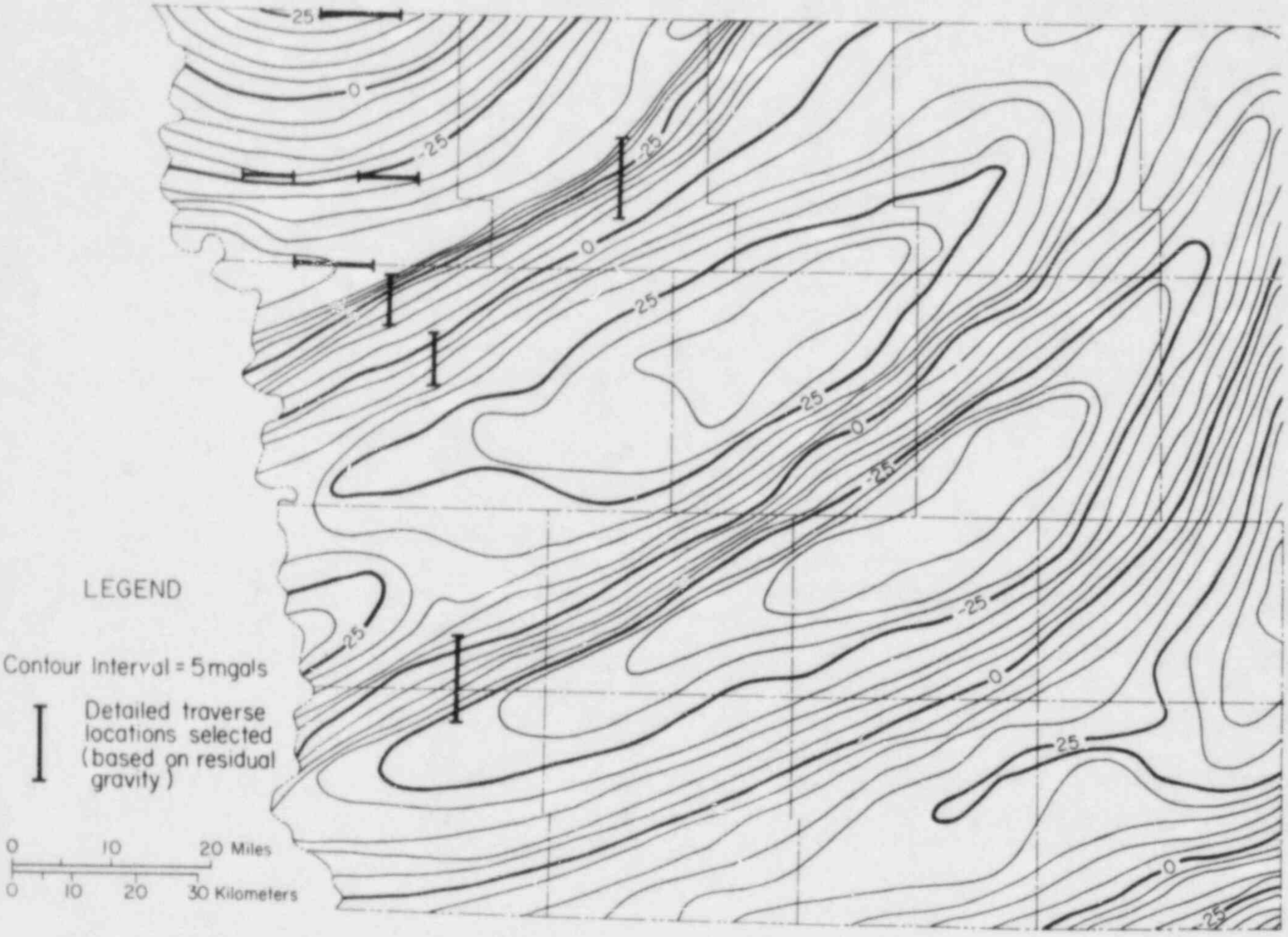


Figure C3. Calculated 4th degree residual gravity surface.

to 3rd degree surfaces while the regional data for the Logan and Beebeetown traverses were fit to 2nd degree surfaces. By subcontracting the regional value at each station from the total Bouguer gravity value, residual values were obtained (Figure C4).

The upper profile in Figure 5C is the 3rd degree residual data for the Malvern traverse. Apparent in the profile, and all others, are a number of very short wavelengths or high frequency "spikes". These spikes are probably the result of errors in densities used in the detailed Bouguer corrections. To help remedy this situation, the residual data was "smoothed" using a simple 3-point moving average. The smoothed data is the lower profile of Figure C5.

SUBSURFACE MODELING AND GEOPHYSICAL INTERPRETATIONS

Two-dimensional modeling of the smoothed residual Bouguer gravity data for all traverses was conducted using the program GRAVZDO developed by Shanabrook, et al (1977) at Michigan State University and modified by Ross Black to run on the Perkin-Elmer. The program calculates a gravity profile over buried bodies of arbitrary shapes that have infinite length perpendicular to the profile. For the modeling, densities of 2.99 gm/cm^3 for volcanics, 2.47 gm/cm^3 for Precambrian clastics and 2.55 gm/cm^3 for the overlying Paleozoic package were used (Anderson and Black, 1981). These densities were contrasted against 2.67 gm/cm^3 for granite. Depth constraints were inferred from Iowa and eastern Nebraska well data, and as an additional constraint, several depths estimated by Henderson, et al (1963) from aeromagnetic data collected over central and southwest Iowa were evaluated and used in modeling. Figures C6 through C10 show the final two-dimensional models arrived at using the residual Bouguer gravity data from 5 of the 6 traverses.

It should be kept in mind that there are an almost infinite number of subsurface configurations which will produce the same gravity signature at the surface and thus the values obtained do not uniquely determine any specific configuration. The models presented constitute the best synthesis of all geological and geophysical data available and do not deviate to any great degree from previous interpretations, other than helping to refine them.

a. <u>Malvern Traverse</u> (Figure C6)

The Malvern gravity traverse extends from the common corner of Secs. 2, 3, 10, and 11, T71N, R41W in Mills County south to the common corner of Secs. 10, 11, 14, and 15, T70N, R41W in Fremont County. A total of 29 stations was measured along 11.3 Km (7 miles) of traverse, the northern 8 Km (5 miles) of which coincides with the location of the Malvern seismic reflection traverse (Logel, 1982).

The residual gravity curve shows about 6 milligals of relief with an obvious relative low near the middle of the traverse at station 15, flanked by relative highs. The model was conceived as an attempt to comply with interpretations of tensional rifting, subsidence and fissure eruptions during the late Precambrian (Green, 1979). The model shows blocks of volcanics flanking a small clastic-filled depression which may have resulted from subsidence of volcanics or granite. A comparison of this model with the interpretation of the seismic data collected along the same traverse shows close agreement in depths, lithologies and configuration, however this model

