NUREG/CR-0977

New Madrid Seismotectonic Study

Activities During Fiscal Year 1979

Prepared by T. C. Buschbach

Saint Louis University

Prepared for
U. S. Nuclear Regulatory Commission

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Activities During Fiscal Year 1979

Manuscript Completed: December 1979
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Prepared by
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U.S. Nuclear Regulatory Commission
Washington, D.C. 20555
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SUMMARY

The New Madrid Seismotectonic Study is a coordinated program of geological, geophysical, and seismological investigations of the area within a 200-mile radius of New Madrid, Missouri. The study, funded in part by the U.S. Nuclear Regulatory Commission, is designed to define the structural setting and tectonic history of the area in order to realistically evaluate earthquake risks in the siting of nuclear facilities. An important goal of the research program is to produce useful seismotectonic and seismic zoning maps for the study area.

Participants in the study include geologists from the State Geological Surveys of Illinois, Indiana, Kentucky, Tennessee, Alabama, Arkansas, and Missouri; faculty members of earth science departments at Saint Louis University, Vanderbilt University, Purdue University, Memphis State University, the University of Pittsburgh, the University of Wisconsin at Milwaukee, and the University of Texas at El Paso; and staff members of the U.S. Geological Survey, the U.S. Army Corps of Engineers, and the Tennessee Valley Authority.

Fiscal year 1979 was the third year of a five-year program. A bibliography that lists more than 1000 studies on continental rifts was prepared and published. Aeromagnetic studies in northeastern Arkansas showed a northeast-trending trough in the magnetic basement within the Mississippi Embayment. The trough, interpreted as a rift, appears to have mafic igneous rock intruded in places along its edges.

Gravity and aeromagnetic data were integrated and gridded on a 2 km grid for a large portion of our study area. A new hypothesis, based on the integrated geophysical data, suggests that the linear tectonic features associated with the New Madrid seismic zone may extend northeastward across the Rough Creek Fault Zone toward central Indiana.

The Wabash Valley seismograph array recorded eight earthquakes, five of which had focal depths deeper than 16 km. This makes them the deepest earthquakes ever recorded in the central Mississippi Valley region.

Subsurface geologic studies during the year have:

1. Shown that most of the faulting associated with the Fluorspar District, southeastern Illinois, took place prior to deposition of Late Cretaceous sediments.

2. Resulted in the preparation of a map showing interpreted thicknesses of the pre-Knox strata in the area. The map indicates that the Rough Creek Gaben and Reelfoot Rift are features that subsided significantly prior to deposition of the Late Cambrian to Early Ordovician Knox carbonates.
3. Indicated that the Wabash Valley Fault System of southwestern Indiana consists of chiefly normal, high angle faults of post-Pennsylvanian to pre-Pleistocene age.
4. Shown that faulting known to cut Cretaceous and Tertiary sediments in southeastern Missouri could not be detected in the overlying Pleistocene deposits.

Proposals have been submitted and approved to continue all of the current studies underway. New projects or directions include new aeromagnetic studies in central-eastern Arkansas, at the intersection of the Ouachita front with the Mississippi Embayment, and a combined geological and geophysical investigation along the Ohio River using a boat for recording high resolution reflection seismic data. We also hope to obtain funding to acquire deep seismic reflection (Vibroseis) profiles across the Wabash Valley Fault System and the northeast-trending linear tectonic features of southwestern Indiana and southeastern Illinois.

The U.S. Geological Survey is conducting several interesting earthquake hazard studies in the New Madrid area. They include studies on geophysics, geology, and geomorphology within the region. The U.S. Army Corps of Engineers, St. Louis, Missouri, is preparing seismic zoning maps for the region. Communication and coordination among all researchers in the area continue to be excellent.

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INTRODUCTION

Late in 1811 and early in 1812 the New Madrid area was the site of the strongest series of earthquakes ever recorded in central United States. The Saint Louis University seismograph network recorded and located more than 200 seismic events this past year, indicating that the area continues to be seismically active. Evaluating seismic risk for the surrounding region, especially when consideration is given to the siting of nuclear facilities, requires a better understanding of the structure and tectonics of the area and their relationship to the seismicity than is presently available.

To expand our knowledge of the area geologists from the State Geological Surveys of Illinois, Indiana, Kentucky, Tennessee, Alabama, Arkansas, and Missouri; faculty members of earth science departments at Saint Louis University, Vanderbilt University, Purdue University, Northern Illinois University, Memphis State University, the University of Pittsburgh, the University of Wisconsin at Milwaukee, and the University of Texas at El Paso; and staff members of the U.S. Geological Survey, the U.S. Army Corps of Engineers, and the Tennessee Valley Authority are participating in a cooperative geological, geophysical, and seismological study of the area within a 200-mile radius of New Madrid, Missouri (fig. 1). The study, funded in part by the U.S. Nuclear Regulatory Commission, is designed to define the structural setting and tectonic history of the area in order to realistically evaluate earthquake risks in the siting of nuclear facilities.

PROGRAM SCOPE AND HISTORY

This research effort, initiated in fiscal year 1977, is designed to be a five-year project. A flow chart (table 1) indicates the proposed timing of our efforts within the broad categories of this study.

The early stages of the study were devoted to making an inventory of existing data and supporting research in the areas where the needs were obvious. Aeromagnetic, ground magnetic, and gravity surveys were sponsored to complete geophysical coverage in our most critical regions. A tectonic overview of the region was prepared and published, as was a bibliography of selected references on the structure, tectonics, basement, and geophysics of the New Madrid region. Two significant depressions on the Precambrian basement rocks have been postulated in the area. One is the northeast trending Reelfoot Rift and the other is an east-west depression that has been named the Rough Creek Graben. Both structures appear to have been active late in Precambrian time or early in Cambrian time, and both have shown subsequent reactivation.

A seismograph array was established in the Wabash Valley, and detailed studies of the faulting have been conducted in that area. Maps have been prepared to show the geologic structure and thicknesses of significant rock units in the region. Quaternary deposits have been studied in the area, and numerous relatively shallow borings have been drilled to determine the age of faulting.

Research performed by State Geological Surveys and universities under contracts with the U.S.N.R.C. are fully coordinated in this cooperative study and reports of research activities by those organizations during the past year are included. In addition, virtually all pertinent geologic research performed in the area by Federal and state agencies, and by the major universities, has been coordinated with the research projects funded through the U.S.N.R.C. Only the general scope and regional significance of research sponsored by the other agencies are reported in this summary.

This report is presented as an annual report by the coordinator. Work accomplished earlier under this coordinated program is summarized in NUREG Documents - 0379, "New Madrid Seismotectonic Study - Activ ties during fiscal year 1977," and CR-0450, "New Madrid seismotectonic studies - Activities during fiscal year 1978."

COORDINATED RESEARCH PROGRAMS SUPPORTED BY U.S.N.R.C. CONTRACTS

Ten research proposals were supported by the U.S. Nuclear Regulatory Commission for the cooperative study of geology, geophysics, and seismology in the New Madrid area.

Although contractual procedures for current seismological studies at Memphis State University and at Saint Louis University (I, J) are not included under the aegis of this coordinator, the plans and programs of these organizations are of vital importance to this coordinated study. Their reports of activities are included here for completeness. In addition to the programs funded by U.S.N.R.C. during the past fiscal year, a report on an aeromagnetic survey of parts of northeastern Arkansas, which was funded during the previous fiscal year, is included in this report.

A summary of the annual report prepared at Purdue University is included here. The complete report is published as NUREG CR-1014; An integrated geophysical and geological study of the tectonic framework of the 38th Parallel Lineament in the vicinity of its intersection with the New Madrid Fault Zone; by L.W. Braile, W.J. Hinze, and J.L. Sexton, Purdue University; G.R. Keller, University of Texas at El Paso; and E.G. Lidiak, University of Pittsburgh; September, 1979. The interested reader is referred to the complete report for many excellent illustrations which could not be included in this summary, for abstracts of papers presented at scientific meetings, and for a bibliography of studies (more than 1000) on continental rifts. The research efforts of the group are also reported in three significant papers included in an appendix. Only the abstracts of these papers are included here.

The project titles of the coordinated research programs, the investigators, and the participating organizations are as follows:

A. Coordination of a Cooperative Seismotectonic Study of the New Madrid Area; T.C. Buschbach, Saint Louis University.

B. An Integrated Geophysical and Geological Study of the Tectonic Framework of the 38th Parallel Lineament in the Vicinity of its Intersection with the Extension of the New Madrid Fault Zone; L.W. Braile, W.J. Hinze, and J.L. Sexton, Purdue University; E.G. Lidiak, University of Pittsburgh; G.R. Keller, University of Texas at El Paso.

C. Near Surface Geology of the Reelfoot Lake District of the New Madrid Earthquake Region; R.G. Stearns, Vanderbilt University.

D. Structural Geologic Study of Southeastern Missouri; Ronald Ward, Division of Geology and Land Survey, Missouri Department of Natural Resources.

E. Paleozoic Geology of the New Madrid Area; H.R. Schwalb, Kentucky Geological Survey.

F. A Study of Indiana Fault Locations, Displacements, Attitudes and Ages Within a 200-Mile Radius of New Madrid, Missouri; Dan M. Sullivan and Curtis H. Ault, Indiana Geological Survey.

G. Structural Framework of the Mississippi Embayment of Southern Illinois; Dennis R. Kolata, Illinois State Geological Survey.

H. General Geology, Geophysics, and Seismicity of Northwest Alabama; Jack T. Kidd, Geological Survey of Alabama.

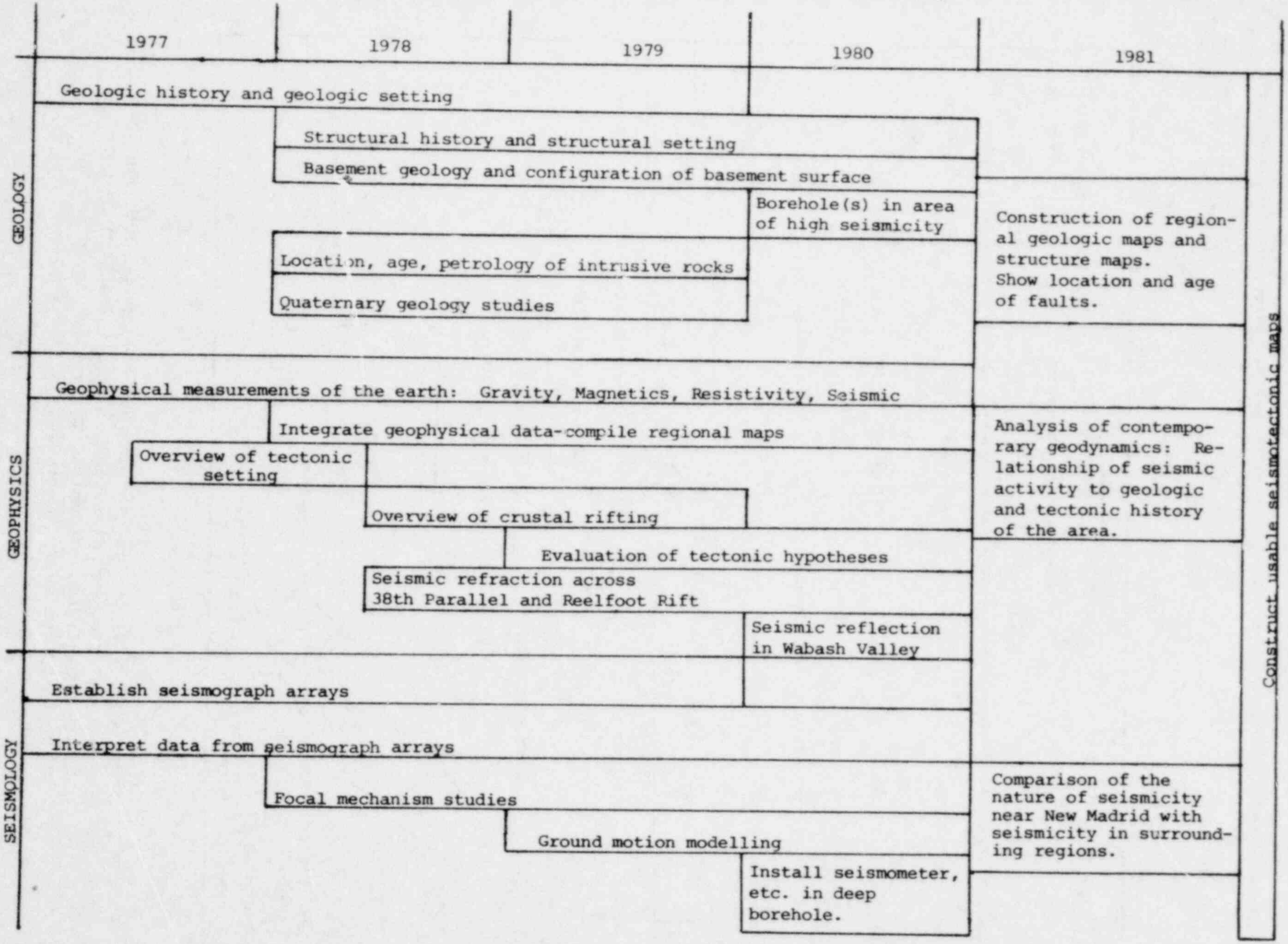
I. Memphis Area Regional Seismic Network; James Zollweg and Arch Johnston, Tennessee Earthquake Information Center, Memphis State University.

J. A Seismological Study of the Northern Extent of the New Madrid Seismic Zone; R. B. Herrmann, Saint Louis University.

K. Report on Aeromagnetic Survey of Parts of Northeast Arkansas; J.D. Hendricks, U.S. Geological Survey, N.F. Williams and D.F. Holbrook, Arkansas Geological Commission.

Table 1

Generalized Flow Chart - New Madrid Seismotectonic Study



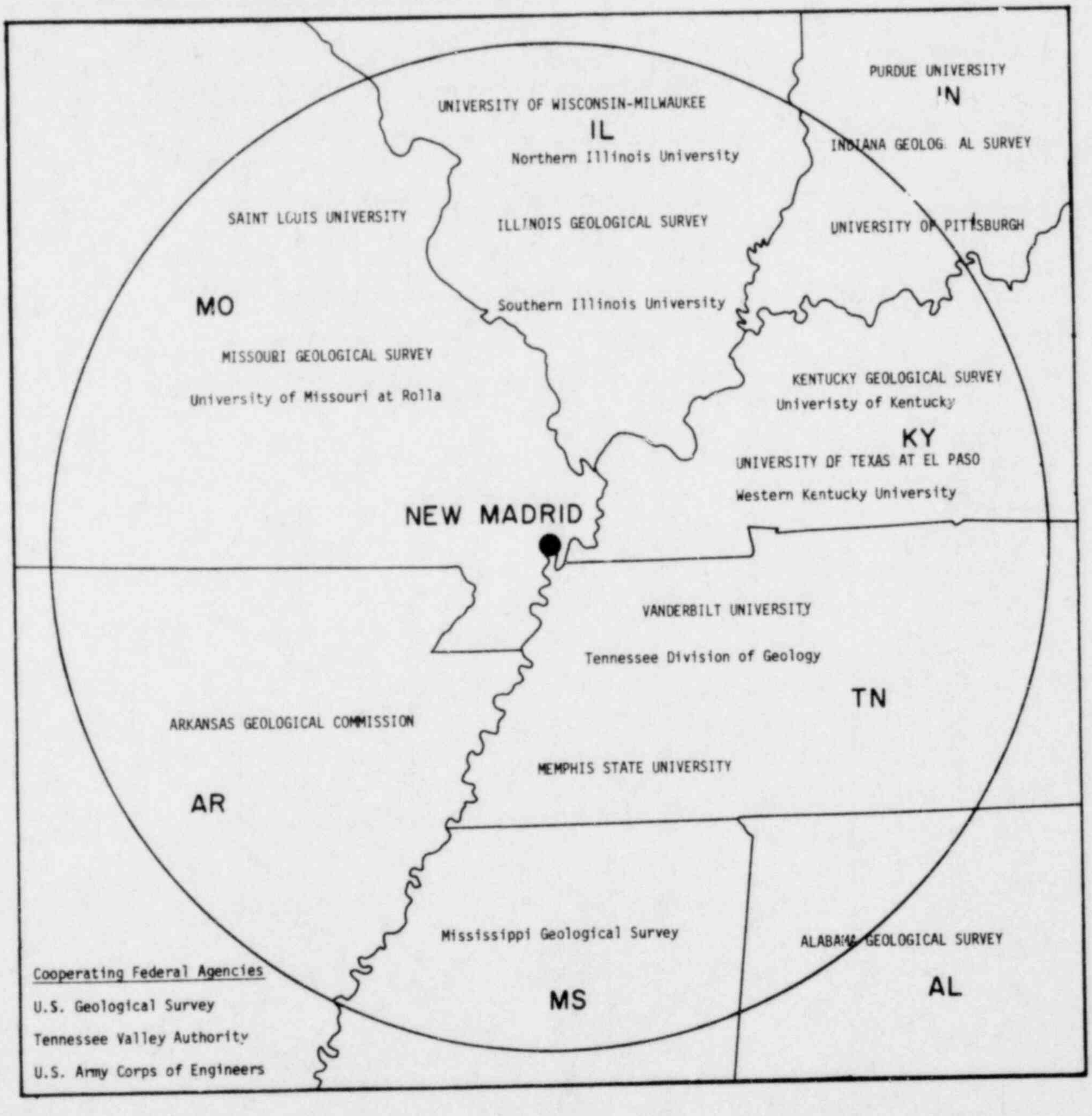


Figure 1 State Geological Surveys and universities cooperating in the New Madrid Seismotectonic Study. Names in capital letters indicate organizations involved in research supported by U.S. Nuclear Regulatory Commission in 1979-1980.

COORDINATION OF A COOPERATIVE SEISMOTECTONIC STUDY OF THE NEW MADRID AREA

Annual Progress Report - Fiscal Year 1979

Contract No. NRC-04-78-251

T.C. Buschbach
Saint Louis University

INTRODUCTION

The objectives of the coordinator's efforts are to encourage, assist, and coordinate the research programs of scientists from organizations participating in significant research on seismotectonics in the New Madrid area. To achieve these objectives the coordinator visited each participating organization once or twice, had coordination meetings with the U.S. Geological Survey at Reston and Denver, and reported on progress of the studies during two trips to the N.R.C. offices in the Washington, D.C. area.

Perhaps the most significant accomplishments of this coordinated study are:

1. A group of about 30 of the most qualified scientists in the region meet together, communicate, and coordinate their research programs.
2. Individual participating organizations have reoriented their research objectives toward active efforts to better understand the seismic and tectonic processes in the New Madrid area.
3. There has been a significant increase in the number of meaningful research projects on the geology, geophysics, and seismology in the New Madrid area since the coordinated studies began.

COORDINATION ACTIVITIES

Progress Meetings

The Midwest meeting of the American Geophysical Union was held late in September, 1978, at Saint Louis University. Several members of the New Madrid study group reported the results of their research at sessions on "Geology and Geophysics of the Central United States" and on "Seismic Networks in the Central United States." T.C. Buschbach was Chairman for the latter session. A progress meeting of the New Madrid study group was held in conjunction with the A.G.U. meeting at Saint Louis. There were 32 participants and invited observers in attendance (Appendix A-1).

The South-Central Section of the Geological Society of America met in April, 1979, at Mountain View, Arkansas. Most of the members of the New Madrid study group presented papers at one of two sessions on "Geology and Geophysics of the Mississippi Embayment" (John Hendricks and Tom Buschbach presided). A progress meeting of the New Madrid study group was held in conjunction with the G.S.A. meeting at Mountain View. There were 28 participants and invited observers in attendance (Appendix A-1).

Significant Publications

During fiscal year 1979 several reports on the research activities in the New Madrid area, supported in part by U.S.N.R.C. funds, were published as NUREG Documents. They are:

1. An integrated geophysical and geological study of the tectonic framework of the 38th Parallel Lineament in the vicinity of its intersection with the extension of the New Madrid Fault Zone by L.W. Braile, W.J. Hinze, G.R. Keller, E.G. Lidiak; NUREG CR-0449, September, 1978.
2. New Madrid seismotectonic study—Activities during fiscal year 1978, by T.C. Buschbach, Coordinator; NUREG CR-0450, October, 1978.
3. Recent vertical movement of the land surface in the Lake County uplift and Reelfoot Lake basin areas, Tennessee, Missouri, and Kentucky, by R.G. Stearns; NUREG CR-0874, June, 1979.

The coordinator reviewed two manuscripts that reported the results of research performed in the New Madrid area by U.S. Geological Survey personnel. The papers are to be published in the November, 1979, Bulletin of the Geological Society of America. They are:

1. Late Holocene faulting and earthquake recurrence in the Reelfoot Lake area, northwestern Tennessee, by D.P. Russ.
2. Recurrent faulting in the vicinity of Reelfoot Lake, northwestern Tennessee, by M.D. Zoback.

The U.S. Geological Survey published:

1. Preliminary seismotectonic map of the central Mississippi valley and environs, by A.V. Heyl and F.A. McKeown; Miscellaneous Field Studies Map MF-1011, 1978.

2. (In cooperation with Missouri Department of Geology and Land Survey) Structure contour map of the buried Precambrian basement-rock surface, Rolla 1° x 2° Quadrange and adjacent areas, Missouri, by Eva B. Kisvarsanyi; Miscellaneous Field Studies Maps MF-1001 A, MF-1001 B.

The Illinois State Geological Survey published:

The Wabash Valley Fault System in southeastern Illinois, by H.M. Bristol and Janis D. Treworgy; Circular 509, 1979.

The U.S. Army Corps of Engineers published two pertinent papers in their series entitled "State-of-the-Art for Assessing Earthquake Hazards in the United States"--Miscellaneous Paper S-73-1. They are Report 10, Attenuation of High-Frequency Seismic Waves in the Central Mississippi Valley, by Otto Nuttli and John Dwyer; and Report 12, Credible Earthquakes for the Central United States, by Otto Nuttli and Bob Herrmann.

A large number of papers have been presented at scientific meetings by participants in the New Madrid study. For this reason no attempt has been made to include the abstracts in this report. The interested reader is referred to: (1) American Geophysical Union-Midwest Meeting, Program and Abstracts, Saint Louis University, September 25-27, 1978; (2) Geological Society of America - 13th Annual Meeting of South-Central Section, Abstracts and Programs, Ozark Folk Center, Mountain View, Arkansas, April 9-10, 1979; and (3) NUREG CR-1014.

RESEARCH HIGHLIGHTS

A considerable amount of integration and compilation of geophysical and geological data was accomplished during fiscal year 1979. Several new hypotheses have been proposed, and the study group will be evaluating them. Some of the most significant developments during the year are:

1. Aeromagnetic and gravity data previously available or acquired during this study were integrated for the area bounded by 36.5° to 39° North latitude and 85° to 90° West longitude. These data have been gridded on a 2 kilometer grid to facilitate computation of interpretive maps.
2. A potential extension of the New Madrid seismic zone northeastward across the Rough Creek Fault Zone toward central Indiana has been postulated. This hypothesis is based on similarities

of linear trends of nearly circular, positive gravity and magnetic anomalies which bound a central zone of low magnetic and gravity relief both in the New Madrid area and also to the northeast.

3. Crustal structure studies, using short to intermediate Rayleigh waves, showed the crustal thickness of the northern Mississippi Embayment to be at least 47 km and probably in the range of 50 to 55 km. An anomalously high velocity layer is found in the lowermost crust throughout the region.
4. A bibliography, listing more than 1000 studies on continental rifts, was prepared and published.
5. Subsurface studies in southern Illinois showed that most of the faulting associated with the Fluorspar District Fault Complex took place prior to Late Cretaceous deposition (pre-Gulfian time). There is little or no evidence of post-Gulfian subsidence in the America Graben.
6. A map was prepared to show the thickness of the pre-Knox strata in the area. These strata consist of mostly clastic sediments deposited from late in Precambrian time to late in Cambrian time. The isopachs clearly identify the Rough Creek Graben and Reelfoot Rift as negative features and the Ozark and Nashville Domes as relatively positive features before deposition of the Late Cambrian to Early Ordovician Knox carbonates.
7. Detailed structure mapping of the Wabash Valley Fault System in Indiana was correlated with mapping of that fault system in Illinois. The faults were found to be chiefly normal, high angle faults (70° or more) of post-Pennsylvanian to pre-Pleistocene age. Faulting appears to be less complex with depth.
8. Closely spaced drilling along the Reelfoot Scarp suggests that most of the relief on this feature can be explained by the dip of the modern sediments. Only minor faulting was detected at the toe of the scarp in the shallow deposits.
9. Faults known to cut Cretaceous and Tertiary sediments in southeastern Missouri were drilled to ascertian if any displacement occurs in the overlying Pleistocene and Holocene deposits. No faulting was detected in these younger deposits.

10. Aeromagnetic studies in northeastern Arkansas showed a strong northwest trend of magnetic anomalies in the Ozark province and a series of positive magnetic anomalies along the west edge of the Mississippi Embayment and Reelfoot Rift. The latter anomalies are thought to be expressions of mafic igneous bodies intruded along zones of weakness formed at the edge of the rift. Within the Mississippi Embayment magnetic basement deepens to more than 7 km and forms a northeast-trending trough that is 80 to 100 km wide.
11. The joint NRC and USGS seismograph array, operated in the New Madrid area by Saint Louis University, detected 632 earthquakes during 1978. Of these earthquakes 244 were located. The Wabash Valley seismograph array detected and located 8 earthquakes during that period. The focal depths of 5 of those earthquakes are deeper than 16 km, which makes them among the deepest earthquakes ever recorded in the central Mississippi Valley region. The earthquakes appear to be related to the Fairfield Basin of southeastern Illinois rather than with the Wabash Valley Fault System 30 km to the east.

A map showing the interpreted configuration of the top of Precambrian igneous rocks was prepared by the coordinator in 1977. Since that time it has been revised to reflect new data and new concepts. The current map (fig. A-1) has been modified with regard to a new map of the thickness of pre-Knox sediments by H.R. Schwalb which suggests a deeper Rough Creek Graben than had been indicated earlier. Eva Kisvarsanyi published a map showing the Precambrian configuration in Missouri. Although the contours changed only slightly from earlier interpretations, her map shows faults that have been projected to the Precambrian surface base on subsurface data. The Missouri faults have been added to the coordinator's work map.

Modifications of the mapping in the Mississippi Embayment are largely the result of several geophysical studies that produced maps showing interpreted depths to magnetic basement. Tom Hildenbrand and John Hendricks, U.S. Geological Survey furnished most of the interpretations. The Big Chief - Taylor well in Gibson County, Tennessee, previously considered a Precambrian datum point, is now considered an anomalously high elevation on igneous rock of Paleozic rather than Precambrian age.

A map published by the Indiana Geological Survey in 1978 (Bulletin 57, p. 12) did not defend the rather complex ridge and depression on the top of the Precambrian in the Wabash Valley area. The complex interpretation as proposed by Rudman, 1960, based on seismic reflection profiles (see Indiana Department of Conservation, Report of Progress No. 18) has been simplified on the new workmap.

APPENDIX A-1

Attendance at Progress Meetings

NEW MADRID STUDY GROUP

Progress Meeting - St. Louis, Missouri
September 27, 1978

NAME	ORGANIZATION
Curtis Ault	Indiana Geol. Survey
John Mackey	Indiana Geol. Survey
Dan Sullivan	Indiana Geol. Survey
David E. Willis	Univ. of Wisconsin - Milwaukee
Rutlage Brazee	U.S.N.R.C.
Edward O'Donnell	U.S.N.R.C.
Neil Steuer	U.S.N.R.C.
Ernie Glick	U.S.G.S. - Denver
Tom Hildenbrand	U.S.G.S. - Denver
David P. Russ	U.S.G.S. - Denver
Chuck Bufe	U.S.G.S. - Menlo Park
Mark D. Zoback	U.S.G.S. - Menlo Park
Tom Buschbach	Saint Louis Univ.
Bob Herrmann	Saint Louis Univ.
Otto Nuttli	Saint Louis Univ.
Larry Lackey	Memphis State Univ.
C. Patrick Ervin	Northern Illinois Univ.
Lyle McGinnis	Northern Illinois Univ.
Randy Keller	Univ. of Texas - El Paso
Ed Lidiak	Univ. of Pittsburgh
Jeff Ahbe	Purdue Univ.
Bill Hinze	Purdue Univ.
Rex Bohm	Missouri Geol. Survey
Ira Satterfield	Missouri Geol. Survey
Ron Ward	Missouri Geol. Survey
Dick Stearns	Vanderbilt Univ.
Dennis Kolata	Illinois Geol. Survey
Janis Treworgy	Illinois Geol. Survey
Howard Schwalb	Kentucky Geol. Survey
Vincent T. Larson	Billings, Montana
Robert Hamilton	U.S.G.S. - Reston
Sheila Steele	Carbondale, Illinois

NEW MADRID STUDY GROUP

Progress Meeting - Mountain View, Arkansas
April 9, 1979

NAME	ORGANIZATION
Tom Buschbach	Saint Louis Univ.
Dennis Kolata	Illinois Geol. Survey
Janis Treworgy	Illinois Geol. Survey
Tony Crone	U.S.G.S. - Denver
Ernest E. Glick	U.S.G.S. - Denver
John D. Hendricks	U.S.G.S. - Denver
Thomas G. Hildenbrand	U.S.G.S. - Denver
Dennis O'Leary	U.S.G.S. - Denver
David Russ	U.S.G.S. - Denver
Curtis H. Ault	Indiana Geol. Survey
Nick Stellovata	Indiana Geol. Survey
Dan M. Sullivan	Indiana Geol. Survey
Howard Schwalb	Kentucky Geol. Survey
Jack Kidd	Alabama Geol. Survey
Edward O'Donnell	U.S.N.R.C.
Ellis L. Krinitzsky	Corps of Engineers WES Vickburg, MS
Rex Bohm	Mo. Div. Geol. & Land Survey
Ron Ward	Mo. Div. Geol. & Land Survey
Jeffrey W. Pferd	Rondout Assoc., NRC Subcontractor
Pat Barosh	Weston Observatory
John Trapp	Dames & Moore
Dick Stearns	Vanderbilt Univ.
Stephen Obermeier	U.S.G.S. - Reston
James L. Baldwin	Purdue Univ.
Larry Braile	Purdue Univ.
Bill Hinze	Purdue Univ.
J. Reed	Purdue Univ.
John Sexton	Purdue Univ.

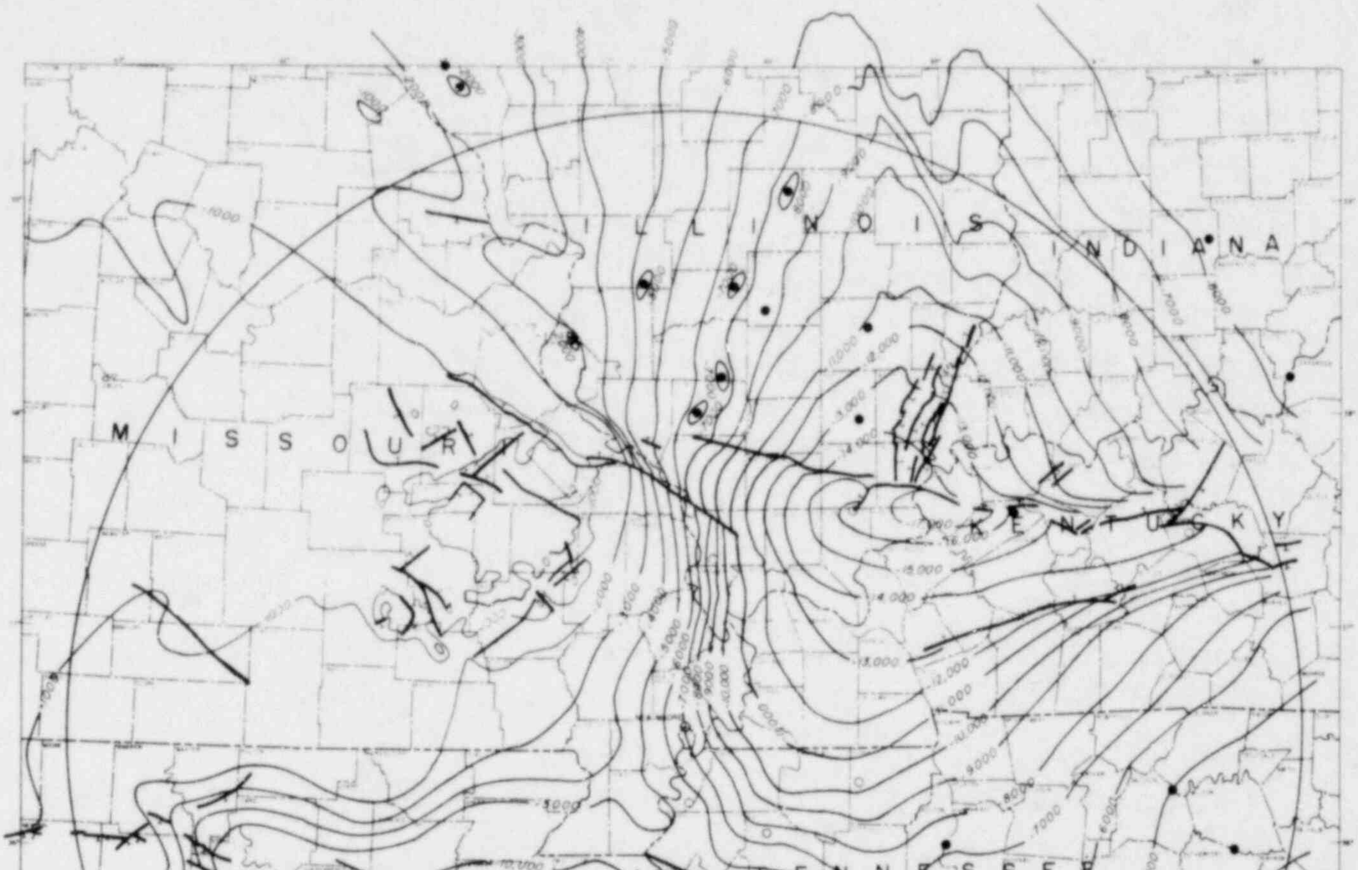

MISSOURI
ILLINOIS
INDIANA
KENTUCKY
TENNESSEE
ARKANSAS
MISSISSIPPI
ALABAMA
TOP OF PRECAMBRIAN IGNEOUS ROCKS
● Borehole reaching Precambrian igneous rocks
○ Other significant deep borehole
Work map by T.C. Buschbach
Dec., 1979

Figure A-1

AN INTEGRATED GEOPHYSICAL AND GEOLOGICAL STUDY OF THE TECTONIC FRAMEWORK OF THE 38th PARALLEL LINEAMENT IN THE VICINITY OF ITS INTERSECTION WITH THE EXTENSION OF THE NEW MADRID FAULT ZONE

Summary of
Annual Progress Report - Fiscal Year 1979

Contract No. NRC-04-76-323

L.W. Braile, W.J. Hinze, and J.L. Sexton
Purdue University

G.R. Keller
University of Texas at El Paso

E.G. Lidiak
University of Pittsburgh

ABSTRACT

An integrated gravity, magnetic, crustal seismic refraction and basement geology study is being conducted of the northeastern extension of the New Madrid Fault Zone in the vicinity of the 38th Parallel Lineament. Gravity and magnetic anomaly maps prepared of this area plus regional seismicity suggest that the basement structural feature associated with the New Madrid seismicity extends northeasterly into southern Indiana to at least 39° N. latitude. Gravity and subsurface data indicate that the Rough Creek Fault Zone, a major element of the 38th Parallel Lineament, is the northern boundary of a complex graben which formed in late Precambrian-early Paleozoic time and since has been reactivated. Surface wave studies indicate that the crustal thickness of the northern Mississippi Embayment is probably in the range of 50-55 km and the structure of the crust obtained from these studies is highly suggestive of a failed rift.

TECHNICAL SUMMARY

A suite of geophysical data sets is being collected, processed analyzed, and interpreted using observed geologic constraints from the basement and overlying sedimentary rocks to investigate the tectonic and geologic history of the 38th Parallel Lineament and the extension of the New Madrid Fault Zone and associated features, and to determine the variations in structure and properties of the crust and their relationship to the regional contemporary geodynamics. Gravity and magnetic anomaly data have been collected and reduced to complete coverage over the study area from 36.5° to 39° N. latitude and from 85° to 90° W. longitude. Preliminary compilations have been completed in the vicinity of the extension of the New Madrid Fault Zone and all data are being gridded in preparation for compiling the regional maps and for the computation of interpretative maps. Several seismic refraction profiles have been observed in Indiana and Illinois to study the velocity structure of the crust. These profiles have centered on the Wabash Valley Fault Zone and the New Madrid Fault Zone extension. In addition, petrologic studies of the mafic and ultramafic dikes and related intrusions have shown that the mantle was involved in the tectonic development of the region. Furthermore, various basement geologic maps including age, lithology, configuration and geophysical provinces are being developed to assist and constrain the geophysical interpretation.

Although the principal effort has been directed toward collecting and processing data, several significant preliminary results have been obtained which bear strongly on the tectonic history or contemporary geodynamics of the region. Interpretation of the regional gravity and magnetic anomaly maps indicates parallel linear trends of isolated nearly circular, correlative positive gravity and magnetic anomalies which bound a central zone of low gravity and magnetic anomaly relief and are associated with the New Madrid Seismic Zone. These trends can be traced northeast across the 38th Parallel Lineament and related prominent west-northwest striking geophysical anomalies into southern Indiana at least to 39° N. latitude. These trends of circular anomalies which are interpreted as having a source within the basement are associated with the trend of earthquake epicenters in the New Madrid area and to the northeast. This suggests that a linear basement structural feature is a primary control on the location of earthquake epicenters in the New Madrid region. The extension of the New Madrid structural feature to the northeast does not necessarily imply that it is or will be seismically active along its entire length. The frequency of occurrence of earthquakes to the northeast of the New Madrid area is clearly lower than along the New Madrid Seismic Zone. Thus, although the entire length of the feature (35-39°) is interpreted as a structural unit, it is unclear that it must be considered as a single unit for seismic regionalization.

Gravity and subsurface data indicate that the Rough Creek Fault Zone, a major element of the 38th Parallel Lineament near its intersection with the northern Mississippi Embayment, is the northern boundary of a complex graben. The scale and deep seated nature of the faulting suggest an origin by extensional tectonic forces related to intracratonic rifting. The graben was formed in late Precambrian-early Paleozoic time, has been reactivated and is now approximately 5 km deep.

Short to intermediate period (5-80 sec) Rayleigh waves recorded at St. Louis, Missouri and Oxford, Mississippi have been analyzed to determine group and phase-velocity dispersion curves. These data were used to determine crustal and upper mantle shear-velocity structure of the northern Mississippi Embayment. The derived models show the crustal thickness to be at least 47 km and probably in the range of 50-55 km. An anomalously high-velocity layer (V_s = 4.0 km/sec) occurs in the lowermost crust. These results together with previous studies are highly suggestive of a failed rift zone (aulocogen).

The results of the investigation to date demonstrate the importance of regional, integrated geological and geophysical studies in investigations of contemporary tectonics and seismicity in the Midcontinent region. These data also provide striking evidence for basement structural control of contemporary stresses.

ACKNOWLEDGMENTS

The progress on this project discussed in this report is the result of the combined effort of a large group of undergraduate and graduate students as well as faculty of Purdue University, Univeristy of Texas at El Paso, and the University of Pittsburgh. The authors of this report acknowledge the significant contribution of the following students: Purdue University - Jeff Ahbe, Mark Baker, James Baldwin, Tim Fogarty, Duane Gibson, Richard Lewis, Bruce Losee, John McGinnis, Keith Peregrine, John Reed, James Richards, Mark Sparlin, David Taylor, and Donald Turner. University of Texas at El Paso - C. B. Austin, Howard Cornelius, Robert Graham, Stephan Harden, Robert Lund, Randall Mandock, Henry Popesh, David Russell, and R. K. Soderberg. University of Pittsburgh - David Becker, Cheryl Birciw, Mark Dadosky, Ken Ichikawa, and Robert Marbury.

INTRODUCTION

The central Midcontinent of the United States has characteristically been considered part of the stable craton. However, contemporary seismicity and a broad range of geologic structures reflect a long, complex mid-plate tectonism. The purpose of this investigation as well as many others currently underway is to specify this tectonism and understand its origins. Two of the most important tectonic features of the continental interior are the New Madrid Fault Zone and the 38th Parallel Lineament. These features, especially their zone of intersection (Figure B-1), have been under intensive study over the past several years (Heyl, 1972, Buschbach, 1977; Hildenbrand and other, 1978; Hinze and others, 1977 and 1979, Braile and others, 1979a) and are the subject of an integrated, continuing program by a consortium of geoscience investigators.

The 38th Parallel Lineament is a band of geologic features extending across eastern U.S. along the 38th parallel of latitude. It is manifested in many ways, but primarily by a series of east-west trending fault zones which were active at least through the Paleozoic era. It may represent a Precambrian fracture zone or crustal boundary extending deeply into the crust and possibly the mantle. The northeasterly-trending New Madrid Fault Zone has been the site of several intermediate and major earthquakes in historic time and is the most seismically active area in eastern North America. The trend of the New Madrid Seismic Zone extends into southern Illinois and Indiana in the vicinity of the Wabash River Valley Fault System. This trend intersects the 38th Parallel Lineament in the vicinity of the confluence of the Wabash and Ohio Rivers. Additional details of these tectonic features are discussed by Hinze and others (1977). Fundamental questions of the New Madrid Seismic Zone are its extension to the northeast and the nature of its intersection with the 38th Parallel Lineament. These questions are particularly significant to the evaluation of the earthquake risk in the region.

In 1976 an integrated geological and geophysical study program was initiated of the tectonic framework of the 38th Parallel Lineament in the vicinity of its intersection with the extension of the New Madrid Seismic Zone. The objectives of this program are to investigate the tectonic and geologic history of the 38th Parallel Lineament and the extension of the New Madrid Seismic Zone and associated features, and to determine the variations in structure and properties of the crust and their relationship to the regional contemporary geodynamics. To accomplish these goals several hypotheses have been considered as the source of the contemporary tectonism. These hypotheses which include crustal rifting, regional thermal expansion and contraction, crustal boundaries and zones of weakness, local basement inhomogenities, and isostatic warping are reviewed by Hinze and others (1977 and 1979) and are illustrated schematically in Figure B-2. Consideration of them has led to the design of a comprehensive, intergrated data collection, synthesis, and interpretation program. The principal area of interest (Fig. B-1) is bounded by 85° W. and 90° W. longitude and 36° 30' N. and 39° N. latitude. However, recent studies (Braile and others, 1979b) have shown the importance not only of investigating this entire area but expanding the area because of the need to develop regional relationships.

The principal progress in this integrated study program has been in acquiring and sythesizing critical magnetic, gravity, and geologic data; conducting crustal seismic investigations; and in interpretation of the available data. The following sections describe the progress and results to date.

