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THE UNIVERSITY OF OKLAHOMA
GRADUATE COLLEGE

TECTONICS, SEDIMENTATION, AND HYDROCARBON POTENTIAL OF THE REELFOOT AULACOGEN

A THESIS
SUBMITTED TO THE GRADUATE FACULTY
in partial fulfillment of the requirements for the
degree of
MASTER OF SCIENCE

[redacted]

BY
JAMES ROBERT HOWE
Norman, Oklahoma
1985

TECTONICS, SEDIMENTATION, AND HYDROCARBON POTENTIAL OF THE REELFOOT AULACOGEN

A THESIS

APPROVED FOR THE SCHOOL OF GEOLOGY AND GEOPHYSICS

By

[redacted]

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ABSTRACT

The Reelfoot aulacogen, an early Paleozoic failed-rift basin, lies concealed beneath the Gulf Coastal Plain strata of the upper Mississippi Embayment. Many similarities exist between the geologic history of the Reelfoot aulacogen and the coeval histories of the adjacent Paleozoic continental margins of North America. Plate tectonic theory provides useful concepts to explain the histories of both continental margins and intracratonic structural features.

Widespread continental extension (continental break-up) occurred in the latest Precambrian-Early Cambrian and initiated rifting in intracratonic areas. Rifting proceeded in some areas to drifting with generation of oceanic crust and formation of the Paleozoic continental margins of North America. Other areas, such as the Reelfoot rift, ceased rifting and subsided passively to form broad downwarped troughs above rift graben systems. Post-rifting subsidence in the Reelfoot area resulted primarily from cooling of the anomalous lithosphere that formed beneath the rift during extension and corresponds to post-rifting, passive subsidence of the continental margins.

Convergent plate interactions affect the interiors of continents as well as their margins, especially along lines of pre-existing weakness. Late Paleozoic plate convergences and continental collisions caused both compressive and extensional reactivation of certain ancient normal faults in the Reelfoot aulacogen that had formed initially during rifting. Post-Paleozoic faulting, generally related to reactivated basement normal faults, occurred in the Late Cretaceous, Tertiary, and Quaternary. Earthquakes in the Reelfoot aulacogen indicate continued faulting that results from the present-day stress field acting on certain ancient crustal weaknesses, usually reactivated rift stage faults.

The hydrocarbon potential of the Reelfoot area is discussed in terms of source rocks, reservoirs, and traps. Potential hydrocarbon prospects include broad anticlines, horst block highs, forced and compaction folds over block edges, normal and reverse faulted anticlines, submarine fans, carbonate buildups and shoals, stratigraphic pinchouts, truncation traps, unconformities, fracture reservoir trends, and shelf-basin hingelines. Reflection seismic profiles show examples of prospect types.

TABLE OF CONTENTS

PAGE

PAGE

LIST OF TABLES

TABLE PAGE

LIST OF ILLUSTRATIONS

FIGURE PAGE

FIGURE PAGE

INTRODUCTION

An early Paleozoic failed-rift basin, named the Reelfoot aulacogen, lies concealed beneath the gently dipping coastal plain strata of the upper Mississippi Embayment. Many similarities exist between the geologic history of the Reelfoot aulacogen and the coeval histories of the Paleozoic continental margins of North America.

Soviet geologists, especially Shatski (1946a,b, 1947, 1955, and 1961), first used the term aulacogen (lit. "born as furrow") to describe linear deep troughs filled with sediments that extend at high angles into cratons from orogenic belts. They recognized that the structural histories of aulacogens generally parallel those of the adjacent orogenic belts.

Burke and Dewey (1973), Hoffman (1973), Hoffman et al. (1974), Burke (1977), Wickham (1978), and Burke (1980) explained the geologic stages of aulacogen development in terms of plate tectonic theory, relating these stages to the opening and closing of oceans and the evolution of continental margins.

Sloss (1979a) demonstrated that cratonic-interior basins and pericratonic basins adjacent to continental margins often have roughly synchronous subsidence histories and concluded that a common mechanism must control both cratonic and pericratonic subsidence.

Continental break-up can provide the common mechanism for aulacogen and cratonic interior basin formation. Widespread continental extension (continental break-up) initiates rifting in intracratonic areas. Some rifts proceed to form oceanic crust and continental margins while others remain as failed-rifts within the continental fragments. Pericratonic basins form by the passive subsidence of rifted continental margins and many intracratonic basins form above or adjacent to intracratonic rifts as a result of the passive subsidence of anomalous lithosphere that was emplaced during rift extension. Both types of basins often have similar subsidence histories because they often form by the same roughly synchronous processes.

In a similar manner, convergent plate interactions at continental margins reasonably affect the interiors of continents as well as their exteriors, especially along lines of pre-existing crustal weakness. Molnar and Tapponier (1975) have shown that the Cenozoic continent to continent collision between

India and Asia produced complex structural movements deep inside of Asia.

Objectives and Purpose

The objectives of this paper are threefold: to explain the tectonic and sedimentation histories of the Reelfoot aulacogen, to relate these histories to plate interactions at the continental margins, and to provide an analysis of the Reelfoot basin's hydrocarbon potential. The geologic history of the Reelfoot aulacogen may add insights into the history of the rest of the United States Midcontinent and the early Paleozoic evolution of the adjacent passive continental margins that have been obscured by late Paleozoic orogenic activity. Methods employed to achieve the objectives of this thesis are discussed in the following section.