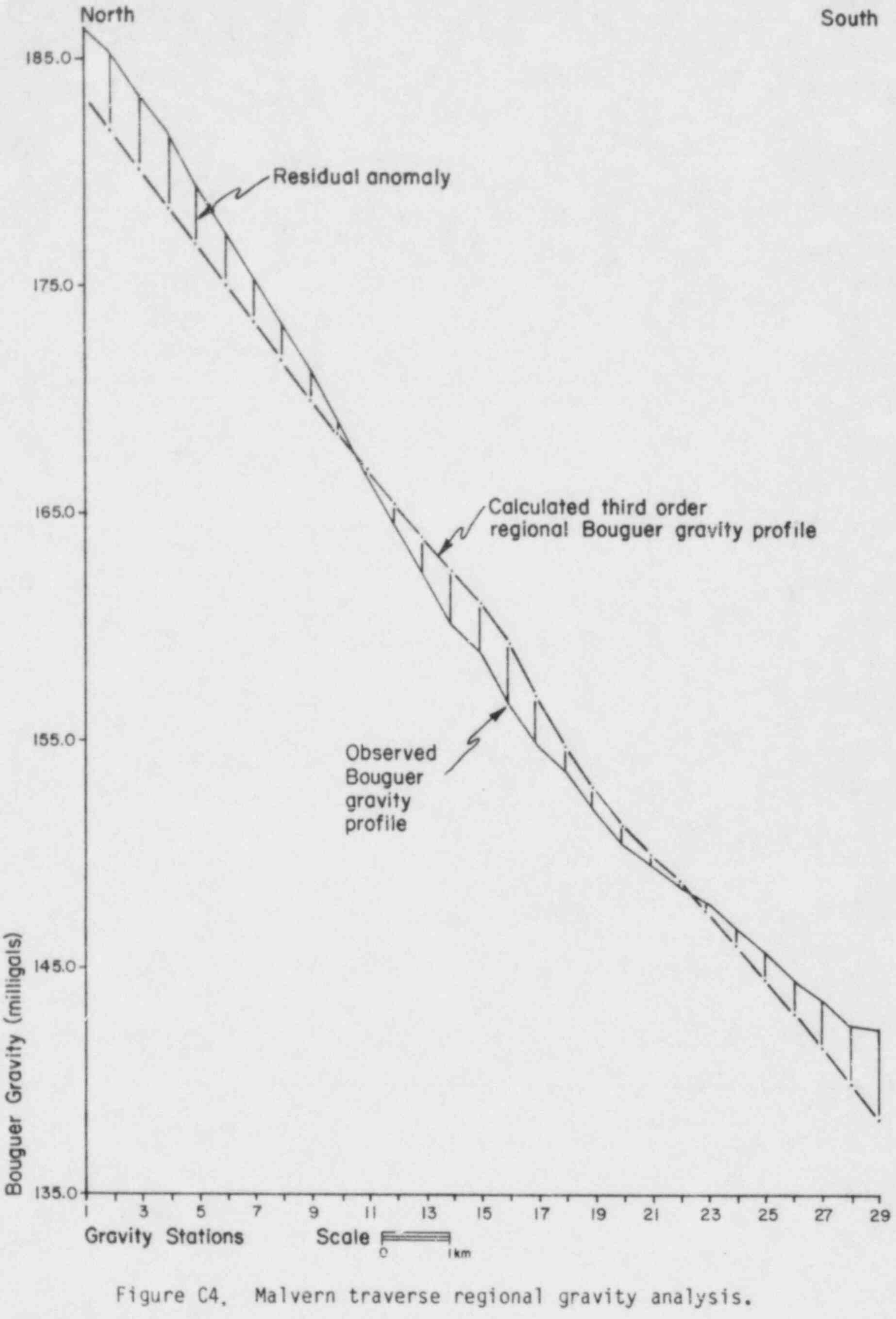
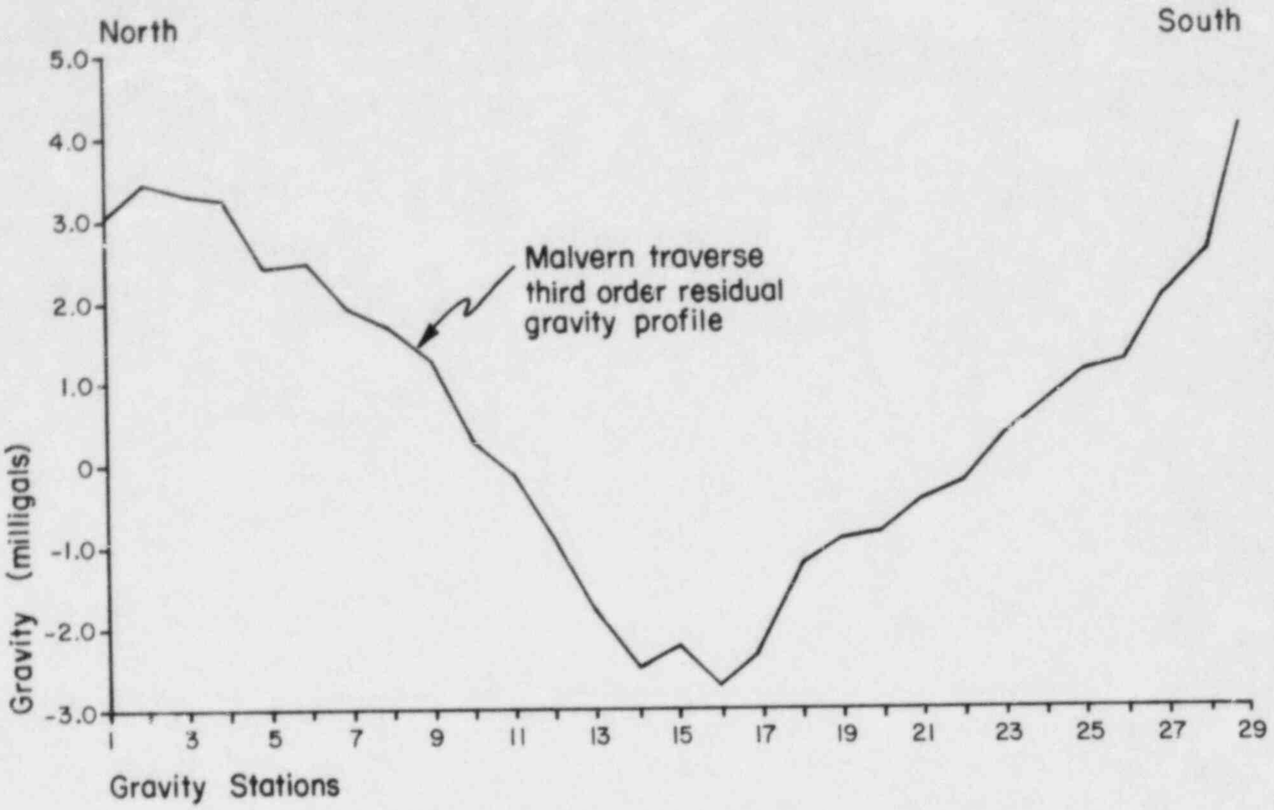


Figure C4. Malvern traverse regional gravity analysis.



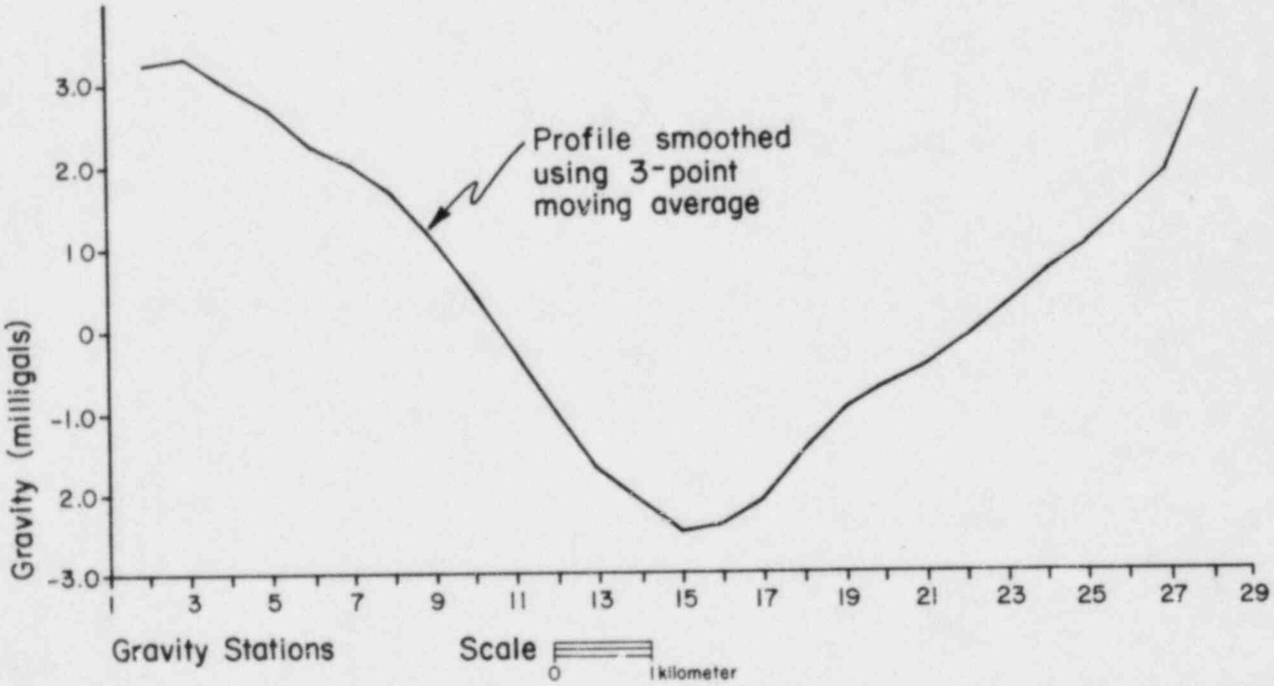


Figure C5. "Smoothing" residual gravity data with 3-pt. moving average.

shows considerably more throw on faults than shown by Daut's detailed work in the same area (Daut, 1980).

b. Harlan Traverse (Figure C7)

The Harlan gravity traverse extends from the common half section point of Secs. 2 and 3, T79N, R38W south to the common corner of Secs. 5, 6, 7, and 8, T78N, R38W in Shelby County. A total of 31 stations were measured along 12 Km (7.5 miles) of traverse. Since the northern 4 Km (2.5 miles) of the traverse are located approximately 400 m (.25 miles) east of the southern 8 Km (5 miles) portion, the residual gravity curve is shown in 2 parts.