Oral presentations on the progress and results of the study were made to the New Madrid Study Group at St. Louis, Missouri on 27 September, 1978 and on 9 April, 1979 in Mountain View, Arkansas. Three technical papers reporting the results of this study were presented at the Fourth Annual Midwest American Geophysical Union Meeting, 25-27 September, 1978; one paper was presented at the Geological Society of America annual meeting on 25 October, 1978; one paper was presented at the International Symposium on the Rio Grande Rift during 8-17 October, 1978; and five papers were read before the South-Central Section of the Geological Society of America on 9-10 April, 1979. A paper entitled "Models for Midcontinent Tectonisms" (Hinze and others, 1979) which is an outgrowth of a previous Nuclear Regulatory Commission Report (Hinze and others, 1977) will soon be published in the National Academy of Sciences' Monograph "Continental Tectonics". Furthermore, three manuscripts of principals of this study have been accepted for publication in a forthcoming U.S. Geological Survey Professional Paper dealing with the New Madrid Seismic Zone. They are "High resolution seismic reflection surveying on Reelfoot Scarp, Northwestern Tennessee" by J.L. Sexton, E.P. Frey, and Dave Malicki, "A crustal structure study of the Mississippi Embayment" by C.B. Austin and G.R. Keller, and "The northeastern extension of the New Madrid Fault Zone" by L.W. Braile, W.J. Hinze, G.R. Keller, and E.G. Lidiak. The latter two manuscripts have been prepared with the support of the NRC research funding.

GRAVITY ANOMALY MAPPING AND ANALYSIS

The present status of gravity coverage over the study area is shown in Figure B-3. The entire previously delineated area is covered by stations at intervals of 2 to 3 km wherever access and elevations will permit. The observations have been tied together and to the national network. Further, the data have been reduced and the principal facts have been entered into a master data file. The data file system has been made versatile by a scheme which permits data within a specified area to be purged from the file and new data to be added to the file. The data file is now being gridded at a 2 km interval for further processing and presentation of the data. The data from the recently completed reduction of the Indiana gravity observations are contoured in Figure B-4. Minor adjustments have been made to the data of southwestern Indiana which were observed and reduced in the previous fiscal year. These adjustments were made necessary because of the final ties between gravity data sets. The revisions in this map over previous maps prepared from widely-spaced observations are noteworthy and justify the additional observations. Local anomalies and gradients have been altered and anomalies based on a few erroneous values have been removed. A preliminary compilation map of the Bouguer gravity anomaly values from the New Madrid and adjacent area is shown in Figure B-5. This map has been used in the preliminary interpretation of the northeast extension of the New Madrid linear tectonic feature (Braile and others, 1979b) the abstract of which is presented in Appendix B-1.

MAGNETIC ANOMALY MAPPING AND ANALYSIS

The status of aeromagnetic coverage over the study area and environs is shown in Figure B-6. During the current fiscal year the observation and reduction of the survey in southeastern Illinois west of 89° W. longitude and south of 39° N. latitude has been completed. The survey is based on one mile (1.6 km) north-south flight lines at an elevation of 1500 ft. (457 m) AMT, and the mapped data have been corrected for diurnal variations and the updated 1975 IGRF. Two particularly high-frequency anomalies (37° 51' N, 88° 21' W; 37° 38', 88° 36') on this map have been verified by ground magnetic observations. The character of these anomalies is strongly suggestive that they originate from highly magnetic igneous bodies intruding the Phanerozoic sedimentary rocks. One of these anomalies coincides with the Omaha Oilfield in Gallatin Count.., Illinois. The anomaly in plan view closely resembles the configuration of the Omaha Oilfield where drilling shows mica perioditite bodies within the Devonian sedimentary rock sequence which may explain the abnormal dip within the overlying Mississippian rocks. Preliminary measurements indicate that the igneous rock has a magnetic susceptibility of the order of $10{,}000 \times 10^{-6}$ emu/cc.

Aeromagnetic tie lines were flown across southwest Illinois and Indiana to obtain data for compositing the data sets. The Indiana data were previously gridded and processed to assist in interpretation. In the same manner the data of southwest and southeast Illinois were tied together and gridded at a 2 km interval (Figure B-7). These data were reduced-to-the-pole and upward continued to elevations of 2, 5, 10 and 20 km to eliminate successively longer wavelength anomaly data. Upward continuation serves as a very efficient short-wavelength cut filter. In an effort to emphasize the directional trends of anomalies, the scuthern Illinois anomaly map upward continued to 5 km has been strike-pass filtered in the north, east, northeast and northwest directions. The available total magnetic intensity anomaly data has been composited in a preliminary manner (Figure B-8) to complement the composite Bouguer gravity anomaly map in delineating the northeastern extension of the New Madrid linear tectonic feature. The geologic significance of these magnetic anomaly maps is discussed by Braile and others, 1979b. Currently, the magnetic data of Kentucky and Tennessee are being tied into the other magnetic anomaly data sets and the data are being gridded for further processing.

SEISMIC STUDIES

Seismic refraction profiles have been recorded in the Wabash Valley area (Figure B-9) to investigate the deep structure of the crust in the area of the possible northeastern extension of the New Madrid Seismic Zone. Additional seismic refraction data have been collected at the termination of this contract period, but processing of that data is too incomplete to include results in this discussion. Because the refraction study is incomplete, our current analysis and interpretation of these profiles is limited and must be considered preliminary. The record sections indicate that the Paleozoic sedimentary rocks in the Illinois basin have a average velocity of about

6.8 km/sec. The early arrivals of the 6.8 km/sec phase on the east-west line relative to the north-south line suggest that the lower crustal layer is shallower beneath the east-west line.

Synthetic seismograms have been computed for several crustal models which have been suggested for the Midcontinent area (McCamy and Meyer, 1966; Stewart, 1968). The theoretical seismograms were calculated by a ray theory method and only the primary refracted and reflected arrivals are included. There is general agreement between the observed record sections and the synthetic seismograms for two of the models. In addition to further modeling of the travel-time and amplitude data for the observed seismograms, amplitude-distance curves are presently being computed for the purpose of investigating attenuation of body waves in the crust of the Midcontinent. Preliminary results shown in Figure B-10 indicate attenuation characteristics of body waves similar to those observed in the western United States.

BASEMENT GEOLOGY

Geologic studies are continuing on five related projects. (1) Preliminary maps of selected basement and geophysical parameters and of inferred basement and geophysical provinces have been prepared. These maps will be extremely important in the interpretation of the geologic and tectonic development of the study region. Up-dating and revision of these maps are continuing. (2) The second project involves grain density measurements on the red quartz sandstone from the deep test well (Texas Pacific No. 1 Farley, sec. 34-13S-3E; Johnson County, Illinois) near the center of the Illinois Basin. The measurements carried out at the University of Pittsburgh are listed in Table B-1, and those determined by Core Laboratories, Inc., are listed in Table B-2. The good agreement between laboratories confirms the fact that the rocks have higher densities than most sandstones. These densities of 2.62 - 2.74 gm/cc and the location of the rocks in the Illinois Basin are particularly noteworthy. If these pre-Upper Cambrian sandstones are widely distributed in the deep basin and adjacent regions, their influence on the gravity field in the study area may be appreciable. (3) K-Ar age determinations of basement samples are also underway. Table B-3 lists the determinations that have been completed. Dating of other basement rock samples and samples from mafic and ultramafic dikes in the study area are continuing. (4) The fourth project involves a study of the orientation of faults and dikes in the study area. Rose diagrams of fault

Well Elevation = 594 ft. (KB)

Top of Eau Claire = 11,895 ft.

Top of Mt. Simon = 13,020 ft.

Top of first quartzite = 13,510 ft.

Top of red quartzite - 13,775 ft.

Total Depth = 14,274 ft.

Sample interval (ft.)	Sample number		Specific gravity
13,580 - 13,590	IL-29-1	white quartz sanstone	2.622
13,780 - 13,790	IL-29-2	pink quartz sandstone	2.618
13,800 - 13,810	IL-29-3	pink micaceous quartz sandstone	2.629
13,850 - 13,860	IL-29-4	pink quartz sandstone	2.645
13,900 - 13,910	IL-29-5	pink quartz sandstone	2.655
13,950 - 13,960	IL-29-6	pink quartz sandstone	2.614
14,000 - 14,010	IL-29-7a	pink quartz sandstone	2.666
	IL-29-7b	hematitic siltstone	2.740
14,100 - 14,110	IL-29-8	pink quartz sandstone	2.647
	IL-29-8	hematitic siltstone	2.728
14,130 - 14,140	IL-29-9	pink quartz sandstone	2.662
	IL-29-9	red epidote quartz sandstone	2.693
14,150 - 14,160	IL-29-10a	pink epidote quartz sandstone	2.633
	IL-29-10	red epidote quartz sandstone	2.678
14,200 - 14,210	IL-29-11	pink epidote quartz sandstone	2.654
	IL-29-11	red epidote quartz sandstone	2.646
14,250 - 14,260	IL-29-12	pink epidote quartz sandstone	2.658
	IL-29-12	red epidote quartz sandstone	2.649
14,270 - 14,274	IL-29-13	pink epidote quartz sandstone	2.635
	IL-29-13	red epidote quartz sandstone	2.609

Table B-1. Density measurements of sandstone from the Texas Pacific No. 1 Farley well (sec. 34-13S-3E). Johnson County, Illinois (Univ. of Pittsburgh)

Sample Number	Porosity, percent	Grain density gm/cc	Bulk density gm/cc
IL-29-1	2.2	2.65	2.61
IL-29-5	4.1	2.66	2.59
IL-29-7	1.4	2.73	2.71
IL-29-10a	3.4	2.64	2.58
IL-29-10b	1.7	2.67	2.46

Table B-2. Density and porosity measurements of sandstone from Texas Pacific No. 1 Farley Well (sec. 34-13S-3E), Johnson County, Illinois (Core Laboratories, Inc.).

orientations for selected major fault zones are shown on Figures B-11 and B-12, and dike trends are shown on Figure B-13. The different orientations shown on these diagrams are clear indication that all of the major fault zones need to be taken into account in assessing the paleo-stress system and comparing it to the modern stress system. (5) The fifth project consists of a petrologic study of the mafic and ultramafic dikes and related intrusions. Kimberlitic, carbonatitic, and lamprophyric rocks have been identified. These compositions indicate that the upper mantle was involved in the tectonic development of the region.

INTEGRATION AND INTERPRETATION

Considerable progress has been made in the integration and synthesis of geologic and geophysical data relevant to the possible northeastern extension of the New Madrid Seismic Zone during the project period. For the most part these results have been presented in the ten papers presented orally at scientific meetings and three written papers, the abstracts of which are presented in Appendix B-1. In addition, a bibliography on continental rifts with over 1000 entries has been prepared and is available for distribution to interested geoscientists.

An important element of this project is the integration of direct basement geological information obtained from deep drilling and the results of geophysical mapping. Preliminary maps of selected basement and geophysical parameters and of inferred basement and geophysical provinces have been prepared and are shown in Figures B-14 and B-15. The explanation is presented as Figure B-16.

Well Name & Location	Rock & Sample Type	Material Analyzed	K-Ar age (m.y.)
Associated Oil and Gas No. 1 Sells sec. 3-A-54E Pickett Co., Tenn.	coarse-grained granite cuttings	amphibole	1070
Stauffer Chemical No. 1 Fee sec. 16-12S-28E Maury Co., Tenn	biotite granite cuttings	biotite	1325
NIPSCO No. 1 Ames sec. 21-34N-3E Marshall Co., Ind.	schist(?) core	biotite+ hornblende concentrate	900
Amerada No. 1 Ullman Noble Co., Ohio	quartz diorite core	hornblende	1000

Table B-3. Preliminary K-Ar ages, Midcontinent, U.S.

A major effort of the project activities has been directed toward the identification and interpretation of the northeastern extension of the New Madrid Seismic Zone. The principal conclusion of this study is that a basement structural feature recognized by Hildenbrand and others (1978) in the New Madrid area on the basis of trends of correlative, positive gravity and magnetic anomalies, which are associated with the earthquake activity in the area, can be traced northeastward into southern Indiana at least to 39° N. latitude. This suggests that a continuous basement geologic feature extends from the New Madrid area into southern Indiana and may be a primary control on the locations of earthquake activity. Cross-sections of alternative models of this structural feature are shown in Figure B-17. This northeasterly trend is significant and has a definite correlation with the historical earthquake occurrences reported by Hadley and Devine (1974).

MAJOR PRODUCTS

The major products completed to date include the following:

1) Magnetic anomaly map of southern Illinois and various interpretive maps derived by filtering the original map.
2) Bouguer gravity anomaly data of approximately 25,000 observations within the area bounded by 36.5° - 39° N. latitude and 85° - 90° W. longitude.
3) Preliminary Bouguer gravity anomaly map of New Madrid region and adjacent areas.
4) Complete gravity survey of Indiana south of 39° N. latitude.
5) Preliminary total magnetic intensity anomaly map of New Madrid region and adjacent areas.
6) Grid of Bouguer gravity and total magnetic intensity anomaly values to facilitate computation of interpretive maps under preparation.
7) Seismic record sections of crustal seismic refraction profiles and preliminary interpretation.
8) Preliminary interpretation of the northeast extension of the New Madrid linear tectonic feature.
9) Reports on models for midcontinent tectonism.
10) Bibliography on continental rifts.
11) Updated inferred basement and geophysical province maps.
12) Radiometric dating of selected basement rock samples.
13) Petrologic studies of ultramafic and mafic intrusions.

REFERENCES

Braile, L.W., W.J. Hinze, G.R. Keller, and E.G. Lidiak, 1979a, An integrated geophysical and geological study of the tectonic framework of the 38th Parallel Lineament in the vicinity of its intersection with the extension of the New Madrid Fault Zone: U.S. Nuclear Regulatory Commission Report NUREG/CR-0449, 67 p.

Braile, L.W., W.J. Hinze, G.R. Keller, and E.G. Lidiak, 1979b, The northeastern extension of the New Madrid Fault Zone: Submitted to U.S. Geological Survey Prof. Paper on the New Madrid Fault Zone.

Buschbach, T.C., 1977, New Madrid Seismotectonic Study, Activities during fiscal year 1977: U.S. Nuclear Regulatory Commission Report NUREG-0379, 61 p.

Hadley, J.B. and J.F. Devine, 1974, Seismotectonic Map f the Eastern United States, Misc. Field Studies Map MF-620, U.S. Geol. Survey.

Heyl, A.V., M.R. Brock, J.L. Jolly, and C.E. Wells, 1965, Regional structure of the southeast Missouri and Illinois-Kentucky mineral districts: U.S. Geol. Survey Bull. 1202-B, 20 p.

Heyl, A.V., 1972, The 38th Parallel Lineament and its relationship to ore deposits: Econ. Geology, v. 67, pp. 879-894.

Heyl, A.V. and F.A. McKeown, 1978, Preliminary seismotectonic map of central Mississippi Valley and environs: U.S. Geol. Survey Map MF-1011.

Hildenbrand, T.G., M.F. Kane, and W. Stauder, S.J., 1978, Magnetic and gravity anomalies in the northern Mississippi Embayment and their spatial relation to seismicity: U.S. Geol. Survey Map MF-914.

Hinze, W.J., L.W. Braile, G.R. Keller, and E.G. Lidiak, 1977, A tectonic overview of the central midcontinent: U.S. Nuclear Regulatory Commission Report NUREG-0382 (RGA), 106 p.

Hinze, W.J., L.W. Braile, G.R. Keller, and E.G. Lidiak, 1979, Models for midcontinent tectonism: Nat. Acad. of Science Mon., Continental Tectonics, in press.

McCamy, K. and R.P. Meyer, 1966, Crustal results of fixed multiple shots in the Mississippi Embayment: Am. Geophys. Un. Mon. 10, pp. 370-381.

Stewart, S.W., 1968, Crustal structure in Missouri by seismic refraction methods: Seis. Soc. America Bull., v. 58, pp. 291-323.

APPENDIX B-1

Abstracts of Papers Published with Annual Report (NUREG/CR-1014)

THE NORTHEASTERN EXTENSION OF THE NEW MADRID SEISMIC ZONE

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ABSTRACT

Linear trends of nearly circular, correlative, positive gravity and magnetic anomalies which bound a central zone of low gravity and magnetic relief and are associated with the New Madrid Seismic Zone can be traced northeastward across the 38th Parallel Lineament into southern Indiana at least to 39° N. latitude on regional gravity and magnetic anomaly maps. These anomalies which are interpreted as having a source within the basement are associated with the trend of earthquake epicenters in the New Madrid area and to the northeast. This suggests that a linear basement structural feature is a primary control on the location of earthquake epicenters in the New Madrid region.

A CRUSTAL STRUCTURAL STUDY OF THE MISSISSIPPI EMBAYMENT

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ABSTRACT

Short to intermediate period (5-80 sec) Rayleigh waves recorded at WWSSN stations FLO (near St. Louis, Missouri) and OXF (Oxford, Mississippi) were analyzed digitally to obtain group and phase-velocity dispersion curves. These data were used to determine the crustal and upper mantle shear-velocity structure of the northern Mississippi Embayment. The models derived show the crustal thickness of the northern Mississippi Embayment to be at least 47 km and probably in the range of 50-55 km. An anomalously high-velocity layer (V_s = 4.0 km/sec) is found in the lowermost crust throughout the region. The crustal model derived is in good agreement with previous refraction work.

The results of this study are then intergrated with previous work to produce a hypothetical cross-section for the northern Mississippi Embayment that is highly suggestive of a failed rift (aulacogen ?).

A GRAVITY AND TECTONIC STUDY OF THE ROUGH CREEK FAULT ZONE AND RELATED FEATURES

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ABSTRACT

The Rough Creek Fault Zone is a major element of the 38th Parallel Lineament near its intersection with the northern Mississippi Embayment. Gravity and subsurface data indicate that this fault zone is actually the northern boundary of a complex graben for which the name Rough Creek Graben is proposed. This graben is a major feature formed in the late Precambrian-early Paleozoic, has been reactivated, and is now ~ 5 km deep.

* Now at: Chevron Oil Company
1111 Tulane Avenue
New Orleans, Lousiana 70112

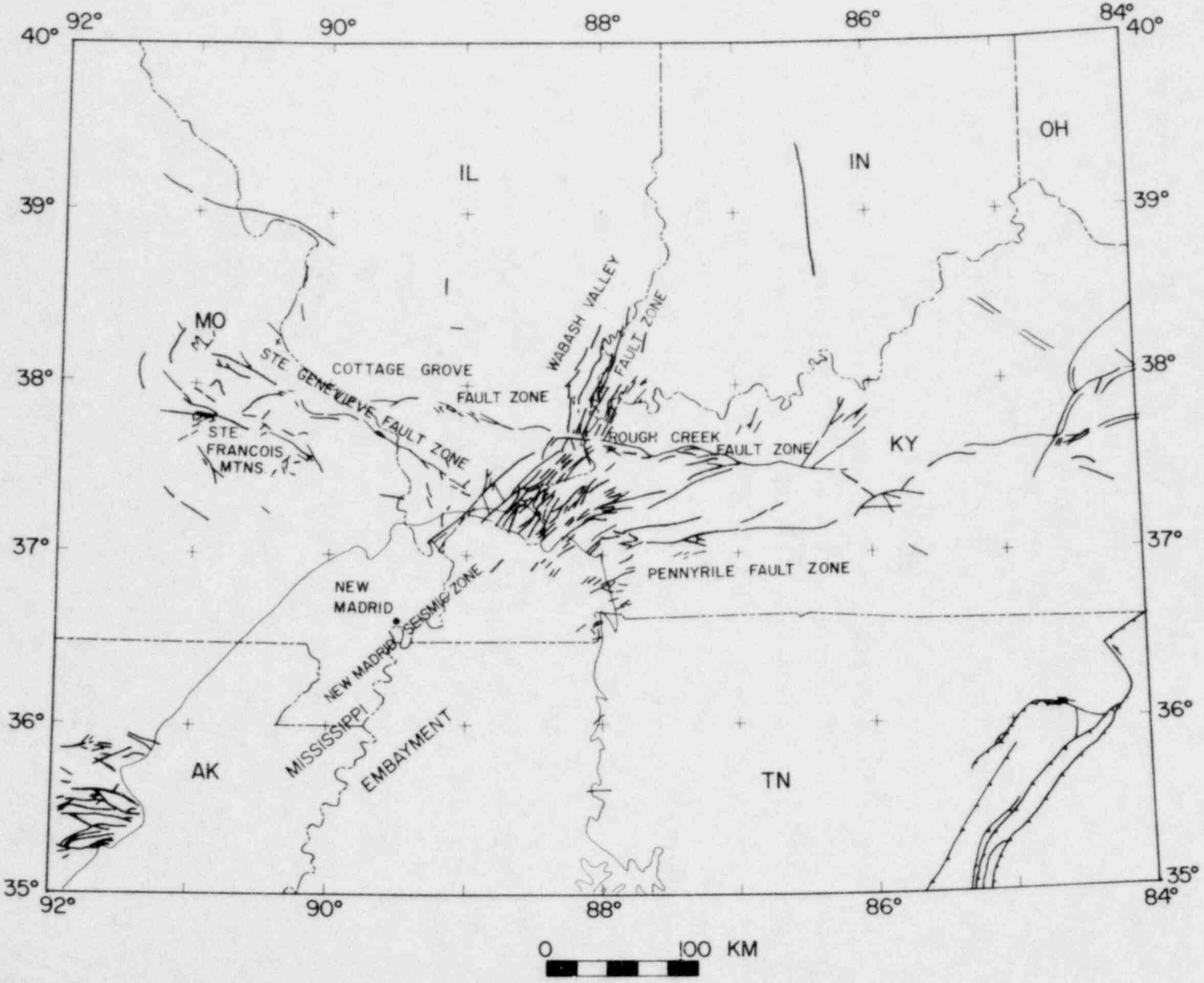


Figure B-1 Tectonic features in the New Madrid Seismic Zone and surrounding area (generalized from Heyl and McKeown, 1978; Heyl, 1972; and other sources).

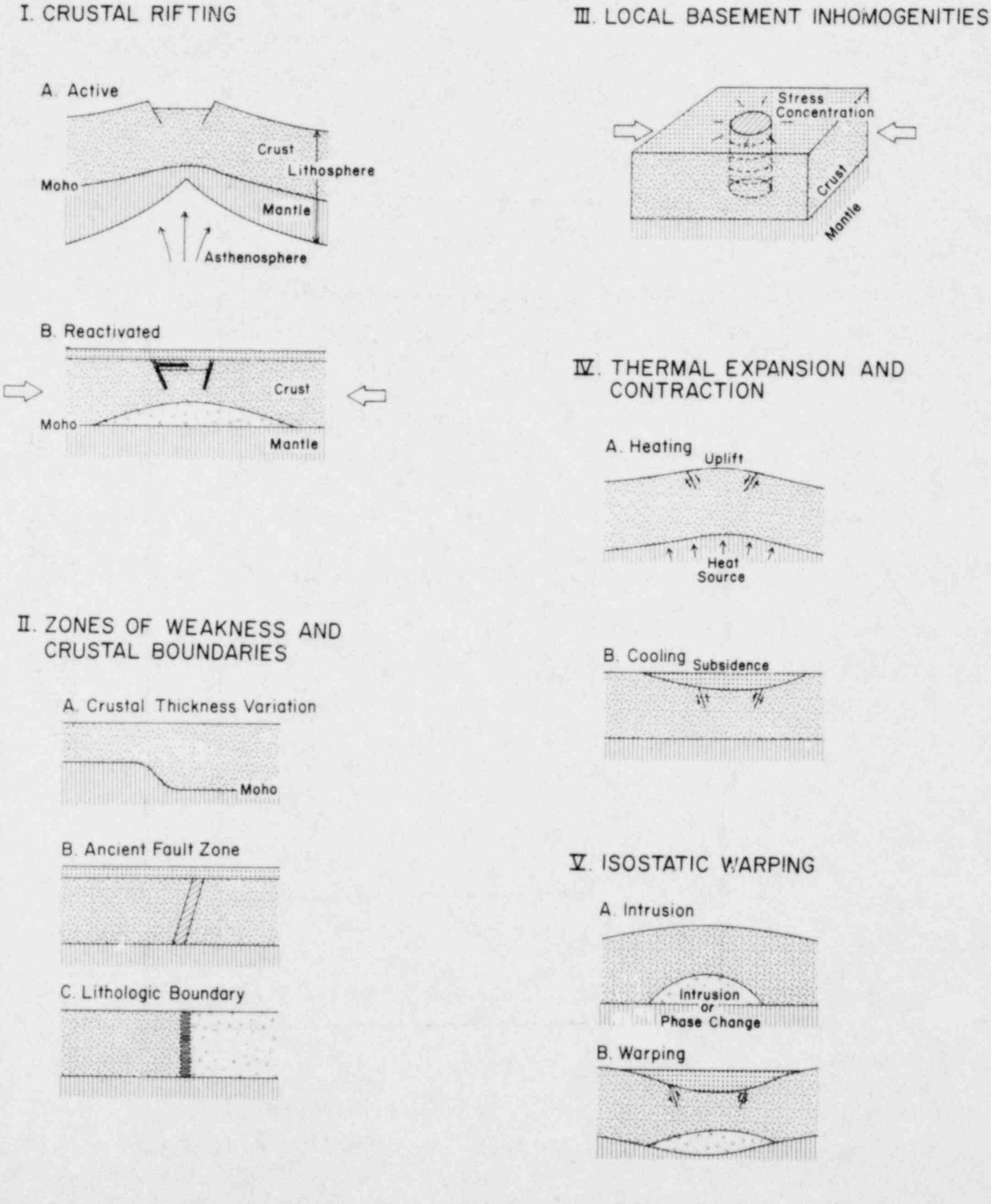


Figure B-2 Schematic diagram illustrating the mechanisms which have been proposed to explain the tectonism in the Midcontinent of North America.

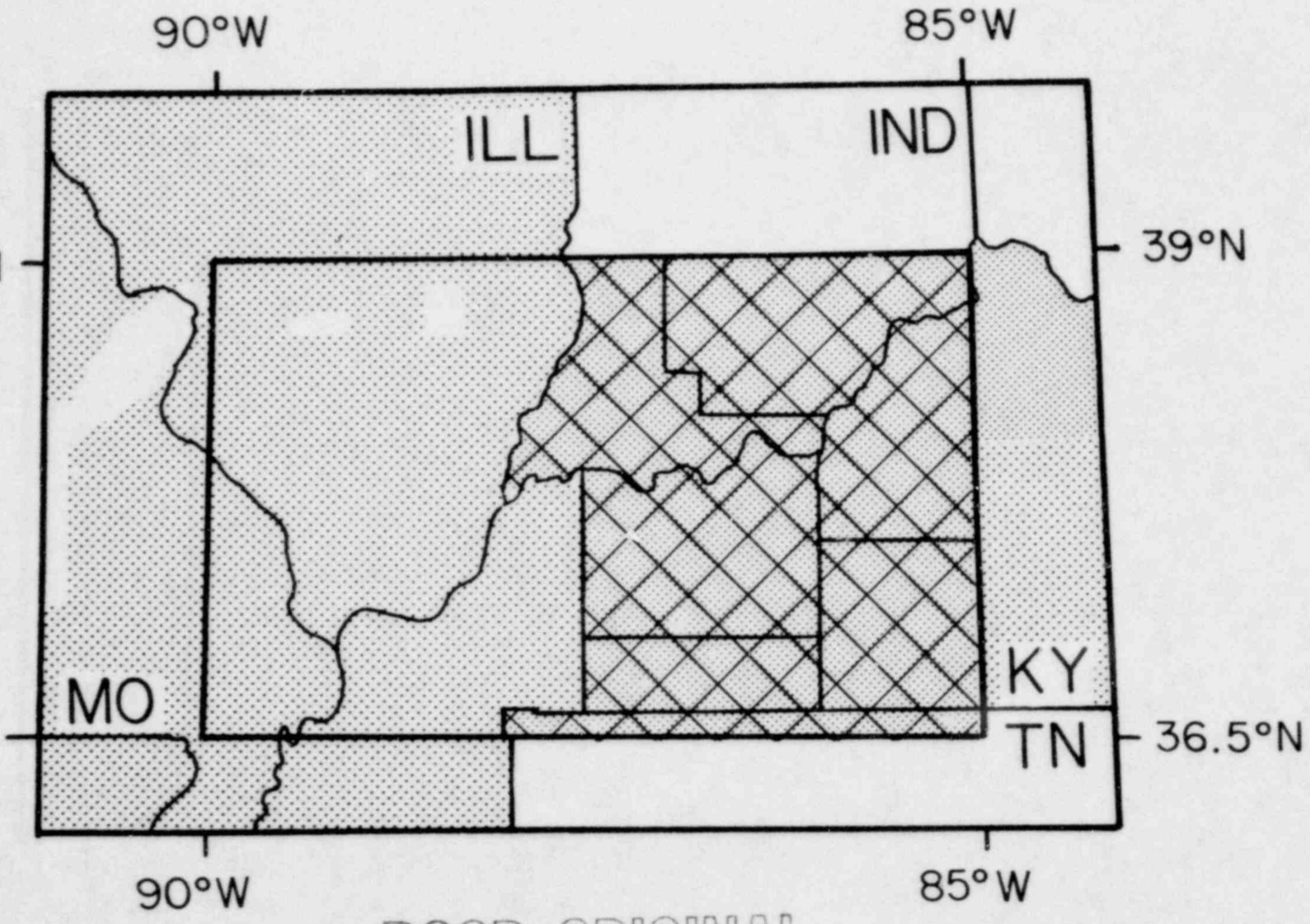


Figure B-3 Map indicating status of detailed gravity observations within the study area which is shown by rectangle. Coarse dotted pattern indicates area of complete coverage before study was initiated. Fine dotted pattern indicates data obtained as part

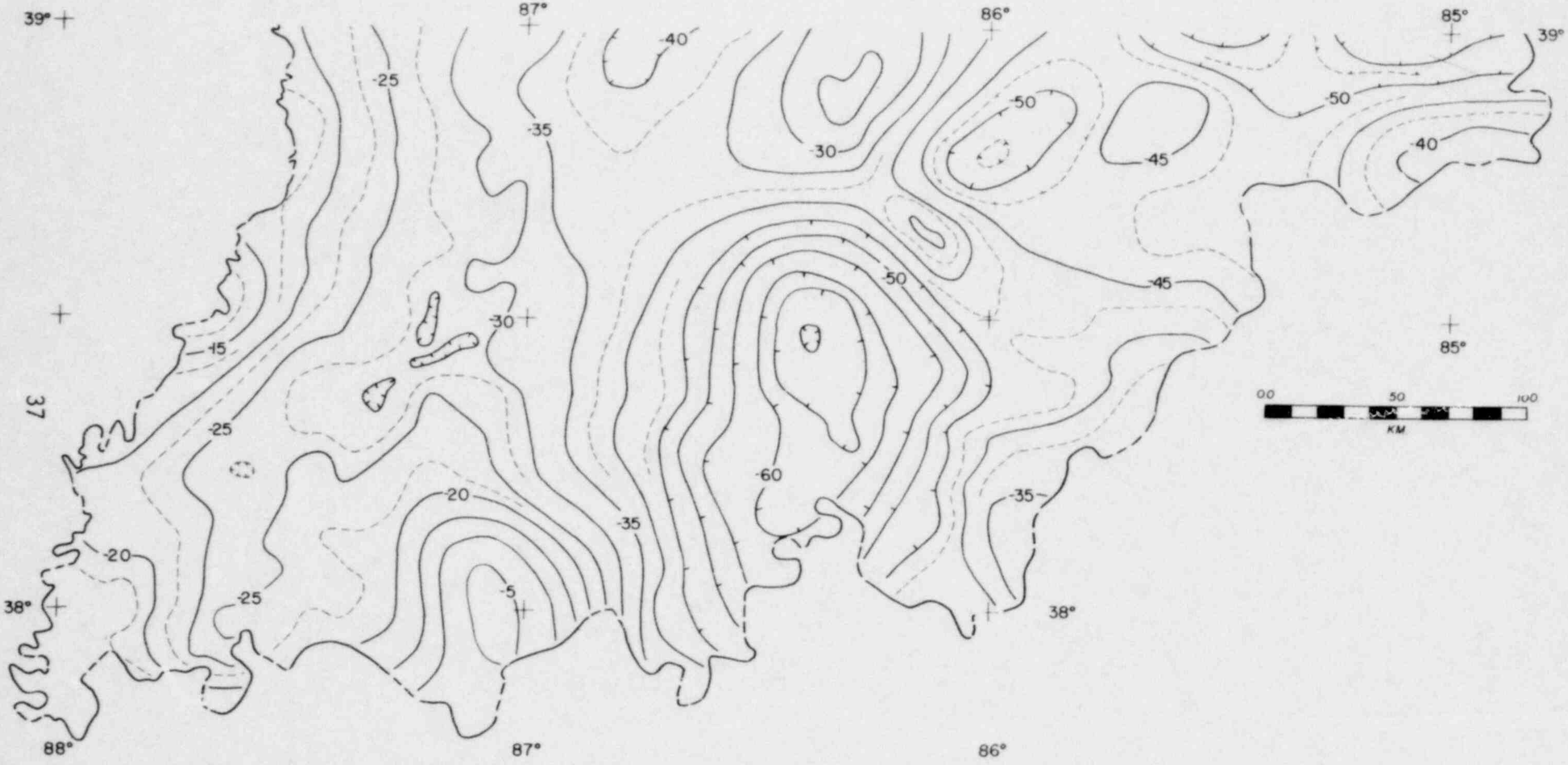


Figure B-4 Bouguer gravity anomaly map of southern Indiana from data observed at 2-3 km spacing during 1977 and 1978. Contour interval is 5 mgal with supplementary contours at 2.5 mgal interval dashed. Reduction rock density is 2.67 gm/cc.

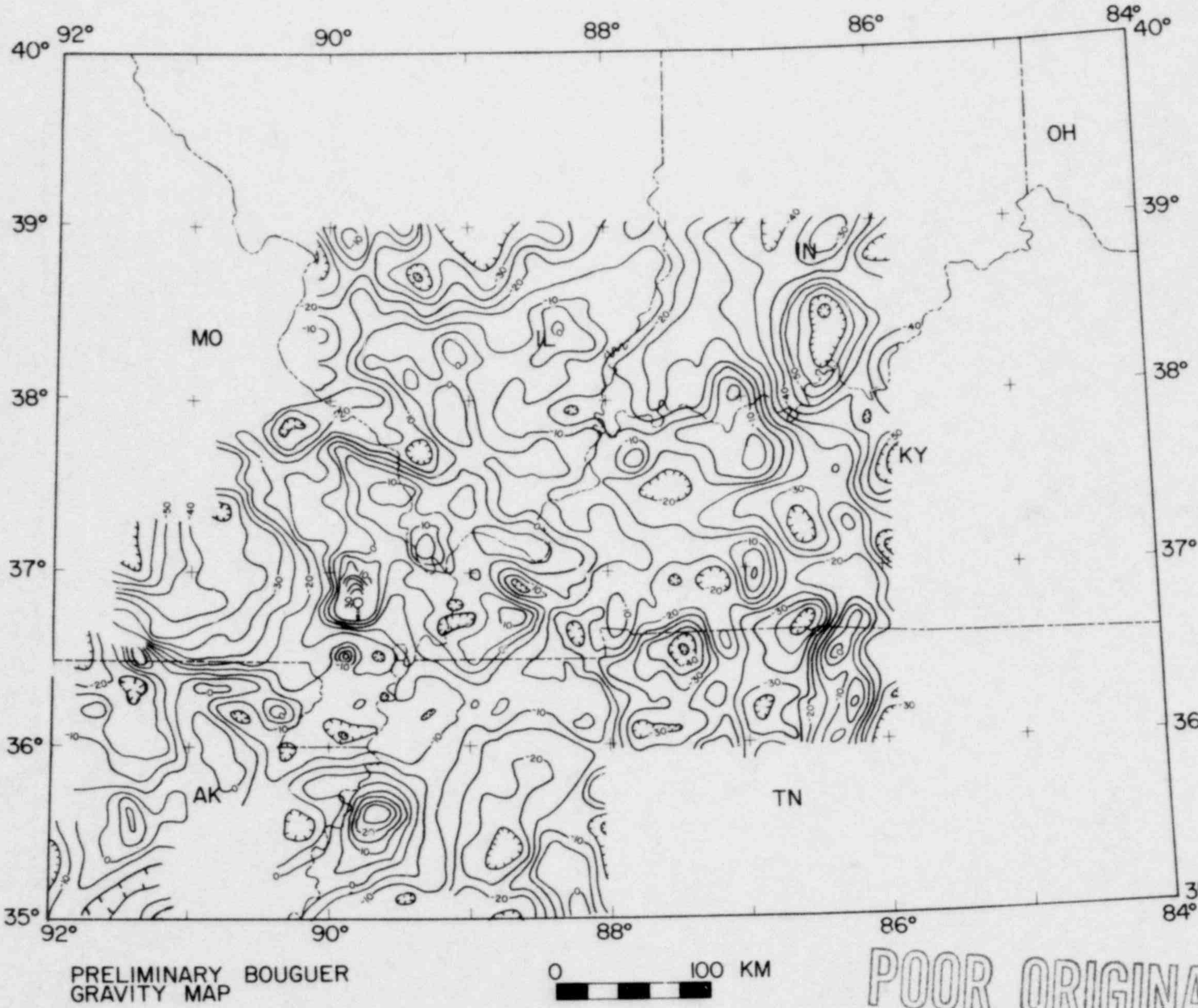


Figure B-5 Preliminary Bouguer gravity anomaly map of the New Madrid Seismic Zone and surrounding area. Contour interval is 5 mgal.

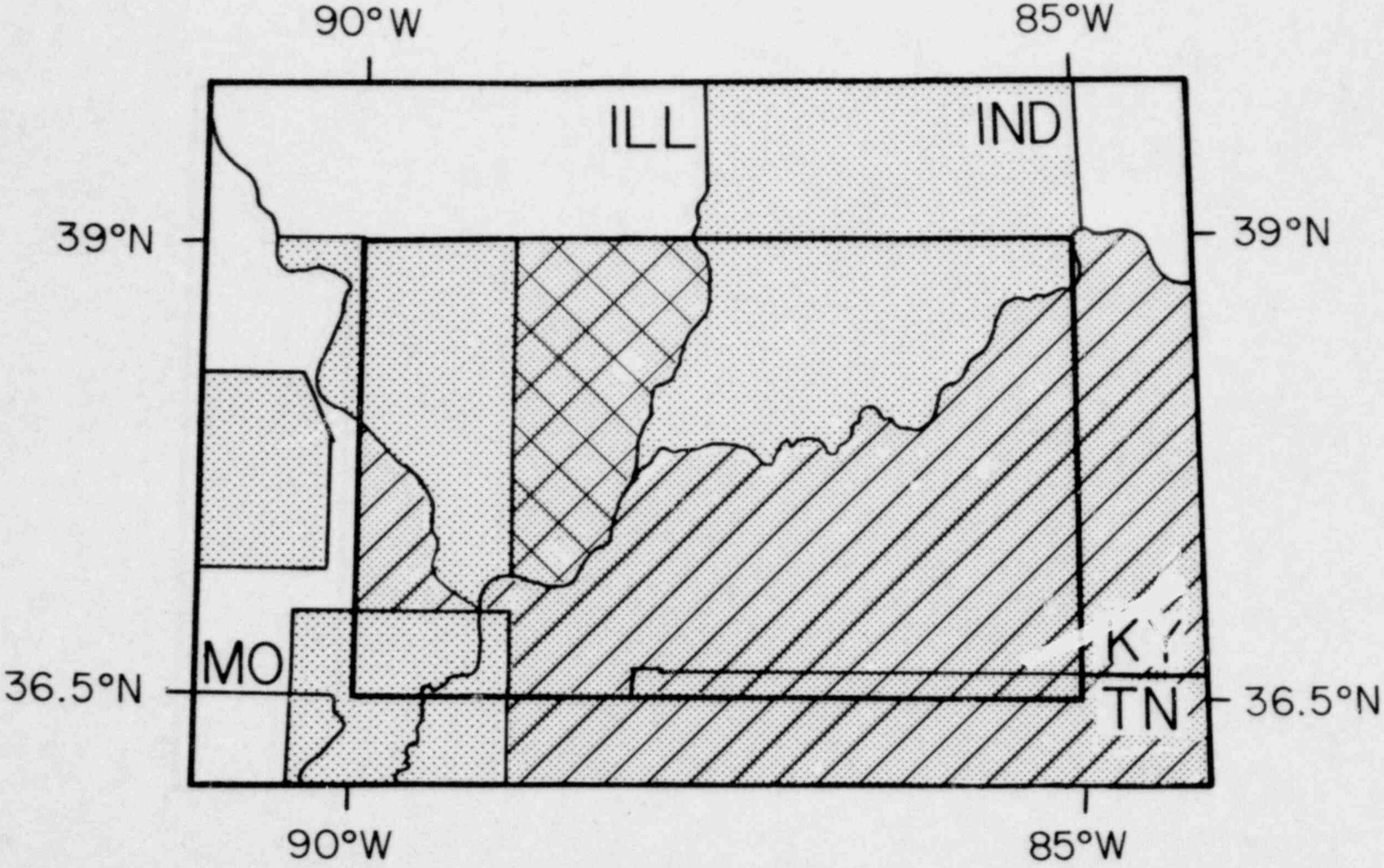


Figure B-6 Map indicating status of aeromagnetic coverage within the study area is shown by the rectangle. Coarse dotted pattern indicates area of coverage before study was initiated. Fine dotted pattern indicates recently acquired data. Diagonal pattern indicates data acquired by funding external to study. Cross-hatched pattern indicates data acquired by funding internal to study.

Figure B-7 Southern Illinois total magnetic intensity anomaly map. Contour interval is 200 gammas.