This curve shows about 13 milligals of relief and has the general shape that one would expect across a vertical or near vertical fault, the steepness of the curve being related to the throw on the fault (Dobrin, 1976). A previous interpretation by Anderson and Black (1981) using gravity values taken from the Bouguer Gravity Anomaly of Iowa showed a vertical fault in the Precambrian surface trending northeast-southwest of about 4 Km (2.5 miles) south of the beginning point of the Harlan traverse. The throw was postulated to be about 2000 m (6500 ft.). During modeling of the current residual gravity values, it was found impossible to obtain a fault block model with throw greater than approximately 1000 m (3300 ft.) that would produce a similar residual gravity signature.

The discrepancy was discovered by the author to stem from the fact that the values picked by Anderson and Black were along a line perpendicular to the trend of the gravity high, while the Harlan traverse runs directly north-south making an angle of approximately 35° with the line perpendicular to the gravity trend. By multiplying the station spacing of the Harlan traverse by cos 35° the traverse length was effectively "collapsed" to 82 percent of its original length simulating a line measured perpendicular to the gravity trend. With the traverse length reduced to approximately 9.8 Km (6 miles) the residual curve was steepened enough to allow a fault block model showing nearly 2000 m (6000 ft.) of throw, in closer agreement with the previous interpretation. An additional downthrown block about 1000 m (3300 ft.) from the southern end of the traverse is also postulated to account for the flattening of the residual curve at that end. This also complies with the interpretation by Logel (1982) of a downthrown block of Paleozoic rocks from seismic reflection data collected along the same traverse.

c. Underwood Traverse (Figure C8)

The Underwood traverse extends from the common corner of Secs. 3, 4, 9, and 10, T77N, R42W south to the common half section point of Secs. 33 and 34, T77N, R42W in Pottawattamie County. A total of 19 stations was measured along 7.2 Km (4.5 miles) of traverse. The residual curve shows approximately 6 milligals of relief over this distance, but once again it was found that this traverse should be collapsed by a factor equal to cos 25°; 25° being the angle made by the traverse and a line perpendicular to the gravity trend in this area. The traverse was thus reduced to 90 percent of its original length or about 6.5 Km (4 miles).

As shown in the model, 2 major faults are postulated. The rapid decrease in residual gravity in the northern part of the traverse can be related to about 4000 m (13,000 ft) of throw for block faulted volcanics. The leveling off of the curve followed by a moderate increase has been related to another block fault with approximately 900 m (3000 ft.) of throw in the southern part of the traverse. The enormous amount of throw on the northern fault is not thought to be unreasonable since previous calculations by Lidiak (1972) suggested vertical thicknesses of up to 3000 m (10,000 ft.) for sediments flanking the gravity high, while Anderson and Black (1981) have modeled clastic sediments at depths approaching 7000 m (23,000 ft.) below sea level in the Defiance Basin.

d. Bentley Traverse (Figure C9)

The Bentley traverse extends from the common corner of Secs. 4, 5, 8, and 9, T76N, R41W south to the southern common corner of Secs. 32 and 33, T76N, R41W in Pottawattamie County, 8 Km (5 miles) east and 1.6 Km (1 mile) south of the Underwood traverse. A total of 21 stations was measured along 8 Km (5 miles) of traverse, which was effectively collapsed to 7.2 Km (4.5 miles) or 90 percent of its original length.

The residual curve shows only about 1 milligal of relief which makes modeling of any significant structures in this area difficult. It is believed that the entire traverse was measured over the Iowa Horst in the western part of the study area discussed by Anderson and Black (1981). If that is the case, then the 1 milligal decrease in residual gravity from the northern to the southern end of the traverse is probably related to i) southerly dip of the horst surface, ii) local topography on the surface of the horst, or at best iii) very minor faulting as postulated in the model.

e) Logan Traverse (Figure C10)

The Logan traverse extends from the common corner of Secs. 20, 21, 28, and 29, T79N, R44W east to the eastern common corner of Secs. 24 and 25, T79N, R44W in Harrison County. A total of 18 stations was measured along 6.4 km (4 miles) of traverse. As mentioned earlier, this traverse was conducted to investigate the possible extension of the Humboldt Fault System.

The residual curve resulting from removal of only a 2nd degree regional trend surface shows practically no relief. Deviation from zero is often less than the expected error of ±.25 milligals. Therefore, it is concluded that no faulting is present below this traverse. Further, the traverse likely overlies a gently sloping granitic basement terrain of the Defiance Basin. Depth to the crystalline surface in this area is estimated to be in excess of 7000 m (23,000 ft.) below sea level (Anderson and Black, 1981).

Modeling of the final traverse, conducted near Beebeetown to investigate the Humboldt Fault System, was abandoned for the following reasons. During surveying of elevations in the field the electronic leveling device was damaged so that elevation data accurate only to ±3 m (10 ft.) for most stations, taken from I.G.S. 7.5 minute topographic maps, were all that was available. This problem was compounded by the traverse being located in an area of considerable surface relief in the Western Loess Hills region of southwest Iowa, making data quality questionable. In addition, the results from the Logan traverse, measured in an area with a regional trend similar to that at Beebeetown, suggest that faulting probably does not occur under this traverse either.

CONCLUSIONS

a.) Perhaps the most significant conclusion to be made stems from the close agreement in depths, lithologies and structures between the seismic reflection data and the gravity model for the Malvern traverse. Faulting in the Paleozoics shown on the seismic interpretation can be related to deeper faulting in the Precambrian, i.e., Paleozoic faulting is basement controlled in this region. This leads to the conclusion that at least the area along the southern flank of the MGA has remained tectonically active throughout most of Paleozoic time.

b.) The Harlan gravity model, on the northern flank, adds a downthrown block of Precambrian volcanic rock between two major faults previously modeled by Anderson and Black (1981) and nearly coincident with a similar structure interpreted from seismic data. Although the seismic data here is not as detailed or as well processed as the Malvern data, basement control of faulting in the Paleozoics should not be ruled out.

c.) At Underwood an additional fault downthrown to the north is postulated and may account for part of the throw modeled on the major fault to the north by Anderson and Black (1981). No additional major structural features can be inferred on the Iowa Horst to the south at Bentley.

d.) The absence of basement faulting indicated by the Logan data has led to the conclusion that the Humboldt Fault System has been terminated south of or within the Iowa Horst.

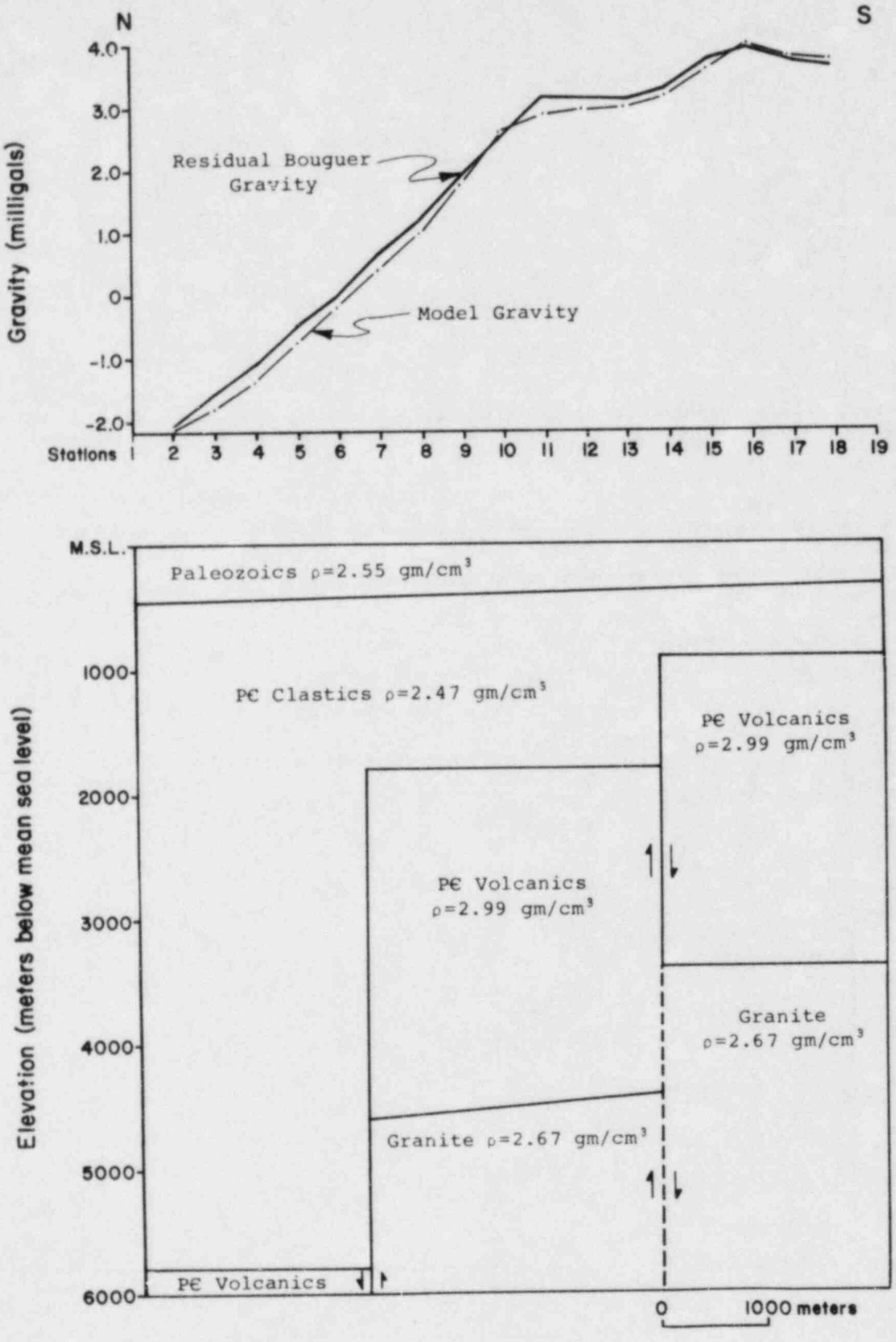


Figure C8. Underwood traverse model

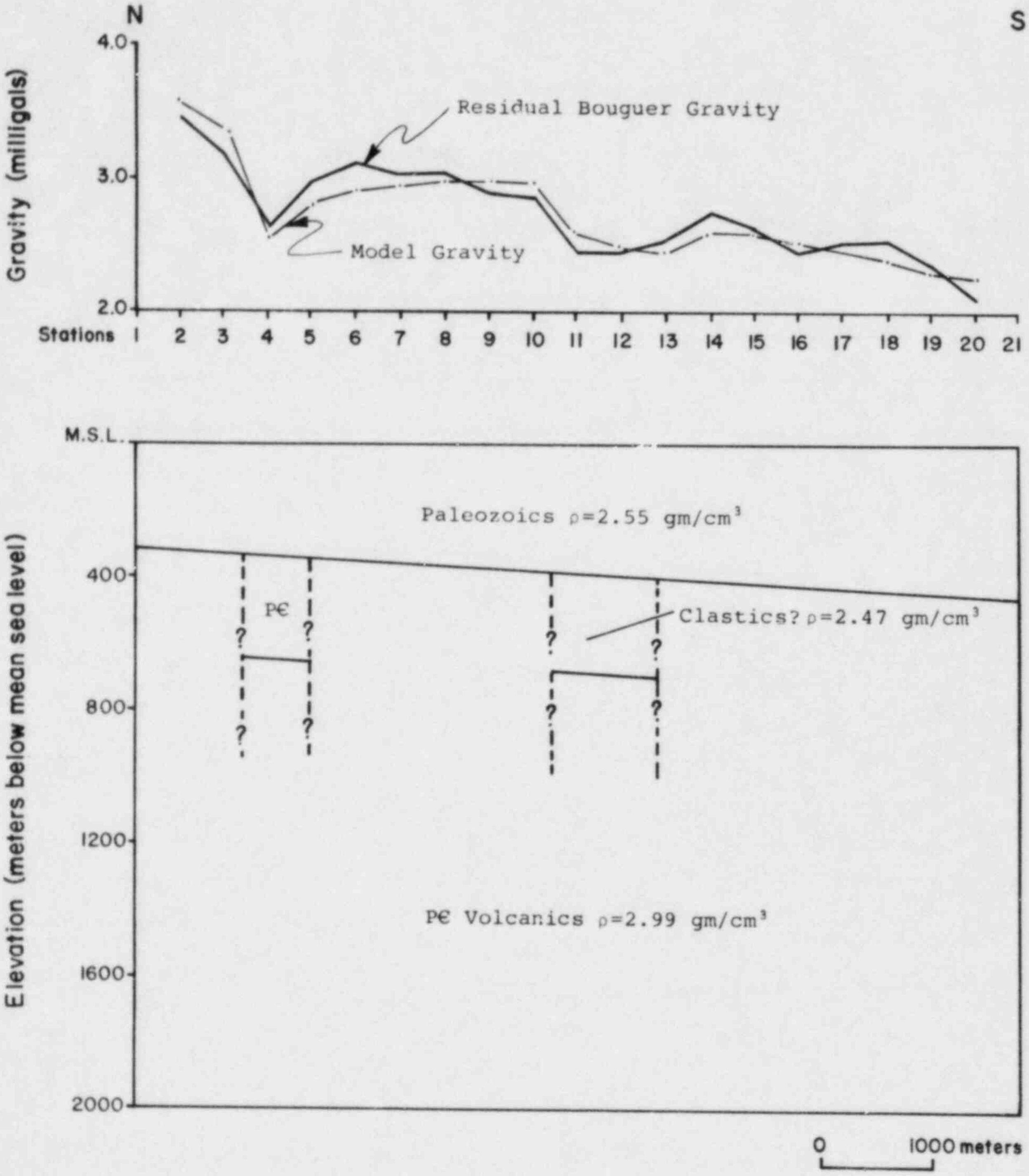


Figure C9. Bentley traverse gravity model.

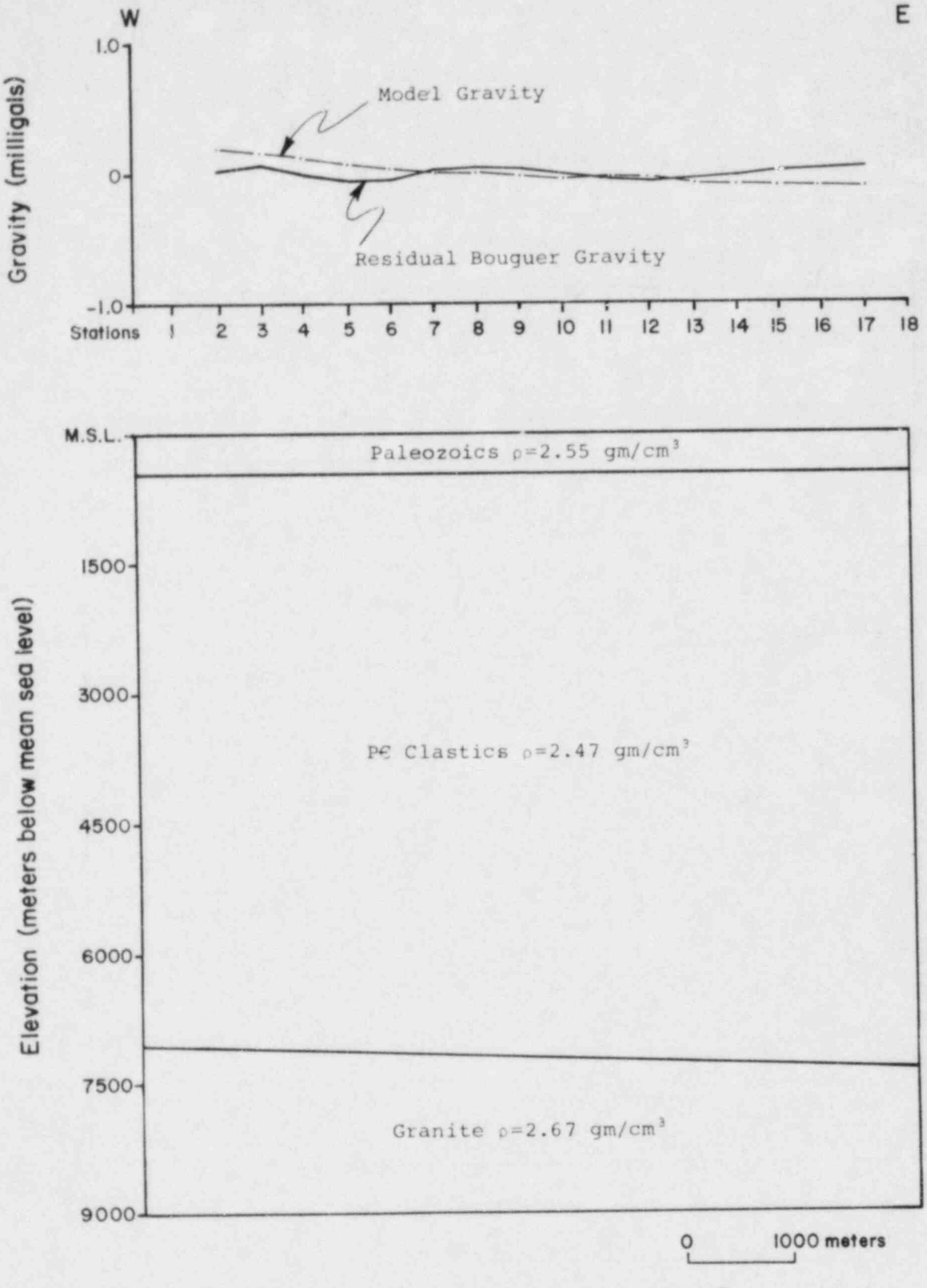


Figure C10. Logan traverse gravity model.