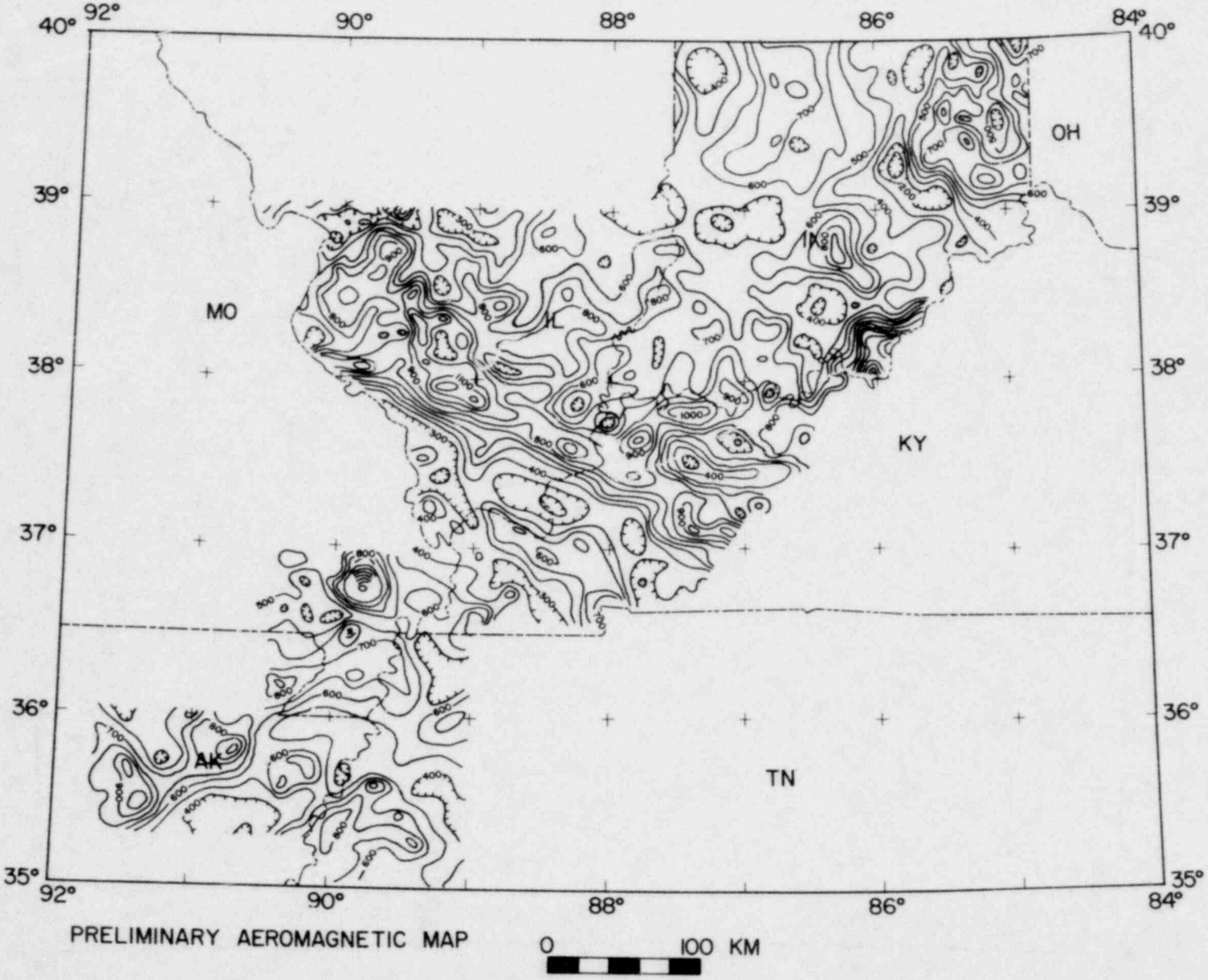


Figure B-8 Preliminary total magnetic intensity anomaly map of the New Madrid Seismic Zone and surrounding area. Contour interval is 100 gammas. Survey elevation is 2 km.

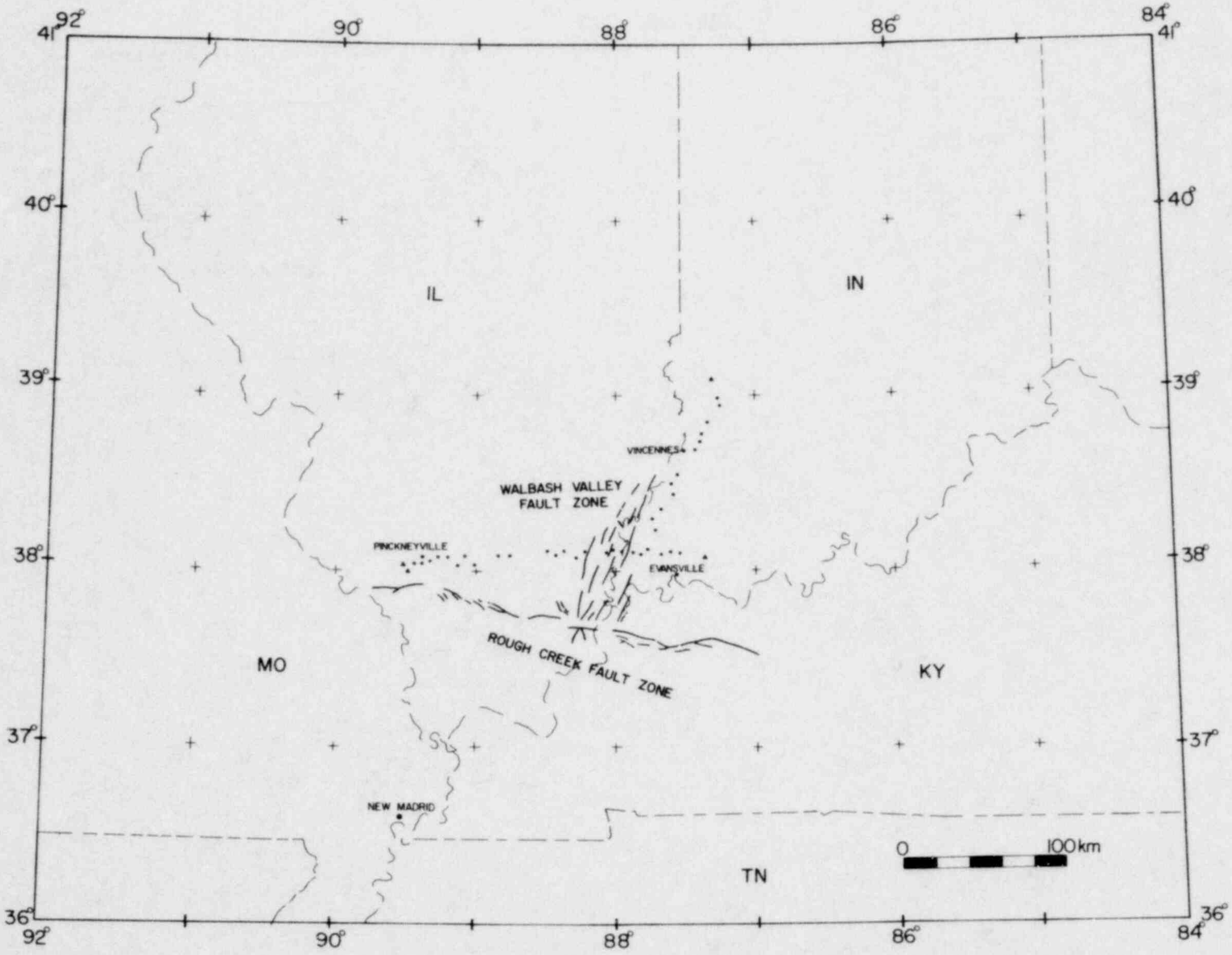


Figure B-9 Location of seismic recording sites (dots) and mines (triangles) used as energy sources for seismic refraction profiles.

POOR ORIGINAL

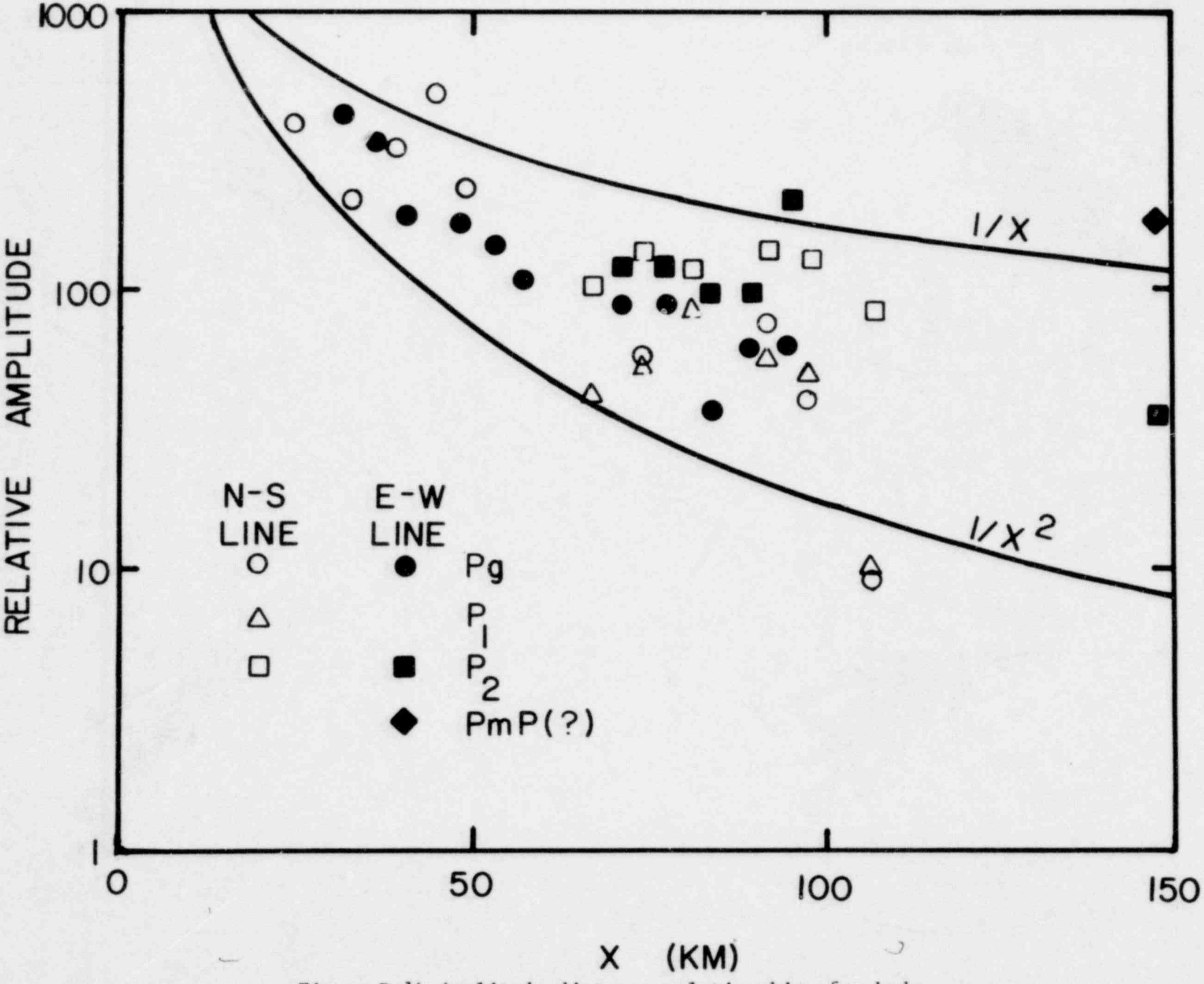


Figure B-10 Amplitude-distance relationships for body waves of seismic refraction profiles.

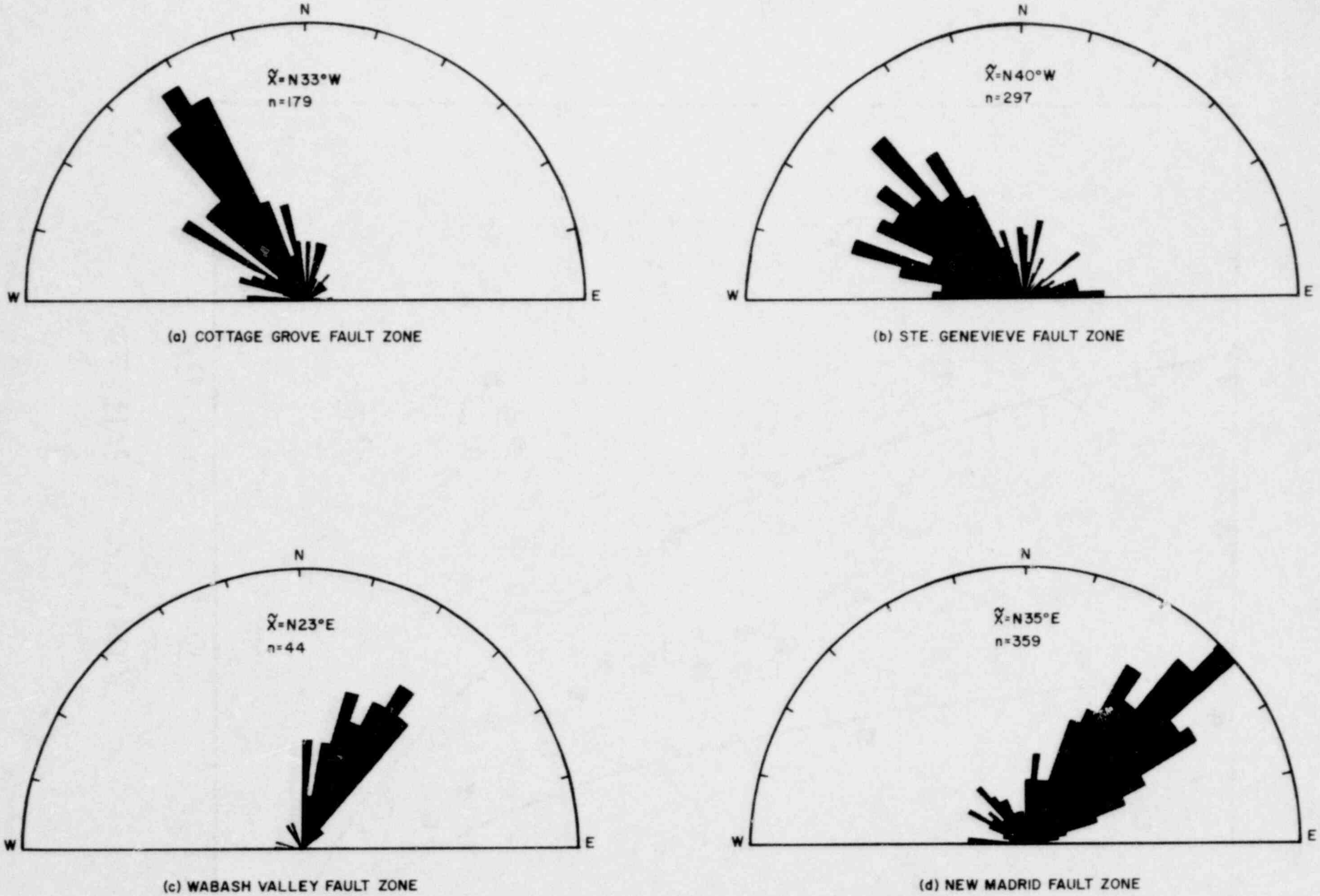


Figure B-11 Fault orientations of the (a) Cottage Grove fault zone, (b) Ste. Genevieve fault zone, (c) Wabash Valley fault system, and (d) New Madrid fault system. Compiled from the maps by Heyl and others (1965).

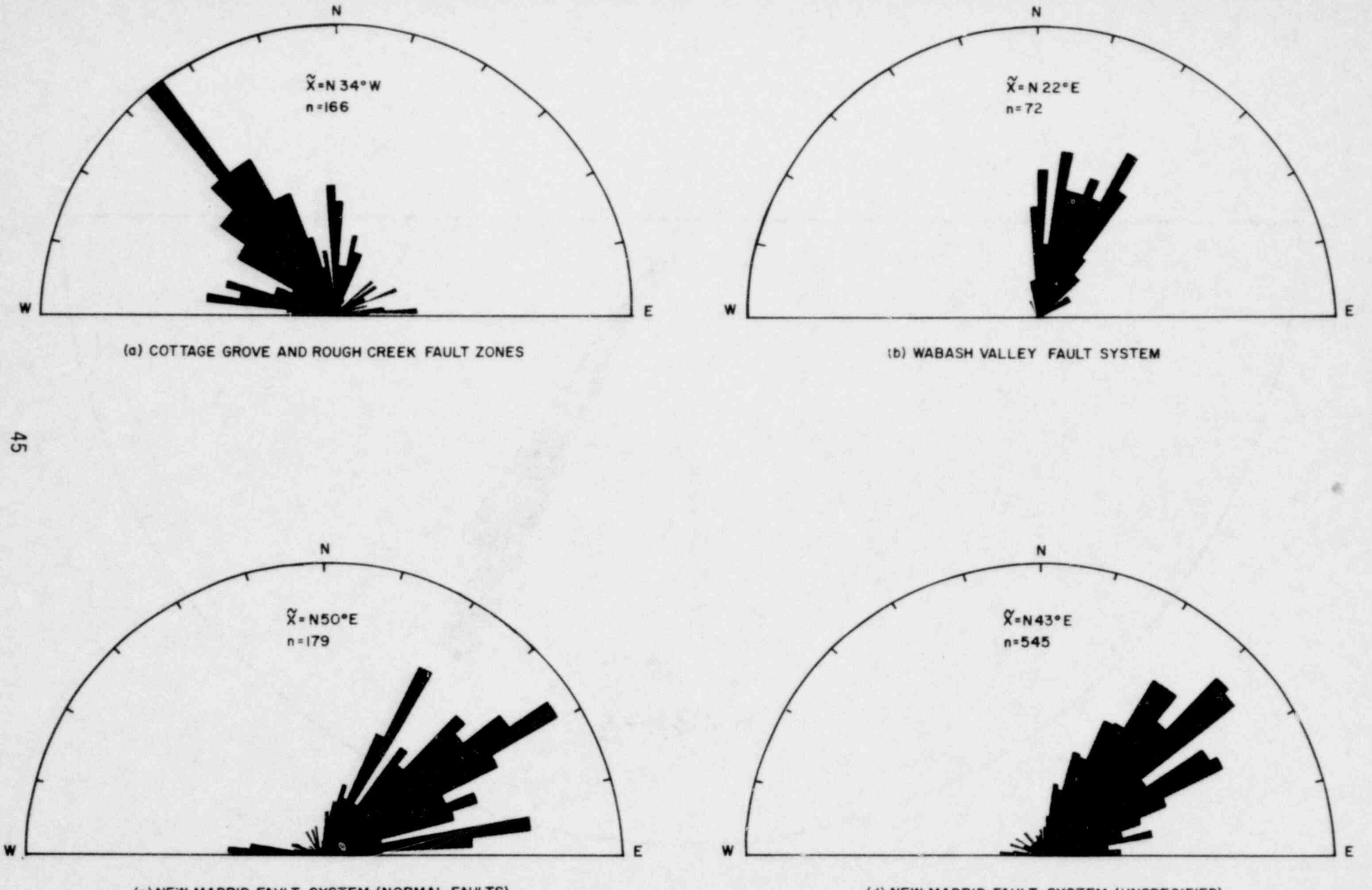


Figure B-12 Fault orientations of the (a) Cottage Grove and Rough Creek fault zone, (b) Wabash Valley fault system, (c) New Madrid fault system (normal faults) and (d) New Madrid fault system (unspecified fault types). Compiled from map by Heyl and McKeown (1978).

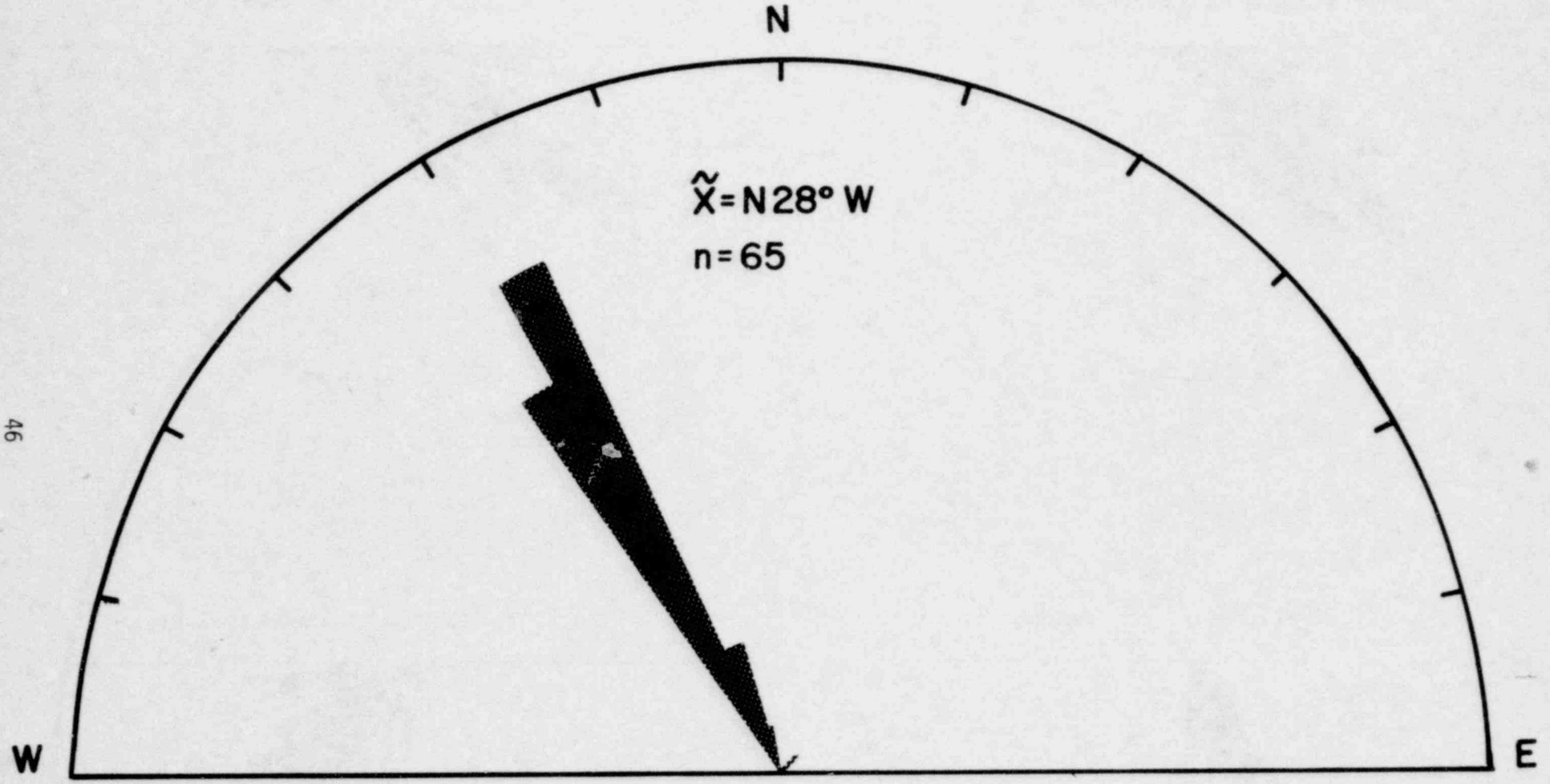


Figure B-13 Dike orientations in the Paducah $1^{\circ}x2^{\circ}$ quadrangle.
Compiled from Heyl and others (1965).

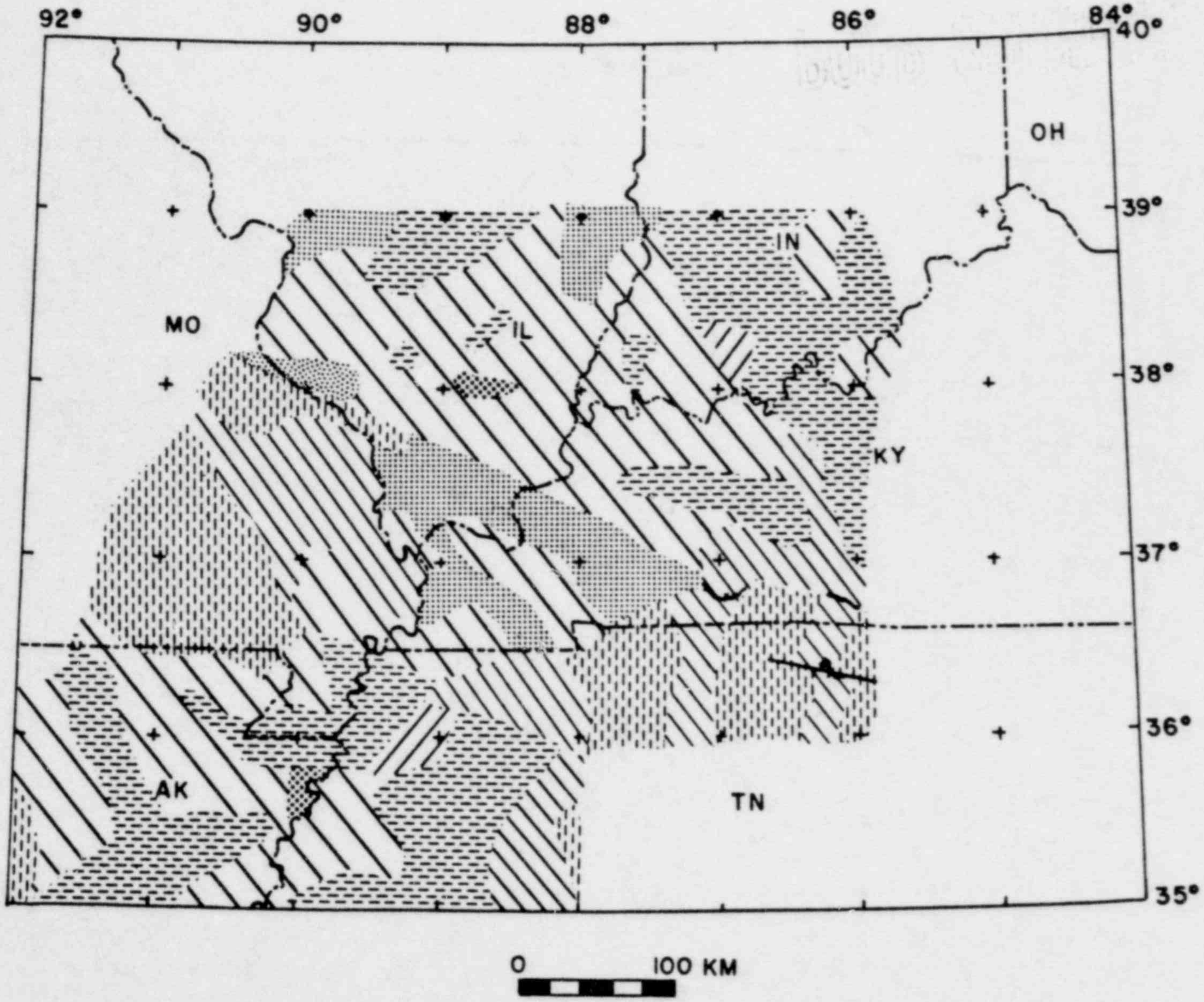
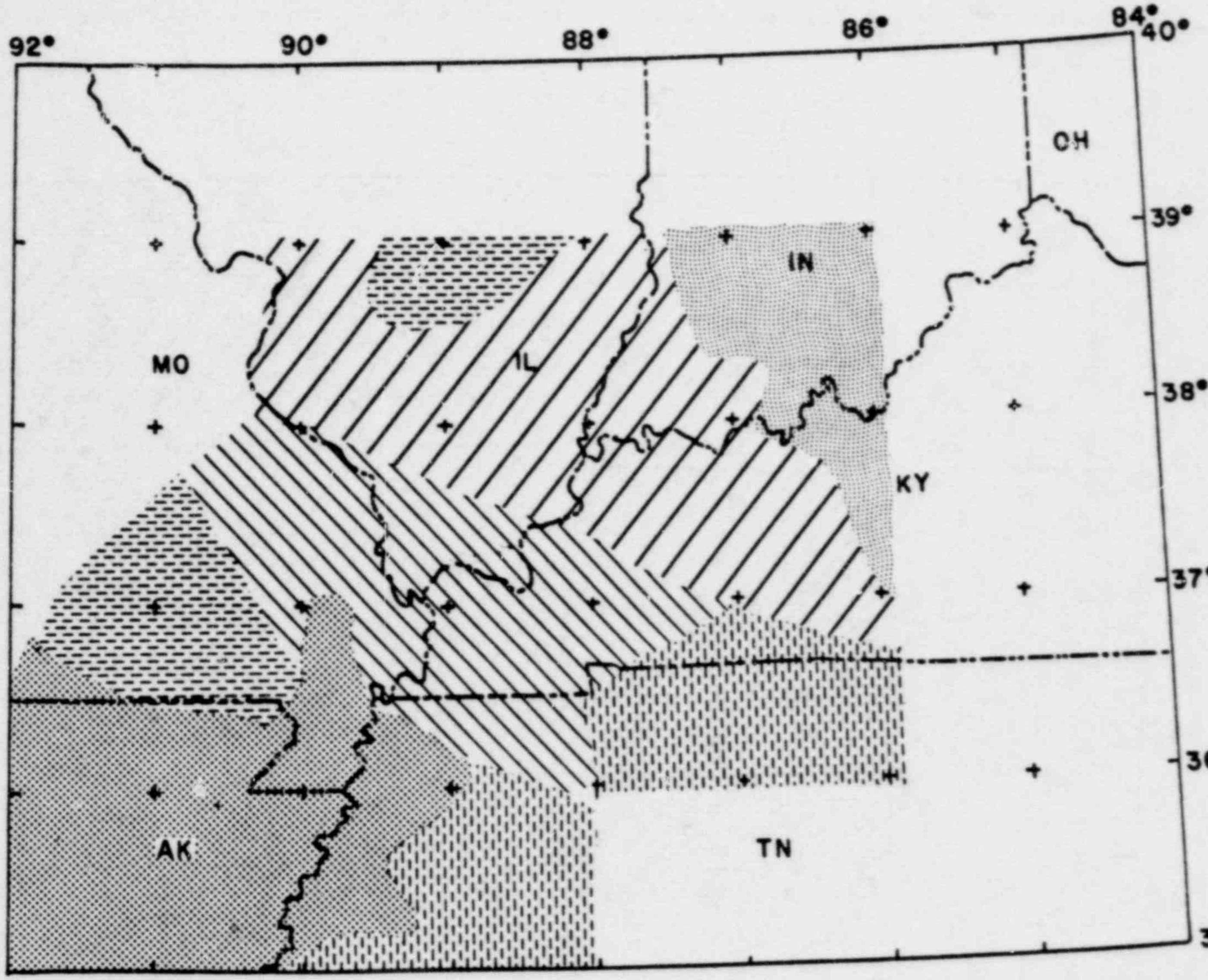


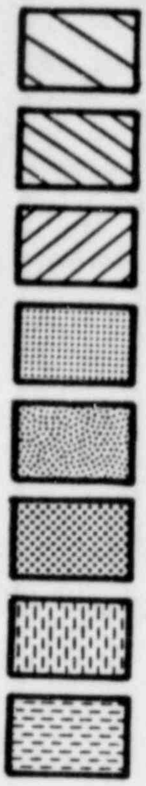
Figure B-14 Preliminary map of selected basement and geophysical parameters.



POOR ORIGINAL

Figure B-15 Preliminary map of inferred basement and geophysical provinces.

EXPLANATION FOR FIGURE B-14



Gravity and Magnetic High

Gravity High

Magnetic High

Gravity High and Magnetic Low

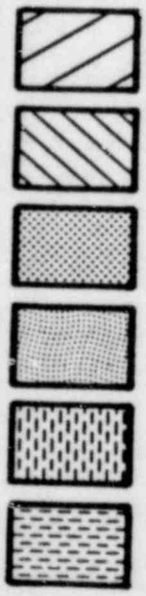
Gravity Low and Magnetic Low

Magnetic Low

Gravity Low

Gravity and Magnetic Low

EXPLANATION FOR FIGURE B-15



Gravity and Magnetic Highs

Gravity Highs and Northwest-Trending Magnetic Highs and Lows

Gravity Highs and Circular or Northeast-Trending Magnetic Highs

Gravity and Magnetic Lows with Local Gravity and Magnetic Highs

Gravity Lows and North-Trending Gravity Highs

Gravity Lows

Figure B-16 Explanation keys to Figures B-14 and B-1

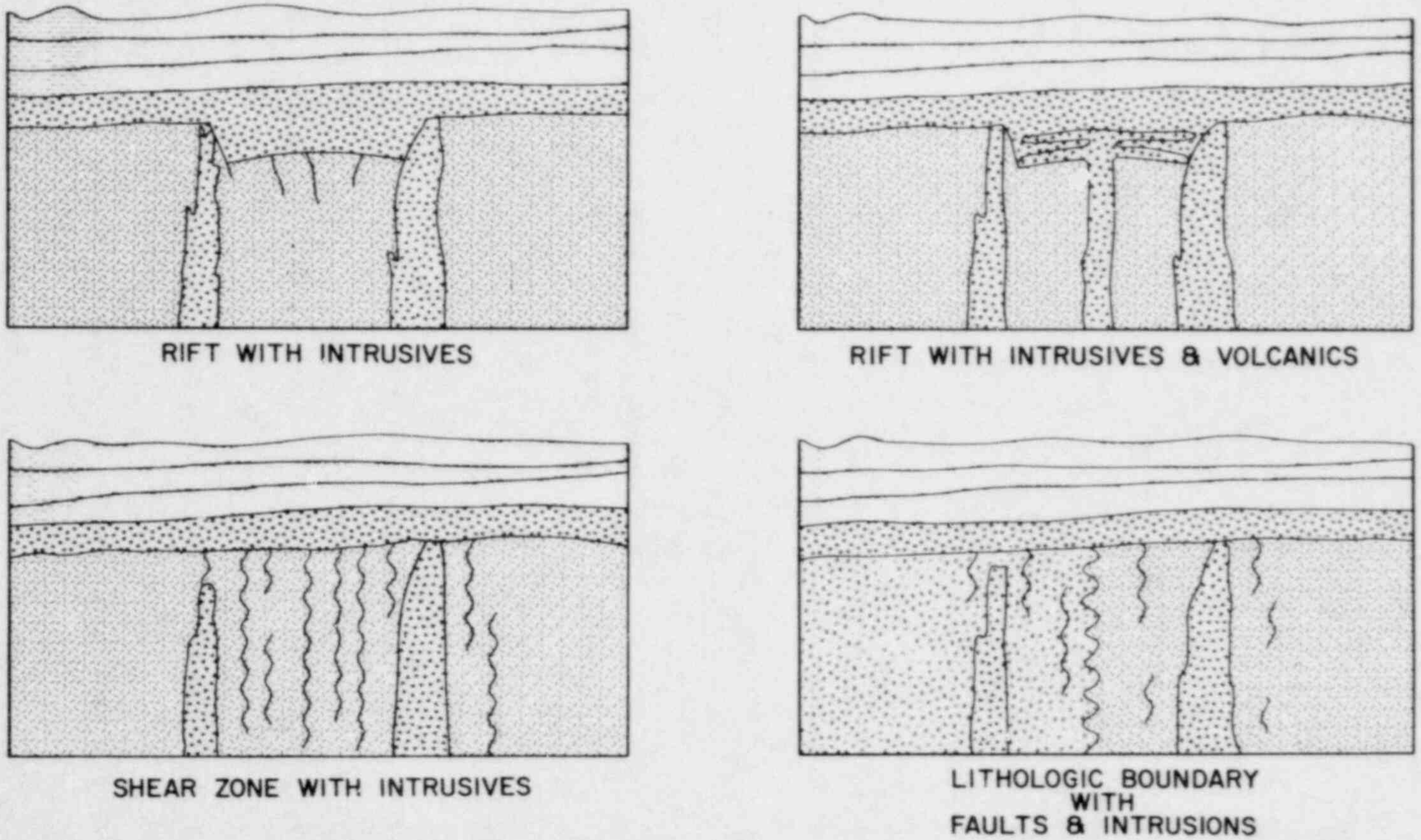


Figure B-17 Schematic geologic models representing possible geologic cross-sections to explain the positive gravity and magnetic anomalies and central gravity minimum in the southern Indiana area. Profile is oriented northwest and crosses the New Madrid Linear Tectonic Feature.

NEAR SURFACE GEOLOGY OF THE REELFOOT LAKE DISTRICT OF NEW MADRID EARTHQUAKE REGION

Annual Progress Report - Fiscal Year 1979

Contract No. NRC-04-77-299

Richard G. Stearns
Vanderbilt University

ABSTRACT

Regional gravity survey of West Tennessee has been completed, computer contoured, and is being prepared for publication. Detailed gravity survey is complete north of 36° and west of 89° 15'. A report on detailed gravity densities and fault block models is in preparation as a thesis. Gravity maps will be published in cooperation with Tennessee Division of Geology. Earth resistivity surveys at Reelfoot scarp show the utility of this near-surface technique. A report is in preparation and a thesis finished.

Logging of samples from oil test wells in the earthquake region of west Tennessee is completed. Logs are available to researchers at Tennessee Division of Geology. A map of configuration of the base of fine-grained topstratum is being prepared from shallow drill holes from various sources. Anomalies on this map could locate fault blocks.

Two graduate assistants, five undergraduate assistants, a consultant and one geologist with Tennessee Division of Geology have been involved with the project. A report on Holocene vertical movement of the land surface was published as NUREG/CR-0874.

TECHNICAL SUMMARY

A regional gravity map has been completed and contoured by computer. It shows major features such as the Covington pluton and the east boundary of the Reelfoot Rift plus many others, mainly relating to deep density contrasts. It is ready to be prepared for printing. Detailed gravity shows shallower features, most relating to (probably faulted) variations in depth to dense pre-Cretaceous Paleozoic rock within 3000 feet of the land surface. Some gravity patterns also relate to Holocene surface features (e.g. Ridgely Ridge is a high). This map is completed for Tennessee and closely adjacent areas north of 36° and west of 89° 15'. It is being extended southward. A report on some of the detailed gravity features with density data and models is in preparation as a thesis. We have related earth resistivity soundings, circle soundings and profiles to faults and old Mississippi River channels within 50 feet of the land surface. Simple techniques, such as Barnes Layer models have been proved useful. A report in thesis form was presented, and a summary is in preparation.

Shallow drilling, and even hand augering has proved useful to locate faults precisely. We have located a graben with about 3 feet of throw at the foot of Reelfoot Scarp (with holes less than 3 feet apart), and have shown the essentially monoclinal structure of Reelfoot Scarp (with holes about 25 to 100 feet apart). A draft copy of the manuscript on drilling is attached to the annual report (see Appendix C-1 or abstract).

A report on Holocene vertical movement of the land surface was submitted and published as NUREG/CR-0874.

GENERAL

Regional and detailed gravity surveys are in process of publication. The detailed gravity survey area is also being extended. Drilling and earth resistivity projects on the Reelfoot scarp are also being prepared for publication. Logging oil wells in the earthquake region of Tennessee is complete. Three graduate students, five undergraduate students and one consultant have been involved with this project, as has a geologist with Tennessee Division of Geology.

GEOPHYSICS

Regional Gravity

Regional gravity survey with stations spaced about 2½ miles apart has been completed with the cooperation of the Tennessee Division of Geology. Terry Templeton, Geologist with that agency, completed the "fill-in" surveys and resetting of stations needed for publication. That survey will be published on a scale of 1:250,000 by Tennessee Division of Geology. It is now (July 27) being drawn on the stable base by us using computer drawn maps as the interpretive guide.

Detailed Gravity Surveys

Detailed gravity surveys of Tennessee, and adjacent portions of Missouri, Arkansas, and Kentucky, north of 36° and west of 89° 15' were completed during the first quarter with a spacing of 1 mile or closer. This includes the vicintiy of Reelfoot Lake and the areas of concentrated micro-earthquakes near Dyersburg, Ridgely, and Caruthersville. Tennessee Division of Geology is ordering base maps at a scale of 1:62,500. This map will also be published by that agency.

Susan Towe has completed a draft of her thesis on modeling the detailed gravity survey, but it is not yet turned in. She is working part time on it while employed elsewhere. I believe it will be completed this year. This thesis will be a report on microgravity as well as the detailed gravity.

Meanwhile during the last quarter of this year, we have extended the detailed survey southward to the north edge of the Covington anomaly (from 36° southward to 35° 45'). It is believed that this area includes post-Eocene faults east of the Mississippi River alluvial plain. We plan to extend the survey in detail to the east edge of the Reelfoot Rift the first half of next year.

Earth Resistivity

Much of the results of our earth resistivity surveys have already been submitted in the form of two theses, that of Haselton, August, 1977, and that of Tsau, August, 1978. We continue surveys during the first quarter on the Reelfoot scarp, and are now preparing a report on the main results. This report is to be a companion to that based on drilling (Appendix C-1). We believe that the utility of earth resistivity has been established here, and we are particularly gratified that some relatively simple techniques have proved useful (Profiling for mapping, and Barnes Layer modeling for cross sections).

Testing Hammer Seismic Equipment

We have expended some effort (about 2 man weeks) in hammer seismic surveying. We failed to obtain results from shallow refraction. We had hoped for success, as preliminary tests made with equipment from the Tennessee Highway Department in 1976 correlated with shallow drilling. We have not yet given up, and plan to try reflection as well as refraction.

DRILLING

Drilling at the Reelfoot Scarp

A report has been completed as a draft (see Appendix C-1 for abstract) on drilling at the Reelfoot Scarp. Nearly all the holes we drilled have "companion" earth resistivity soundings, hence the companion report now in preparation.

Compilation of Existing Drill Data

From existing drill data it is possible to map the base of the fine grained topstratum sediment on the Mississippi River alluvial plain. A map has been drawn in the Ridgely Area where earthquakes are so abundant, and it may be that shallow drilling there has encountered land collapse areas (grabens) where structurally lowered areas filled in with fine grained flood water deposits. An abstract has been submitted for the Columbus, Ohio, AGU meeting in September; an oral report will be presented there on this situation and the drilling at Reelfoot scarp.

Logging Oil Test Wells

We have been fortunate to retain the services of H. B. Burwell, ex-State Geologist of Tennessee and expert on logging oil well samples. He has finished logging all available wells in the earthquake area of Tennessee, and the logs will soon be sent to Buschbach, Schwalb, Tenn. Division of Geology, and other researchers who need such data.

PUBLICATIONS

The report "Recent vertical movement of the land surface in the Lake County uplift and Reelfoot Lake basin areas, Tennessee, Missouri and Kentucky" has been published as NUREG/CR-0874. A paper on gravity modeling of the Reelfoot Scarp and Ridgely Ridge was presented at the Midwest AGU meeting in September (copy was attached to the first quarter report).

Jau-Ping Tsau's thesis on resistivity soundings and modeling was also attached to the first quarter report.

It is hoped that the attached report on drilling will be edited for publication as a NUREG document. Suggestions for changes are solicited.

PERSONNEL

Jau-Ping Tsau graduated. Susan Towe is working on her thesis while employed as a geophysicist. Virginia Lee Hagee joined us at the end of the year as graduate assistant. Undergraduates Bob Perry and Parrish Erwin graduated and are continuing their education elsewhere (Perry has joined St. Louis University Geophysics Department). Mike Shea, Sue Nava, and Sharon Wilson are the present undergraduate assistants.

H. B. Burwell has continued as a consultant, logging oil test well cuttings in Tennessee.

Terry Templeton of the Tennessee Division of Geology has continued gravity surveying in cooperation with this project.

APPENDIX C-1

Abstract of Paper Submitted with Annual Report.

MONOCLINAL STRUCTURE AND SHALLOW FAULTING OF THE REELFOOT SCARP AS ESTIMATED FROM DRILL HOLES WITH VARIABLE SPACINGS

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ABSTRACT

The Reelfoot scarp is an east-facing slope on the Mississippi River alluvial plain. It descends eastward about 20 feet across a distance of about 600 feet. Within 15 feet of the land surface the scarp is mainly a monocline, but there is a small fault at the foot of the slope. The monoclinal structure was clearly shown by six drill holes spaced about 100 feet apart. A fault was indicated by these holes, but was not demonstrated until holes were drilled closer together than 10 feet.