REFERENCES

Anderson, R.R., 1981, Bouguer Gravity Anomaly Map of Iowa, Misc. Map Series 7, Iowa Geological Survey.

Anderson, R. R., and Black, R. A., 1982, Geologic Interpretations from Geophysical Models of the Midcontinent Geophysical Anomaly in Southwestern Iowa: in Regional Tectonics and Seismicity of Southwestern Iowa, NRC report NUREG/CR-2548, pp. 27-41A.

Burchett, R.R. and Carlson, M.P., 1966, Twelve Maps Summarizing the Geologic Framework of Southeastern Nebraska, Report of Investigations no. 1, Nebraska Geological Survey, 14 p.

Carlson, M.P., 1976, Precambrian Well Data in Nebraska including Rock Type and Surface Configuration, Nebraska Geological Survey Bulletin no.25, 123 p.

Coons, R.L., 1966, Precambrian Basement Geology and Paleozoic Structure of the Midcontinent Gravity High, Ph.D. thesis, University of Wisconsin, 296 p.

Cumerlato, C.L., 1981, Supplementary Regional Gravity Data for Southwest Iowa, Iowa Geological Survey Open File Report, 26p.

Daut, S.W., 1980, Gravity Study of the the Thurman-Redfield, Structural Zone in Southwest Iowa, M.S. thesis, University of Iowa, 118p.

Dobrin, M.B., 1976, Introduction to Geophysical Prospecting, 3rd ed., McGraw-Hill, 630p.

Green, J.C., 1979, Field Trip Guidebook for the Keweenawan (Upper Precambrian) North Shore Volcanic Group, Minnesota, Minnesota Geological Survey Guidebook Series no. 11, St. Paul, 22p.

Hase, D.H., Campbell, R.B. and Van Eck, O.J, 1969, Iowa Gravity Base Station Network, Iowa Geological Survey Report of Investigation no.8, 17p.

Henderson, J.R., et al, 1963, Preliminary Interpretation of an Aeromagnetic Survey in Central and Southwestern Iowa, U.S. Geological Survey Bulletin no. 15, 151p.

Kwon, B.D., Rudman; A.J. and Blakely, R.F., 1977, Fortran Program for Reduction of Gravimeter Observations to Bouguer Anomaly, Indiana Geological Survey Occasional Paper 23, 32p.

Lidiak, E.G., 1972, Precambrian Rocks in the the Subsurface of Nebraska, Nebraska Geological Survey Bulletin no. 26, 41p.

Logel, J. D., 1982, Interpretation of Seismic Profiles Across the Thurman-Redfield Structural Zone: in Regional Tectonics and Seismicity of Southwestern Iowa, NRC report NUREG/CR-2548, pp. 12-26.

Shanabrook, D., Ciolek, W., and Locher, M., 1977, Documentation of the Gravity and Magnetic Modeling Programs of the Department of Geology of Michigan State University, unpublished.

Van Eck, O. J, Daut, S. W., and Anderson, R. R., 1982, Regional Tectonics and Seismicity of Southwestern Iowa: NRC report NUREG/CR-1876, 36 p.

APPENDIX D

RESULT OF GEOLOGICAL AND GEOPHYSICAL STUDIES IN SOUTHWEST IOWA, 1979-1982

by

Raymond Anderson

ABSTRACT

For the last four years the Iowa Geological Survey (IGS) has been involved in a study of the depositional and tectonic history of southwestern Iowa and adjoining areas as it might relate to past, present, or future seismicity in the area. The study, conducted under contract with the U.S. Nuclear Regulatory Commission (NRC), included the review of pertinent literature, examination of well cutting and core logs, acquisition of new geophysical data, and interpretation of new and extant geophysical data. A series of maps was compiled early in the study and subsequently modified and expanded with additional data. Reviews of the Phanerozoic (Bunker, 1982) and Proterozoic (Anderson and Black, 1982) histories of the southwestern Iowa study area were published in the 1981 annual report to the NRC (NUREG/CR-2548) by the IGS. Studies of individual structures within the study area were conducted by Daut (Van Eck, Daut, and Anderson, 1981), Logel (1982 and this volume) and Cumerlato (1982 and this volume). These studies suggest that the region probably experienced episodic seismic activity from about 1200 to 50 million years ago. Activity in the last 50 million years has probably been minor.

INTRODUCTION

From May 1978 through July 1982 the Iowa Geological Survey (IGS) participated with the state geological surveys of Oklahoma, Kansas, and Nebraska in a study of seismicity along the Nemaha Uplift and the structural features associated with the Midcontinent Geophysical Anomaly. This work, funded by the U.S. Nuclear Regulatory Commission, was directed towards obtaining information that would permit a scientific assessment of the earthquake risks inherent in the siting and design of nuclear facilities in the study area. To this end it was necessary to develop an understanding of the sources, mechanisms, and propagation characteristics of earthquakes in the region by studying its depositional and tectonic history. In the southwest (S.W.) Iowa portion of the study area all available sources of data were utilized, including previous studies, strip logs from well cuttings, core and core logs, and extant geophysical data. Almost 2000 additional gravity stations were obtained, reduced, and merged with extant data. Extensive computer analyses and modeling of this gravity as well as aeromagnetic data was conducted. Refraction and reflection seismic profiles were collected at 6 locations in the study area (see J. Logel, this volume).

To examine present seismicity the IGS constructed 5 earthquake monitoring stations (see T. Faller, 1982 and this volume). The examination of all of these data sources has led to a much improved understanding of the geological history of S.W. Iowa and formed the basis for predictions of future seismicity in the area.

TECTONIC AND DEPOSITIONAL HISTORY OF S.W. IOWA

Proterozoic

Little is known about the pre-Proterozoic or early Proterozoic geological history of the S.W. Iowa study area. The first tectonic activity known to have occurred in the area was the rifting and extrusive vulcanism associated with the opening of the Central North American Rift System (CNARS) during the Keweenawan, about 1200 m.y. ago. (There is some evidence that the rifting may have followed a pre-existing crustal feature, but this is purely speculative at this time). Graben development and subsidence was contemporaneous with the vulcanism and continued even after cessation of the extrusive activity, forming deep, overlying, clastic-filled troughs. Reactivation and uplift of the graben to form the Iowa Horst (Figure D1) followed and led to erosional exposure of the volcanics in many areas of S.W. Iowa. Erosion of the Iowa Horst as well as additional subsidence and deposition in the flanking clastic-filled basins continued to the end of the Proterozoic and into the Paleozoic Cambrian Period.

Modeling of gravity data suggests that total vertical displacements on the Northern Boundary Fault Zone and the Thurman-Redfield Structural Zone, the northern and southern flanks of the Iowa Horst respectively, are locally in excess of 9 kilometers. The clastic-filled marginal basins, the Defiance Basin to the north and Shenandoah Basin to the south, appear to reach similar maximum depths of about 10 kilometers. Reactivation of these fault zones and basins occurred sporadically throughout the later history of the region. For a more detailed description of the Proterozoic geology and history of the region see Anderson and Black, 1982.

Phanerozoic

To facilitate the discussion of the depositional and tectonic history of the Phanerozoic, depositional sequences as defined by Sloss (1963) will be utilized (Figure D2). These sequences are valuable, since they include almost all sediments in which are found the geologic record of the area. They are separated by periods of regional emergence and erosion. For more details on the Phanerozoic history of S.W. Iowa, see Bunker, 1982.

Sauk Sequence

The rocks of the Sauk Sequence record the initial Phanerozoic marine transgressions into the midcontinent in Late Cambrian time. Anomalous thicknesses of all units in this sequence, especially the Mt. Simon Formation (Fm.) where clastics reach thicknesses in excess of 1100 feet (less than 100 feet would be considered a normal thickness) in areas overlying the Shenandoah Basin suggest a continuing subsidence of the basin throughout Sauk time. Although there is no direct evidence, a similar subsidence may have occurred in the Defiance Basin area.

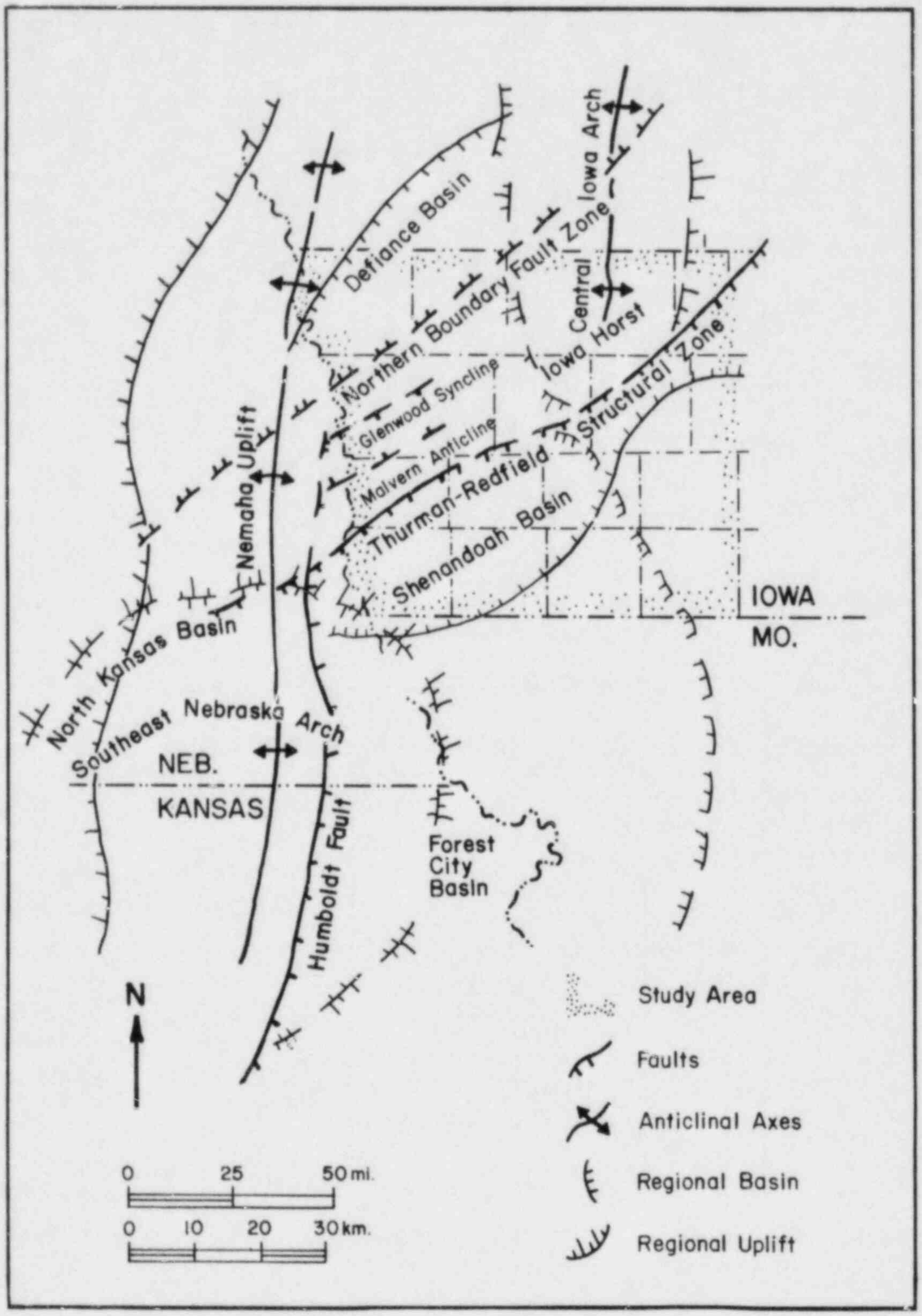
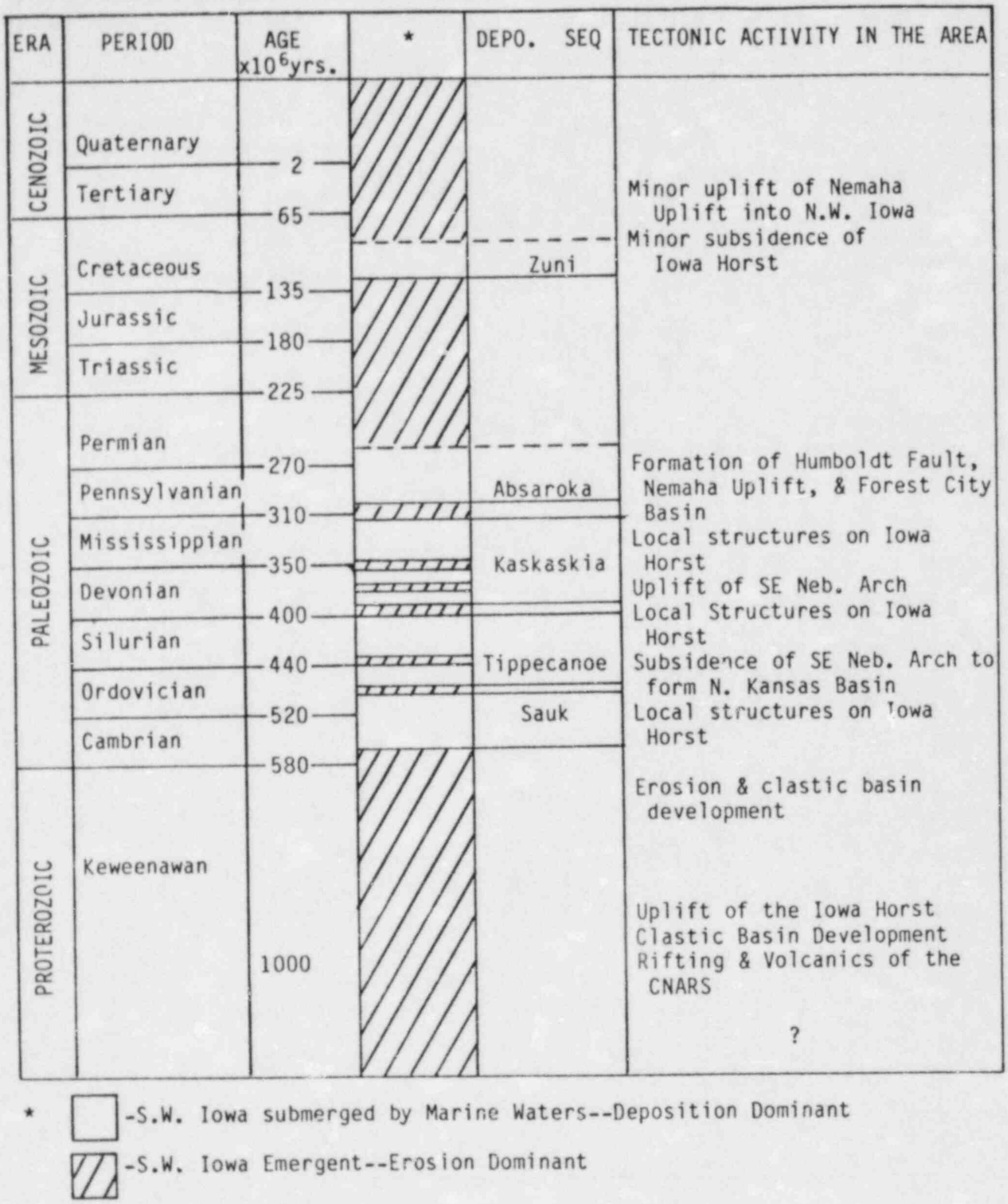


Figure D1. Structural Features in the History of S.W. Iowa.

Figure D2. Tectonic and Depositional History of Southwest Iowa



Thinning occurs in all Sauk Sequence units over the Central Iowa Arch, suggesting a slow uplifting of that region. The Southeast (S.E.) Nebraska Arch, a precursor of the Nemaha Uplift, was also uplifted at this time. Block faulting on the Iowa Horst led to local nondeposition, erosional thinning, or complete erosional truncation of some Sauk units.

Units of the Sauk Sequence thicken to the east reflecting the subsidence of the Hollandale Embayment in eastern Iowa.

Tippecanoe Sequence

The Tippecanoe includes the carbonates and shales of the Middle and Upper Ordovician and Silurian periods. At this time the Shenandoah and Defiance Basins continued minor subsidence yielding units with anomalous increases in thickness of a few hundred feet. The S.E. Nebraska Arch subsided during this time forming the North Kansas Basin. Tippecanoe units, like Sauk units, thin across the Central Iowa Arch, and local block faulting on the Iowa Horst led to the development of structural features including the Malvern Anticline and Glenwood Syncline. Rocks along the Thurman-Redfield Structural Zone also show also show relative movement to the south at this time.