Drilling proceeded in five stages:

1. Data were obtained from test holes drilled about 500 feet apart in 1944 by the U.S. Corps of Engineers. These were suggestive of the monoclinal structure and suggestive of two faults with estimated maximum throws of 28 (buried) and 18 feet (near surface).
2. Six test holes were drilled about 100 feet apart. These clearly indicated the monoclinal structure of the scarp with vertical offset of about 15 feet. These holes also were suggestive of the near surface fault at the foot of the scarp with a maximum throw of 14 feet. These and subsequent monoclinal vertical offset and fault throw measurements are made in silts and clays close to the land surface.
3. Fourteen hand auger holes were drilled about 25 feet apart (fig. C-1). These certainly proved the monoclinal structure, and showed that the monocline steepens where the fault was indicated at the foot of the topographic slope so that monoclinal offset (about 22 feet) is greater than the descent of the land surface. The fault was shown to be minor if present (maximum throw of about 2 feet).
4. Four hand auger holes were drilled 10 feet apart. These were still suggestive of, but did not demonstrate faulting. They did show that faulting, if present, is still smaller (about 1 foot of throw).

5. Five hand auger holes were drilled 2½ feet apart (fig. C-2). These indicate a graben involving layers as shallow as 4 feet, perhaps redeposited soil washed into a depression where the surface collapsed by faulting after the 1811-12 earthquakes, with about 3.5 feet of throw in the graben and 1 foot of throw across the graben.

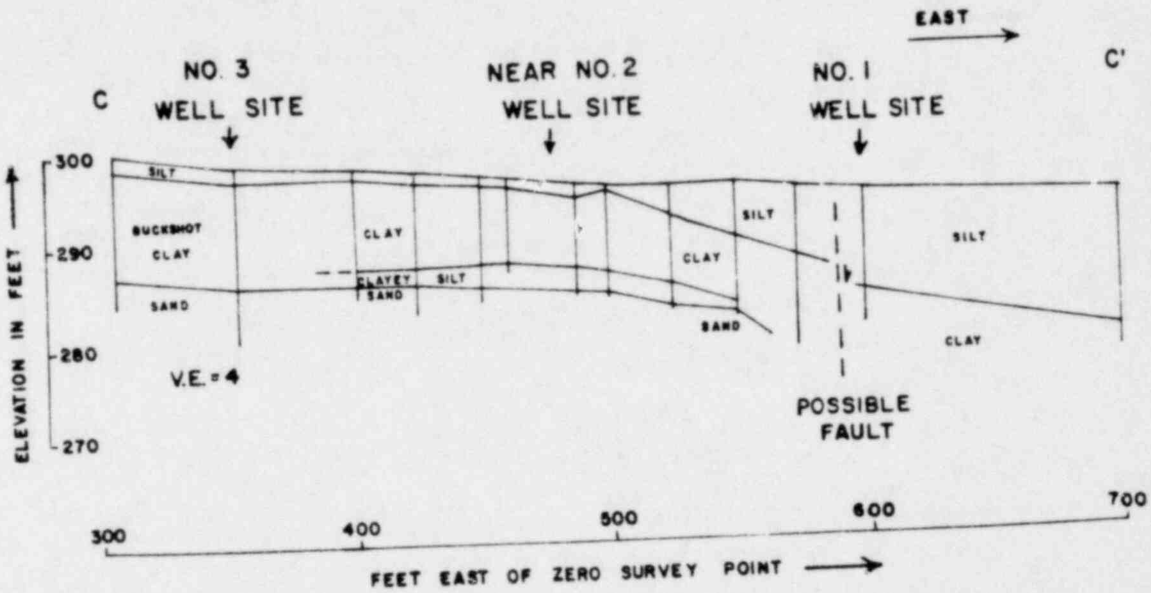

Figure C-1 Fault interpretation of the 14 hand auger holes on Line CC'. The throw estimate is based on projecting the base of the silt to the fault. Note that the estimated throw is sensitive to the fault location. The closer it is to hole No. 1, the less the throw.

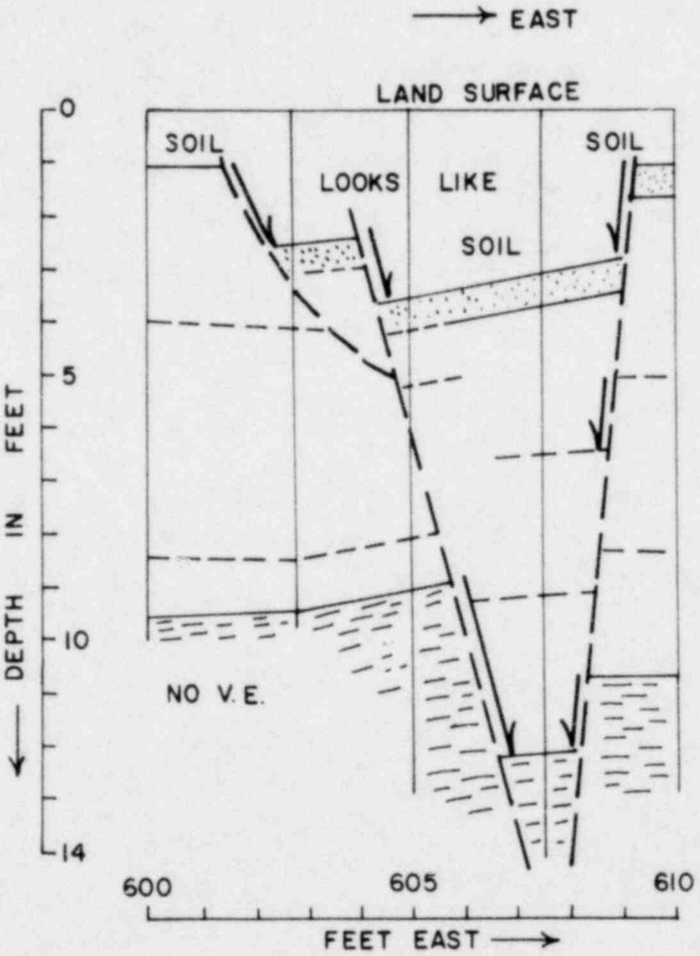

Figure C-2 Fault interpretation of the five hand auger holes on Line EE'.

STRUCTURAL GEOLOGIC STUDY OF SOUTHEASTERN MISSOURI

Annual Progress Report - Fiscal Year 1979

Contract No. NRC-04-78-206

Ronald A. Ward
Missouri Department of Natural Resources
Geological Survey

ABSTRACT

This year's activities have included the development of an investigative technique needed in order to establish the involvement of Pleistocene-Holocene age deposits with faulting which displaces older underlying Cretaceous and Tertiary deposits. A procedure involving the drilling and gamma ray logging of test holes drilled along a line perpendicular to a known fault has been carried out at the Beech Grove Branch site, 3 3/4 miles northeast of Bloomfield, Missouri. At this location, a significant northwest-southeast fault crosses the area. While the Porters Creek Clay (Paleocene) and perhaps the Ackerman Formation (Eocene) are faulted at this site, there is no evidence that the "Holly Springs" (Eocene) or Pleistocene-Holocene deposits are disturbed. Office studies have included the investigation of three sites within test area II (Benton Hills). Existing well boring information from the WPA drilling operation (1930-40) indicates the presence of Cretaceous and Tertiary faulting at these locations and offers potential sites for future investigation.

SUMMARY

1. Much of the activity this year has been spent in the development of a technique for the investigation of faulting involving Cretaceous and Tertiary deposits in order to establish whether the same faulting has displaced the younger, overlying, Pleistocene and Holocene deposits along Crowleys Ridge and Benton Hills. A technique has been developed which utilizes survey-owned equipment and involves the drilling and gamma ray logging of test holes across known faults, providing evidence, either for or against, the presence of structural offset of Pleistocene and Holocene deposits related to the deeper faulting.

2. An investigation of the Beech Grove Branch site, Sec. 9, T. 26 N., R. 11 E., has been conducted with the drilling of four deep test holes (100 feet or greater) and three shallow test holes. The site overlies faulting known to involve Tertiary deposits. Northwest-southeast faulting which has displaced Tertiary Porters Creek Clay (Paleocene) as well as Ackerman Formation (Eocene) appears not to have involved Pleistocene or Holocene deposits at this location. An additional test hole will be drilled at this site to further substantiate this conclusion.
3. A limited investigation of the T. C. Martin site, Sec. 14, T. 26 N., R. 11 E., was conducted with the drilling of two deep test holes for purposes of developing investigative techniques and establishing stratigraphic control. It was determined from this effort that the stratigraphic variability within deposits of the Wilcox Group (Eocene) would not permit detailed lateral correlation in order to demonstrate faulting within the Tertiary section. Thus, it was determined that the underlying Porters Creek Clay would have to be used as a correlation zone.
4. Detailed structural and isopach maps with accompanying cross sections have been constructed for the English Hill area, Sec. 34, T. 29 N., R. 14 E., (test area II). Faulting involving Createaceous and Tertiary deposits is indicated, and hopefully the area can be investigated in the upcoming year.
5. Detailed cross sections and maps have been made for two additional areas, Sec. 13 and 14, T. 23 N., R. 13 E., and Sec. 26 and 27, T. 29 N., R. 14 E., both of which indicate the presence of Cretaceous and Tertiary faulting. These sites also offer potential areas for study in the upcoming year.

PURPOSE OF INVESTIGATION

We have been studying two areas (figure D-1) located along Crowleys Ridge and Benton Hills where faulting, which affects the lower Cretaceous and Tertiary deposits of the area, is known to exist. The investigation for this year and the year to follow has been designed to aid in understanding what effect deeper faulting involving Cretaceous and Tertiary deposits has had on the overlying, younger Pleistocene and Holocene units. It has been and will continue to be the purpose of our work to demonstrate whether or not these fault planes penetrate the younger deposits and to what degree. A better understanding of when the faulting occurred will be gained by knowing whether or not the younger units had been affected by deeper faulting. Total penetration of the Porters Creek Clay (Tertiary), into the McNairy Formation

(Creta ous) below, has not been accomplished this year due to the drilling depth capabilities of survey-owned equipment.

BACKGROUND

General Statement

In the first year of activity, the Division of Geology and Land Survey conducted an inventory of information for all the Missouri portion of the area covered by a 200-mile radius around the town of New Madrid. Second year activities concentrated on the presentation of a geologic map for the Crowleys Ridge-Benton Hills area of southeastern Missouri based on existing field records and additional field work. This year's activities have been involved with two test areas within the Crowleys Ridge-Benton Hills area. Specifically, field activities have been restricted to test area 1 (figure D-1).

The geologic map of Crowleys Ridge and Benton Hills (scale of 1:62,500) presented last year was based in part on previous work done by Willard Farrar and Lyle McManamy in the mid 1930's (The Geology of Stoddard County, Missouri). In addition, unpublished work by Dan Stewart and Lyle McManamy was carried on in Dunklin and Scott Counties in the late 1930's and early 1940's. It was during this time that 1,875 hand-augered holes were drilled as part of a Federal Works Progress Administration project. This information, along with water well records and recent field mapping by those individuals involved with the project, was utilized in the compilation of the map.

Structural Geology

The structural trend along Crowleys Ridge-Benton Hills is dominated by a northeast-southwest fault set (figures D-1 and D-2). A subordinate fault set trends northwest-southeast, reflecting the major fault trend to the northwest in the Ozark Highlands.

The concept that faulting has disturbed the Pleistocene-Holocene deposits along Crowleys Ridge-Benton Hills was expressed by Dan Stewart and Lyle McManamy (1942 unpublished manuscript) as well as by others working in the area more recently. Stewart, as one of the principal geologists working in the area during the WPA project, is convinced (personal communication) that, in many instances, the faulting which effects Pleistocene loess is related to deeper faulting and not slump.

Stratigraphy

This brief discussion of the stratigraphy of the area is repeated from last year's report to familiarize the reader.

Figure D-3 is a detailed stratigraphic section of the Cretaceous and Tertiary Systems in southeast Missouri. A more detailed description of the stratigraphy as well as a geologic history will be included in the final report.

Along the Missouri portion of Crowleys Ridge-Benton Hills, the Mesozoic Era is represented by the McNairy and Owl Creek Formations of the Cretaceous System; subsurface data suggests that older Cretaceous sediments are present in the extreme southeast corner of the Missouri Bootheel. The McNairy can be broken into two identifiable units: a lower sand unit with locally a quartzitic boulder bed near the top, and an upper unit consisting of alternating sands and clays. The thickness of this formation ranges from 0 to slightly more than 200 feet. Overlying the McNairy is the Owl Creek Formation, consisting of essentially sandy clay, with green and brown glauconite disseminated throughout. On fresh exposure the Owl Creek is dark gray as opposed to a brownish-blue on weathered exposures. Thickness ranges from 0 to 20 feet.

Overlying the Mesozoic, there are Cenozoic deposits of the Tertiary System. Within the Tertiary, two, and possibly three, series are present - Paleocene, Eocene, and Pliocene (?), (figure D-3). The Clayton Formation, ranging in thickness from 0 to 10 feet, is the basal Tertiary unit and is lithologically very distinctive. It is green due to the presence of glauconite, and is composed of sand, clay, limonite, and some fossilized material. The Porters Creek Clay, lying above the Clayton, has a thickness ranging from 0 to 200 feet. This unit is quite distinguishable from the other formations in that it is a dark gray, massive clay on fresh, damp exposure and is fairly uniform throughout. The clay unit contains many joints along which small amounts of iron oxide staining usually occur. Near the top of the Porters Creek, seveal boulders of siderite have been observed. Above the Porters Creek Clay lies the Ackerman Formation. This formation is a clayey unit similar to the Porters Creek, although it is lighter in color and contains some quartz silts and sands. In certain areas small gravels occur at the base. The thickness of this unit ranges from 0 to approximately

40 feet. The "Holly Springs"* Formation stratigraphically overlies the Ackerman and has a thickness range from 0 to approximately 250 feet. The lithology of this formation is variable, being composed of clays, sandy clays, sands, and in some areas, gravels. The clays are usually white to gray, although red and green clays are present with quartz silt and sand sometimes present. On weathered exposures iron stained and orange units are common. Usually near the base highly-polished, black, clear quartz and pink gravels are present. As a general rule, the "Holly Springs" can be divided into a lower and an upper unit (figure D-3). The sands and polished gravels are common to the lower unit along with some clay balls, whereas the upper unit contains more shaley beds. Overlying the "Holly Springs" are gravels probably equivalent to the Mounds Gravels of Illinois Geological Survey usage. These gravels are assigned to the Pliocene Series or, as has been suggested by some, are possibly Pleistocene Series. The gravels have a thickness ranging from 0 to about 60 feet and occur at higher elevations on the hilltops. There is a wide variety of lithologies and colors occurring in the gravels, but the majority are brown cherts. There are minor amounts of clay, sands, and pebbles present throughout the unit.

The entire upland area is blanketed by three loess formations. The basal Loveland silt (Illinoian age) has a well-developed soil at the top (Sangamon Soil). The overlying Roxana Silt is of early Wisconsinan age. The upper most loess is referred to as the Peoria Loess and is extensively developed. Color, texture and stratigraphic position are useful criteria for recognizing these units in the field.

PLAN OF INVESTIGATION

The plan of investigation has been and will continue to be an attempt to establish whether or not faulting that occurred within the older Cretaceous and Tertiary formations has effected the younger overlying Pleistocene and Holocene deposits. Nearly all exposures of faulting that involved the younger units are in side slope positions and thus are commonly discounted as being the results of slumping. Our attempt in this study has been to drill a series of test holes along a line perpendicular to a suspected or known fault displacing Cretaceous-Tertiary deposits. By drilling along a ridge crest and avoiding the side slopes, we hope to avoid slump structures not associated with deep faulting. Major efforts this year have been

* "Holly Springs" is herein used in an informal sense awaiting further stratigraphic investigation in Missouri.

concentrated in sections 9 and 10, T. 26 N., R. 11 E., northeast of Bloomfield along Beech Grove Branch. A compromise was made in the selection of the site for the traverse in favor of an area lower in elevation where the present depth capability of the survey drilling equipment would suffice.

DEVELOPMENT OF INVESTIGATIVE TECHNIQUES

A great part of this year's activity has centered around developing the technical capability to study the problem of shallow faulting related to deeper faulting. The Survey owns two pieces of equipment used in this year's work. The track-mounted Versa-drill TR-4000 has been used as flight auger unit and as a core and rock drilling unit. In addition, a truck-mounted Giddings soil probe has been used for sampling the Pleistocene loesses and associated paleosol(s). Our geophysical equipment includes a gamma ray logging unit used for purposes of correlation between test holes.

Initially, an area to be investigated is selected on a ridge or upland area, which is crossed by a fault or series of faults, known to have cut Cretaceous-Tertiary age deposits. A transect, along which test borings are to be made, is positioned at the crest of the location so as to avoid, if possible, mass movement and slumping associated with side slopes.

The local stratigraphy of the site must be understood. A soil probe test (push tube) is made with samples gathered to the depth of refusal (normally the base of the Sangamon paleosol). This is followed by the use of hollow stem auger in order to gather undisturbed samples through the auger by means of a thin-wall sample tube. This is a very slow process but is a very good way to establish the stratigraphy of the test site. The compentency of the lithologic unit determines the depth to which thin-wall sampling will continue to work. Below this point the drilling unit must be converted to a rock coring device using the hollow-stem auger as a temporary casing. Rock coring allows for the complete documentation of the stratigraphic record at the site. The test hole is then gamma ray logged; the recorded trace of which, when joined with the stratigraphic data gathered, provides the basic correlation tool for the remaining test holes to be drilled.

Following drilling operations of the initial test hole and the selection of a suitable test hole spacing, the remaining test holes are drilled using a standard rock drilling procedure with sample cuttings collected on five foot intervals or at significant changes in drilling character. The rock drilling is followed by gamma ray logging.

The gamma ray logs for each test hole with accompanying lithologic data can be correlated in order to determine if there is faulting and if faulting has affected the Pleistocene-Holocene deposits present.

As is indicated in the above discussion, drilling and logging operations in the deposits present along Crowleys Ridge-Benton Hills offer unusual and difficult problems. The units composed of clays, silts, and sand are not well consolidated; and while push tube sampling works well in the shallower, less well consolidated deposits, it will not suffice as conditions change. Likewise, rock coring with a water circulation system rapidly softens and erodes the underlying deposits. In particular, there was a problem in test hole No. 103-13. A drilling depth of 150 feet was achieved; however caving and bridging of the hole at the base of the casing prevented logging operations below the depth. Hopefully, this problem can be eliminated in the future by means of more rapid drilling and use of less hollow-stem auger as a temporary casing.

FIELD AND OFFICE INVESTIGATIONS

Beech Grove Branch Site

The Beech Grove Branch site (figures D-2 and D-4) is located in Stoddard County, 3 3/4 miles northeast of Bloomfield, Missouri, in the east half of the southeast quarter of the southeast quarter, Sec. 9, T. 26 N., R. 11 E. The investigation was conducted on the property of James Robinson and was accessed through the property of W.J. Downen. Locally the area is characterized by narrow ridges and steep-sided ravines with relief of 175 feet. Nearby to the southwest, the topography changes to a rolling landscape with average relief of 100 feet.

The site is located in an area characterized by faulting involving Tertiary age deposits as was observed by Stewart and McManamy (1942) and others more recently. In particular, a notable northwest-southeast fault(s) crosses the area. Evidence for faulting has been obtained from field mapping, WPA (1936-42) test boring information, and from lineation seen from aerial photography. An initial test hole (103-7) was drilled in the extreme northeastern corner of Sec. 16, T. 26 N., R. 11 E. (figure D-4) from which it was determined that a location lower in surface elevation would have to be selected in order to penetrate the Porters Creek Clay (Paleocene). The Porters Creek Clay is considered to be an acceptable unit for purposes of correlation; the base of the Porters Creek Clay was not encountered in drilling as the unit is assumed to average 200 feet in thickness locally. At present, the combined thicknesses are beyond our drilling depth capability.

The stratigraphy of the site includes a capping loess, 18 feet in average thickness (figure D-5). The deposit is composed of two Wisconsinan loesses (Peoria Loess and Roxana Silt), a major buried soil (Sangamon Paleosol), and an older Illinoian loess (Loveland Loess). The basal Loveland Silt is intermixed with underlying (Tertiary) Wilcox sand and clays and is not always distinguishable in samples. No Plio-Pleistocene gravels ("Mounds" equivalent) were observed at this site. The sand and clays of the Wilcox are here referred to as the "Holly Springs" Formation awaiting revision of the regional stratigraphic nomenclature. The "Holly Springs" varies in thickness from 20 to 35 feet in the study area and is composed of intermixed clay and fine to medium sand in the upper five feet, grading downward into a medium to coarse, moderately well rounded buff sand. The sand ranges from 15 to 25 feet in thickness and has a sharp lower contact with a grayish-buff mottled, plastic, clayey silt. This silt unit is 7 to 10 feet thick locally, grading into gray clayey silt with poorly developed partings, and abundant lignite; the unit ranges in thickness from 15 to 35 feet. A basal fine-grained sand containing lignite occurs in test holes No. 103-9 and 11 and averages 9 feet in thickness. The silts and underlying sand are included in the Ackerman Formation which rests unconformably on the Porters Creek Clay. The Porters Creek Clay is a massive gray clay with very distinctive physical characteristics. The top of the Porters Creek Clay is an uneven erosional surface in much of the region.

Figures D-5 and D-6 represent the results of our activities at the site. Four deep tests 100 feet or more in depth were drilled in addition to three shallow probe tests; one of which (103-10) is not shown in the cross section. Unfortunately, this year's effort to gamma ray log the entire test hole at each location was not always successful.

A fault is interpreted to exist between holes 103-11 and 13 having a displacement of 9± feet (figure D-5). This fault cuts the Porters Creek Clay and the Ackerman Formation above but does not appear to continue higher. The unconformable upper surface of the Porters Creek Clay is not in itself a good marker to use in order to demonstrate structural offset; however, significant gamma ray trace features recorded for holes 103-9, 11 and 8 (markers B and C, figure D-5) support the existence of a fault at the location shown in figure D-5. The Ackerman appears to thicken and thin laterally very rapidly, which makes the vertical extent of the fault difficult to establish.

If our observations are correct regarding fault displacement between holes 103-11 and 13, then the conclusion is that the faulting along this northwest-southeast fault has not affected the upper portion of the Wilcox ("Holly Springs") or the younger Pleistocene and Holocene record (figure D-6) at this location. Slightly less than one mile northwest along the trend of what is assumed to be the same fault, "Holly Springs" is faulted against Porters Creek; however, this may be explained as the result of deposition of a lower "Holly Springs" clay and sand unit at the northwest site or subsequent removal prior to deposition of a similar unit at the Beech Grove Branch site.

The presence of a second fault (figure D-4) 150 feet northeast of the fault shown in cross section A-B, is based on one control point from the early WPA drill records. The possibility of this second fault being a slump feature is more likely in that it is located nearer to the nose of the ridge along which the investigation has taken place. It is our intention to drill one additional test hole at the Beech Grove Branch site before abandonment.

English Hill Site

The English Hill site is located within section 34, T. 29 N., R. 14 E., Scott County (test area II, figure D-1). The area was studied in detail by Stewart as part of the WPA project in the late 1930's and early 1940's. Structure contour maps and cross sections have been prepared as preliminary data for future test drilling in the upcoming year. Stewart and McManamy (1942) held the firm opinion that Pleistocene-Holocene deposits had been involved with faulting in this area.

Other Sites For Future Study

Sites within test area II for possible future study for which time has been spent preparing structure contour maps and cross sections include and area 1 1/2 miles southwest of Benton, Missouri (test area II, figure D-1). Specifically, WPA (1936-42) test borings, located within section 13 and 14 T. 28 N., R. 13 E., show faulting involving Cretaceous and Tertiary deposits and offer a possible site to demonstrate the presence or absence of fault displacement involving the Pleistocene-Holocene record. A second area studied is located one mile west of Jackson Hill in sections 26 and 27, T. 29 N., R. 14 E. For here again, there is evidence for a Cretaceous and Tertiary faulting as determined from field work and WPA test boring information.

Structure contour maps and the various cross sections completed this year are on file with the Division of Geology and Land Survey, Rolla, Missouri.

PROPOSED PROGRAM FOR 1979-80

The 1979-80 program will be addressed to the following activities:

1. Continue to establish the age of the youngest deposits (Pleistocene-Holocene) that have been effected by faulting in the Crowleys Ridge-Benton Hills area.
2. Evaluate the regional trend of faulting and its effect on Pleistocene and Holocene age deposits, assuming that evidence of faulting can be established.
3. Conduct a detailed water sampling study in the Bernie, Missouri, area to define potential faulting from anomalous water quality values. (This objective has a second order priority and its completion will be dependent on timely completion of fault studies).

PERSONNEL

The principal investigator has been aided in this year's study by Mark Reising, Geologist 1, working on contract. In addition, Ira Satterfield, who was principal investigator under the previous year's contract, has aided in an advisory capacity. Other part-time and full-time staff personnel who have worked either in the field or in the laboratory include Dennis Harris, Mike McFarland, Lee Reising, Tom Thompson, Mike Tolbert, and Robert Wright.

REFERENCES

Farrar, Willard, Donald S. Grenfell, and Victor T. Allen, 1935, The Geology and Bleaching Clays of Southeastern Missouri: Missouri Geological Survey and Water Resources, 58th Bien. Report, 78 p.

Farrar, Willard, and Lyle McManamy, 1937, The Geology of Stoddard County, Missouri: Missouri Geological Survey and Water Resources, 59 Bien. Report, 92 p.

Stewart, Dan R. and Lyle McManamy, 1942, The Mesozoic and Cenozoic Geology of Southeastern Missouri: unpublished manuscript, Missouri Department of Natural Resources, Division of Geology and Land Survey, 122 p.

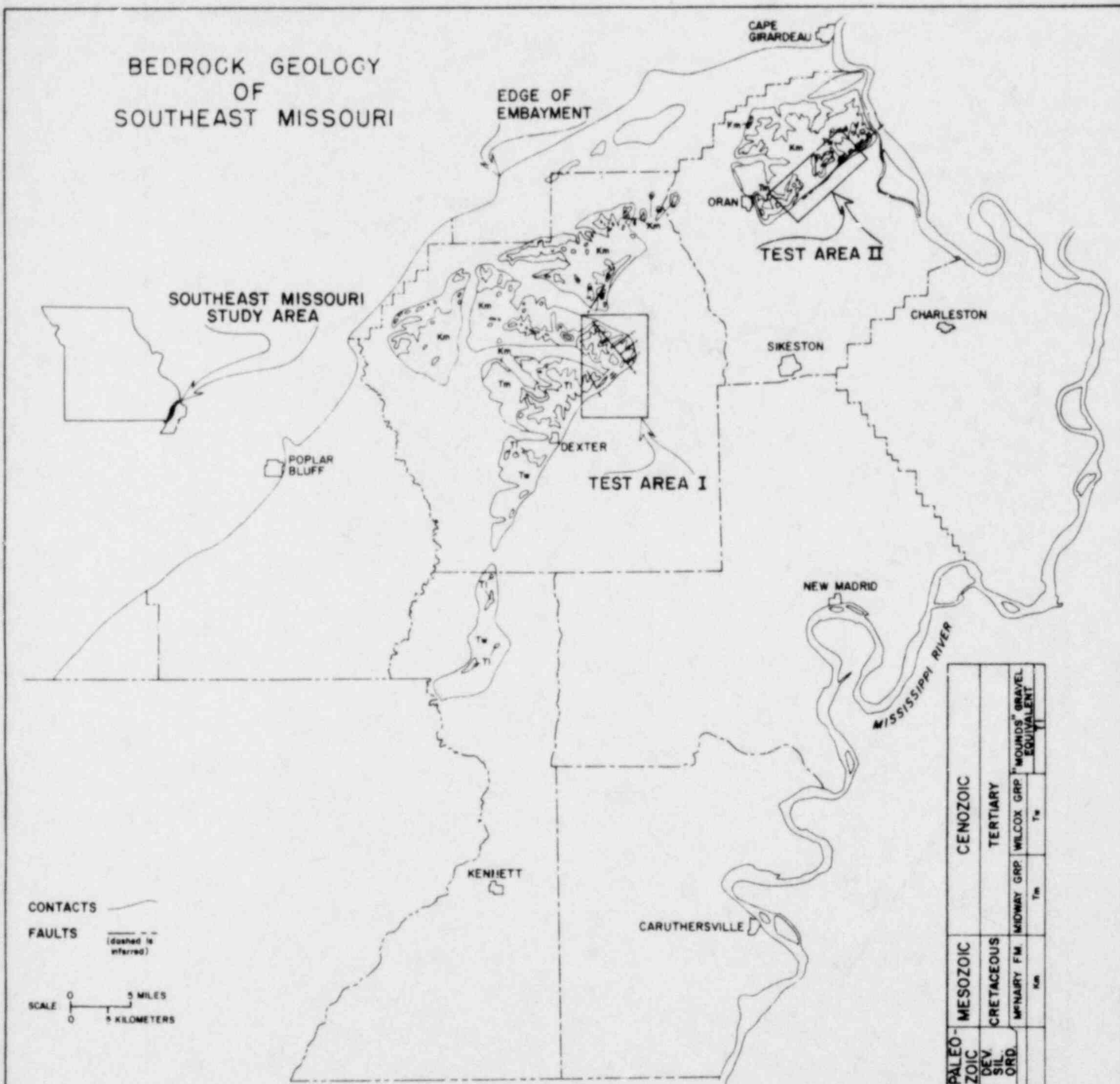

Figure D-1 A generalized geologic map of the Crowleys Ridge-Benton Hills area, southeastern Missouri lowlands, with emphasis on the Mesozoic and Cenozoic geology. Area of this year's field activity located within test area 1.

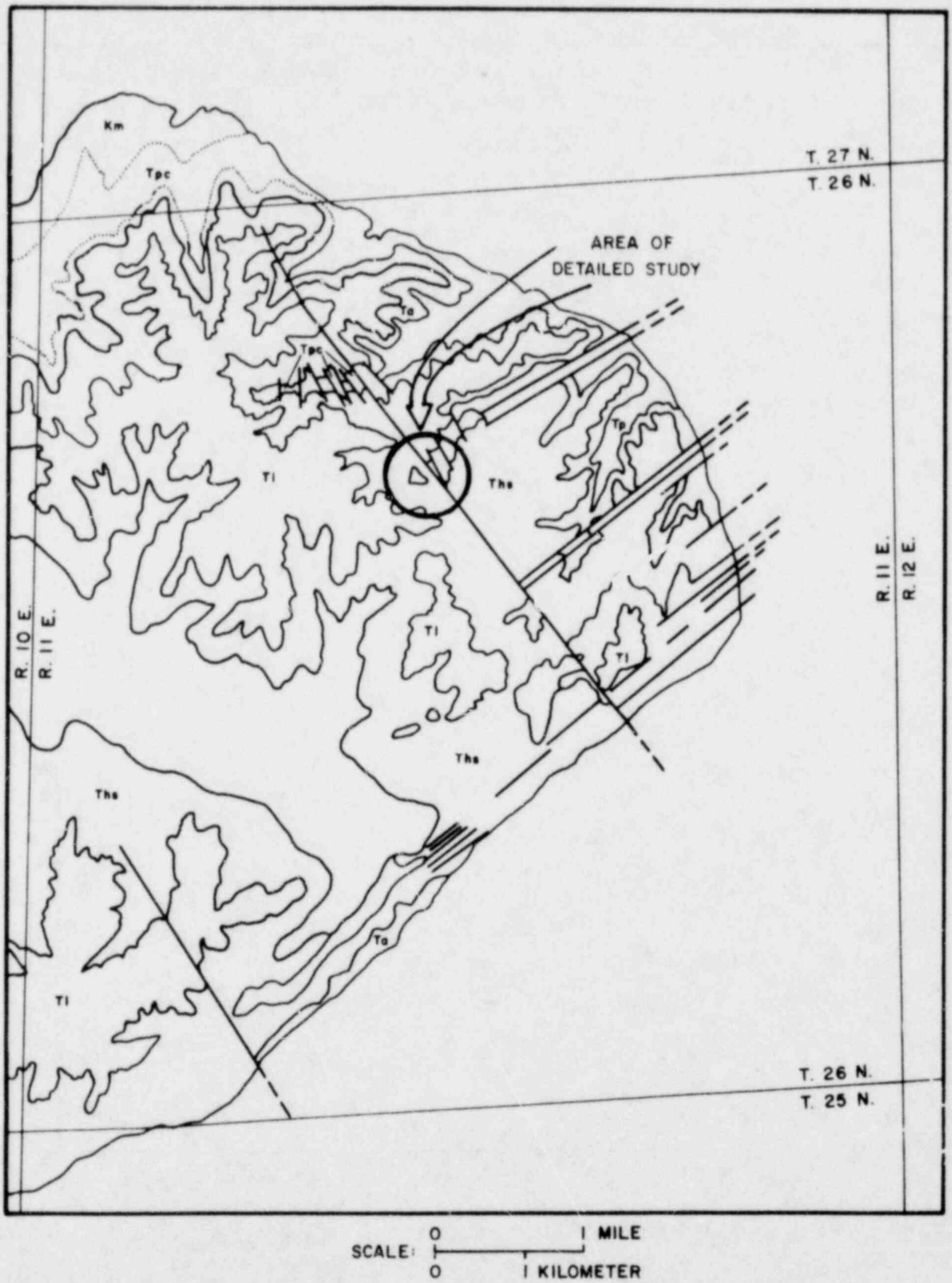

Figure D-2 Detailed geologic map of the Bloomfield Missouri area (test area 1). Site of this year's field activities located within circled area.

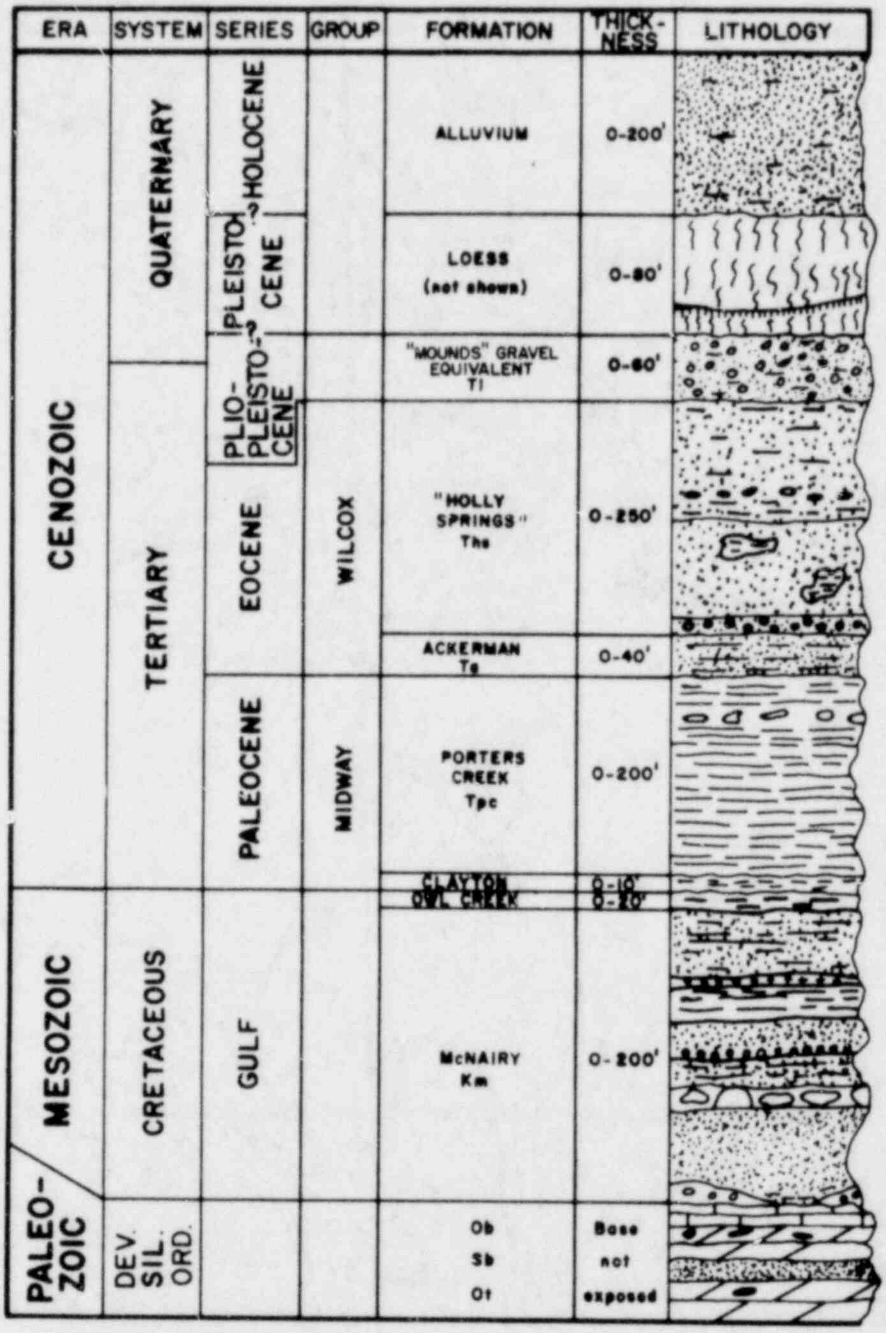

Figure D-3 A detailed stratigraphic section of the units exposed in the prominent ridges of Missouri's Bootheel with emphasis on the Gulf (Cretaceous), Paleocene, Eocene, and Pliocene (Tertiary) Series.

LEGEND

- ○ DEEP TEST HOLES DRILLED UNDER THIS YEAR'S CONTRACT
- △ SHALLOW TEST HOLES (PROBE TESTS) DRILLED UNDER THIS YEAR'S CONTRACT
- □ EXISTING TEST HOLE INFORMATION WPA 1936-42
- — — FAULTS

STRUCTURE AND TOPOGRAPHIC CONTOUR INTERVAL 10'

Figure D-4 Contour map on top of Porters Creek Clay, Beech Grove Branch site - Sec. 9, 10, 15, and 16, T.26N., R.11E. (test area 1). Test hole locations illustrated along cross section line A-B (figures D-5 and D-6); suggested Tertiary faulting shown by heavy dashed line.

STRUCTURAL CROSS SECTION A-B

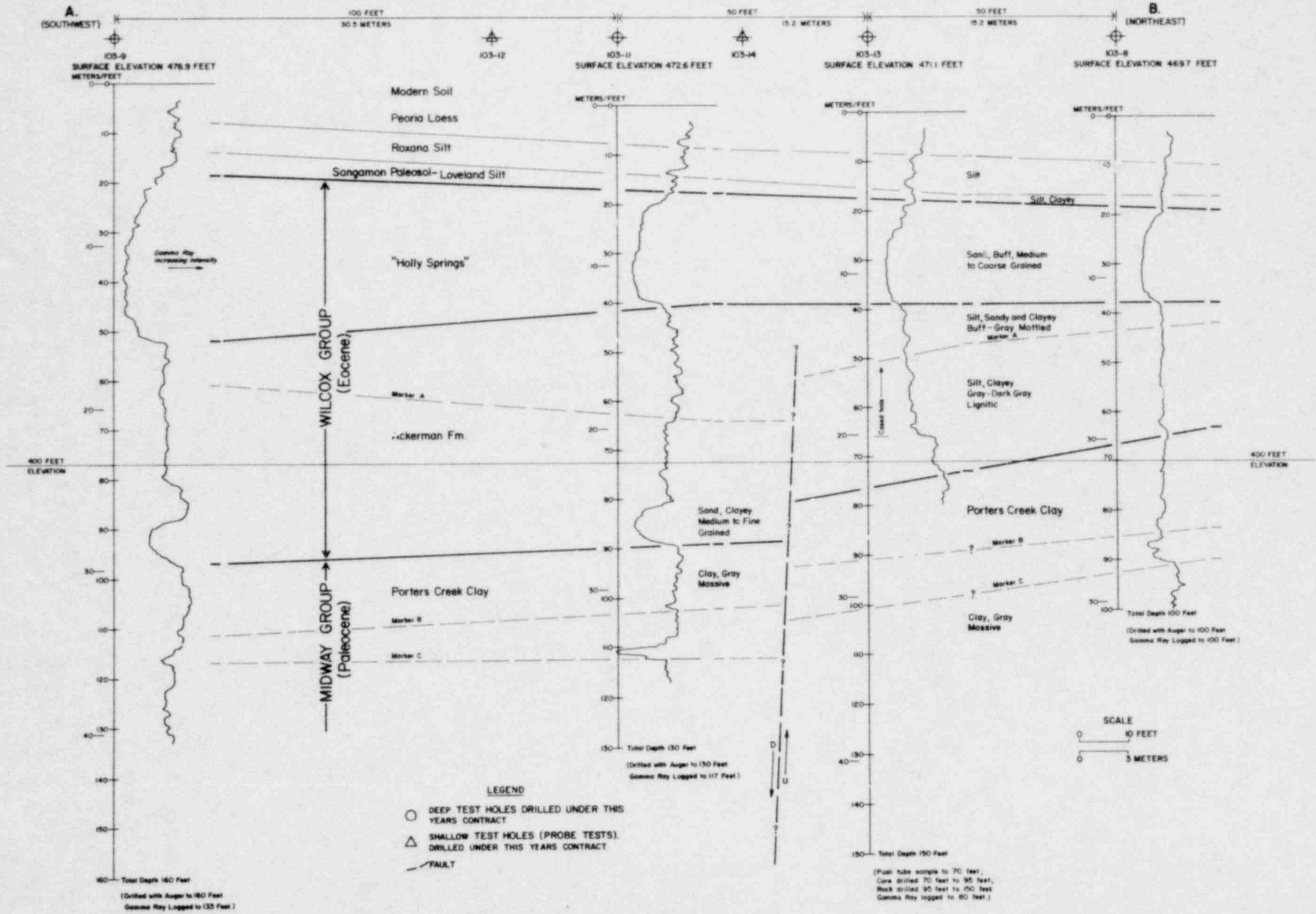

Figure D-5 Cross section A-B with test holes penetrating the Porters Creek Clay illustrated. Gamma ray trace and lithologic information depicted in order to demonstrate correlation and location of suggested faulting affecting Porters Creek Clay and overlying Ackerman Formation. Displacement of Wilcox (Eocene) sand and overlying Pleistocene deposits is not indicated.

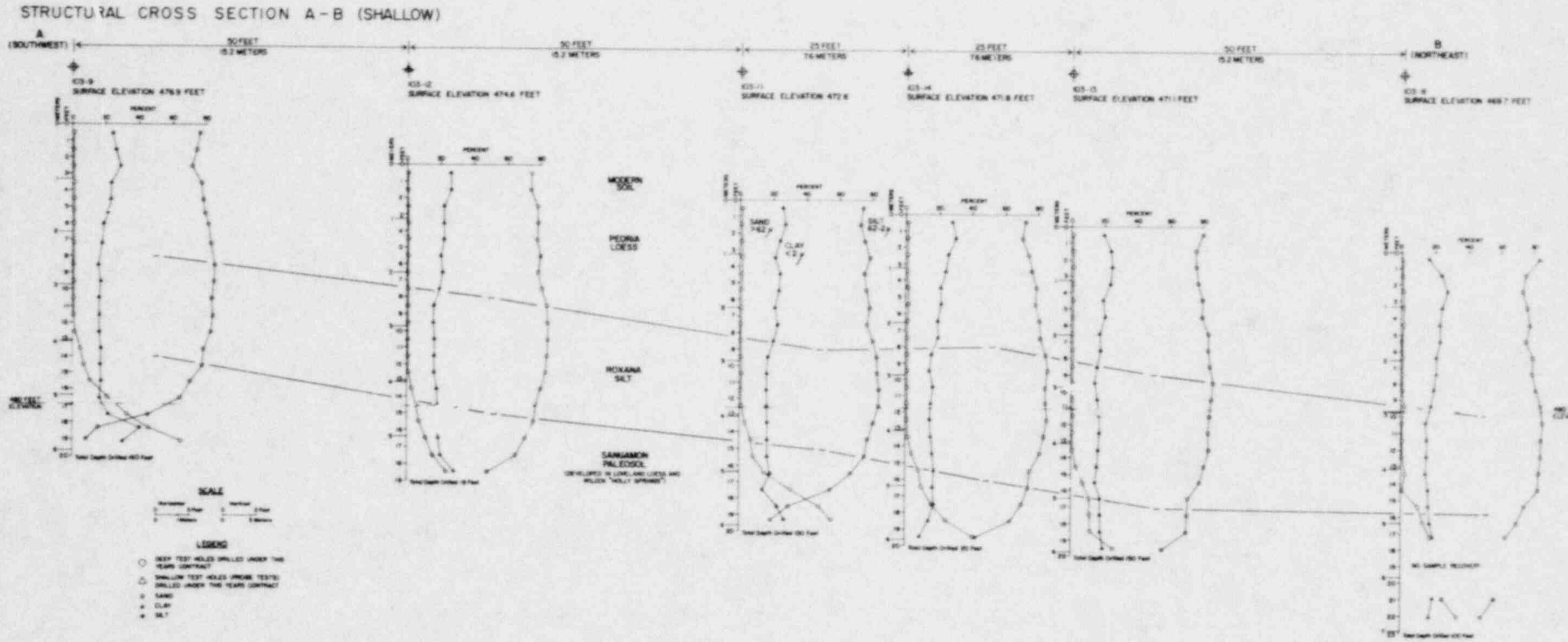

Figure D-6 Correlation of sand, silt, and clay distribution plots of Pleistocene loess for test holes along cross section A-B (figure D-5). Only shallow hole information is available for test holes 103-12 ans 14.

PALEOZOIC GEOLOGY OF THE NEW MADRID AREA

Annual Progress Report - Fiscal Year 1979

Contract No. NRC-04-76-321

H.R. Schwalb*
Kentucky Geological Survey

SUMMARY

During the third year of the continuing study of "Paleozoic Geology of the New Madrid Area," a total of 156 hours of work was performed.

Visits were made to the Geological Surveys of all the states involved with the exception of Alabama. Presentations of new and revised work were made at both the St. Louis, Missouri, and Mt. View, Arkansas, study group work sessions.

Additional deep well information was gathered, and sample studies were completed for western Kentucky, and an Illinois deep test is now in the process of examination. Age dates for basement rocks were gathered from several sources, and additional samples were collected for dating.

The Everton-Knox structure and isopach maps have been completed for final drafting, and a preliminary isopach map of the pre-Knox strata has been prepared.

Two north to south cross sections have been drafted, and the lithologic column is almost completed for the first of these sections.

RESEARCH HIGHLIGHTS

The newly prepared isopach map of the pre-Knox strata (figure E-1) indicates some of the depositional trends that began early in Cambrian time. The down faulted or depressed areas of the Pre-Cambrian surface were invaded by marine sediments, and after these trough-like depressions were filled, the topographically high areas of Pre-Cambrian crystalline rocks still remained well above sea level. By Upper Cambrian time, the Bonneterre-Eau Claire formations finally blanketed the region, and the Pre-Cambrian was never re-exposed except for the Ozark uplift.

The source of the earliest sediments appears to have been from the southeast and southwest whereas the Upper Cambrian sandstones which have a depocenter in northern Illinois are derived from a northern source.

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The lines of cross section in preparation will show the changes in lithology from north to south as well as the changes in thickness of the sedimentary units. The thick sections of Upper Pre-Cambrian strata south of the Rough Creek fault zone, and on the Pascola Arch are of special interest because they occur in the graben-like troughs that were formed in either Pre-Cambrian or early Cambrian time. No tests drilled to date have penetrated the entire sedimentary section in these trough areas, and the time of formation of downwarping of the Pre-Cambrian crystalline rocks cannot accurately be established until the age and lithology of the early sediments is determined by drilling.

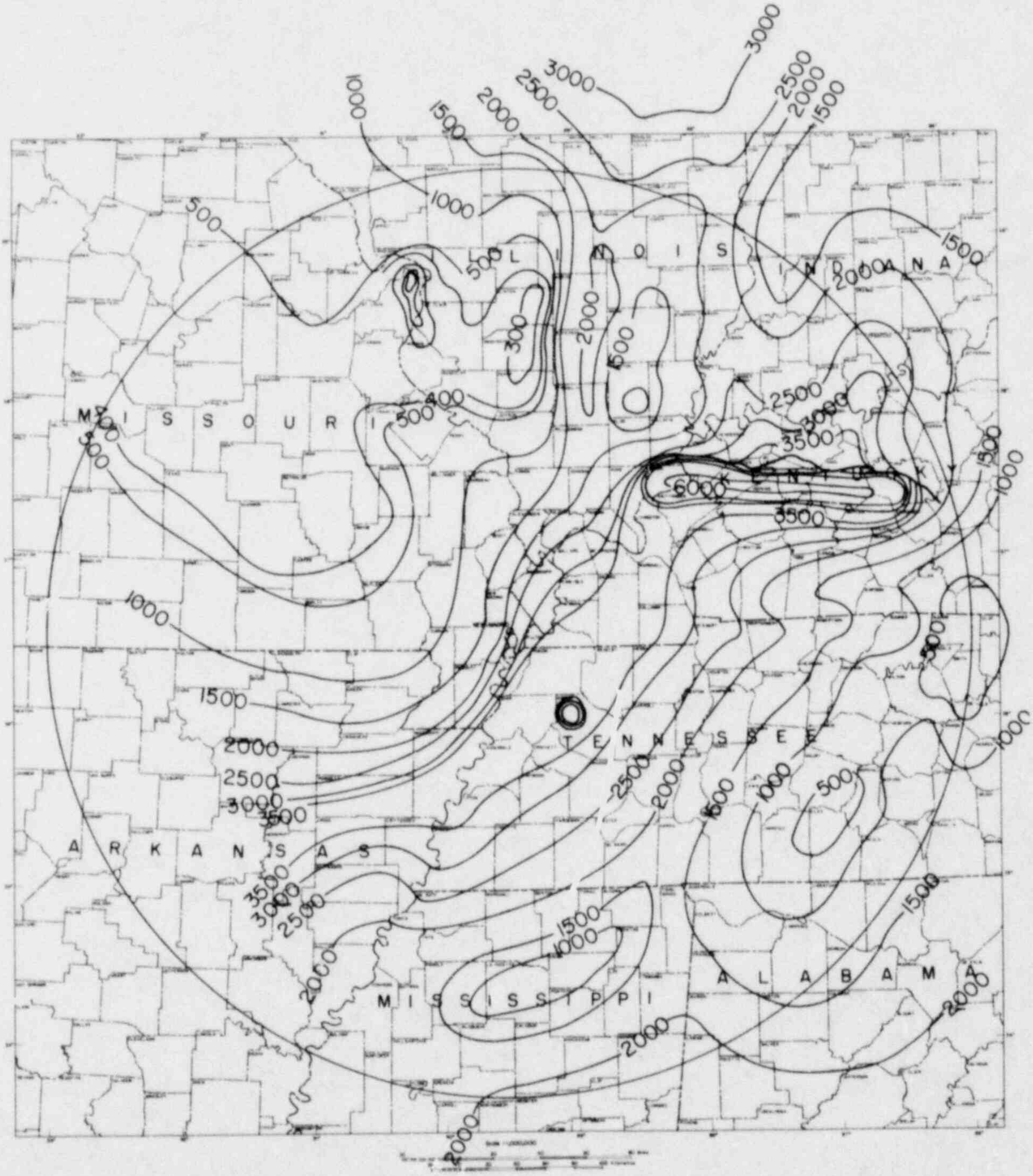
The revised structure map on the top of the Everton-Knox carbonates was able to be more accurately drawn with the aid of the revised Everton-Knox isopach map. Within the area of partial to total erosion of the Knox, projections upward from lower datum points provided a basis for restoring the pre-erosion structure. The crest of the Pascola Arch was found to exceed by 6000 feet the crest of the Nashville Dome. Although of smaller areal dimensions than the Nashville Dome the Pascola Arch is a most significant buried structure The lack of any appreciable basement uplift to be indicated by the geophysical data beneath the Pascola Arch is puzzling.

The first movement on the Rough Creek fault zone began either in Pre-Cambrian or early Cambrian time. Growth faulting is identified from early Silurian through Devonian time with all of the displacement in a down to the south direction. Depocenters of Paleozoic sediments are to the south of the fault and they migrated gradually northward until Pennsylvanian time when the depocenter moved into the Fairfield Basin north of the fault. Marine sedimentation continued in the region into Permian time proved by the idenification of early Permian fossils in limestones preserved in a graben within the Rough Creek fault zone.

The last movement on the Rough Creek fault zone occurred sometime after the early Permian and may have been much later. Crustal loading to the north of the fault probably contributed to the final displacement, which is in a down to the north direction while steep southward tilt was imposed on the sediments to the south of the fault. To accommodate the steep southward tilt of beds, a deep fault extending into the basement must be postulated near the axis of the trough of the Moorman Syncline. No significant lateral movement is recognized along the trend of the Rough Creek fault zone in the sedimentary section, although lateral movement may have taken place in the basement rocks before deposition of sediments occurred.

The revision of maps and the preparation of cross sections is expected to be completed in the coming year.

PRELIMINARY ISOPACH OF PRE-KNOX STRATA



COMPILED BY HOWARD SCHWALB
PRELIMINARY DRAFT 7-79

VARYING ISOLITH INTERVAL
SEE LINE VALUES

Figure E-1 Thickness of pre-Knox Strata

A STUDY OF INDIANA FAULT LOCATIONS, DISPLACEMENTS, ATTITUDES AND AGES WITHIN A 200 - MILE RADIUS OF NEW MADRID, MISSOURI

Annual Progress Report - Fiscal Year 1979

Contract No. NRC-04-77-164

Dan M. Sullivan
Curtis H. Ault
Indiana Geological Survey

ABSTRACT

Faulting of the Wabash Valley Fault System extending from Illinois and Kentucky into Posey and Gibson Counties, Indiana has been investigated in detail, primarily through the use of more than 6,000 geophysical logs of petroleum tests. Subsurface data on six structural horizons have been tabulated and plotted on base maps, and maps showing fault interpretations on the top of the Springfield Coal Member (Petersburg Formation), and the top of the Cypress Formation will be published by the Indiana Geological Survey. Northeastward-trending fault zones bound both horst and graben structures. The individual faults within the fault zones are discontinuous and they overlap. All are normal faults which dip between 60° to 80° and are post-Pennsylvanian in age. Faulting becomes less complex with depth based on interpretations of Pennsylvanian and Mississippian age rocks. Some deep faulting is indicated by sparse drilling to Devonian age rocks in Posey County, and faulting is inferred to penetrate to basement rocks, although sub-Devonian well control is lacking.

OBJECTIVES

The objective of this study is to determine the location, extent, attitude, displacement, and other geologic and seismic characteristics of faulting in that part of Indiana that lies within a 200-mile radius of the New Madrid seismic center to help characterize the tectonic processes in that region.

WORK PERFORMED

During the second year of the project, Mr. Joseph Stellavato, geologist with the Indiana Geological Survey, under the direction of the principal investigators, completed the compilation of structural data from geophysical logs of petroleum tests and other test holes in all of Posey County and the southern third of Gibson County, Ind. These counties are closely associated with the Wabash Valley Fault System in Indiana. Approximately 6,000 wells have been reviewed, and data on six structural horizons in rocks of Mississippian and Pennsylvanian age have been recorded. Much of the data compilation in the past year has been concentrated in eastern Posey County and southern Gibson County. In parts of these areas, the spacing between drill holes has generally been greater than that reviewed in western Posey County during the first year of the project, but sufficiently close enough to adequately characterize the faulting.

Detailed structural mapping of the fault system, on two horizons, in the area mentioned above is complete. Faulting trends extending into Illinois were correlated with geologists investigations for the Illinois Geological Survey. The faults were named informally and correspond to terminology of the Illinois Geological Survey for faults in the Wabash Valley system. In addition, fault extensions into Kentucky to the south have been correlated from available USGS maps and from discussions with personnel of the Kentucky Geological Survey.

Mr. Stellavato, assisted by Mr. George Tanner, has begun the review and compilation of all subsurface data available in western Vanderburgh County and parts of Spencer and Perry Counties. These counties are east of the Wabash Valley Fault System but are areas of known faulting and are within the investigation area of this project. In addition, fieldwork has begun in Perry County and will proceed through 1979.

The computer program designed to retrieve the basic subsurface file on hand at the Indiana Geological Survey is now finalized. Integration of these data with a computerized mapping system (ILLIMAP) prepared for southwestern Indiana by the Illinois Geological Survey allows us to produce at any desired scale accurate base maps showing selected well locations and various structural datum points in the study area.

Subsurface

Subsurface data, primarily, geophysical logs, from more than 6,000 wells in Posey and Gibson Counties were tabulated and plotted (data on some horizons east of R. 12 W. are not plotted) on base maps for the following structural horisons:

Pennsylvanian Age

1. Top of the West Franklin Limestone Member, Shelburn Formation.
2. Top of the Herrin Coal Member, Dugger Formation.
3. Top of the Springfield Coal Member (Coal V), Petersburg Formation.

Mississippian Age

4. Base of the Menard Formation.
5. Top of the Cypress Formation.
6. Top of the Renault Formation.

Included in this report are maps showing faults in Posey County and southern Gibson County based on the top of the Springfield Coal Member (Coal V) and the top of the Cypress Formation (figs. F-1 and F-2).

Structure-contour maps for both these horizons are complete for the Posey-Gibson area and are currently being drafted on a base of 2 inches to 1 mile. These maps will show structural control to a density of one control point per 10 acres. Fault interpretations, as well as all faulted wells, the amount of section missing, and the subsea elevation of the fault disruption within the wells, will also be shown on the maps. These maps will be published by the Indiana Geological Survey.

In addition to earlier cross sections necessary for correlating the Pennsylvanian and Mississippian stratigraphy, relatively short sections were made in those areas where interpretation of the number and extent of the faults is difficult. Figure F-3 of this report is a cross section across southern Posey County (line of section shown on fig. F-1). Sections have also been constructed for Spencer and Perry Counties. Because of erosion of the upper parts of the Pennsylvanian rock section in these counties and the loss of some shallow structural data, additional Pennsylvanian markers were used.

Surface Fieldwork

Surface fieldwork in both Posey and Gibson Counties is virtually complete. Following a search of the literature for available maps or theses dealing with faults in Perry and Spencer Counties, fieldwork has begun in Perry County. Preliminary reconnaissance has indicated two or three faults in the Cannelton-Deer Creek area. These faults will be correlated with faults mapped by the USGS in the Cannelton-Cloverport Quadrangle in Kentucky.

Subsurface data in both Perry and Spencer Counties are sparse in the areas of indicated faulting.

Seismic Investigations

Although earlier seismic work by the Indiana Geological Survey in northwestern Posey County was not successful in locating faulting, additional work is planned for 1979-80.

Stratigraphic Test Drilling

As part of a drilling program for evaluating deep coals in Indiana, the Survey plans to drill two stratigraphic tests in Posey County during the next year. Much of the rock section of the Dugger and Petersburg Formations (Pennsylvanian) will be cored. Stratigraphic information from these tests will aid in correlating Pennsylvanian rock strata for this report. Preliminary plans are for one of the tests to be near a fault which trends northeastward from Mt. Vernon, Ind.

PRELIMINARY RESULTS

Our work to date in determining the location and characteristics of faulting in southwestern Indiana has been primarily through the use of geophysical logs. Because of thick surficial overburden in much of the area investigated, neither seismic nor surface fieldwork has made any significant impact on our study.

The faults of the Wabash Valley system in Indiana mapped from rock strata of Pennsylvanian and Mississippian age trend N. 15°-30° E. (figs. F-1 and F-2). Faults in Pennsylvanian rocks occur mostly in zones with as many as five or more individual faults having more than 20 feet of displacement. As many as four separate faults have been recognized on a geophysical log from a single well.

Faulting becomes less complex with depth. Several individual faults mapped in the Pennsylvanian die out or possibly coalesce in rocks in Mississippian age (fig. F-3).

Absence of a shallow marker in a upthrown block and its presence in an adjacent downthrown block, together with some anomalous local thinning of some intervals, originally posed the possibility of pre-Pennsylvanian movement on one or more faults. But cross section work and some isopach mapping have convinced us that the faults are all post-Pennsylvanian in age.

Our preliminary mapping indicated strike-slip faults. If present, these faults have not been discernible from geophysical logs, and the faults of the Wabash Valley system are currently shown as overlapping fault traces.

All faults are the normal type with dips ranging from 60° to 80°; most of them have dips of more than 70°. The faults are downdropped to both the east and west, which produces both horst and graben structures (fig. F-3).

The deepest structural horizon indicating any Wabash Valley faulting in Indiana is the top of the New Albany Shale (fig. F-4). The fault bounding the west side of the Mt. Vernon Graben is evident from the data available and is consistent with evidence on shallower horizons. Only two wells are deeper than the Devonian in the general area, but we do find that fault displacements are consistent with depth in rocks of Pennsylvanian and Mississippian age. Bristol and Treworgy (1978, p. 107) believe this evidence indicates that faulting reaches the basement rocks, and we also make this inference.

FUTURE WORK

Collection of data and examination of all subsurface data available for parts of Vanderburgh, Perry, and Spencer Counties will be completed in the coming year. Investigation of the faulting, particularly in Perry County, will entail detailed surface fieldwork.

The Indiana Geological Survey will expand its fault studies to include two additional major faults: the 50-mile-long Mt. Carmel Fault of south-central Indiana and the Georgetown Fault in Harrison and Floyd Counties.

These faults, although outside the 200-mile radius of New Madrid, Mo., are an integral part of the same Illinois Basin tectonic system that is being examined in our present study area.

We also plan to supplement our surface and subsurface mapping by correlating known fault traces with lineaments previously mapped from ERTS data and aerial photographs of southwestern Indiana.

REPORTS AND STUDY PRODUCTS

In addition to the structure-contour maps for the Posey-Gibson County area to be published by the Indiana Geological Survey, other papers were prepared and presented during the year. A progress report, "Faulting in Southwestern Indiana," was presented at a meeting of the Indiana-Kentucky Geological Society, and a modified version of the same talk was given at an

Indiana Geological Survey colloquium. "The Wabash Valley Fault System in Indiana and Its Economic Implication" was presented to the Kentucky Oil and Gas Association. This paper will be published by the Kentucky Geological Survey as Series X, Special Publication. An abstract, "Faulting in Posey and Gibson Counties, Indiana," has been prepared for submission to the Indiana Academy of Science in the fall of 1979.

REFERENCES

Bristol, H. M., and Treworgy, J. D., 1978, The Wabash Valley Fault System in southeastern Illinois, report of research activities - fiscal year 1978, *in* Buschbach, T. C., ed., New Madrid seismotectonic study - activities during fiscal year 1978: U.S. Nuclear Regulatory Commission Report NUREG/CR-0450, p. 105-112.

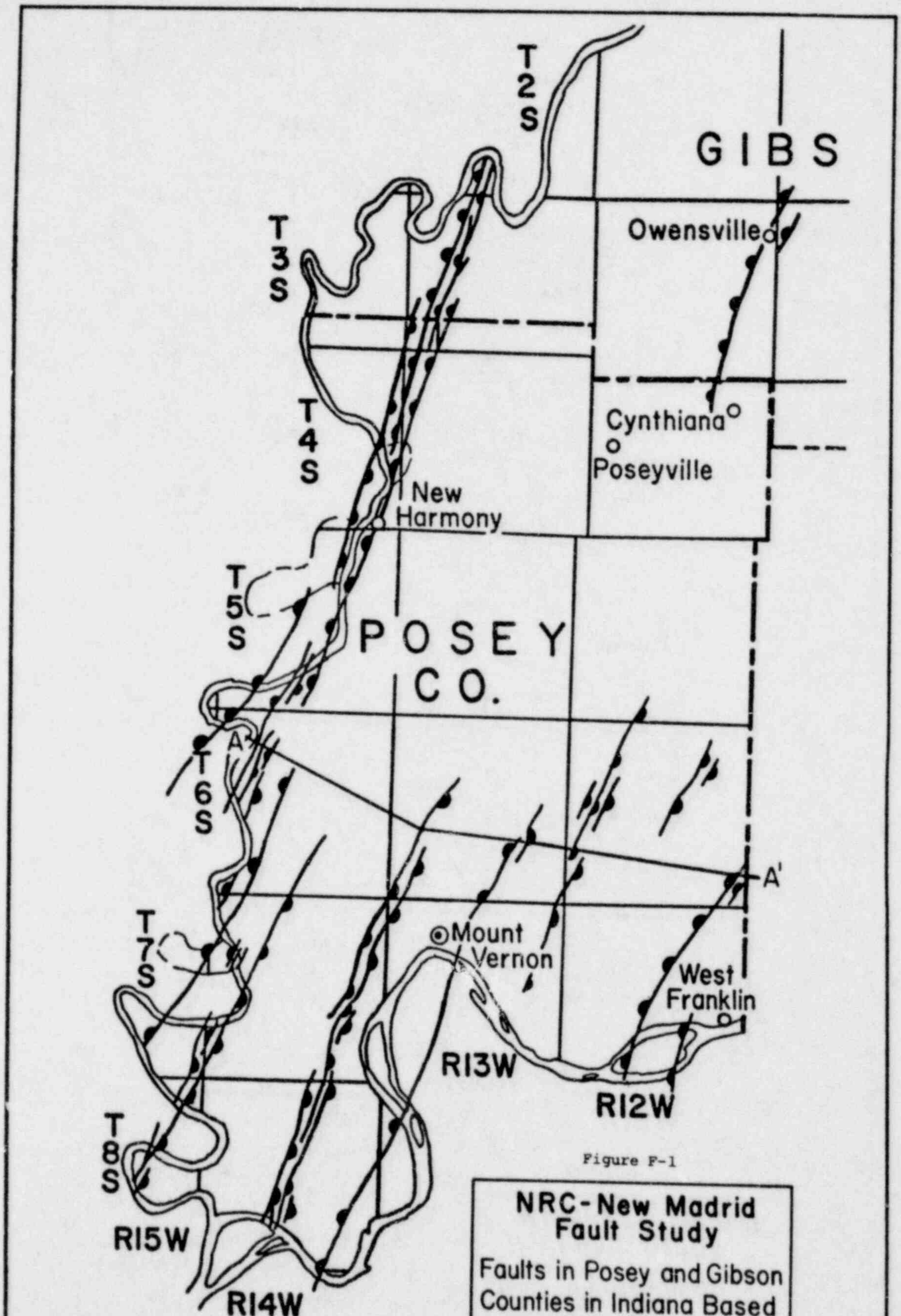
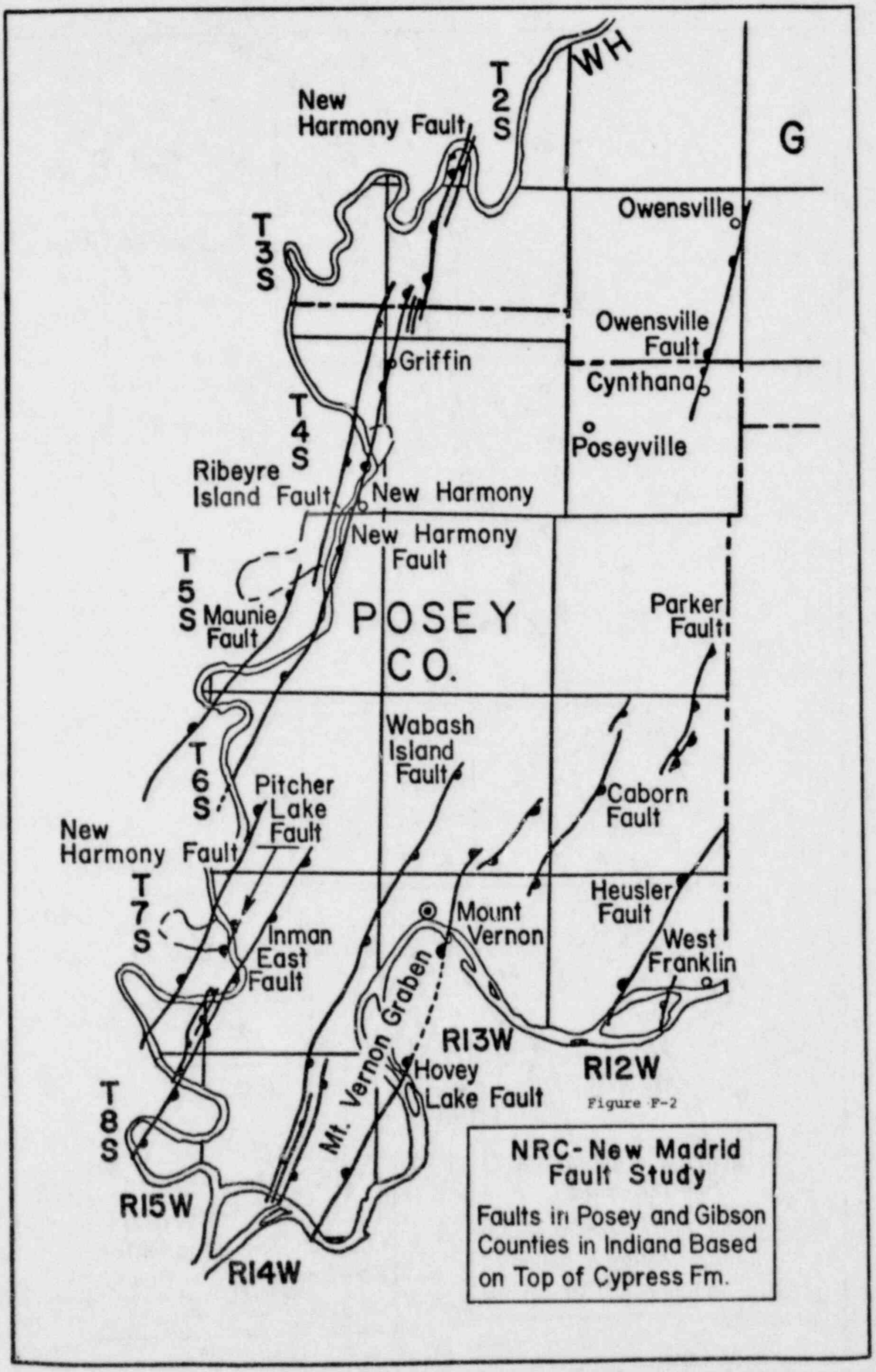


Figure F-1

NRC-New Madrid Fault Study

Faults in Posey and Gibson Counties in Indiana Based on Top of Coal V.


WH
G
T2S
New Harmony Fault
T3S
Owensville
Owensville Fault
Griffin
Cynthana
T4S
Poseyville
Ribeyre Island Fault
New Harmony
New Harmony Fault
T5S
Maunie Fault
POSEY CO.
Parker Fault
Wabash Island Fault
T6S
Pitcher Lake Fault
Caborn Fault
New Harmony Fault
T7S
Mount Vernon
Heusler Fault
Inman East Fault
West Franklin
Mt. Vernon Graben
R13W
Hovey Lake Fault
R12W
T8S
R15W
R14W
NRC-New Madrid Fault Study
Faults in Posey and Gibson Counties in Indiana Based on Top of Cypress Fm.
Figure F-2

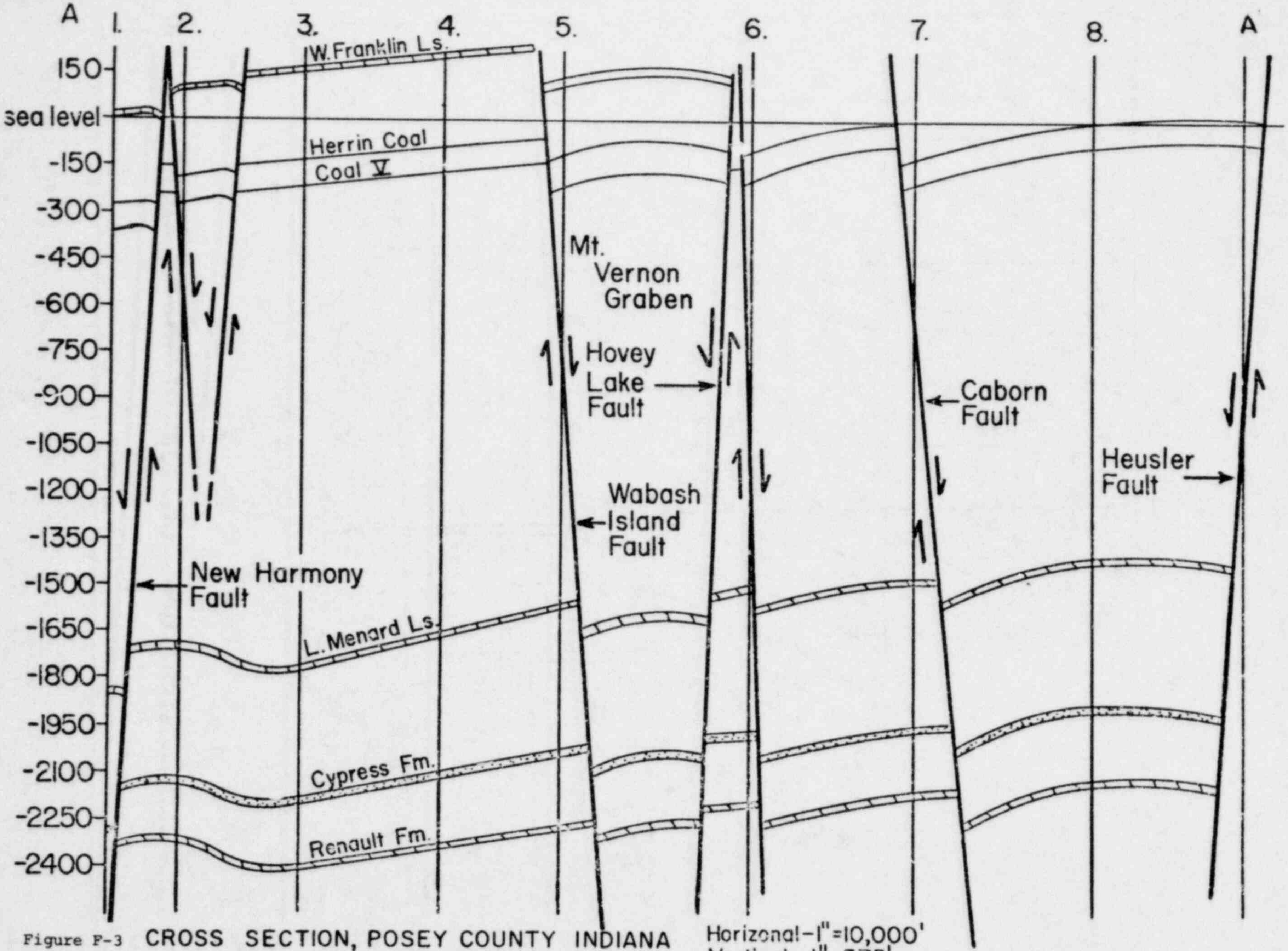


Figure F-3 CROSS SECTION, POSEY COUNTY INDIANA Horizontal - 1" = 10,000' Vertical - 1" = 375'

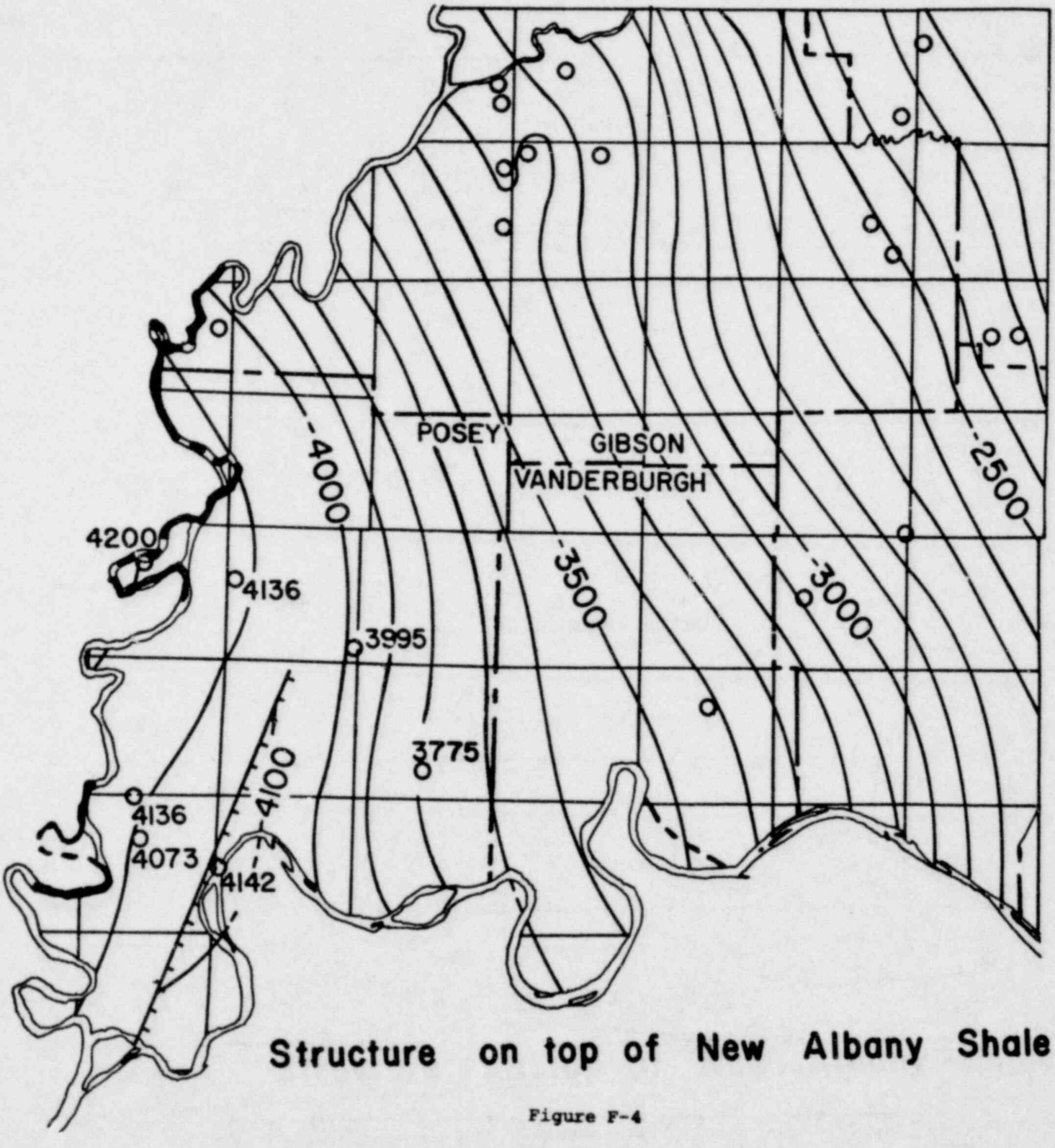

POSEY
GIBSON
VANDERBURGH
-4000
-3500
-3000
-2500
4200
4136
3995
3775
4100
4136
4073
4142
Structure on top of New Albany Shale

Figure F-4

STRUCTURAL FRAMEWORK OF THE MISSISSIPPI EMBAYMENT OF SOUTHERN ILLINOIS

Annual Progress Report - Fiscal Year 1979

Contract No. NRC-04-77-159

Dennis R. Kolata
Illinois State Geological Survey

ABSTRACT

Four maps of the Mississippi Embayment of southern Illinois have been prepared; these include (1) a sub-Cretaceous geologic map, (2) a map showing the configuration of the base of the Gulfian (late Cretaceous) Series, (3) a map showing the thickness and distribution of Gulfian sediments, and (4) a structure map of the base of the Paleocene Clayton Formation. All four maps were compiled at a scale of 1:125,000. The available evidence suggests that there is structural continuity between the Illinois-Kentucky Fluorspar District and the Mississippi Embayment area of southernmost Illinois. The fluorspar district fault system extends into the area but the density, extent, and magnitude of faulting is difficult to determine where the embayment sediments overlap the Paleozoic bedrock. Most of the displacement on the faults took place in pre-Gulfian time. One possible exception is an elongate northeast-trending depression (America Graben of some investigators) in Pulaski County. This feature is 350 feet lower than the elevation of nearby Paleozoic bedrock and is associated with an unusually thick section of Gulfian sediments. This graben-like feature may be the result of faulting that occurred contemporaneously with, or shortly after, Gulfian deposition in the region; however, the possibility that the present relief on the pre-Cretaceous surface represents topographic configuration of the surface before deposition of Gulfian sediments cannot be ruled out.

PURPOSE

The purpose of this investigation is to determine the nature, age, extent, and magnitude of faulting in the Mississippi Embayment of southernmost Illinois in order to gain a better understanding of the structural framework and tectonic history of that area.

WORK PERFORMED

During the past year four maps of the Mississippi Embayment of southern Illinois were prepared; these include (1) a sub-Cretaceous geologic map, (2) a map showing the configuration of the base of the Gulfian (late Cretaceous) Series, (3) a map showing the thickness and distribution of Gulfian sediments, and (4) a structure map of the base of the Paleocene Clayton Formation. All four maps were compiled at a scale of 1:125,000. A discussion of these maps follows.

Sub-Cretaceous Areal Geology

Throughout most of the study area the Paleozoic bedrock is buried beneath Gulfian (late Cretaceous) and younger sediments (fig. G-1). The few bedrock outcrops that are exposed in the area are situated in the upland adjacent to the Cache Valley and Ohio River bluffs in Pope and Massac Counties, in the Post Creek Cutoff in southeastern Pulaski County, and in the bluffs of the Mississippi River Valley south of Thebes, Alexander County. Subsurface control is very limited for the study of Paleozoic bedrock in the area. There are relatively few drill holes that penetrate the bedrock, and those that do commonly are not drilled deep enough to confidently identify a particular stratigraphic unit. Due to the cyclic nature of some parts of the stratigraphic sequence and to lateral facies changes, especially in the Mississippian units, a thick section of rock must be studied to make a positive identification. Some formations are relatively thick and uniform, so unless formation tops have been encountered it is very difficult to locate faults in the bedrock even where the well control is dense. Many drill holes in the area have been completed in a cherty unit suspected to be the top of bedrock, but it is difficult to tell from the driller's description or well cuttings, if they are available, whether this is cherty bedrock, residual chert lying over the bedrock, the Tuscaloosa Formation or a cherty bed in the McNairy Formation. Because of these difficulties we suspect that bedrock has not always been picked consistently by those who have studied the samples.

An interpretation of the distribution of Paleozoic bedrock is shown on the sub-Cretaceous geologic map (fig. G-2). The contacts between stratigraphic units on this map are based on subsurface control and the southward projection of outcrop data. Generally, the bedrock dips northeastward away from the Ozark Dome and Pascola Arch toward the Illinois Basin. Pre-Gulfian erosion beveled the bedrock to a relatively flat surface. As a result of the northeastward dip and truncation of the Paleozoic rocks successively younger strata occur at the bedrock surface from Champlainian (middle Ordovician) in western Alexander County to Chesterian (upper Mississippian) in northern Massac and southern Pope Counties.

The faults that are shown on figure G-2 are based on apparent stratigraphic anomalies at the bedrock surface. Trends of the faults are established on control points and inferred from the regional trend of faulting, which is northeast-southwest. Most of the faults that are shown in eastern Massac and southern Pulaski Counties cannot be connected confidently to the faults that project into the area from the Illinois-Kentucky Fluorspar District. We suspect from the structural continuity that is suggested by geophysical evidence (Braile and Hinze, 1979; Hildenbrand et al., 1979) that the fluorspar district faulting extends into the area, but the density, extent, and magnitude of faulting is difficult to substantiate with the available subsurface data.

Ross' (1963, fig. 6, p. 15) sub-Cretaceous areal geology map of the same area differs from the map presented here in that he shows the bedrock to be a mosaic of fault segments. We believe that the interpreted faults on his map are much more numerous and extensive than is permitted with the available information. Besides having a fundamentally different approach to geologic mapping of the embayment area, there are several reasons for the disagreement between our map and Ross': (1) a check of the landowners or contractors listed in the well records against the county plat books showed that several critical datum points on Ross' map were mislocated. This was due mainly to errors in the geologic records used in his study. (2) A restudy of all drilling samples in the area indicate that some stratigraphic units at the bedrock surface were misidentified. Some of the stratigraphic information used by Ross was obtained from sample studies made by various people over a long period of time and it lacked the consistency that is needed in this type of subsurface mapping. (3) New subsurface information has become available since Ross' work that requires a different interpretation.

Ross (1963) described four major northeast-trending graben belts in the embayment of southern Illinois including the America, Dixon Springs, Rock Creek, and Paducah Grabens. The America Graben, which shows clearly on our sub-Cretaceous geologic map (fig. G-2), is a zone of faults and grabens that lies parallel to the Ohio River and appears to extend from near Mounds City to near Olmstead in southern Pulaski County, a distance of about 10 miles. The main subsurface control on the America Graben is provided by the Case Engineering Co. No. 1 Omlstead city well (SE SE SE SW Sec. 22, T. 15 S., R. 1 E.) which encountered the Mississippian Fort Payne Formation in the bedrock at 161 feet below sea level. Two miles west of here the White No. 1 John Goza well (SE SE Sec. 20, T. 15 S., R. 1 E.) encountered the Devonian New Albany Shale Group at 54 feet below sea level. Three miles southwest of the Olmstead city well the Vick Oil Co. No. 1 Boyd (SW Sec. 5, T. 16 S., R. 1 E.) and the Vick Oil Co. No. 1 Roberts (SE SE Sec. 5, T. 16 S., R. 1 E.) wells both encountered lower Devonian bedrock at sea level elevations of -2 and +13 feet respectively. The stratigraphic relationships shown by these wells and several others in the area suggest that at least three parallel faults displace the Paleozoic bedrock. In addition, the configuration map of the base of the Cretaceous (fig. G-3) in the area of the America Graben shows the Paleozoic bedrock surface to be at a significantly lower elevation than the surrounding area, which also supports a graben interpretation. Part of the structure may lie on the Kentucky side of the Ohio River. A thrust fault described by Schwalb (1969, p. 16) in the Indian Camp Development Co. No. 1 T. J. Wilson test in Carlisle County, Kentucky, may be the southward extension of the structure.

The Dixon Springs Graben is well documented in the outcrop area north of the Cache River Valley. It extends from the northeast corner of Pope County southwestward to northwestern Massac County and appears to pass beneath the embayment sediments. The graben is bounded by fault zones and is itself faulted. Cumulative displacement of the faults that bound the graben is nearly 1000 feet in places (Weller and Krey, 1939, p. 11). On the basis of subsurface data Ross (1963) extended the graben beneath the embayment sediments through the area just west of Joppa and across the Ohio River into Kentucky. We agree that a graben probably underlies the area but we interpret the bedrock within the graben to be Ste. Genevieve Limestone rather than Chesterian rocks. The key datum to this interpretation is the Layne Western No. 1 Missouri Portland Cement Co. (NW Sec. 15, T. 15 S., R. 3 E.) boring which encountered Ste. Genevieve Limestone at the bedrock surface.