Kaskaskia Sequence

The Kaskaskia is represented by carbonates and shales of Middle and Upper Devonian and Mississippian age rocks. During this sequence a pronounced depositional basin formed, centered over the Shenandoah Basin. The Malvern Anticline, Glenwood Syncline, and Thurman-Redfield Structural Zone continued the development which was initiated during the Tippecanoe. To the west, the center of the North Kansas Basin was uplifted and emerged as the S.E. Nebraska Arch once again.

Absaroka Sequence

The Absaroka Sequence is presently represented in S.W. Iowa only by Pennsylvanian age rocks. It seems likely that some Permian rocks were deposited in the area but have subsequently been lost to pre-Zuni erosion. At this time the Malvern Anticline, Glenwood Syncline, and Thurman-Redfield Structural Zone continued to develop. Sediments once again thin over the Central Iowa Arch. To the west the Humboldt Fault formed and subsided to the east creating the Forest City Basin. The much reduced S.E. Nebraska Arch became the Nemaha Uplift.

Zuni Sequence

The Zuni Sequence in S.W. Iowa was represented by Cretaceous fluvial and marine units including the Dakota Sandstone Fm, and probably through the Pierre Shale Fm. Most of these rocks have since been removed by erosion. However, fluvial sands and shales of the lower Dakota Fm. Nishnabotna Member have been preserved. Because of this widespread erosion little is known about the depositional and tectonic events of Zuni time.

Post-Zuni Tectonics

Although Zuni rocks in S.W. Iowa have been extensively eroded, two lines of evidence exist for postulating Post-Zuni (Laramide) tectonic activity in the area. The first is the distribution of the remaining Zuni rocks as is presently understood. A tongue of Nishnabotna sandstones and conglomerates about 60 miles long and 15-20 miles wide has been mapped in S.W. Iowa. It trends in a northeasterly direction and is located on the Iowa Horst. Its location strongly suggests structural preservation by minor subsidence of the horst.

The second line of evidence suggests Laramide reactivation of the Nemaha Uplift. Observation of the present distribution of Cretaceous rocks in northeastern Kansas, eastern Nebraska, southeastern South Dakota, southwestern Minnesota, and western Iowa (see Bunker, 1982, p. 55) show increasingly younger rocks away from the axis of the Nemaha Uplift and its extension to the Iowa/Minnesota border. A structure contour map constructed on the top of the Cretaceous Greenhorn Limestone Fm. by Bunker (1982, p. 53) bears out this observation by showing the unit to be dipping off the axis and its extension. A structural relief of about 500 feet can be postulated for S.W. Iowa based on this map.

IMPLICATIONS FOR FUTURE TECTONIC ACTIVITY IN S.W. IOWA

A review of the tectonic history of S.W. Iowa reveals several areas that have been persistently tectonically active. The most active area appears to be the zone along the Thurman-Redfield Structural Zone and by inference, since drill data is limited, the Northern Boundary Fault Zone. The area associated with the Glenwood Syncline and Malvern Anticline have also been active, particularly since Tippecanoe deposition. It is these areas which have the greatest potential for future seismicity in S.W. Iowa (see Figure D3).

Areas which have a more limited tectonic history and probably have a more limited potential for future seismic activity include areas of the Iowa Horst (exclusive of the Glenwood and Malvern areas) and the areas of the Shennandoah and Defiance Basins. The southeast and northwest corners of the study area are the least likely areas for future seismic activity.

These predictions are, in part, substantiated by examination of records from the five microseism stations which have been in operation in the S.W. Iowa study area since mid 1980 (see Figure D3). Although some disparities exist, since the materials in which the stations were constructed and depths to bedrock were variable, stations CAI and ESI displayed the largest number of probable, local microseisms. Stations RFI and TPI displayed a lesser number of local events, and station PHI the fewest.

Additional evidence suggesting future seismicity on and along the Iowa Horst comes from an isostatic gravity anomaly map (Wollard, 1965). On the map (Figure D4) the Iowa Horst and its dense volcanics can be seen as a trend of positive isostatic isograds with individual contours as high as +90, the flanking clastic-filled basins as low as -40. The total anomaly, between the horst highs and the basin lows, is unequalled in magnitude anywhere in the United States. With the downward force exerted by dense basalts attempting to subside to reach isostatic equilibrium and the upward force exerted on the light clastics as the basins attempt to equilibrate, tremendous stresses are developed on the intervening fault zones. These stresses have kept the fault zones active for the entire Phanerozoic; however, the vertical movements have been minimal, a few hundreds of feet, over the last 500 million years. It is probably the release of these stresses that has generated the numerous micro-

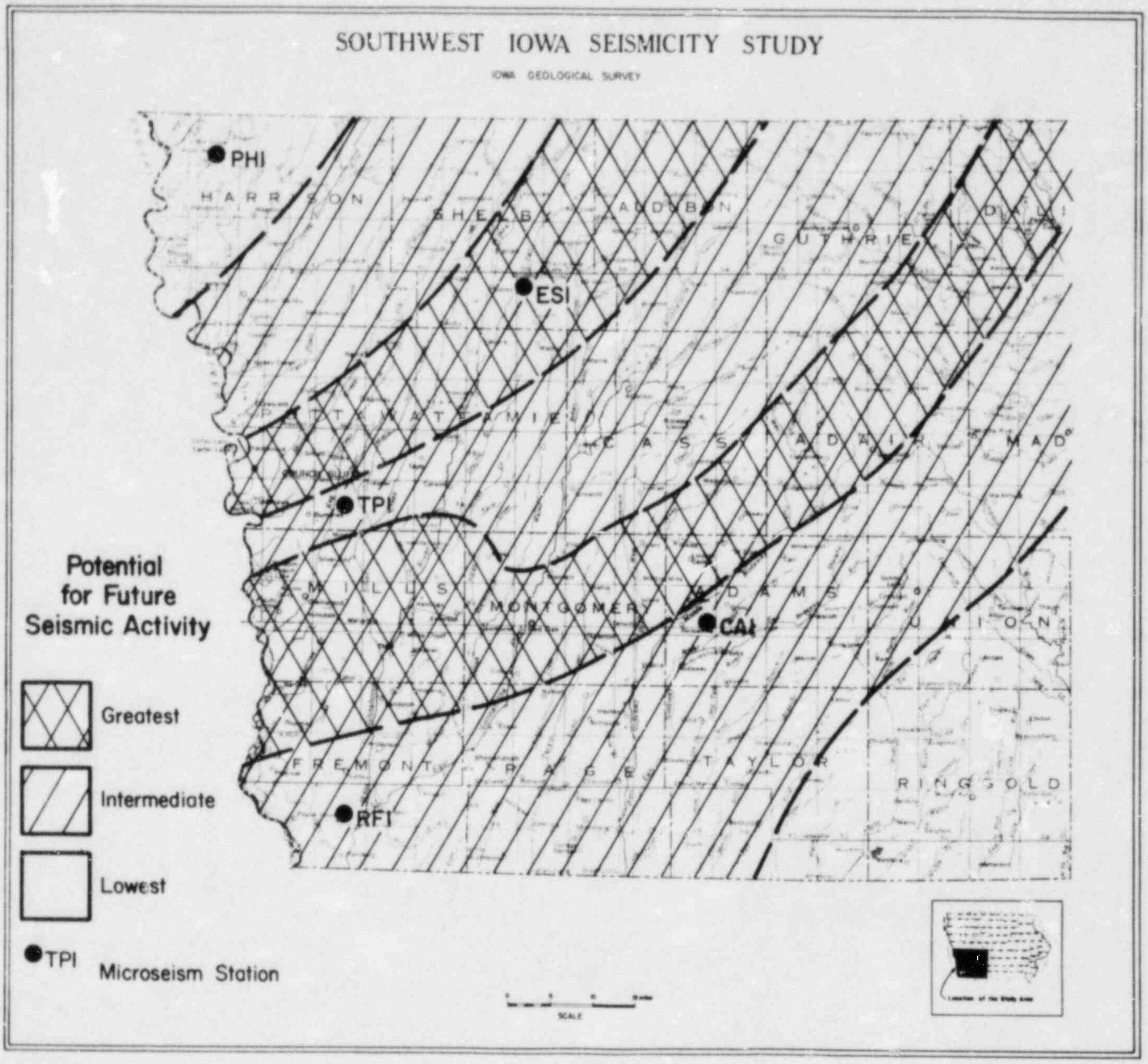


Figure D3. Potentially Seismically Active Areas in S.W. Iowa.