The nearest subsurface control to the east and west of this boring show Ullin Limestone at the bedrock surface at a slightly higher elevation. The boring is also interesting because the St. Louis and Salem Limestone Formations appear to be faulted out with the Ste. Genevieve resting on top of the Ullin Limestone.

The Rock Creek Graben extends from the northeast corner of Hardin County southwestward through western Livingston County, Kentucky, and back into Illinois west of Bay City in Pope County. The graben apparently continues southwestward for some distance beneath the embayment sediments. In Hardin County the bounding faults have as much as 2000 feet of displacement (J.M. Weller et al., 1952, p. 79) but this diminishes considerably to the southwest. An interpreted graben situated to the east to Metropolis (figs. G-1 and G-2) may be the southern extension of the Rock Creek Graben.

The Paducah Graben, described by Ross (1963) as "a narrow complex fault zone in its Illinois length," cannot be defined clearly with the available subsurface control.

Configuration of the sub-Gulfian surface

A configuration map of the Paleozoic bedrock surface beneath the Cretaceous sediments is shown in figure G-3. The most reliable data used in constructing this map are concentrated in the densely drilled area near Joppa and four or five miles west of here near the Pulaski-Massac County line where the bedrock can be seen in outcrop. The data provided by the Paducah Dam Site borings in southeastern Massac County also provide relatively good subsurface control. The area of least information is in southern Pulaski and Alexander Counties. Throughout the area the bedrock is covered by either the Little Bear Soil, Tuscaloosa Formation or the McNairy Formation.

Generally, the map shows a gently undulating surface that dips southward toward the embayment trough. The most unusual feature is an elongate depression in southeastern Pulaski County that generally coincides with the America Graben. The depression is about six miles across and close to 350 feet lower at its center than the elevation of the Paleozoic bedrock in the surrounding area. The northern limit of the feature appears to be in the area of Grand Chain. The southern extent, however, is not clear. It may continue south through Ballard and Carlisle Counties, Kentucky, in the manner shown by Schwalb (1969, fig. 4, p. 10).

The faults and grabens that project into the study area in Massac and Pope Counties have little or no expression on the configuration map indicating that most of the movement on these structures occurred before the overlap of Gulfian sediments. There also had to have been sufficient time for the faulted Paleozoic bedrock to be beveled by erosion before Gulfian deposition.

Several drill holes in the area show the bedrock to be at an anomalously low elevation. Judging from the close proximity to drill holes that encountered bedrock at a consistently shallower elevation, these anomalies are considered to be very localized. Evidence obtained from closely spaced exploratory drilling near the Post Creek Cutoff in eastern Pulaski County indicates that solution has lowered the bedrock surface by as much as 90 feet within a horizontal distance of 50 to 100 feet. We suspect that solution commonly follows the joints and faults in areas where limestone occurs at the bedrock surface and that this is the cause of many local anomalies in elevation of the bedrock. The effects of solution can cause problems in determining the age of faults. For example, solution along quiescent pre-Gulfian faults could result in collapse of the overlying embayment or younger sediments giving the impression that the faults have been active in relatively recent times.

Ross (1963) believed that the present relief on the sub-Cretaceous surface in southernmost Illinois is due primarily to post-Tuscaloosa faulting and warping. He reasoned that if the relief on the sub-Gulfian surface was as great when the Gulfian sediments were deposited as it is now, that the Tuscaloosa should be locally much thicker and its distribution more irregular. Further, the close parallel between the major structural features of his sub-Gulfian geologic map, the structure contour of the base of the Gulfian sediments, and the projected trends of structures exposed to the northeast of the embayment, indicated to him that the faults bounding the grabens of Paleozoic strata were sites of renewed movement after Gulfian deposition.

The primary assumption in this hypothesis is that the Tuscaloosa Formation is widespread and uniform in thickness and therefore was deposited on a relatively flat surface, which Ross considered a structural datum for post-Gulfian deformation. The available data, however, does not convincingly support this assumption. In drilling chip samples, which are the main source of subsurface control, the Tuscaloosa commonly is not lithologically distinct from cherty bedrock, residual chert lying over the bedrock or chert gravel within the McNairy Formation. The chert gravel that occurs between the micaceous sand of the McNairy Formation and bedrock is actually variable in thickness and distribution. It is absent in many drill holes throughout the area and in the Layne Western No. 5 Metropolis well (NE Sec. 11, T. 16 S., R. 4 E.) it apparently is over 168 feet thick.

In the closely spaced Paducah Dam site borings in southeastern Massac County the chert gravel ranges from 0 to 50 feet thick. The thicker sections of chert occur where the bedrock surface is at a low elevation and it is absent in those borings where the bedrock is high. Distribution of the chert gravel appear to be controlled by pre-Gulfian topography.

Available evidence suggests that the present relief on the sub-Gulfian surface throughout the Mississippi Embayment of southern Illinois is due to the combined effects of post-Gulfian solution, pre-Gulfian topography and possibly only minor deformation during and after Gulfian time.

Distribution and Thickness of Gulfian sediments and Structure at base of the Paleocene Clayton Formation

The distribution and thickness of Cretaceous sediments (includes the Little Bear Soil, Tuscaloosa Formation and McNairy Formation) are shown in figure G-4. The Cretaceous sediments undoubtedly covered a much greater area in southern Illinois, but they have been eroded back to an area that is confined primarily to the south side of the Cache River Valley. In general, the Cretaceous sediments thicken from north to south.

The thickest Cretaceous deposits are situated in southeastern Pulaski County in an area that generally corresponds to the America Graben. The Cretaceous sediments here are about 300 feet thicker than in the nearby area. From the sparse subsurface control it is not clear whether these sediments filled a graben or series of grabens that subsided during Gulfian time or whether they filled a depression that existed on the sub-Cretaceous surface before the overlap of Gulfian sediments. A third alternative is that a combination of the two preceding processes influenced deposition. The structure contour map (fig. G-5) of the base of the Paleocene Clayton Formation (top of Cretaceous) indicates that the area underwent broad regional sinking as a result of sediment accumulation in the embayment but there is little or no evidence of post-Gulfian subsidence in the America Graben.

In Massac and Pope Counties where the prominent grabens project into the embayment from the northeast the Cretaceous does not appear to be unusually thick. This suggests that most of the movement on those structures took place before the Gulfian sediments overlapped the area.

The Paleocene Porters Creek and Clayton Formations have about the same distribution, both are confined to southern Pulaski and Alexander Counties (fig. G-5). These formations dip southward at about 50 feet per mile. The overlying Eocene Wilcox Formation is confined to a small area north of Cairo and west of Mounds. It is restricted entirely to the area west of the America Graben.

PROPOSED PROGRAM FOR 1979-1980

The 1979-1980 program will involve a seismic reflection survey on the Ohio River between Brookport and Olmstead, Illinois. The purpose of the survey will be to gain a better understanding of the configuration of the bedrock surface and the embayment strata that overlie that surface in an area suspected to be faulted. This will be a cooperative investigation between Drs. David Willis and Robert Taylor of the University of Wisconsin at Milwaukee, Drs. William Hinze and Larry Braile of Purdue University, and the Illinois State Geological Survey. The University of Wisconsin will be subcontracted by the Illinois State Geological Survey and Purdue University to run the seismic reflection survey. Analog data recorded in the field will be digitized by the University of Wisconsin. The final processing and production of the record section will be done at Purdue University. The geologic interpretation will be made by the Illinois State Geological Survey.

PERSONNEL

In addition to the principal investigator, two other members of the Illinois State Geological Survey staff have been involved directly with this study. Janis D. Treworgy, Special Research Assistant, has gathered subsurface data and helped compile the regional maps. John M. Masters, Assistant Geologist, has been involved with the field and laboratory activities.

REFERENCES

Braile, L. and W. Hinze, 1979, What is the northeastern extent of the New Madrid Fault Zone? South-Central Section, Geol. Soc. Am., Abstr. with Programs 11(2):145.

Hildenbrand, T.G., M.F. Kane, and J.D. Hendricks, 1979, Structural control of Upper Mississippi Embayment seismicity inferred from analysis of aeromagnetic and gravity data. South-Central Section, Geol. Soc. Am., Abstr. with Programs, 11(2):149

Ross, C.A., 1963, Structural framework of southernmost Illinois. Illinois Geol. Surv. Circ. 351, 27 p.

Schwalb, H.R., 1969, Paleozoic geology of the Jackson Purchase Region, Kentucky. Kentucky Geol. Surv., Report of Investigation 10, 40 p.

Weller, J.M., and F.F. Krey, 1939, Preliminary geologic map of the Mississippian formations in the Dongola, Vienna, and Brownfield Quadrangles. Ill. Geol. Surv., Report of Investigations 60, p. 5-11.

Weller, J.M., R.M. Grogan, and F.E. Tippie, 1952, Geology of the fluorspar deposits of Illinois, Illinois Geol. Surv. Bulletin 76, 147 p.

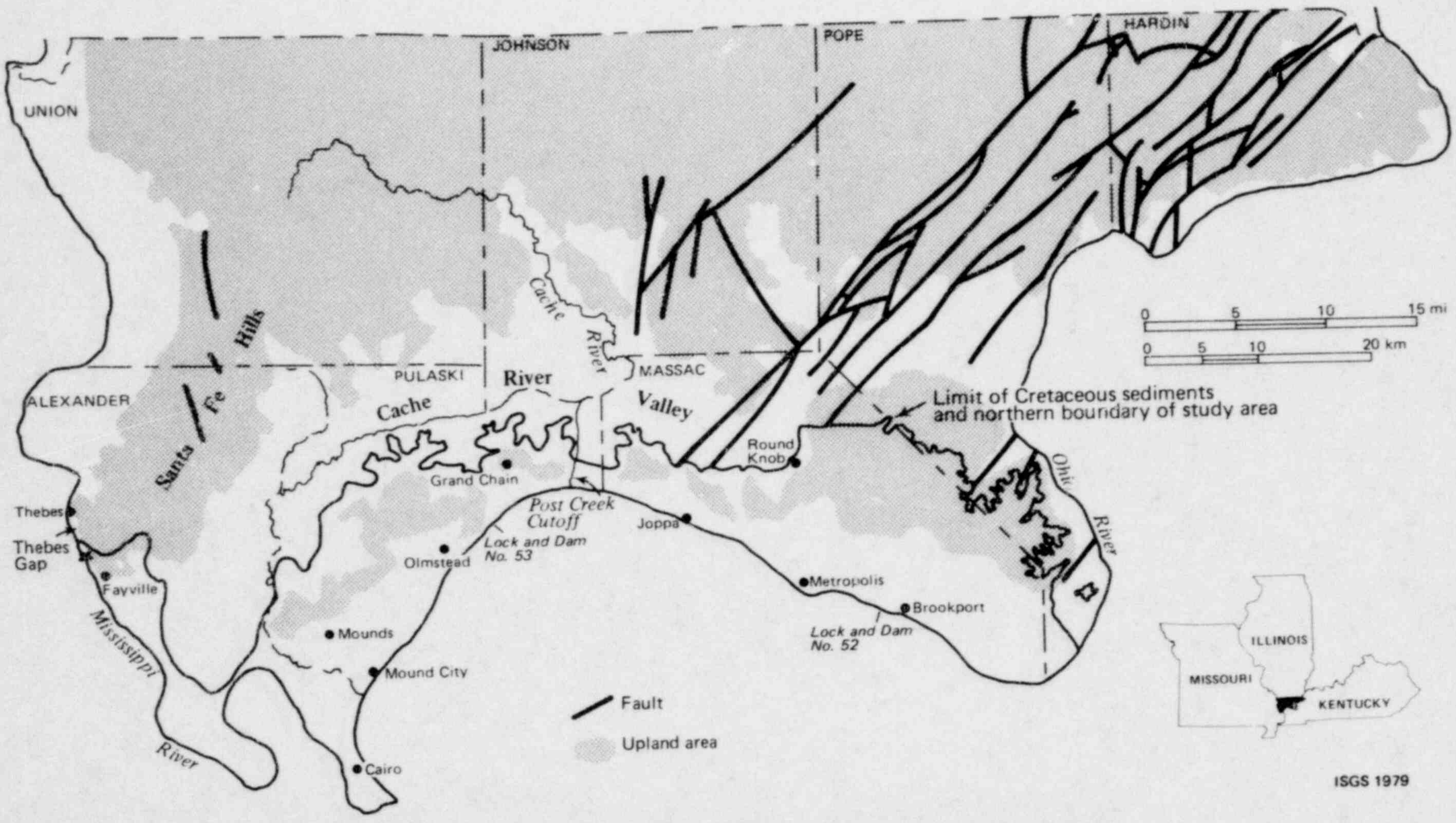


Figure G-1 Study area.

POOR ORIGINAL

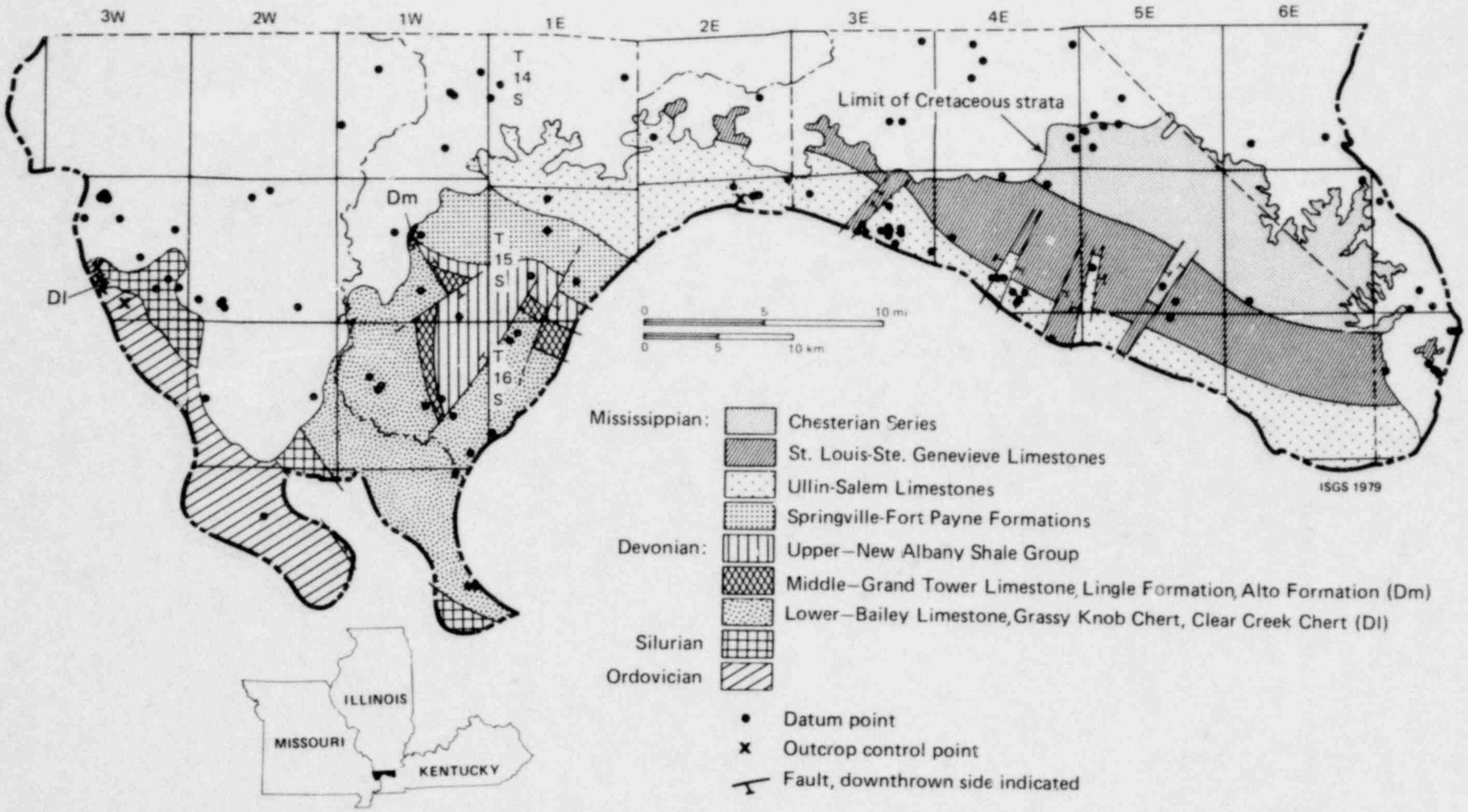


Figure G-2 Sub-Cretaceous geologic map.

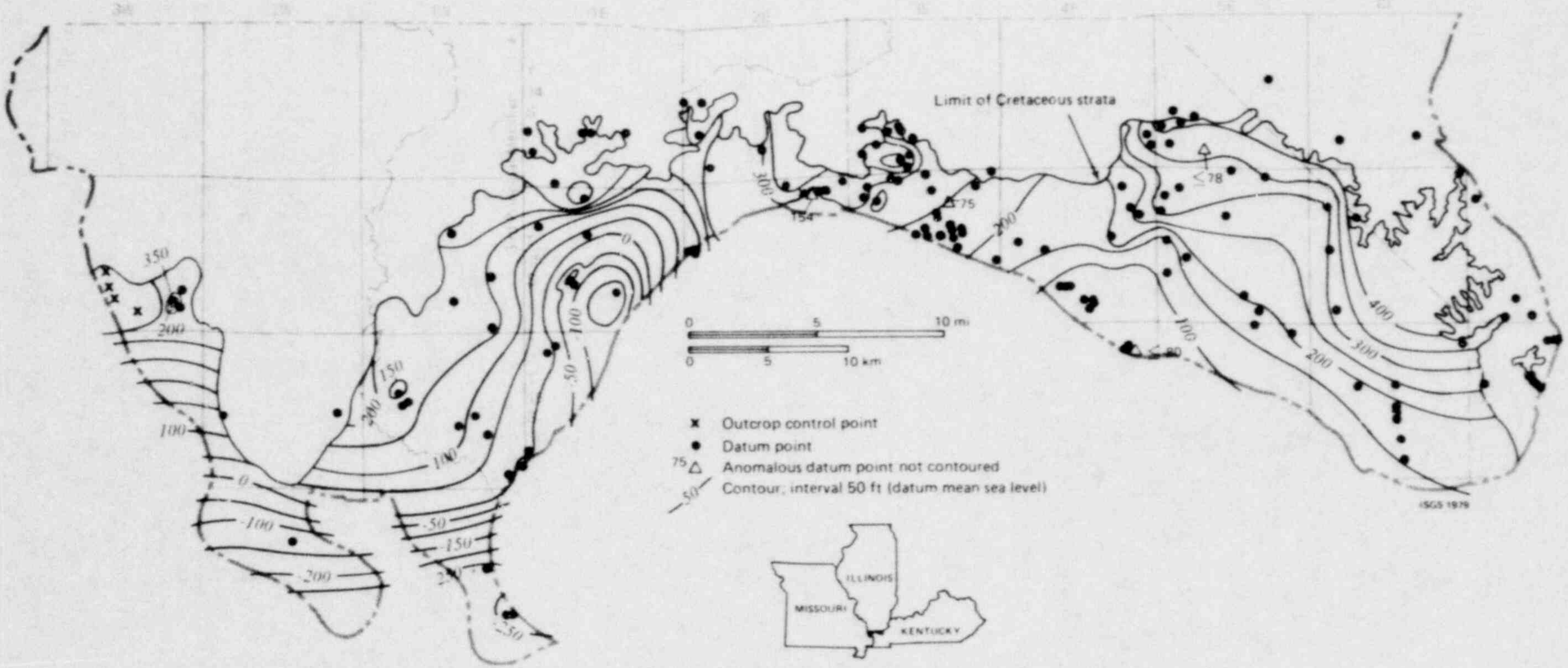


Figure G-3 Configuration of the base of the Cretaceous.

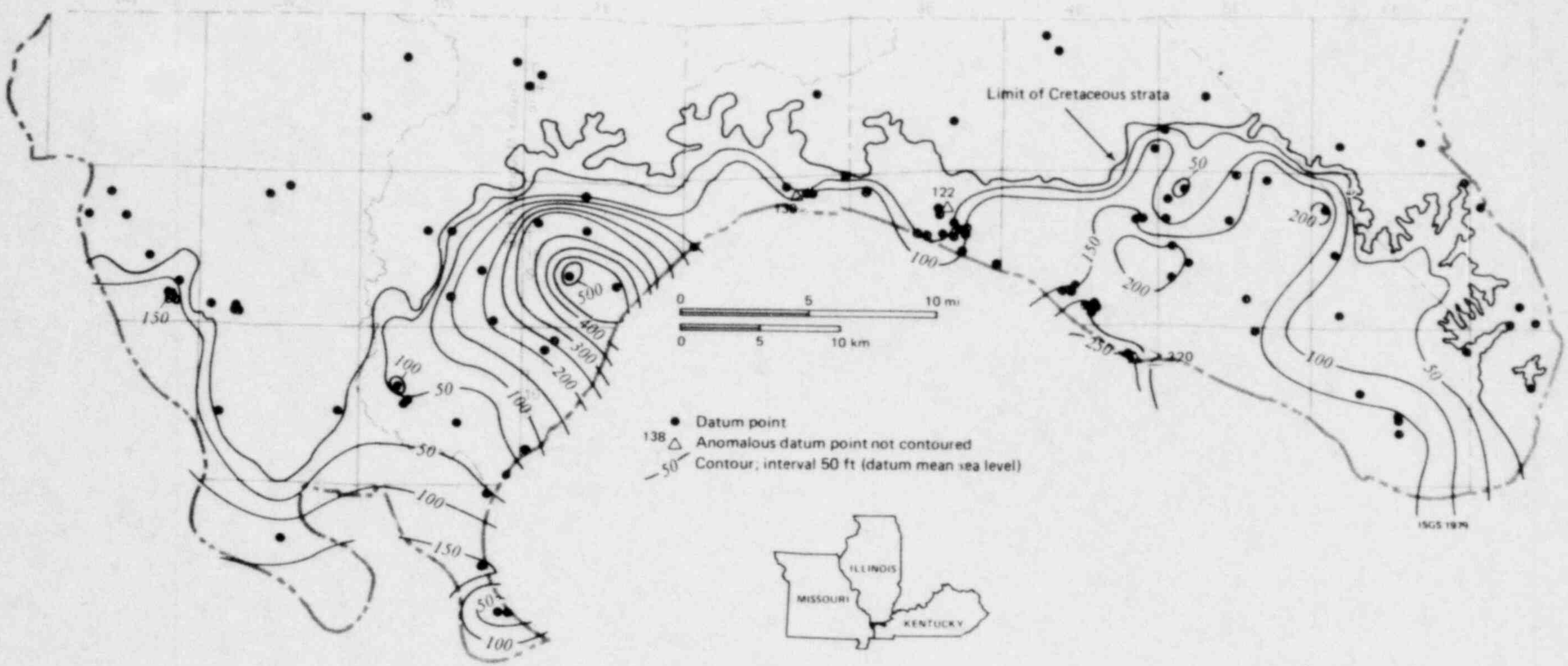


Figure G-4 - Distribution and thickness of the Cretaceous.

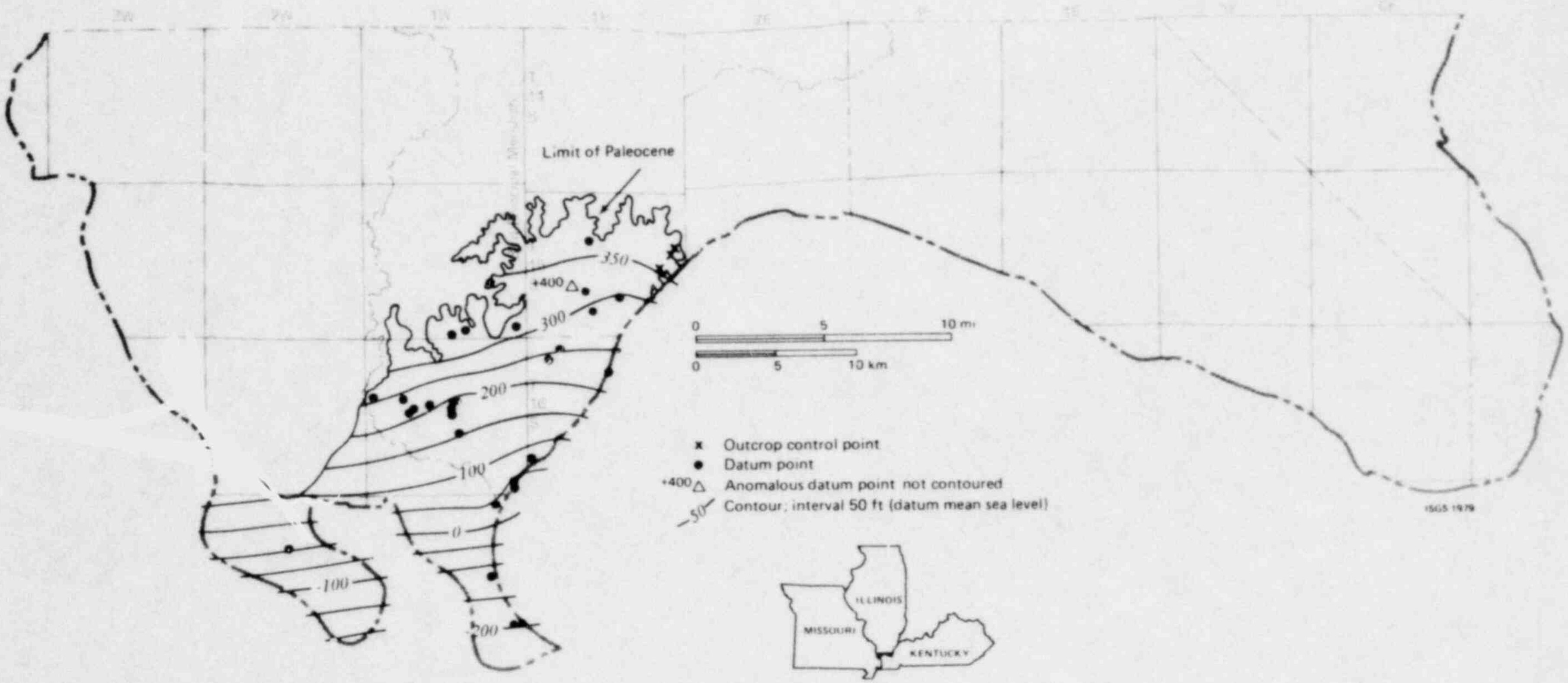


Figure G-5 Structure of the base of the Paleocene Clayton Formation.

GENERAL GEOLOGY, GEOPHYSICS, AND SEISMICITY OF NORTHWEST ALABAMA

Annual Progress Report - Fiscal Year 1979

Contract No. NRC-04-78-262

Jack T. Kidd
Geological Survey of Alabama

ABSTRACT

Data on areal geology, structural features, seismicity, lineaments, fractures, joint orientation, gravity, magnetism, geothermal gradient, radioactivity, and drill holes have been compiled for northwest Alabama. Rocks from Recent to Ordovician in age crop out at the surface in the area. The oldest rocks penetrated in the subsurface are the Cambrian-Ordovician Knox Group. An areal geologic map is being compiled at a scale of 1:250,000. An index to geologic mapping in the study area has been prepared. A map and data table of structural features have been compiled and include 44 faults and 53 folds. Faults occur in rocks as young as Late Cretaceous and possibly as old as Precambrian. Geophysical data available in the area include gravity, magnetic, and geothermal gradient maps. Seismic data compiled include a location map of earthquakes and seismic events in Alabama, a seismic risk map, several intensity and isoseismal maps, and data tables on earthquakes occurring or felt in Alabama. Subsurface data include a location map and data table on significant drill holes in the study area.

SUMMARY

Fiscal year 1979 was the Alabama Survey's first year of participation in the New Madrid seismotectonic study. Objectives of this year's study were to compile the geologic, seismic, and geophysical data available in northwest Alabama. An areal geologic map has been compiled and will be available following modification and final drafting. An index to geologic mapping in the study area was also compiled. The age of surface geologic units in the study area range from Recent to Ordovician. Subsurface information compiled for the study area includes a location map and data table for selected drill holes. The oldest unit penetrated in the subsurface is

the Cambrian-Ordovician Knox Group.

A map and data table of structural features have been compiled which include data on 44 faults and 53 folds. Faults have been mapped in rocks as young as Late Cretaceous and possibly as old as Precambrian. Maps showing joint orientation and lineaments in the study area have been compiled. A joint study in parts of Limestone County indicates two major trends of N. 10-30° W. and N. 60-80° W. Major lineaments in northeast Mississippi and adjacent parts of Tennessee and Alabama, including parts of the study area, are of unknown origin. These lineaments do not appear to reflect faulting as no displacement of beds was observed.

Geophysical data compiled for the study area include gravity maps, a total magnetic intensity map, and a geothermal gradient map. Seismic data compiled include a data table and location map of seismic events in Alabama, a seismic risk map, and several intensity and isoseismal maps. Two earthquakes were reported to have occurred in the study area, one of intensity III (Modified Mercalli) in Colbert County in 1923 and one of intensity VI in Limestone County in 1959.

INTRODUCTION

Fiscal year 1979 was the first year of participation by the Alabama Geological Survey in the New Madrid seismotectonic study. The objectives of this year's study were to compile the geologic, seismic, and geophysical data available in northwest Alabama. The study area includes that part of northwest Alabama lying within a 200-mile radius of the epicenter of the 1811-1812 New Madrid earthquakes. This area of Alabama includes all or parts of the following 10 northwest Alabama counties: Lauderdale, Limestone, Madison, Colbert, Lawrence, Morgan, Franklin, Winston, Marion, and Lamar (fig. H-1).

Data compiled for fiscal year 1979 include maps of areal geology, structural features, seismicity, lineaments, fracture orientation, gravity, magnetism, geothermal gradient, significant drill holes, and radioactivity. Data are being tabulated on earthquakes, structural features, and drill holes. A geologic map index and bibliography are also being compiled.

GENERALIZED GEOLOGY

Rocks in the study area range from Recent alluvium along the rivers and streams to the Cambrian-Ordovician Knox Group penetrated in the subsurface (fig. H-2). Beds generally dip gently to the southwest. The southern part of the study area includes the Warrior Basin of the Cumberland Plateaus province and the onlapping East Gulf Coastal Plain. The northern part of the study area includes the Highland Rim section of the Interior Low Plateaus province. The oldest rocks exposed in the study area are equivalent to the upper part of the Stones River Group. The oldest unit penetrated in the study area is the Cambrian-Ordovician Knox Group. Subsurface data compiled for the study area include a location map (fig. H-3) and data table (table H-1) of selected drill holes. Approximately 25 miles southeast of the study area the Shenandoah Oil Corporation and Occidental Petroleum's F. W. Smith 26-6, No. 1, penetrated the Knox Group and the older Cambrian formations before penetrating the basement complex. The basement complex, consisting of hornblende diorite, was penetrated 7,284 feet below mean sea level (Kidd, 1975).

AREAL GEOLOGY

Numberous geologic maps are available for the study area and a geologic map index has been prepared at a scale of 1;250,000 from selected geologic maps of the study area and will be available following modifications and final drafting. Several problem areas in the geologic map were field checked and modified where appropriate.

STRUCTURAL GEOLOGY

A map of structural features has been compiled showing the faults and folds in the study area. Structural features mapped include 44 faults and 53 folds. The faults include 17 normal, 3 thrust, and 24 unclassified; folds include 17 synclines and 36 anticlines. Several carbonate collapse structures are present in the study area in northwest Alabama but are not included as these appear to be shallow features. Faults have been mapped in rocks as young as Late Cretaceous (Martin, 1965) and possibly as old as Precambrian (Harris, 1975). Data on the structural features in the study area have been compiled listing significant data for each feature.

Data on joint orientation are available for the Athens and Elkmont 7½-minute quadrangles in Limestone County, part of the Phil Campbell and Kinlock Springs quadrangles in Franklin, Marion, and Winston Counties and for four dam sites in western Franklin and northwestern Marion Counties.

The most comprehensive joint study was by Sonderegger and Kelley (1970) of the Athens and Elkmont 7½-minute quadrangles where over 1,300 joints were measured at 95 stations. The two major trends are N. 10-30° W. and N. 60-80° W. The joints were measured in beds of the Fort Payne Chert, Chattanooga Shale, and Ordovician limestones.

A lineament map of the study area has been compiled and reduced to a scale of 1:1,000,000. Some lineaments in Alabama are known to reflect or correspond to faults, fault zones, zones of water movement, joint systems, and mineralized zones (Drahovzal and Copeland, 1970; Powell and LaMoreaux, 1971; and Powell and others, 1970). However, major lineaments in northeast Mississippi and adjacent parts of Alabama and Tennessee were investigated in the field but their origin is still unknown; no displacement of beds was observed (Russell, personal communication, 1979).

GEOPHYSICS

Gravity maps available for the study area include a regional map by Exploration Surveys, Inc. (1962), and detailed county gravity maps by the Geological Survey of Alabama for Limestone, Marion, Lamar, and Winston Counties.

A total magnetic intensity map of the northwestern part of the study area has been published by the Tennessee Valley Authority (1977). This report states that "because rocks of the sedimentary section are relatively nonmagnetic, the close correlation between the observed gravity and magnetic anomalies in the immediate site area would restrict the causitive body to a depth below the base of the sedimentary rocks."

A geothermal gradient map available from the American Association of Petroleum Geologist indicates the geothermal gradient in the study area in northwest Alabama ranges from less than 1.4 degrees Fahrenheit per thousand feet to greater than 1.6. South of the study area in Walker, Fayette, and Tuscaloosa Counties, Alabama, the geothermal gradient ranges from less than 1.3 to greater than 1.8.

SEISMICITY

Drahovzal and Keener (1976) reported 22 seismic events in Alabama from 1866 to 1975 at 22 locations (table H-2). Stover and other (1979) reported 44 seismic events in this period at 19 locations. Since 1975, one earthquake has been reported in Alabama.

Seismic data compiled include: location map of earthquakes and seismic events (fig. H-4), seismic risk map of Alabama, numerous intensity and isoseismal maps, table of earthquakes occurring in Alabama, and table of earthquakes felt in Alabama with epicenters outside the state.

REFERENCES

American Association of Petroleum Geologists, (undated), Geothermal Gradient of North America, geothermal gradient of Alabama-Mississippi: Am. Assoc. Petroleum Geologists Portfolio map, area no. 4.

Drahovzal, J.A., and Copeland, C.W., 1970, Geologic and hydrologic interpretation of multispectral Apollo 9 space photographs in Alabama (abs.): Geol. Soc. America Abs. with Programs, v. 2, no. 3, p. 206.

Drahovzal, J.A., and Keener, M.J., 1976, Earthquakes in Alabama: Alabama Geol. Survey open-file rept., 134 p.

Exploration Surveys, Inc., 1962, Regional gravity map of Alabama, modified by G.W. Wilson: Alabama Geol. Survey open-file map.

Harris, L.D., 1975, Oil and gas data from the Lower Ordovician and Cambrian rocks of the Appalachian basin: U.S. Geol. Survey Map 1-917-D.

Kidd, J.T., 1975, Pre-Mississippian subsurface stratigraphy of the Warrior basin in Alabama: Gulf Coast Assoc. Geol. Socs. Trans., v. 25, p. 20-39.

Martin, R.G., Jr., 1965, Geology of a portion of Franklin, Marion, and Winston Counties, Alabama: Univ. Tennessee unpublished M.S. thesis, 62 p.

Powell, W.J., Copeland, C.W., and Drahovzal, J.A., 1970, Geologic and hydrologic research through space-acquired data for Alabama: Alabama Geol. Survey Inf. Ser. 41, 37 p.

Powell, W.J., and LaMoreaux, P.E., 1971, Apollo 9 photography reveals geologic structures controlling ground-water movement and reservoir leakage in Alabama: Alabama Geol. Survey open-file rept., 9 p.

Sonderegger, J.L., and Kelly, J.C., 1970, Hydrology of limestone terranes, geologic investigations: Alabmama Geol. Survey Bull. 94-B, 146 p.

Stover, C.W., Reagor, B.G., and Algermissen, S.T., 1979, Seismicity map of the state of Alabama: U.S. Geol. Survey Misc. Field Studies Map MF-1059.

Tennessee Valley Authority, 1977, Yellow Creek nuclear plant preliminary safety analysis report, appendix A, early site review report: 71 p.

State Oil and Gas Board Permit No.	Well name	Operator	Location (section, township, range)	County	Elevation[1]	Total depth, feet	Tuscaloosa Group[2]	Pottsville Formation	Parkwood Formation	Bangor Limestone	Floyd Shale	Hartselle Sandstone	Pride Mt. Formation	Tuscumbia Limestone	Fort Payne Chert	Chattanooga Shale	Devonian undifferentiated	Devonian - Silurian undifferentiated	Silurian undifferentiated	Richmond, Maysville, Eden and Nashville Groups undifferentiated	Stones River Group undifferentiated	Knox Group undifferentiated
1714	E. R. and H. B. Abramson No. 1	Bison Oil Company	14 - 1S - 12W	Lauderdale	640 G.L.	3434								S ?	?	300		320	370	530	790	1490
885	G. C. Bridges No. 1	G. W. Jones and Sons	10 - 2S - 3W	Limestone	867 D. F.	2506									S	38				47	315	1050
12	Baldridge No. 1	F. F. Mellen	8 - 1S - 1E	Madison	730 D. F.	1172													S	25	350	1153
576	Mrs. Frances Thomas No. 1	Edward T. Merry	31 - 5S - 13W	Colbert	665 D. F.	1978						S	140	400	595	783			805	1070	1310	1949
21	Conners Well No. G - 130	Reynolds Metals Co.	17 - 5S - 8W	Lawrence	620 D. F.	4500						S	?	252	481	651			667	770	1065	1872
B-264	English No. 1	Albany-Decatur Oil & Gas Co.	6 - 6S - 4W	Morgan	547 D. F.	4130								S	?	350			372	410	?	1790
2051	G. Pierce Webber No.1	Shenandoah Oil Corp.	35 - 8S - 15W	Franklin	692 D. F.	4000	S		?	?	?	919	?	1264	1400	1520	1540		1602	2003	2119	2617
408	Arthur Ritch No. 1	Harry L. Cullet	27 - 11S - 14W	Marion	403 D. F.	4710	S ?	100	460	1040	1435			1830	1995	2047	2051		2203	2561	2605	3215
2284	Bachelor 32 - 14 No. 1	Energy Explorations Inc.	32 - 9S - 10W	Winston	920 D. F.	3218	S ?	?	?	?	?	1315	1646	1700	?	1941			1971	2262	2501	3116
432A	W. L. and F. Ogden No. 1	W. T. Durant	6 - 14S - 15W	Lamar	378 D. F.	4425	S	412	1512		2391			2975	3000	3085	3089		3521 ?	3733 ?	3743 ?	4213

[1]D. F. - Derrick floor; G. L. - Ground level.

[2]S. - Surface; depths shown indicate top of unit.

Table H-1.-Subsurface data from selected wells in northwest Alabama.

No.[1]	Date - Time[2]	Location	Intensity[3] and/or magnitude	Depth	Area
1	Feb. 4, 1886 20:00	Valley Head (34.6N., 85.6 W.)	III		
2	Feb. 5, 1886 07:00 - 08:00	Linden - Jefferson (32.3N., 87.8W.)	III		
3	Feb. 13, 1886 Daybreak	Tombigbee River (32.3N., 87.9W.)	V		
4	Jan. 27, 1905 22:10	Tumlin Gap (34.0N., 86.2W.)	Dynamite blast		
5	Oct. 18, 1916 16:04	Central Alabama (33.5N., 86.5W.)	VII		100,000 mi^2 (259,000 km^2)
6	June 29, 1917 20:23, 20:50	Rosemary (32.7N., 87.5W.)	IV ?		
7	Oct. 28, 1923 11:15	Riverton (34.9N., 88.1W.) (Actual epicenter at Marked Tree, Ark.)	III		
8	June 16, 1927 07:00	Scottsboro (34.7N., 86.0W.)	IV		2,000 mi^2 (5,180 km^2)
9	June 13, 1929 08:44	Mobile (30.7 N., 88.0W.)	I - II		
10	Dec. 1, 1930 09:10 - 09:45	Bessemer (30.4N., 87.0W.)	Possibly not seismic		
11	May 5, 1931 06:18	North Alabama (33.7N., 86.6W.)	V		6,500 mi^2 (16,800 km^2)
12	May 4, 1939 20:45	Anniston (33.7N., 85.8W.)	V		
13	June 24, 1939 04:27	Huntsville (34.7N., 86.6W.)	IV		500 mi^2 (1,300 km^2)
14	Feb. 6, 1952 10:12	Birmingham (33.5N., 86.8W.)	Dynamite blast		50 mi^2 (130 km^2)
15	April 23, 1957 03:23:39	North Alabama (34.5N., 86.8W.)	VI		11,500 mi^2 (29,700 km^2)
16	Aug. 12, 1959 13:06:07	Alabama - Tennessee (35.0N., 87.0W.)	VI		2,800 mi^2 (7,250 km^2)
17	Feb. 18, 1964 03:31:12	Alabama - Georgia (34.5N., 85.5W.)	IV	9 mi (15 km)	
18	Mar. 14, 1971 11:27:52	Carrollton (33.1N., 87.9W.)	I - II (3.9)	0.6 mi (1 km)	
19	Dec. 10, 1974 00:01:03	Huxford (32.35N., 87.47W.)	V (3)	6.2 mi (10 km)	
20	Mar. 1, 1975 05:50:01	Kennedy (33.55N., 87.99W.)	II (3.4)	11 mi (18 km)	
21	June 24, 1975 05:11:36	Fayette (33.7N., 87.8W.)	IV (4.5)	6.2 mi (10 km)	
22	Aug. 28, 1975 22:22:52	Cedar Springs (33.89N., 86.61W.)	VI (4.4)	6.2 mi (10 km)	27,000 mi^2 (70,000 km^2)
23	May 4, 1977 2:00:23	Eiler (31.98N., 88.42W.)	V	3.1 mi (5 km)	

[1]Number refers to location on figure.

[2]Central standard time.

[3]Intensity - Modified Mercalli Scale of 1931 shown by Roman numerals; Magnitude - Richter magnitude shown by Arabic numbers.

Table H-2.-Earthquakes of Alabama 1886-1978 (modified from Drahovzal and Keener, 1976).