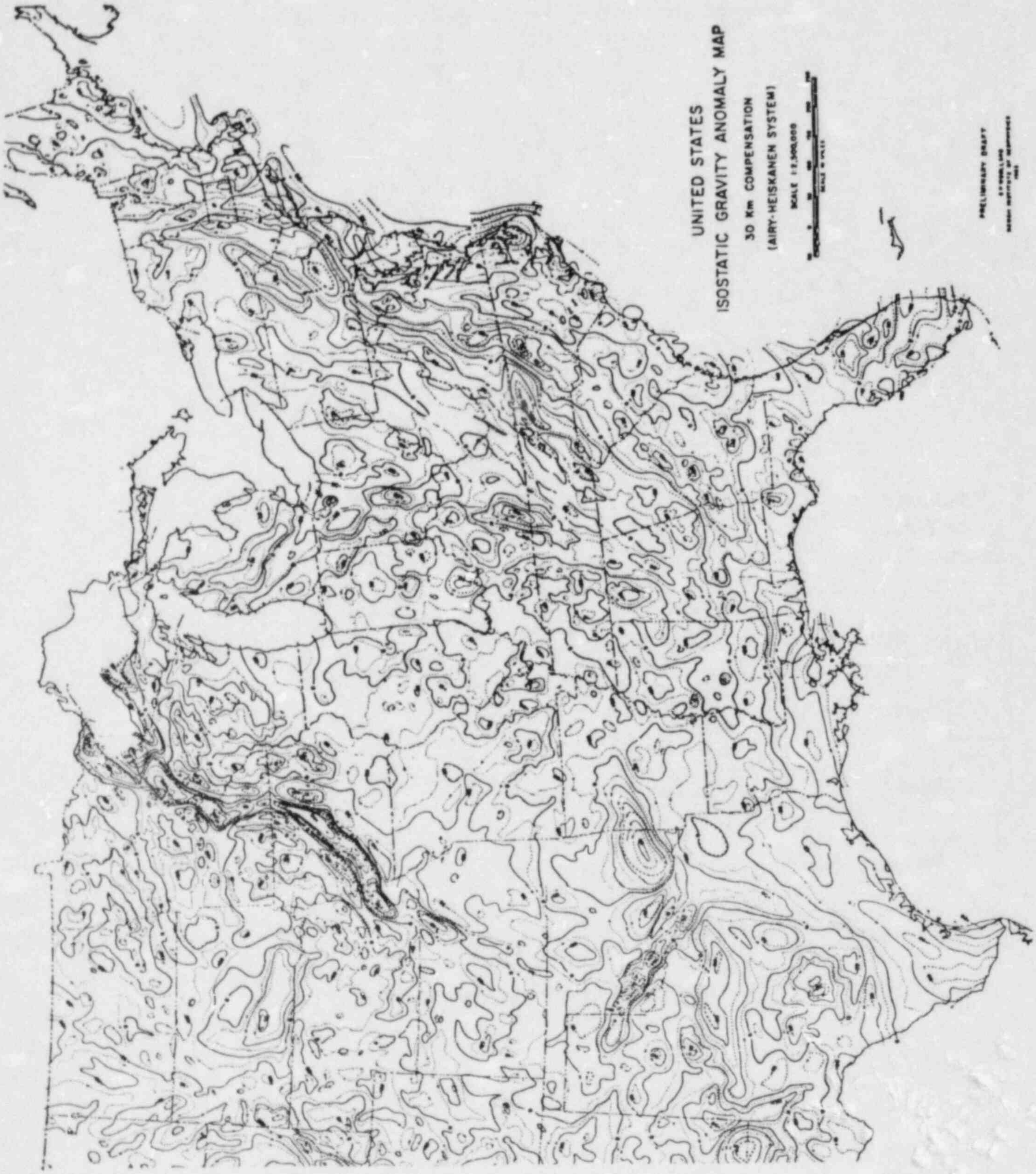


Figure D4. U.S. Isostatic Gravity Anomaly Map by G. P. Wollard, 1965.

earthquakes recorded by the IGS seismic stations.

While microearthquakes are expected to continue in those areas identified as having the greatest potential for seismic activity (Figure D3) there is no way to predict any larger magnitude events. There are no reliable historical reports of damaging earthquakes with epicenters in the S.W. Iowa study area. The potential, however, for large and damaging earthquake activity in the area is present and should be a major consideration in the future construction of nuclear power plants or other critical facilities.

REFERENCES

Anderson, R. R., and Black, R. A., 1982, Geologic Interpretations from Geophysical Models of the Midcontinent Geophysical Anomaly in Southwestern Iowa: in Regional Tectonics and Seismicity of Southwestern Iowa, NRC report NUREG/CR-2548, pp. 27-41A.

Bunker, B. J., 1982, Phanerozoic Structural Development in the Area of the Forest City Basin, Southwestern Iowa: in Regional Tectonics and Seismicity of Southwestern Iowa, NRC report NUREG/CR-2548,, pp. 42-61.

Cumerlato, C., 1982, Southwest Iowa Gravity Data Collection and Analysis: in Regional Tectonics and Seismicity of Southwestern Iowa, NRC report NUREG/CR-2548, pp. 5-11.

Faller, T. H., 1982, Seismic Activity in Southwest Iowa: in Regional Tectonics and Seismicity of Southwestern Iowa, NRC report NUREG/CR-2548, pp. 62-71.

Logel, J. D., 1982, Interpretation of Seismic Profiles Across the Thurman-Redfield Structural Zone: in Regional Tectonics and Seismicity of Southwestern Iowa, NRC report NUREG/CR-2548, pp. 12-26.

Sloss, L. L., 1963, Sequences in the Cratonic Interior of North America: Geol. Soc. Am. Bull., v. 74, pp. 93-114.

Van Eck, O. J, Daut, S. W., and Anderson, R. R., 1982, Regional Tectonics and Seismicity of Southwestern Iowa: NRC report NUREG/CR-1876,p.36.

Woolard, G. P., 1965, United States Isostatic Gravity Anomaly Map, Preliminary Draft: Hawaii Institute of Geophysics.

NRC FORM 335
(11-81)

U.S. NUCLEAR REGULATORY COMMISSION

BIBLIOGRAPHIC DATA SHEET

1. REPORT NUMBER *(Assigned by DDC)*
NUREG/CR 3021

4. TITLE AND SUBTITLE *(Add Volume No., if appropriate)*
Regional Tectonics and Seismicity of Southwestern Iowa
Final Report 1978-1982

2. *(Leave blank)*

3. RECIPIENT'S ACCESSION NO.

7. AUTHOR(S)
O. J. Van Eck and others

5. DATE REPORT COMPLETED

MONTH	YEAR
October	1982

9. PERFORMING ORGANIZATION NAME AND MAILING ADDRESS *(Include Zip Code)*
Iowa Geological Survey
123 N. Capitol Street
Iowa City, Iowa 52242

DATE REPORT ISSUED

MONTH	YEAR
November	1982

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.
B6312

13. TYPE OF REPORT
Final Technical Report

PERIOD COVERED *(Inclusive dates)*
August 78 - July 1982

15. SUPPLEMENTARY NOTES

14. *(Leave blank)*

16. ABSTRACT *(200 words or less)*

Utilizing gravity and aeromagnetic data, a series of geophysical profiles were constructed across the Midcontinent Geophysical Anomaly (MGA) which extends across southwestern Iowa. By combining the information provided by modeling techniques with limited deep well data, a map of the Precambrian basement was generated. The interpretation that emerged includes a central horst of igneous material, extensively faulted, and overlain in some areas by Keweenawan clastics. The horst is flanked by a series of high angle faults, with the majority of the faults displaying vertical displacement along two structural zones, the Thurman-Redfield Structural Zone, southeast of the MGA, and the Northern Boundary Fault Zone to the northwest. The total vertical displacement present along these fault zones is about maximum of 9 Km. Two clastic-filled basins flank the horst, one of which has an interpreted depth of 10 Km. Seismic profiling indicates extensive folding and faulting of Paleozoic rock units, although the scale of deformation is minor when compared to Precambrian features in the same area. Although the Paleozoic Era was the most tectonically active of the post-Precambrian eras there are indications of post-Cretaceous movement. Recent tectonic activity is suggested by the numerous microearthquakes that were recorded by the monitoring array that was installed for this study.

17. KEY WORDS AND DOCUMENT ANALYSIS
Seismicity
Tectonics
Iowa
Mid-Continent Gravity Anomaly

17a. DESCRIPTORS

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
$

UNITED STATES
NUCLEAR REGULATORY COMMISSION
WASHINGTON, D.C. 20555

OFFICIAL BUSINESS
PENALTY FOR PRIVATE USE, $300

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