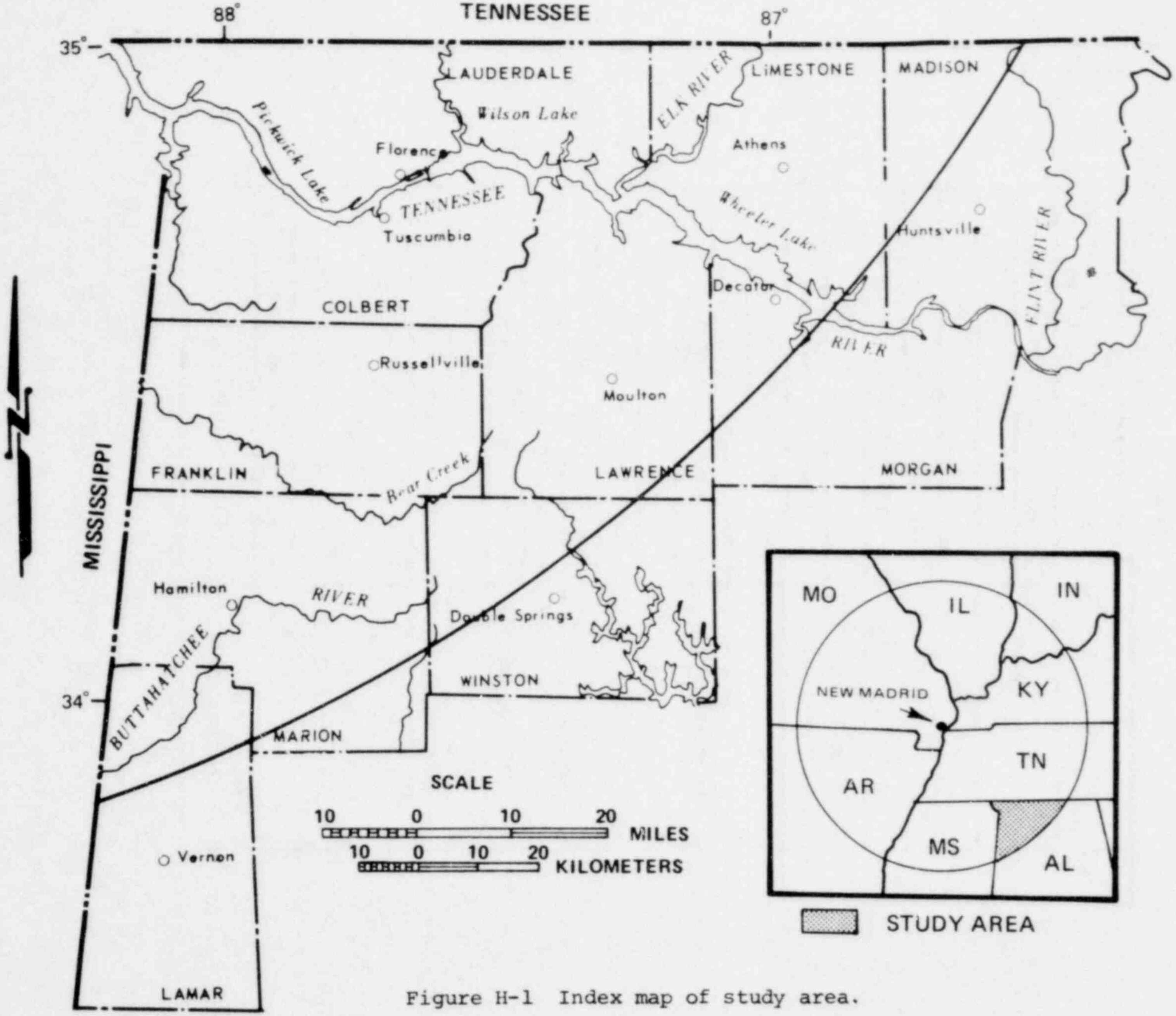


Figure H-1 Index map of study area.

SYSTEM	UNIT	
QUATERNARY	ALLUVIAL AND LOW TERRACE DEPOSITS	
	HIGH TERRACE DEPOSITS	
CRETACEOUS	EUTAW FORMATION	
	TUSCALOOSA GROUP	GORDO FORMATION
		COKER FORMATION
PENNSYLVANIAN	POTTSVILLE FORMATION	
?—?—?	PARKWOOD FORMATION	
MISSISSIPPIAN	BANGOR LIMESTONE	
	FLOYD SHALE	HARTSELLE SANDSTONE
		PRIDE MOUNTAIN FORMATION
	TUSCUMBIA LIMESTONE	
	FORT PAYNE CHERT	
	MAURY FORMATION	
DEVONIAN	CHATTANOOGA SHALE	
	ROSS FORMATION	
	DEVONIAN UNDIFFERENTIATED	
SILURIAN	SILURIAN UNDIFFERENTIATED	
ORDOVICIAN	RICHMOND, MAYSVILLE, EDEN AND NASHVILLE GROUPS UNDIFFERENTIATED	
	STONES RIVER GROUP UNDIFFERENTIATED	
?—?—? CAMBRIAN	KNOX GROUP UNDIFFERENTIATED	

Figure H-2 Geologic units in the study area.

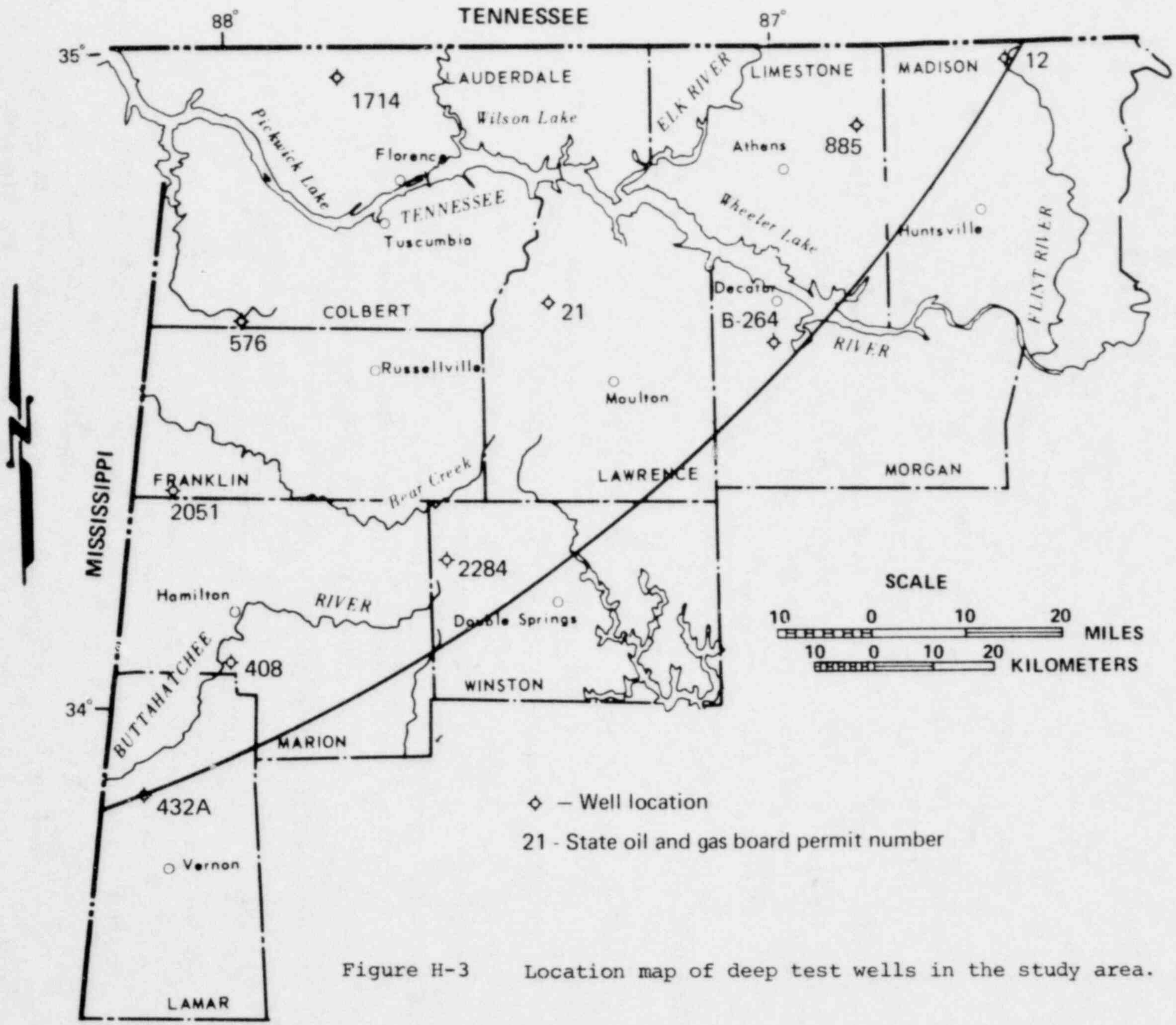


Figure H-3 Location map of deep test wells in the study area.

Figure H-4--**Location of earthquakes and other seismic events in Alabama. Roman numerals refer to modified Mercalli scale intensities. Arabic numbers refer to event number** (Table H-2) **(Modified from Drahovzal and Keener, 1976).**

MEMPHIS AREA REGIONAL SEISMIC NETWORK

Annual Progress Report - Fiscal Year 1979

Contract No. NRC-04-78-200

James E. Zollweg
Arch C. Johnston
Tennessee Earthquake Information Center
Memphis State University

NETWORK INSTALLATION

The six-station Memphis Area Regional Seismic Network (MARSN) is designed to detect and accurately locate microearthquakes in the quiescent region of the Mississippi Embayment between the apparent southern end of the New Madrid Seismic Zone (at latitude 35.5° North) and the east-west trending Ouachita Front, which cuts across the Embayment at about 34° North latitude. Figure I-1 displays the MARSN as well as many other existing and planned stations in the region. Due to numerous problems encountered with the original choice of seismometers and amplifier/VCO units, the installation of the telemetry stations of the MARSN only began in July, 1979. A Geotech Portacorder has been operated near the WLA site intermittently since September, 1978.

Station sites were chosen with several factors in mind. The overriding concern was to provide reasonably good areal coverage with the small number of stations being installed. Within this constraint, availability of clear telemetry shots into Memphis was important. Finally, the probable background noise level due to both cultural and geological factors was considered. The noise level at each potential site was monitored with a Sprengnether MEQ-800 portable siesmograph, and the final choices were based on comparison of these background levels.

The extreme eastern and western stations were chosen to be on hard Paleozoic rock. The PWLA site, while a difficult telemetry problem, is exceptionally quiet and the 10 Hz gain on a Develocorder screen should be in the neighborhood of 5 million. OLY, while not as quiet, is still a good site and should operate at a gain of about 2 million at 10 Hz. The remaining stations are all located on unconsolidated Tertiary or Quaternary sediments. LGAR is the best of the sites, being located in the St. Francis National

Forest more than 5 kilometers from the nearest human habitation. It is expected to operate at about 500K at 10 Hz. PGM and WLA are much worse sites, in spite of having been located in remote areas that are nearly free of nearby cultural activity. Both will operate at 10 Hz gains between 100 and 250K. SFTN is located in a borehole 468 feet below the surface. It has not yet been calibrated so the gain level is not known at present.

Each station except SFTN consists of a single critically-damped vertical 1 Hz SS-1 "Ranger" seismometer, an amp/VCO, and an RF transmitter powered by batteries or solar cells. For stations in the unconsolidated sediments, the seismometer is buried in a small concrete-and-sewer-tile vault about 2 to 3 meters below the surface. LGAR and WLA are repeater sites for PGM and OLY, respectively. The central receiving site is a tall building in Memphis, at which the data channels are multiplexed and put on a phone line for the 6 mile trip to the recording site at Memphis State. There the signal is discriminated and the individual channels recorded on pen-and-ink systems and/or a Develocorder. SFTN uses a Mark Products L-15 borehole package consisting of three orthogonal 8 Hz geophones. It is transmitted and recorded in the same manner as the other stations.

Some elements of a portable telemetry net were acquired during the year. When this net is completed, it will be used for monitoring swarm and aftershock sequences and for special studies. It should be operational some time in 1980.

Other stations in the New Madrid study group region are being installed or partially supported by the TEIC. The TEIC central station in Memphis is MPH, and a back-up station is located in the old MET vault about 0.3 kilometer away. The OXF World-Wide Standard station will be reactivated in 1979 or 1980. A telemetry station will be established in 1979 near Covington, Tennessee. The TEIC has provided some equipment to the University of Tennessee at Martin for installation of two stations near there, UTM and MRT. Finally, a dense eight-station net is being established near Ridgely in northwest Tennessee.

EARTHQUAKE STUDIES

Two very unusual clustered sequences were investigated by the TEIC using portable seismographs. The first began near Ridgely, Tennessee on 2 February 1979, and over the next three days over 150 earthquakes of

$-1 \leq mb \leq 2.7$ were recorded at Saint Louis University's GRT station. About ten were felt; maximum intensity was III M. M. The TEIC fielded an MEQ-800 and a Geotech Portacorder within 4 kilometers of the epicenters during a sleet storm late in the evening of 2 February. The location of these stations as well as a later site for the Portacorder are shown in Figure I-2. Unfortunately, both units malfunctioned. Usable arrival time data was obtained for about 35 quakes, but both stations were fully operational for only two events. For about 10 additional events an S-P interval could be read at LEEP while P and S could be times at SHAW. No events were recorded at LEMO. The Portacorder suffered terminal failure after about 30 hours of recording at LEMO and has been returned to the manufacturer. The quality of the records it produced at SHAW was exceptionally poor owing to frequent electronics glitches. The MEQ-800 failure was due to a run-down battery and the instrument was made operational again with a trickle charger. It remained at LEEP until 27 February, when it failed after the internal batteries again ran down. The trickle charger had apparently been damaged by a lightning-induced transient during a storm on 23 February. The two portable instruments deployed were the only ones available to the TEIC, since our other Portacorder was being used at WLA as a fixed station.

Most of the events recorded by the temporary stations were also recorded at GRT, but only two or three of the largest were recorded at more distant stations. For these events, amplitudes at the temporary stations were too large to read S or S-P intervals, and times for P were only available at SHAW. Therefore, details of the location and progression of the swarm have been lost. S-P intervals at LEEP ranged from 0.6 to 0.85 second and three general types of event could be distinguished on the basis of S to P amplitude ratios. S-P intervals at SHAW and GRT were less variant: 0.5 to 0.65 second at SHAW and 0.7 to 0.9 second at GRT. These meager data are suggestive of a focal region slightly northwest of SHAW. The range of possible focal depths is about 2 to 6 kilometers; the upper two kilometers consist of unconsolidated sediments lacking sufficient rigidity to generate earthquakes.

The second sequence began on 27 February 1979 near Strawberry, Arkansas. Figure I-3 shows the approximate locations of Ridgely and Strawberry. The Strawberry sequence consisted of several foreshocks with $m_b \leq 2.5$, two $m_b = 3.4$ shocks about 18 seconds apart, and about thirty aftershocks. The last event recorded was on 3 March.

The TEIC MEQ-800 was still at Ridgely and the Portacorder used there had been shipped back to Geotech, where it remains. Therefore, we decided to pull out the WLA Portacorder and use it to monitor the aftershock activity. This was done and the instrument was installed in a snow drift in an abandoned quarry near Black Rock about 2 A.M. local time on 28 February, 9 hours after the occurrence of the largest events. Five aftershocks, the largest with m_b about 2¼, were recorded in the next 14 hours, but the microprocessor controlling the Portacorder's internal clock failed after ten hours of recording and after that there were no more time marks. The Portacorder was pulled out and the long trip made to Ridgely to fetch the MEQ-800. It, too was in need of repairs due to a lightning-induced transient on 23 February. Nevertheless, we got it installed at Strawberry on 2 March and it recorded two more aftershocks on 3 March. Repairs were made to the Portacorder, but it failed again upon installation near Strawberry on 4 March. It was returned to Geotech and remains there today. The MEQ-800 was moved to Lake Charles State Park late on 4 February, but nothing was recorded there and the instrument was removed about 36 hours later.

Since none of the aftershocks was recorded at more than one temporary station, detailed locations for individual events are uncertain. This is a problem, since the events are located outside Saint Louis University's net and azimuthal control on all events was very poor, with a minimum gap of about 220° for even the best-recorded shocks. Saint Louis University's Powhatan station was located within 30 kilometers of the cluster and its records showed two types of events based on S to P amplitude ratios. The S-P intervals only ranged from about 2.8 to 3.2 seconds, though, and perhaps 0.2 second of this variance seems to be due to normal reading scatter. It was therefore decided to make up fictitious readings from the temporary stations for the main shock, based on their relative times with respect to POW for the aftershocks. This, of course, assumes that all the events occurred in the same place. The resultant location was consistent with all data, though, and is probably accurate to ± 2 kilometers. It is shown in Figure I-4 along with the temporary station locations. We had chosen BRQA for a station based on high intensity reports (V+) for the Black Rock-Powhatan area; it later developed that an area about 55 kilometers long had experienced intensity IV - V effects. The depth of focus obtained for the main shock using the fictitious readings made up from the temporary stations were 13 kilometers; it seems reasonable as careful inquiry failed to locate anyone in the epicentral region who had felt any of the foreshocks or aftershocks, although some had magnitudes of nearly 3.

It is interesting to compare the tectonic settings of the two sequences. The Ridgely swarm occurred in perhaps the most active area of the New Madrid Seismic Zone. Two of the major seismicity trends of the zone intersect nearly at right angles close to Ridgely. Swarms have been noted there before, although none with so many events as the 2 to 5 February cluster.

The Strawberry sequence occurred at the physiographic boundary between the Ozark Uplift and the Mississippi Embayment. The boundary is marked by an abrupt change in elevation as one reaches the Paleozoic rocks of the Uplift and has been interpreted by some as a fault. However, very few earthquakes are known to have occurred along the Escarpment either in historical times or since the installation of sensitive seismographs in the central U.S. A major sequence at Ridgely is but little surprise, but one at Strawberry was completely unexpected.

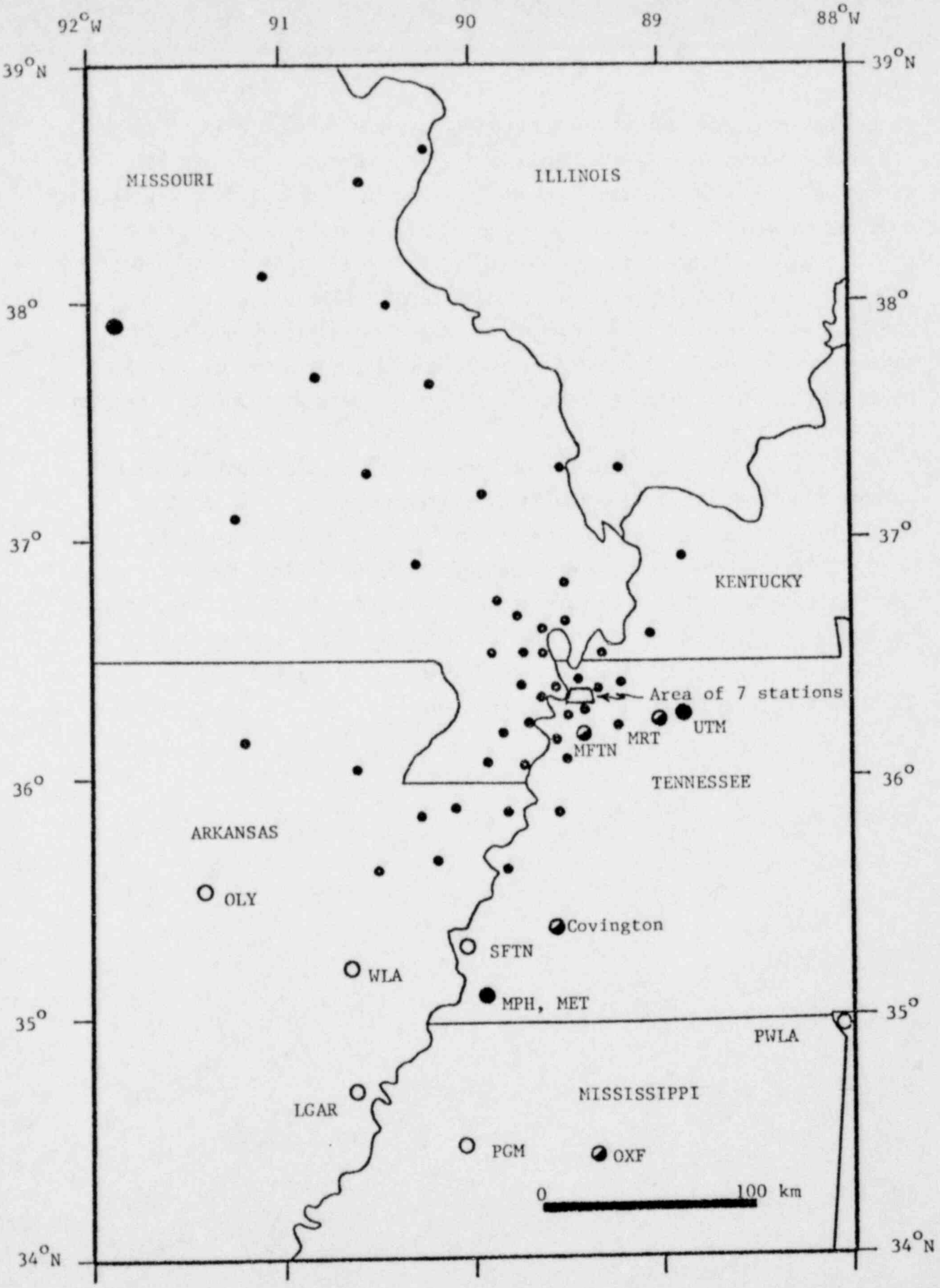


FIGURE I-1 LOWER MISSISSIPPI VALLEY REGIONAL SEISMOGRAPH STATION NETWORK (7/79)

○ MARSN STATION • ST. LOUIS U. STATION ● OTHER REGIONAL STATION

◐ PLANNED TEIC STATION

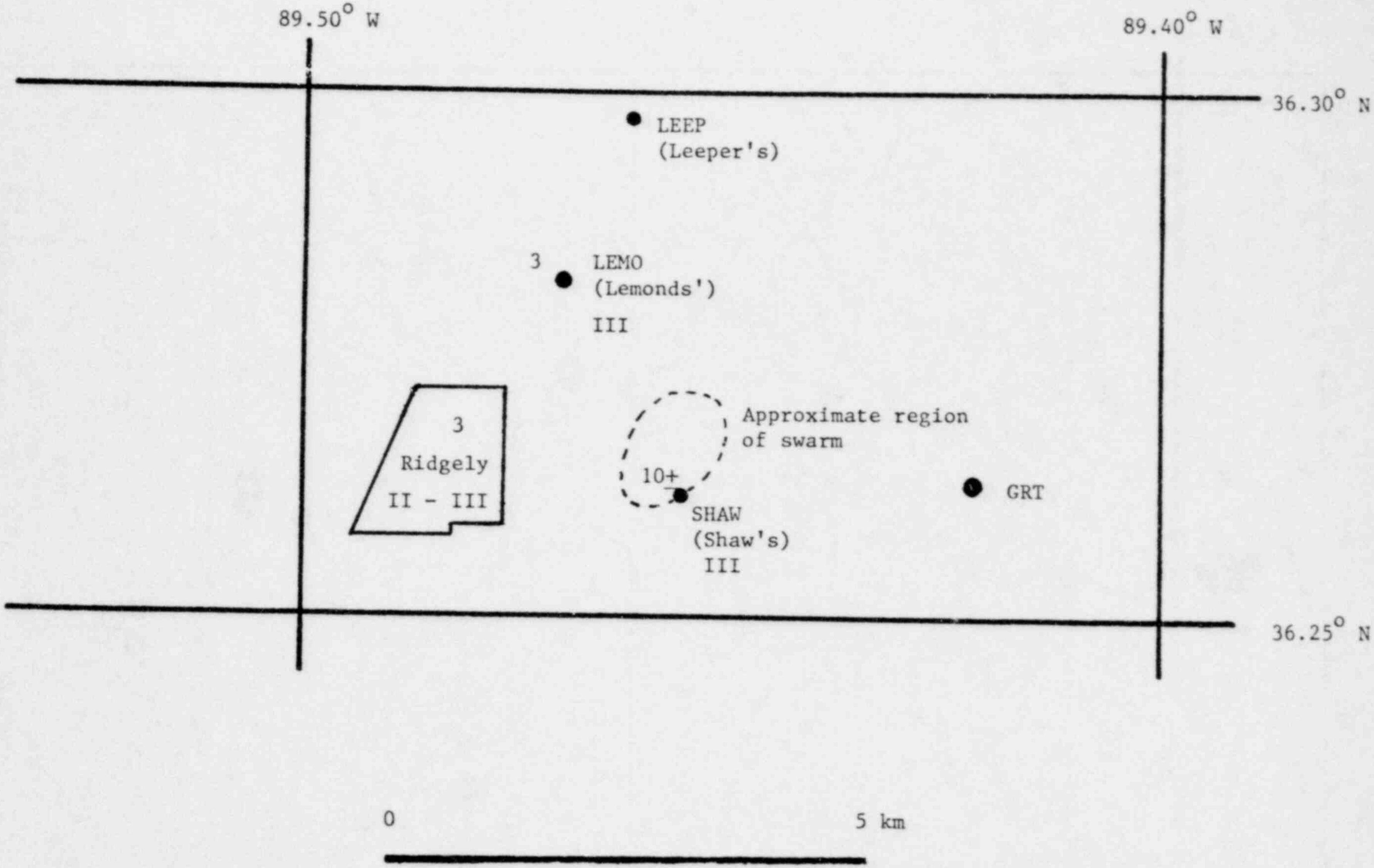


FIGURE I-2 LOCATION MAP OF RIDGELY SWARM OF 2 - 5 FEBRUARY 1979, SHOWING TEMPORARY STATIONS. Roman numerals indicate maximum observed modified Mercalli intensities for largest events. Arabic numerals indicate number of shocks felt on 2 and 3 February.

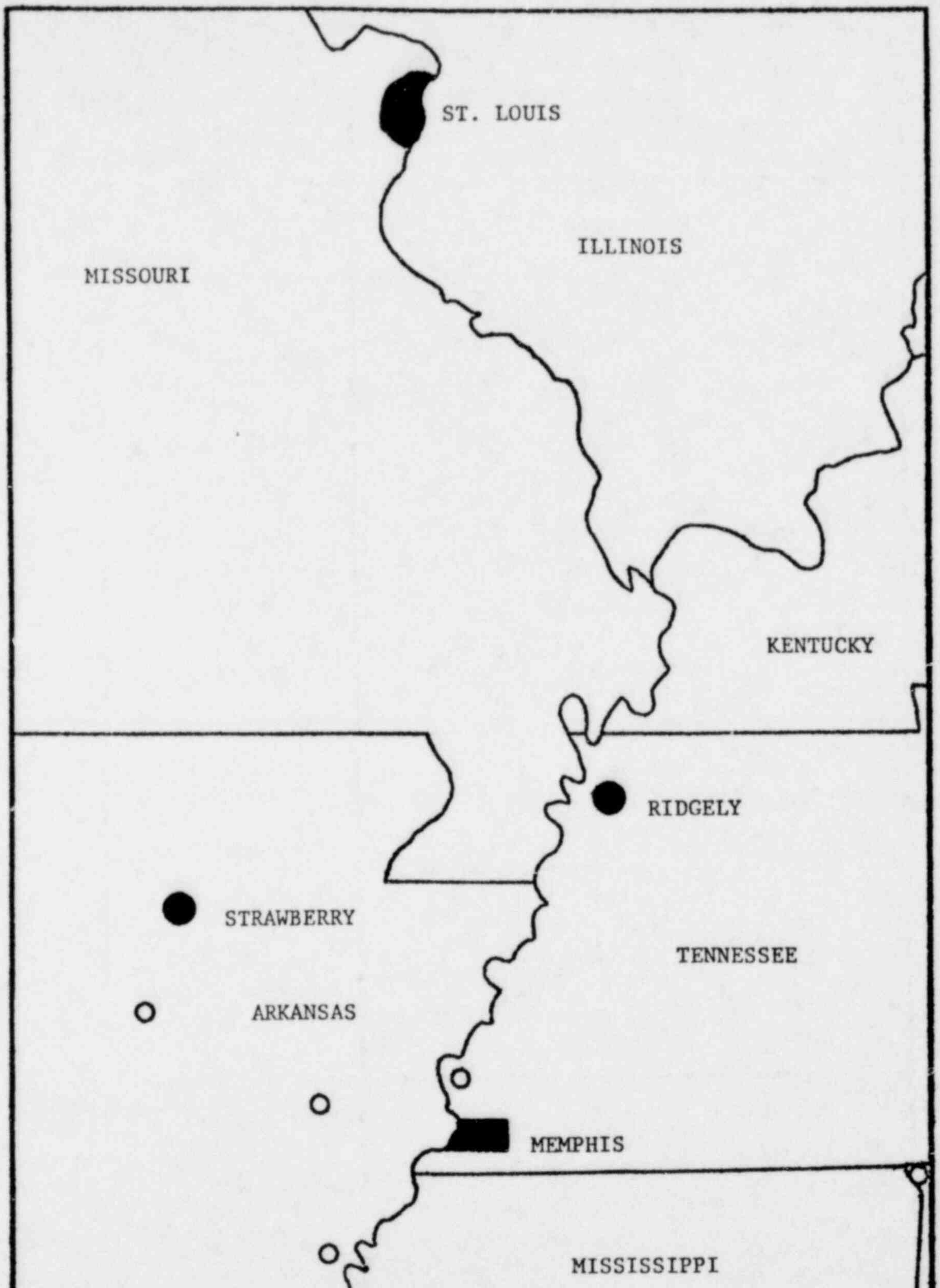


FIGURE I-3 LOCATIONS OF RIDGELY, STRAWBERRY ○ MARSN STATION

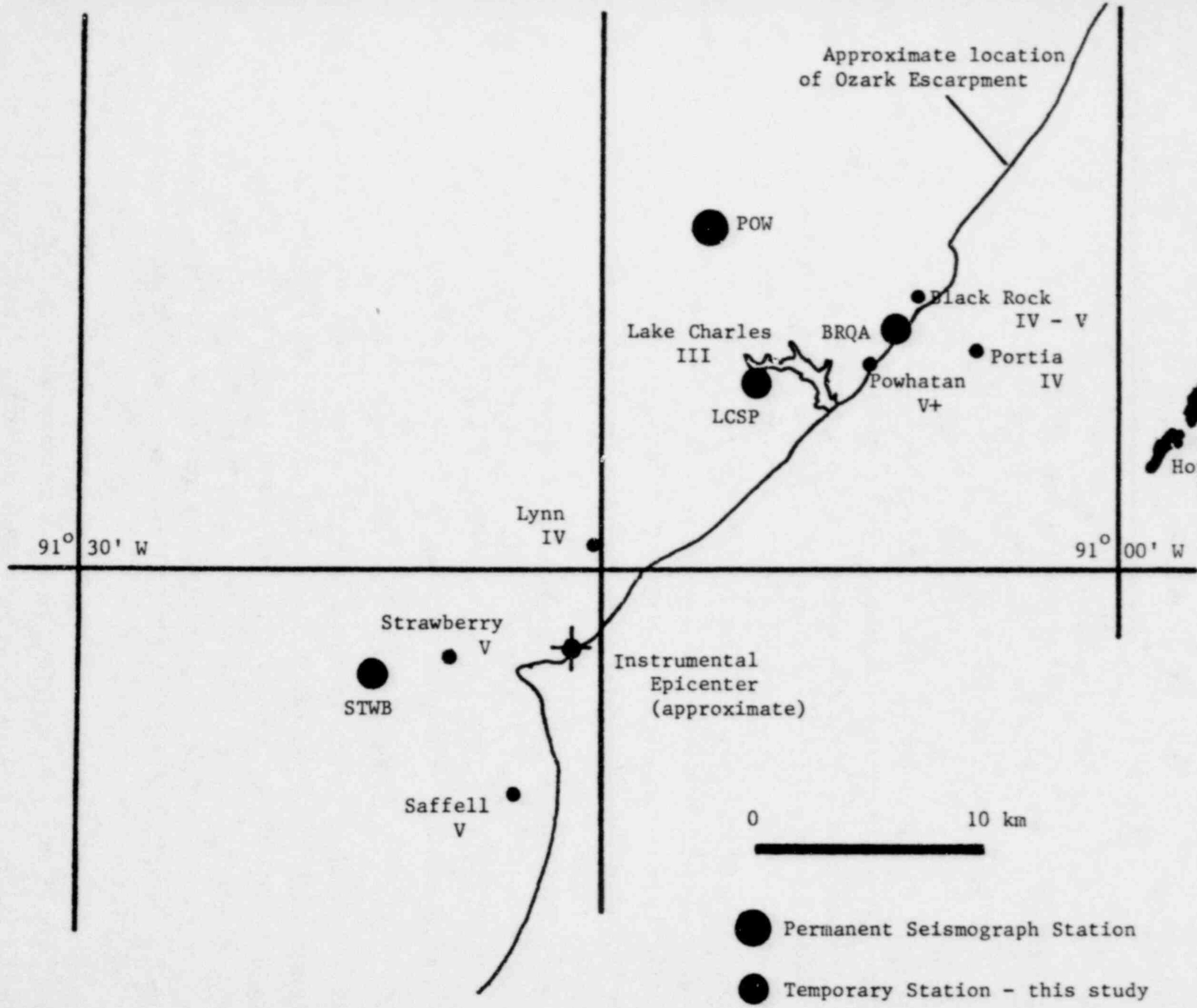


FIGURE I-4 LOCATION MAP OF STRAWBERRY EARTHQUAKE SEQUENCE, 27 FEBRUARY - 03 MARCH 1979

A SEISMOLOGICAL STUDY OF THE NORTHERN EXTENT OF THE NEW MADRID SEISMIC ZONE

Annual Progress Report - Fiscal Year 1979

Contract No. NRC-04-76-282

Robert B. Herrmann
Saint Louis University

ABSTRACT

The seismological study of the northern extent of the New Madrid Seismic Zone is part of a coordinated study of the nature of earthquakes of the New Madrid Seismic Zone and neighboring areas. Primary effort is directed toward the location of earthquakes as recorded by a twenty-four element regional seismic network. During 1978, 632 earthquakes were detected with the array, of which 244 were located. Most occurred in the previously defined high seismicity zone near New Madrid, MO. Many of the Wabash Valley earthquakes were characterized by focal depths greater than 16 km, which make them some of the deepest earthquakes observed in the eastern United States.

Estimation of source parameters of larger earthquakes continues, with the determination of focal mechanism parameters for the June 16, 1978 Snyder, Texas (m_b = 4.7) and the January 23, 1966 Dulce, New Mexico (m_b = 5.4) earthquakes. Both earthquakes were shallow with focal depths of 3 km.

INTRODUCTION, PURPOSE, AND PREVIOUS WORK

This research was funded in 1976 for the purpose of monitoring seismic activity in the Wabash River Valley of southern Illinois and Indiana. To accomplish this an eight station telemetered seismograph array was designed and installed in early 1978. Due to the large aperture of the array and to topography, a complete land-line telemetry system was installed. Equipment has been obtained to add an additional eight seismograph stations near New Madrid, Missouri.

This research has as its primary purpose the operation of and analysis of data from a sixteen element microearthquake array in the New Madrid Seismic Zone in order to understand the nature of and geographical limits of earthquakes within the zone. It is the nature of the research that much time be spent in the routine, even boring, task of keeping the array functional and of reading seismograms in order to locate earthquakes. As time goes on and the data base grows, important questions as to the location of future large earthquakes may be resolved.

Another aspect of this research effort is the determination of source parameters of larger earthquakes occurring east of the continental divide through detailed, sophisticated analysis of surface wave and body wave generation by these earthquakes. The techniques used seem to be the only ones which can determine focal mechanisms and focal depths for many of the eastern United States earthquakes. Since the frequency of usable earthquakes is at most one or two a year, it is important that these be studied thoroughly so that as much as possible is learned about eastern earthquakes.

CENTRAL MISSISSIPPI VALLEY EARTHQUAKES - 1978

During 1978, 632 earthquakes were detected by the twenty-four station joint NRC and USGS sponsored Saint Louis University regional seismograph array. Of these earthquakes, 244 were located. Figure J-1 shows the earthquakes located within a $4^\circ \times 4^\circ$ region centered on 37.0° N. and 89.5° W. Seismograph station locations are indicated by the triangles, with the station code adjacent to the symbol. The magnitudes are indicated by the size of the open circles. It is seen that most of the epicenters lie in a well defined linear segment near the Missouri bootheel.

An enlargement of the seismically active area is given in Figure J-2, which shows the locations and magnitudes of 210 earthquakes located within a $1.5^\circ \times 1.5^\circ$ region centered at 36.25° N. and 89.75° W. The linear trends first noted by Stauder et al. (1976) are readily apparent and continue to be active. The present seismograph distribution within this $1.5^\circ \times 1.5^\circ$ region has station separations on the order of 40 km. This large aperture is not very amenable for accurate depth determination or for uniform detection of small earthquakes. This situation is being altered by the addition of twenty-four additional seismograph stations through NRC and USGS funding. The station separation will be reduced to 10 km at most places on the seismicity trend with the intention of improving hypocenter accuracies and detection thresholds.

Significant earthquakes in the central Mississippi Valley during 1978 include the following:

1. 2 June 1978, 0207 UTC, 38.4N, 88.5W, felt in Fairfield, IL, m_{3Hz} = 3.7 (FVM).
2. 29 August 1978, 0705 UTC, 38.5N, 88.2W, felt in West Salem, IL, m_{3Hz} = 2.4 (FVM).
3. 31 August 1978, 0031 UTC, 36.1N, 89.4W, felt in Dyersburg, TN, MM V, m_b = 3.5 (FVM).
4. 20 September 1978, 1224 UTC, 38.6N, 90.3W, felt in St. Louis, MO, MM IV, m_b = 3.0 (BLA).
5. 21 November 1978, 2331 UTC, 36.0N, 89.9W, felt in Blytheville, AR, m_{3Hz} = 2.3 (FVM).
6. 5 December 1978, 0148 UTC, 38.6N, 88.4W, felt in West Salem, IL, and in five neighboring counties, m_b = 3.5 (FVM).

A microearthquake survey using portable seismographs was conducted near Ridgely, TN for four weeks in May and June. The results are reported by Nicholson and Singh (1978). The survey was centered near the seismicity cluster adjacent to the seismograph station GRT in Figure J-2. Significant results are a well defined epicenter trend in a northwest-southeast line. A southwesterly dipping reverse fault was identified on the basis of composite focal mechanisms and vertical depth profiles. The hypocenters have depths between 2 and 10 km. The composite focal mechanism is similar to that found by Herrmann and Canas (1978) for their Zone F. The importance of the Nicholson and Singh (1978) study is that an active fault has been defined for the first time in the central United States.

WABASH VALLEY EARTHQUAKES - 1978

A cursory glance at Figure J-1 shows that not many earthquakes occurred within the eight station array in the Wabash Valley. In fact, only eight were detected and located. This is not an unexpected result since a recent study by Nuttli and Herrmann (1978) shows that historically the Wabash Valley earthquakes occurred six times less frequently than earthquakes in the region of intense seismicity of Figure J-2, e.g. near New Madrid, MO. The coordinates of the eight epicenters are given in Table J-1.

There are two points of particular interest, the locations and depths of the earthquakes. The focal depths of many of the earthquakes are deeper than 16 km, which would make them the deepest earthquakes recorded so far in the central Mississippi Valley. Surface wave studies (Herrmann, 1979) indicate that the only earthquake in the eastern United States with a depth deeper than 16 km in the past twenty years was the $m_b = 5.5$ November 9, 1968 southern Illinois earthquake with a depth of 22 km, which was located at 38.0°N and 88.5°W. An $m_b = 4.7$ earthquake with a depth of 15 km occurred on April 3, 1974 at 38.6°N and 88.1°W. These deep earthquakes seem to be associated geographically with the Fairfield Basin of southeastern Illinois, rather than with the Wabash Valley fault system 30 km to the east. This was surprising since it was expected that the earthquakes might be distributed more toward the east. It was on this presumption that the seismic array was designed. It turned out that the earthquakes are occurring on one edge of the array, between the stations BPIL and WSIL, approximately.

In an attempt to see how station distribution affected the locations and focal depths, a joint hypocenter program was written. The initial hypocentral coordinates for seven selected earthquakes are given in Table J-2, together with the eighth iteration, for which the process converged. In the joint hypocenter determination process used here, the September 22, 1978 earthquake was held fixed, station corrections for P wave arrivals were determined, and no station correction was applied to the S wave travel time. As can be seen, there are no great changes in the hypocentral coordinates, the differences in hypocentral coordinates being no more than one or two kilometers. This points out the common observation that good locations by regional arrays will not be modified much. Another way of looking at the results is that they indicate that the initial solutions were quite good.

The joint hypocenter program was not developed just to test good locations. Instead, the exercise was a good trial for the computer program. After some more modification, the computer program will be used to relocate epicenters prior to 1978, for which seismograph readings exist. It is hoped that such as exercise might define a seismicity pattern for southeastern Illinois.

SURFACE WAVE STUDIES

The study of surface wave excitation by earthquakes in order to determine source parameters is an involved and time consuming process. It involves collecting seismograms, digitizing selected portions, performing Fourier and multiple filter analysis, sieving the spectral amplitude data for inconsistencies, running a systematic search through focal depth, strike, dip and slip angles to match observed spectral amplitudes, comparing theoretical and observed surface wave phase spectra at selected stations and selecting that surface wave solution which best fits the observed P wave first motions. For a suitably trained analyst, one man-month is expended in analyzing a particular earthquake. Fortunately, the earthquakes that can be studied occur rather infrequently so that each can be thoroughly studied.

A recent earthquake analyzed is a subject of a paper by Voss and Herrmann (1979). The June 16, 1978 Snyder, Texas earthquake occurred at 11:46:53.2 UT at 33.0°N and 100.7°W and had an m_b = 4.7 (NEIS). The surface-wave analysis indicated a northeast striking normal fault solution. The tension axis trends at 329° and plunges at 9°, while the pressure axis trends at 216° and plunges at 60°. The focal depth was determined to be 3 km and the seismic moment to be 6.5 E + 22 dyne-cm. A study of the Lg spectra indicates a stress drop of about 1.5 bars rather than the 6 bars expected for a similar sized earthquake in the central United States. A particularly interesting characteristic of this earthquake is that its focal depth is shallow and that it also occurred in an active oil field where secondary recovery is being performer. There may be some causal relation between the earthquake and the oil field operations.

Another earthquake analyzed is that of January 23, 1966 which occurred at 01:56:38.0 Ut near Dulce, New Mexico. A description of the affects of this earthquake is given by Hoffman and Northrop (1977). These authors determined a focal mechanism which consists of a northwest striking reverse fault. A surface-wave study was performed for the same earthquake. The result was an almost north-south striking normal fault at a depth of 3 km and a seismic moment of 3.5 E + 23 dyne-cm. The focal mechanism parameters are that the tension axis trends at 73° with a plunge of 1° while the pressure axis trends at 166° with a plunge of 83°. The discrepancy between these results and those of Hoffman and Northrup (1977) is due to the fact that those authors relied strongly on 22 P wave first motions reported in the Bulletin of the International Seismological Centre. An examination of WWSSN, LRSM and Canadian data in this study showed that only five first motions could be unequivocally identified. Surface wave data strongly constrained the strike and slip angles. The solution reported here also satisfies observed long period seismograms waveforms at ALQ and GOL from the P wave arrival through the surface wave arrivals.

The surface wave studies here bring to 23 the number of earthquakes east of the continental divide for which surface wave source parameter estimates exist (Herrmann, 1979). This data set represents most of the larger eastern U.S. earthquakes that occurred since 1960. The surface wave depth estimates are reliable and the possiblity of comparing maximum source intensities with focal depth and magnitude exists. Perhaps large source intensities can be correlated with shallow earthquakes.

PUBLICATIONS

During this report period, the following publications were prepared:

Herrmann, R.B. (1979). Surface wave focal mechanisms for eastern North American earthquakes with tectonic implications, J. Geophys. Res. (in press).

Voss, J.A. and R.B. Herrmann (1979). A surface wave study of the June 16, 1978 Texas earthquake, Earthquake Notes (submitted).

Central Mississippi Valley Earthquake Bulletin, Quarterly Report No. 17, Third Quarter 1978, 1 July -30 September 1978.

Central Mississippi Valley Earthquake Bulletin, Quarterly Report No. 18, Fourth Quarter 1978, 1 October - 31 December 1978.

Central Mississippi Valley Earthquake Bulletin, Quarterly Report No. 19, First Quarter 1979, 1 January - 31 March 1979 (in press).

Central Mississippi Valley Earthquake Bulletin, Quarterly Report No. 20, Second Quarter 1979, 1 April - 30 June 1979 (in preparation).

REFERENCES

Herrmann, R.B. (1979). Surface wave focal mechanisms for eastern North American earthquakes with tectonic implications, J. Geophys. Res. (in press).

Herrmann, R.B. and J.A. Canas (1978). Focal mechanism studies in the New Madrid Seismic Zone, Bull. Seism. Soc. Am. 68, 1095-1102

Hoffman, J.P. and S.A. Northrup (1977). The Dulce, New Mexico earthquake of January 23, 1966, Earthquake Notes 48, 3-20.

Nicholson, C. and S. Singh (1978). A detailed microearthquake study of the New Madrid Fault System's western Tennessee segment (abstract), Earthquake Notes 49, 19.

Nuttli, O.W. and R.B. Herrmann (1978). State of the Art for Assessing Earthquake Hazards in the United States: "Credible Earthquakes for the Central United States," Misc. Paper 5-73-1, Report 12, December 1978, U.S. Army Engineer Waterways Experiment Station, Vicksburg, Miss.

Stauder, W., M. Kramer, G. Fischer, S. Schaefer, and S.T. Morrissey (1976). Seismic characteristics of southeast Missouri as indicated by a regional telemetered microearthquake array, Bull. Seism. Soc. Am. 66, 1953-1964.

Voss, J.A. and R.B. Herrmann (1979). A surface wave study of the June 16, 1978 Texas earthquake, Earthquake Notes (in press).

Table J-1.

Earthquakes Detected in Wabash Valley Area, 1978

Date	Origin Time UTC	Lat	Lon	Depth (km)
28 Jan 78	16 40 59.2	38.23 N	88.05 W	6.0
02 Jun 78	02 07 28.7	38.43 N	88.49 W	18.5
19 Jun 78	08 54 16.1	38.21 N	88.39 N	6.7
29 Aug 78	07 05 50.5	38.52 N	88.21 W	17.0
22 Sep 78	11 29 10.0	38.31 N	88.42 W	18.6
14 Nov 78	18 32 30.9	37.52 N	88.15 W	1.4
05 Dec 78	01 48 01.3	38.58 N	88.40 W	18.4
11 Dec 78	07 48 58.0	38.09 N	88.82 W	19.2

Table J-2.

Joint Hypocenter Determination

Initial Coordinates

Date	Origin Time UTC	Lat	Long	Depth (km)
28 Jan 78	16 40 59.18	38.2273	88.0453	6.04
02 Jun 78	02 07 28.65	38.4338	88.4900	18.54
19 Jun 78	08 54 16.09	38.2113	88.3939	6.65
29 Aug 78	07 05 50.45	38.5224	88.2148	16.99
22 Sep 78	11 29 10.01	38.3088	88.4242	18.61
05 Dec 78	01 48 01.28	38.5827	88.4011	18.40
11 Dec 78	07 48 58.02	38.0870	88.8185	19.23

Eight Iteration

28 Jan 78	16 40 59.17	38.2265	-88.0417	6.62 ± .95
02 Jun 78	02 07 29.07	38.4178	-88.5056	19.72 ± .99
19 Jun 78	08 54 16.15	38.2068	-88.3957	7.39 ± .69
29 Aug 78	07 05 50.49	38.5218	-88.2175	17.27 ± .68
22 Sep 78	11 29 10.01	38.3088	-88.4242	18.61 ± 1.00
05 Dec 78	01 48 01.52	38.5655	-88.4048	19.56 ± 1.12
11 Dec 78	07 48 58.10	38.0820	-88.8193	19.84 ± 1.15

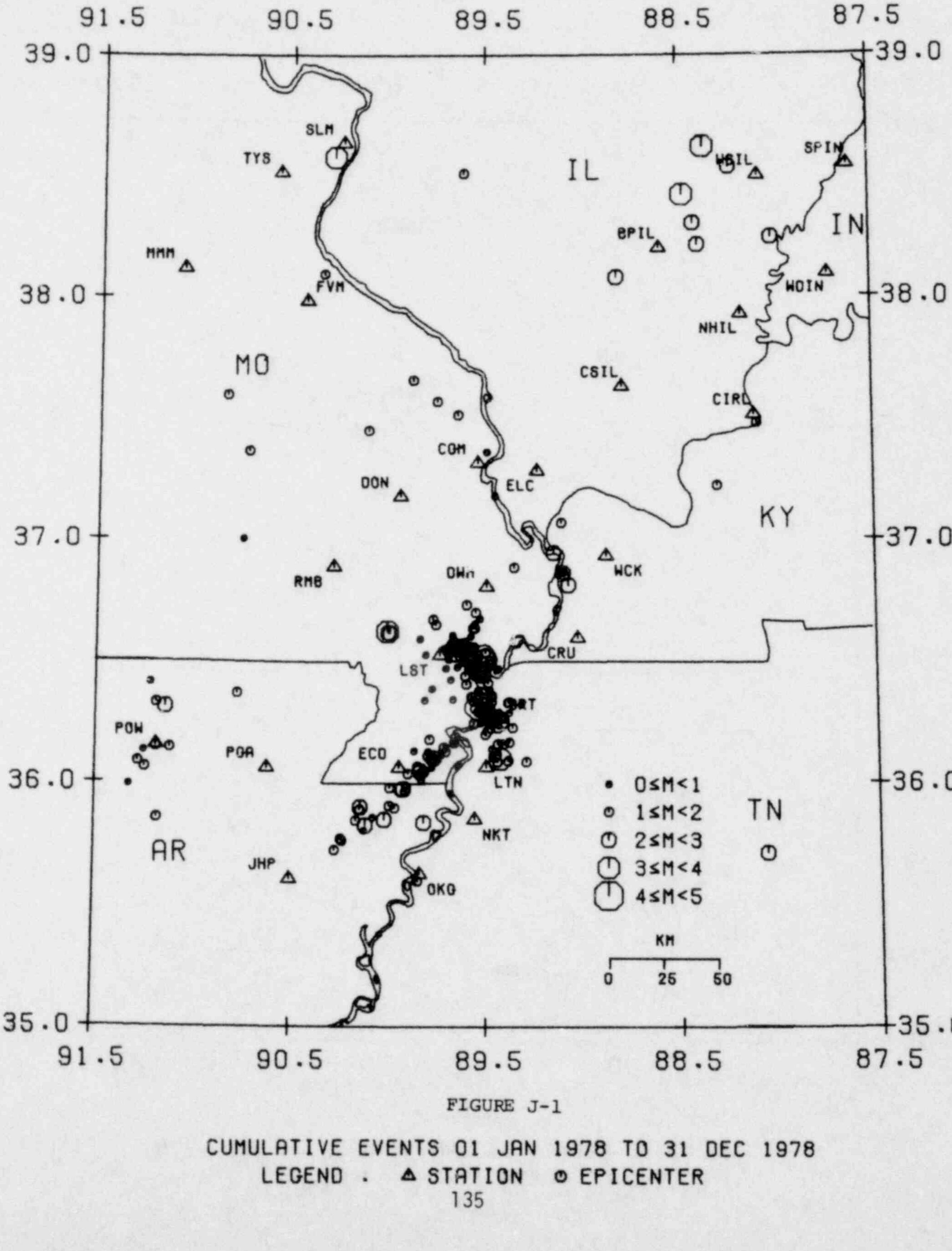


FIGURE J-1

CUMULATIVE EVENTS 01 JAN 1978 TO 31 DEC 1978
LEGEND . △ STATION ⊙ EPICENTER

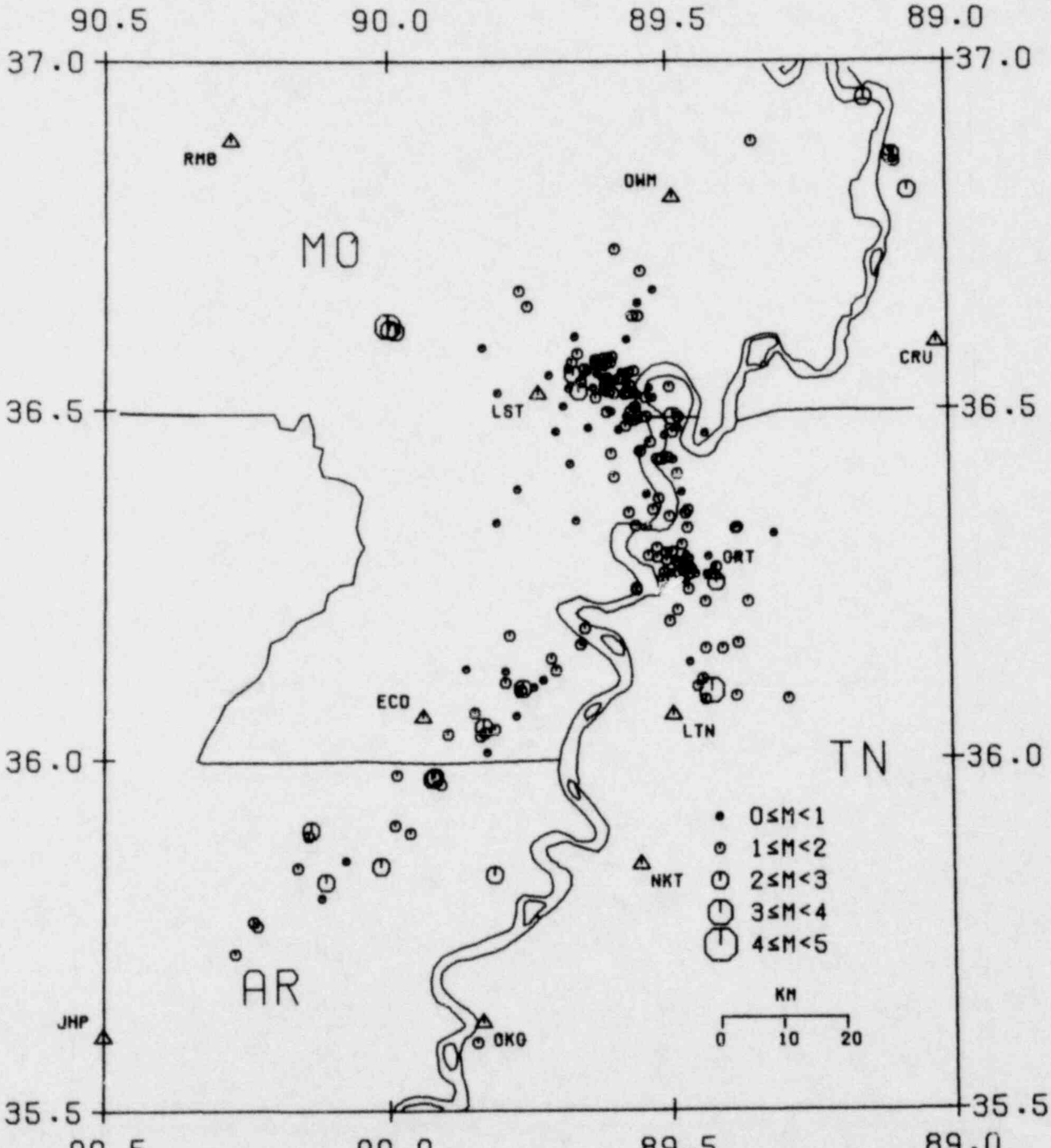


FIGURE J-2

CUMULATIVE EVENTS 01 JAN 1978 TO 31 DEC 1978
LEGEND ▲ STATION ⊙ EPICENTER

REPORT ON AEROMAGNETIC SURVEY OF PARTS
OF NORTHEAST ARKANSAS

Final Report - September, 1978

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INTRODUCTION

This report presents the preliminary interpretation of aeromagnetic surveys in northeastern Arkansas. A map of the residual total field aeromagnetic measurements, submitted to the N.R.C. with our Final Report, was compiled from four separate surveys:

(1) Aeromagnetic maps of Augusta, Bald Knob, Cave City, Newport, Pleasant Plains, and Strawberry quadrangles, in Independence and adjacent counties, northeastern Arkansas: U.S. Geological Survey open-file maps, 1951.

(2) Aeromagnetic map of the New Madrid region, Missouri, Kentucky, Arkansas, and Tennessee: U.S. Geological Survey, open-file report 74-360, 1975.

(3) Aeromagnetic map of the Jonesboro region, Arkansas, Missouri, and Tennessee: U.S. Geological Survey, open-file report 76-318, 1976.

(4) Aeromagnetic survey of northeast Arkansas: unpublished data, survey conducted by Applied Geophysics Inc. for the Arkansas Geological Commission in cooperation with the U.S. Nuclear Regulatory Commission.

These data were compiled by the U.S. Geological Survey, Denver, Colorado. Interpretation of the aeromagnetic anomaly map consists of subsidiary maps of: depth of magnetic basement (fig. K-1), well defined trends in the residual magnetic field (fig. K-2), and the relation of observed surface structures and present-day earthquake epicenters to the magnetic field (fig. K-3). A discussion of each of these maps is included in this report along with the geological implications of the aeromagnetic anomalies.

AEROMAGNETIC SURVEYS

All surveys listed in the introduction of this report, henceforth referred to as (1) (2) (3) and (4), were made using a total field magnetometer, either trailed behind or enclosed within an aircraft. Flight line spacing was approximately 0.8 km. and 0.4 km. for (1) and 1.6 km. for (2) (3) and (4). Flight elevation was 305 km. barometric for (1) (2) and (3) and 610 km. for (4). Survey (1) was available in analog form only and was hand digitized by the U.S. Geological Survey, Branch of Regional Geophysics, Denver, Colorado. Surveys (2) (3) and (4) were recorded digitally in the field. All data were compiled and the various surveys "fitted"on a digital computer. The four surveys were compatible and did not require the use of special techniques in order to make the surveys fit. All surveys were corrected for diurnal variations in the earth's field and changes in flight elevation. The main component of the earth's field was removed using the 1965 IGRF values. The residual aeromagnetic anomaly map and contoured variations are the result of: changes in the magnetic susceptibility of material in the immediate area below the aircraft, distance of the causative body from the magnetometer, and the vectors of the induced and remanent magnetization.

INTERPRETATION OF AEROMAGNETIC ANOMALIES

Depth of Magnetic Basement

To begin this section a definition of magnetic basement (MB) should be made. MB simply means that point in the earth's crust below which rocks have a magnetic susceptibility large enough to cause changes in the magnetic field that can be detected by a magnetometer. The term MB does not have any age or lithologic connotation. Rocks that comprise MB are usually igneous or metamorphic, although situations exist where iron-rich sedimentary rock could be classified as MB. The first encounter of igneous rock in a geologic section does not necessarily imply magnetic basement (example - in a non-magnetic section of sedimentary rock which includes an igneous flow or sill the igneous rock would not be considered MB).

Vacquier et al., (1951) provide a method whereby rapid determination of the distance (depth) to a magnetic source from a magnetometer may be estimated. Seventy-seven anomalies were analyzed by T.G. Hildenbrand, U.S. Geological Survey. Using this method the resulting depth to magnetic basement map (fig. K-1) was constructed. Error in calculated depths using this method generally increase with depth of the magnetic rock. Also small magnetic susceptibility contrasts between the magnetic source rocks will produce small anomalies which are more difficult to work with and, therefore, increase the margin of error. The more anomalies that are analyzed, the less the total error factor becomes. For igneous rocks at the surface the error in computing the distance from aircraft to source is generally less than 10% which may increase with depth-of-source and small susceptibility contrasts to as much as 35% with magnetic basement at depths greater than 3 km. (Vacquier, et al., 1951, p. 10). It can be seen from figure K-1 that in the Ozarks region magnetic basement is relatively shallow (< 1 km. to about 3 km. below M.S.L.) and gradually deepens to the southeast. The shallowest magnetic rocks form an arcuate pattern at the top of the map. The implied dip of the magnetic basement along the outside of the arc reaches a maximum value of 11°. A reentrant of deeper magnetic basement occurs in the vicinity of the valley of the White River and follows the same general northwesterly trend as the river. In the Mississippi Embayment magnetic basement deepens to more than 7 km. and forms a northeast-trending trough. The width of this trough is approximately 80-100 km., roughly parallel to, and off-set 60 km. northwestward, from the present course of the Mississippi River. Near the Mississippi River magnetic basement steeply rises again to the southeast into Tennessee.

Trends in Residual Aeromagnetics

Very well-defined magnetic trends are developed in the Ozarks region and along the edge of the Mississippi Embayment (fig. K-2). Within the Embayment magnetic lineations are not noticeable. The strong northwest trend in the Ozarks appears to be truncated by a northeasterly oriented line of magnetic "highs" along the edge of the Embayment. The cause of the magnetic lineations in the Ozarks is not known, however, it must be the result of either a similarity in rock-type and magnetization, and/or relief in the magnetic rocks forming as valley and ridges, elongate in the direction of the lineation. The implied depth to magnetic basement (fig. K-1) suggests that relief on this surface may account for part of the strong northwest magnetic trends. This relief may be the result of faulting and folding or erosion on the surface of these rocks. Surface exposures and drill hole information in this part of the Ozarks indicate that the Paleozoic and younger units do not contain rocks that have magnetic susceptibilities sufficient to account for any of the observed anomalies. It is believed therefore that the source for the magnetic variations in the Ozarks portion of the survey lie entirely within the Precambrian. The nearest outcrops of Precambrian rocks are in southern Missouri some 60 km. north of the survey area. At this location Precambrian igneous rocks, mainly felsic rhyolites and tuffs, have been eroded into isolated hills and knobs. Further north in the St. Francois Mountain area Precambrian igneous rocks show similar erosional features. Stratigraphic relief in these areas is less than one kilometer. Sparse drill hole information in southern Missouri and northern Arkansas suggests that this erosional pattern continues in the subsurface toward the south. There is no evidence that Precambrian erosion could produce the amount of difference in depth to magnetic basement as indicated in figure K-1. The conclusion is, therefore, that the major differences in the depth to magnetic basement, up to 2.5 km. in the Ozark segment of the map, are structurally controlled. Paleozoic sedimentary rocks in the map area are relatively flatlying. This suggests that development of the relief on the magnetic basement occurred prior to the deposition of the oldest non-deformed sedimentary unit (> 1320 m.y.), and that relief of the magnetic basement is not a significant factor in the northwest trends in the Ozarks. Small scale faulting occurs in the Paleozoic rocks of the southeast Ozarks region. At least one set of these faults correspond, in direction, to the larger displacements in the magnetic basement. The age of this faulting is younger than older Mississippian and older than Cretaceous (B.R. Haley, oral comm.) and in all likelihood represents reactivation of older structures during the Ouachita orogney.

Differences in the magnetic susceptibility and polarization vectors must account for most of the lineation in the Ozarks region. In some places the lineation cuts across the proposed basements highs. If the Precambrian in this region is similar to that in the St. Francois Mountain area, large differences in the magnetic susceptibility can be expected. These range from very low susceptibility granites to very iron-rich diabases. Allingham (1960) notes the magnetic signature of the various igneous rocks of the St. Francois region. In addition to susceptibility contrasts both normal and reversely polarized igneous rocks have been identified in the St. Francois Mountains (Scharon, et al., 1961). A combination of similarity in rock-type and polarization along the northwest trend is sufficient to account for the observed anomalies.

The distinct change in the magnetic pattern from the Ozarks to the Mississippi Embayment indicates different types of magnetic basement exist in the two regions. These two regions are separated by a line of positive magnetic anomalies that lie along the structural edge of the Mississippi Embayment or Reelfoot Rift (Ervin and McGinnis, 1975). The magnetic highs are presumably caused by mafic igneous intrusions (Hildenbrand, et al., 1977). Although the age of these intrusions are unknown, no drill hole has encountered any igneous rock in this area and the bodies are believed to be confined to the Precambrian complex. Other igneous intrusions are noted along this same line beyond the boundaries of this survey. To the northeast, in Missouri, at least two major geophysical anomalies, which are interpreted as mafic to ultrabasic intrusions (Hildenbrand, et al., 1977), occur along the projection of this trend. Southwestward alkalic igneous rocks crop out in central Arkansas and are in alignment with the above inferred intrusions.

Relation of observed surface structures and present-day earthquake epicenters to the magnetic field (fig. K-3):

1. In the Arkansas Valley region of the survey area Paleozoic rocks were faulted and folded prior to and during the Ouachita Orogeny. Here normal faulting is the predominant style although high-angle reverse displacements occur along the crests of sharp anticlinal flexures developed in the Atoka Formation. Most of these faults strike in an easterly direction. Since only a small part of the Arkansas Valley province is covered by this survey, it is impossible to tell if there exists any systematic change in the magnetic field corresponding to these faults.

2. In the Ozarks region of the survey numerous normal faults occur in Pennsylvanian age rocks south of the White River. Displacements on these faults is relatively small (generally less than 0.06 km.). North of the White River at least one set of normal faults correspond to lineations of the magnetic anomalies.

3. Surface faulting has not been documented in the Mississippi Embayment in Arkansas and drill hole information is not sufficient to draw any conclusions about the relation of off-sets in the Paleozoic cubcrop and magnetic anomalies.

Large displacements in the magnetic basement are suggested as occurring along the northwest edge of the Mississippi Embayment (fig. K-1). Paleogeographic maps by Caplan (1954) indicate no relation between sub-crop patterns and magnetic anomalies. This again suggests that displacements of the magnetic basement occurred prior to deposition of the Paleozoic sedimentary units. There is a general thickening of Paleozoic age rocks southeastward from the Ozarks toward the Embayment indicating a deepening trough was present in this direction during early Paleozoic time. This northeast trending trough has been named the Reelfoot Rift (Ervin and McGinnis, 1975) and is theorized to represent the arm of a failed rift system. It is suggested that this rift began in late Precambrian and has been active to the present time. Downwarping of the present Mississippi Embayment began in Middle to Late Mesozoic by reactivation of this ancient rift system and may be presently active. The fact that present-day seismicity is associated with the Embayment would support this conclusion.

4. Maps of epicentral locations of historical earthquakes (Nutti, 1973, Stauder, 1977) show an alignment of events which follow the deepest (to magnetic basement) part of the Mississippi Embayment. These shallow focus events are thought to coincide with the center of the rift system. Recent earthquakes also tend to be concentrated around the edges of positive gravity and magnetic anomalies (Kane, 1976, Hildenbrand and Kane, 1976, and McKeown, 1978). The suggestion is that stress is concentrated at the edges of mafic bodies which provide likely zones for rock failure.

SUMMARY

Recent aeromagnetic surveys in northeast Arkansas provide information about the depth and nature of magnetic basement in the southeastern Ozarks and western Mississippi Embayment regions. In the Ozarks province basement varies in depth from less than one to more than three kilometers, deepening toward the southeast. Magnetic relief in the Ozarks is up to 800 gammas suggesting large variations in susceptibilities and polarization of the basement rocks. A strong northwest trend in the magnetic anomalies is present in this part of the Ozarks. Exposures of Paleozoic age rocks here show very little relation between this trend and surface structures.

A series of positive magnetic anomalies is present along the northwest edge of the Mississippi Embayment. These anomalies are thought to be expressions of mafic igneous bodies intruded along zones of weakness formed at the edge of the Mississippi Embayment or Reelfoot Rift. The age of these intrusives is unknown but they are believed to be confined to the Precambrian basement rocks.

In the Mississippi Embayment magnetic basement deepens to more than seven kilometers and forms a northeast trending trough some 80 to 100 km. wide. Well developed trends in the magnetic field are not present in the Embayment and anomalies are relatively wide spaced. This would suggest that the character of the basement differs beneath the Ozarks and Mississippi Embayment.

REFERENCES CITED

Allingham, J.W., 1964, Low amplitude aeromagnetic anomalies in southeast Missouri: Geophysics, v. 29, n. 4, p. 537-552.

Caplan, W.M., 1954, Subsurface geology and related oil and gas possibilities of northeastern Arkansas: Arkansas Div. of Geol., Bull. 20.

Ervin, C.P. and L.D. McGinnis, 1975, Reelfoot Rift: reactivated precursor to the Mississippi Embayment: Geol. Soc. America Bull., v. 86, n. 9, p. 1287-1295.

Hildenbrand, T.G., and M.F. Kane, 1976, Spatial relations between mafic/ultramafic plutons and seismicity in the northern Mississippi Embayment: (abs.) EOS, Transactions, American Geophys. Union, v. 57, n. 12, p. 963.

Hildenbrand, T.G., M.F. Kane, and W. Stauder, S.J., 1977, Magnetic and gravity anomalies in the northern Mississippi Embayment and their special relation to seismicity: U.S. Geol. Survey miscellaneous field studies map MF-914.

Kane, M.F., 1976, Correlation of major eastern U.S. earthquake epicenters with mafic/ultramafic masses: (abs.) EOS, Transactions, American Geophys. Union, v. 57, n. 12, p. 963.

McKeown, F.A., 1978, Hypothesis: many earthquakes in the central and southeastern United States are casually related to mafic intrusive bodies: U.S. Geol. Survey, Jour. Research, v. 6, n. 1, p. 41-50.

Nuttli, O.W., 1974, The Mississippi Valley earthquakes of 1811 and 1812: Earthquake Inf. Bull., vol. 6, n. 2, p. 8-13.

Scharon. L.H., Walter Hays, and R.E. Anderson, 1961, Paleomagnetic investigations in the St. Francois Mountains: <u>in</u> Guidebook to the geology of the St. Francois Mountain area, p. 106-114.

W. Stauder, S.J., 1977, Microearthquake array studies of the seismicity in southeast Missouri: U.S. Geol. Survey, Earthquake Info. Bull., v.9, n. 1, p. 8-13.

Vacquier, V., C.S. Nelson, R.G. Henderson, and Isidore Zietz, 1951, Interpretation of aeromagnetic maps: Geol. Soc. America Mem. 47.

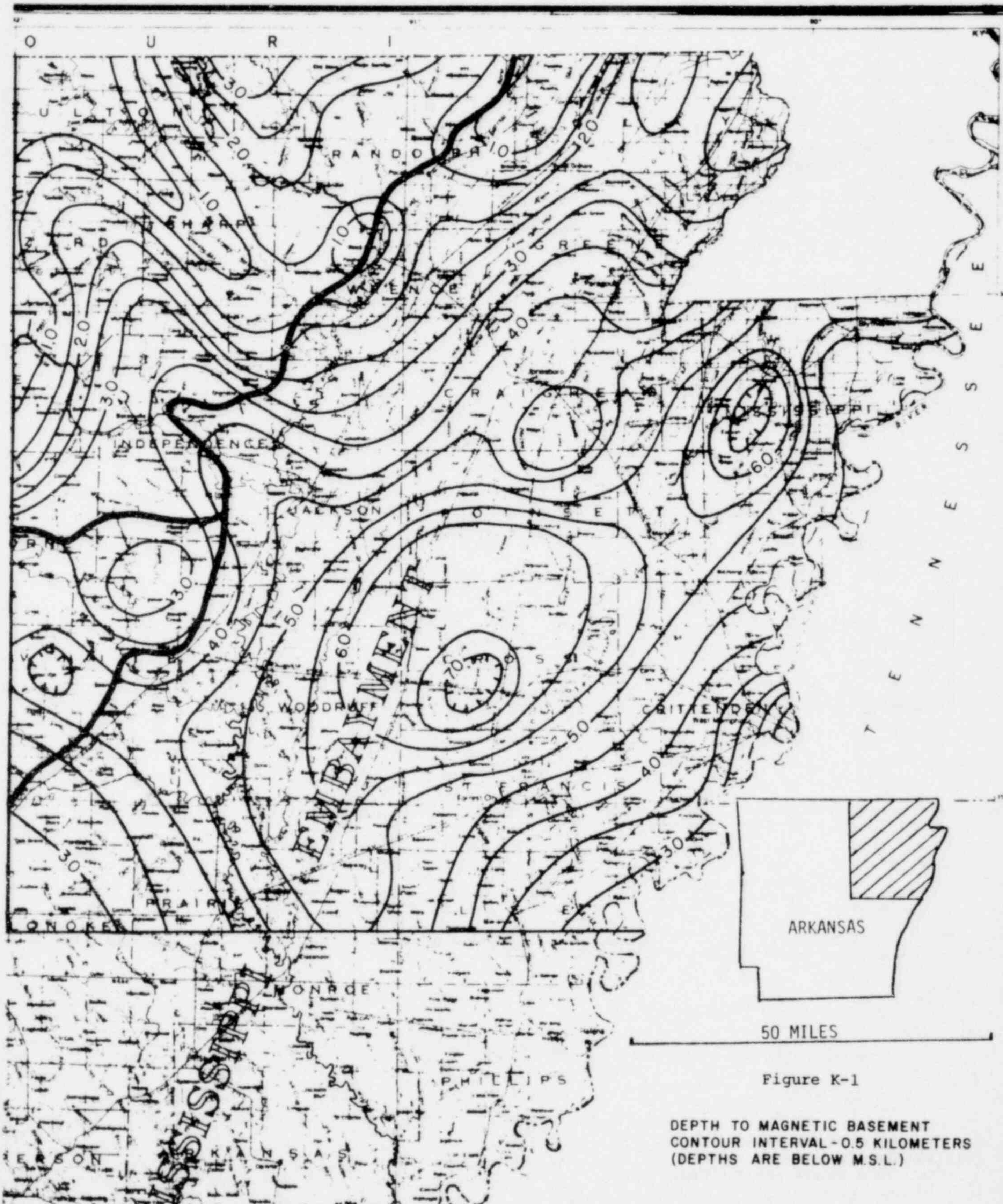

Figure K-1

DEPTH TO MAGNETIC BASEMENT
CONTOUR INTERVAL - 0.5 KILOMETERS
(DEPTHS ARE BELOW M.S.L.)

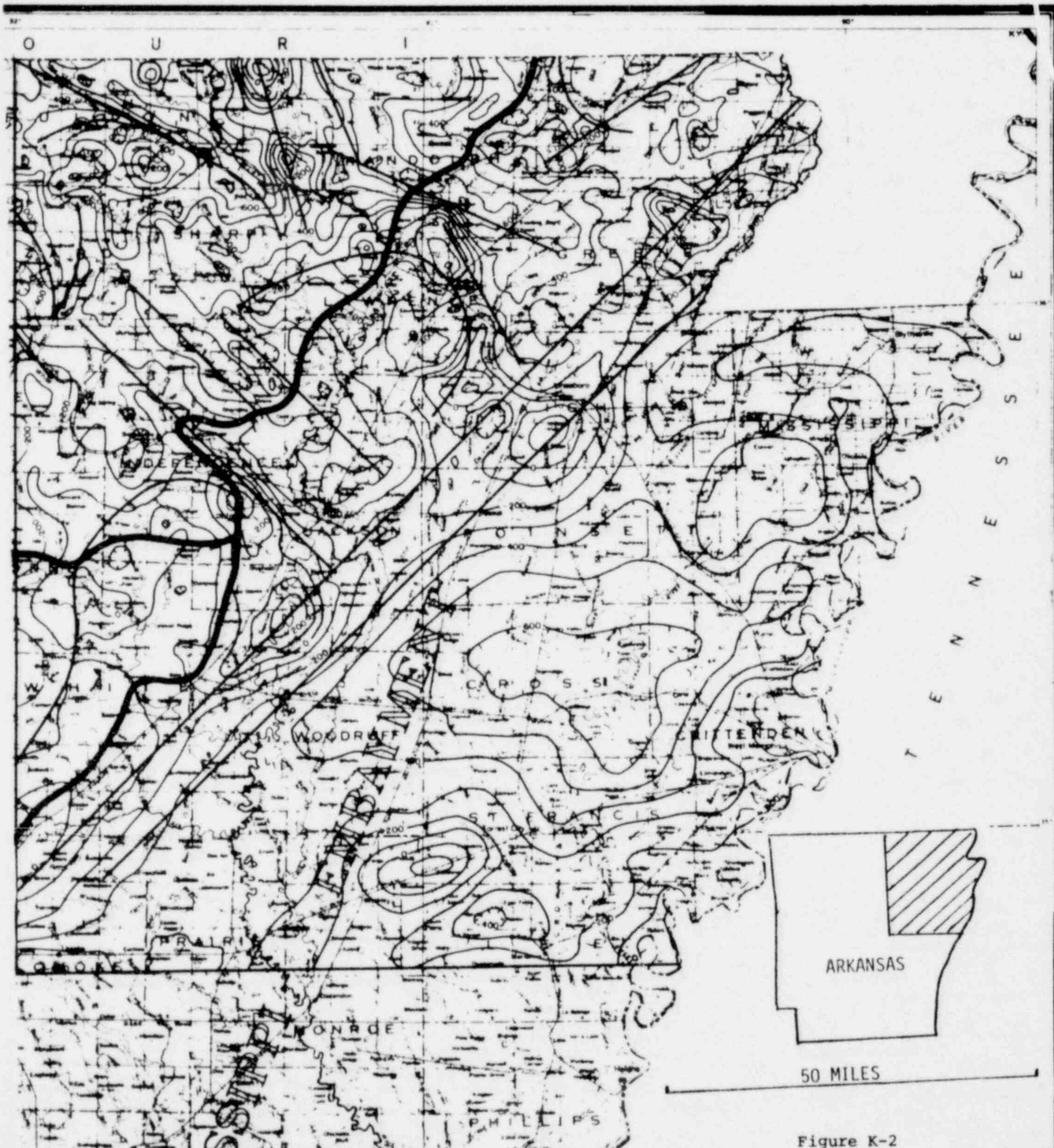

Figure K-2

TRENDS IN AEROMAGNETIC ANOMALIES

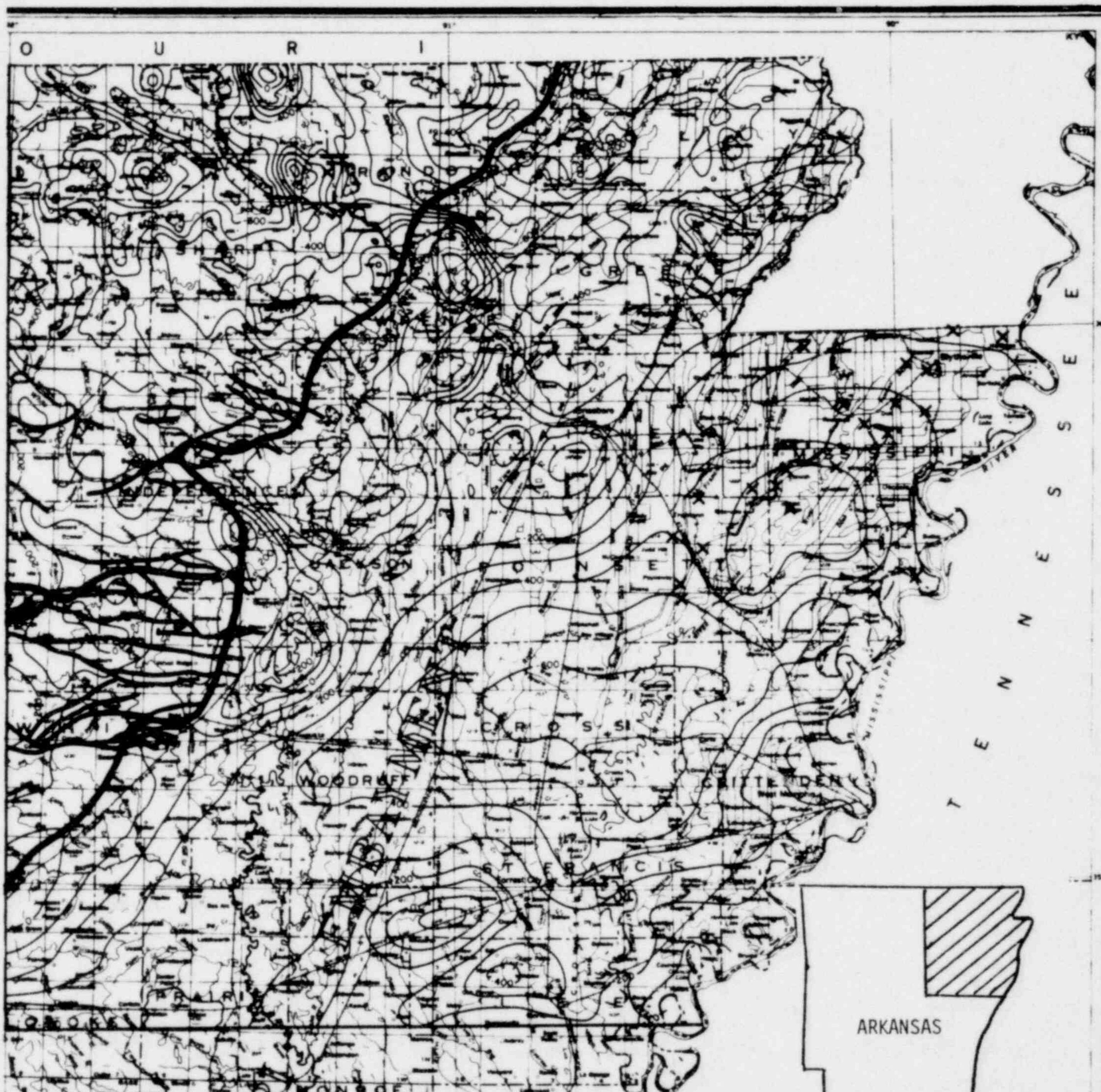

Figure K-3

SURFACE STRUCTURAL FEATURES, PRESENT-DAY EARTHQUAKE EPICENTERS AND AEROMAGNETIC ANOMALIES OF NORTHEAST ARKANSAS

POOR ORIGINAL

RESEARCH PROGRAMS IN THE NEW MADRID AREA
SPONSORED BY OTHER AGENCIES

During the fiscal year 1979 staff members of the U.S. Geological Survey completed studies that resulted in the release of a seismotectonic map of the central Mississippi Valley (Miscellaneous Field Studies Map MF-1011). In cooperation with the Missouri Department of Geology and Land Survey they have been engaged in studies of the Rolla $1^{\circ} \times 2^{\circ}$ Quadrangle. These studies resulted in the publication of several maps including one showing structure contours on the Precambrian surface (Miscellaneous Field Studies Maps MF-1001A and MF-1001B). The U.S.G.S. continued their studies on seismotectonics, geomorphology, and geophysics of the New Madrid area. Interpretations of their reflection seismograph surveys in the Reelfoot Lake area have been released, and they indicate the presence of growth faults in the area. Some of the current U.S.G.S. Earthquake Hazards Reduction programs that are of significance to the coordinated studies of seismotectonics in the New Madrid area are shown on table 2.

The U.S. Army Corps of Engineers, St. Louis District, continued its geological and seismological review of the midwestern United States. They are currently preparing seismic zoning maps for the region. The Corps recently published two pertinent papers in their series entitled "State-of-the-Art for Assessing Earthquake Hazards in the United States" - Miscellaneous Paper S-73-1. They are Report 10, Attenuation of High Frequency Seismic Waves in Central Mississippi Valley, by Otto Nuttli and John Dwyer; and Report 12, Credible Earthquake for the Central United States, by Otto Nuttli and Robert Herrmann.

Members of our group have cooperated with the Tennessee Valley Authority, especially during the processing of geophysical data. Cooperation and communication have been excellent among all of the organizations participating in the New Madrid Seismotectonic Study.

Table 2

Earthquake Hazards Reduction Programs
New Madrid Area - FY 1979

TECTONIC HISTORY OF EASTERN OZARK UPLIFT, E.E. GLICK, U.S. Geological Survey, Branch of Central Environmental Geology, Denver Federal Center, Denver, Colorado 80225, (303) 234-3353.

TECTONIC ORIGIN OF EASTERN UNITED STATES SEISMICITY, R.M. Hamilton, U.S. Geological Survey, Branch of Earthquake Tectonics and Risk, 12201 Sunrise Valley Drive, Reston, Virginia 22092, (703) 860-7684.

GEOPHYSICS OF THE NEW MADRID SEISMIC ZONE, T.G. Hildenbrand, U.S. Geological Survey, Branch of Regional Geophysics, Denver Federal Center, Denver, Colorado 80225, (303) 234-5464.

MISSISSIPPI VALLEY SEISMOTECTONICS, D.P. Russ, U.S. Geological Survey, Branch of Earthquake Tectonics and Risk, Denver Federal Center, Denver, Colorado 80225, (303) 234-5065.

MICROZONATION OF THE MEMPHIS, TENNESSEE AREA, W.D. Kovacs, Purdue University, School of Civil Engineering, West Lafayette, Indiana 47907.

TILTMETER RESEARCH PROGRAM IN THE NEW MADRID SEISMIC ZONE, W.V. Stauder, Saint Louis University, Department of Earth and Atmospheric Sciences, St. Louis, Missouri 63103, (314) 535-3131, ext. 206.

EARTHQUAKE HAZARD STUDIES IN SOUTHEAST MISSOURI, W.V. Stauder, Saint Louis University, Department of Earth and Atmospheric Sciences, St. Louis, Missouri 63103, (314) 658-3131, ext. 206.

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7. AUTHOR(S): T.C. Buschbach and Others

5. DATE REPORT COMPLETED: MONTH December, YEAR 1979

9. PERFORMING ORGANIZATION NAME AND MAILING ADDRESS (Include Zip Code):
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Dept. of Earth and Atmospheric Sciences
P.O. Box 8099 - Laclede Station
St. Louis , Missouri 63156

DATE REPORT ISSUED: MONTH March, YEAR 1980

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Site Safety Research Branch
Washington, D.C. 20555

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11. CONTRACT NO.: NRC 04-78-251

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16. ABSTRACT (200 words or less)

A bibliography of more than 1000 studies on continental rifts was prepared. Aeromagnetic and gravity data from much of the area were integrated and gridded on a 2 km grid. A new hypothesis, based on the intergrated geophysical data, suggests that the linear tectonic features associated with the New Madrid seismic zone may extend northeastward across the Rough Creek Fault Zone toward central Indiana. Several earthquakes recorded by the Wabash Valley seismograph array had focal depths greater than 16 km, the deepest ever recorded in the central Mississippi Valley region. Most faulting in the Fluorspar District, southeastern Illinois was shown to have taken place prior to deposition of Late Cretaceous sediments. An isopach map of the basal clastic sediments in the area showed the Rough Creek Graben and Reelfoot Rift to be features that subsided significantly prior to Late Cambrian time.

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