METHODS OF INVESTIGATION

Summary of Research Effort

In contrast to many masters thesis projects, I had the good fortune to maintain nearly full-time financial support for my research and have received permission to publish the results. My thesis research was carried out concurrently with a regional hydrocarbon exploration project administrated formerly by Dow Chemical Company's Oil and Gas Division and later by Apache-Dow Company, both of Houston, Texas. Presently, Harrison Interests, Ltd. of Houston, Texas, manages this program.

As the project geologist for this exploration effort, I gathered, interpreted, integrated, and discussed geologic and geophysical data acquired from an area of approximately 20,000 square miles including northeast Arkansas, southeast Missouri, southern Illinois, western Kentucky, and western Tennessee. This amounted to approximately four and one-half man-years of my personal effort to analyze a largely unexplored deep basin that contains 10 to 15,000 feet of previously unrecognized stratigraphic section at its base.

Parts of my research were presented at the 1982 Penrose Conference on the "Tectonic History of the Ouachita Orogen" and in poster session at the 1985 Texas A&M Geodynamics Research Symposium on "Intraplate Deformation: Characteristics, Processes, and Causes." An article briefly summarizing my work was published in the November 12th, 1984 issue of the Oil and Gas Journal.

Methods employed to achieve the objectives of my thesis included geological and geophysical techniques, literature research, field trips, and contacts with other workers. Subsequent numbered paragraphs summarize the details of the methodology.

Detailed Methodology

1. I used general well data to construct a series of regional well information maps at a scale of 1:62,500. This general well data was available to me from throughout the Reelfoot region. This data included geophysical logs, sample and core descriptions, driller's logs, and scout tickets. Some of this data was available to me from company files. Other data was obtained from state geological surveys and state oil and gas commissions. This general well data came mostly from numerous shallow wells (less than 4000 feet deep) and from a few intermediate to deep wells (4,000 to 14,881 feet deep).

2. The study of data from a number of key, intermediate to deep wells in the Reelfoot area together with proprietary seismic reflection data allowed interpretation of the geologic history of the Reelfoot aulacogen and analysis of its hydrocarbon potential. Table 1 lists these key wells, their location, year of completion, total depth, types of data available or analyses performed, and sources of data or analyses.

3. I carried stratigraphic correlations for the Paleozoic section into the Reelfoot aulacogen primarily by examining well cuttings under a binocular microscope and comparing their characteristics with generalized formation descriptions given for the region by Caplan (1954) and Grohskopf (1955). The early Paleozoic stratigraphic section within the Reelfoot aulacogen is notably similar to those of the surrounding cratonic regions except it is usually much thicker. Insoluble residue logs obtained from the Missouri Geological Survey aided correlation of units within the thick Arbuckle-Knox carbonate sequence.

4. When no well samples or sample descriptions were available, I made stratigraphic correlations in the Paleozoic section on the basis of geophysical log character. The Lamotte Sandstone, Bonneterre Formation, Elvins Group, Boone Chert, Chattanooga Shale, and Penters Chert could be correlated regionally using

TABLE I

SOURCES OF KEY WELL DATA

Well Name	Location	Year of Comp.	T.D.	Type of Data Available or Analyses Performed	Sources of Data or Analyses
(1) U.S.B.M. #1 Oliver	29-22N-11E New Madrid Co., Arkansas	1945	3728'	sample descriptions	Grohskopf (1955)
(2) Strake Pet. #1 Russell	24-19N-11E Pemiscot Co., Arkansas	1941	4740'	sample and core descriptions	Grohskopf (1955)
				drilling information	Grohskopf (1955)
				paleontological report	Grohskopf (1955)
				organic geochemical analyses	company proprietary
				well sample examination	James Howe
				well sample chip log	Thomas Thompson & James Howe
(3) Benz Oil #1 Merritt	3-4S-1E Lake Co., Tenn.	1966	6021'	sample descriptions	Tenn. Div. of Geology
				geophysical logs	company files
				organic geochemical analyses	company proprietary
				well sample examination	James Howe
				well sample chip log	James Howe
(4) Killam #1 Pattinson	33-18N-13E Pemiscot Co., Mo.	1941	3345'	sample and core descriptions	Grohskopf (1955)
				organic geochemical analyses	company proprietary
(5) Big Chief #1 Taylor	19-5S-6E Gibson Co., Tenn.	1968	7164'	sample descriptions	Tenn. Div. of Geology
				driller's log	Tenn. Div. of Geology
				geophysical logs	company files
				organic geochemical analyses	company proprietary
				well sample examination	James Howe
				well sample chip log	James Howe
(6) Benedum- Trees; #1 Mack	3-15N-12E Miss. Co., Ark.	1939	4535'	sample descriptions	Grohskopf (1955)
				driller's log	Ark. Oil and Gas Comm.
				drilling information	Grohskopf (1955)
				well sample examination	James Howe
				well sample chip log	James Howe
(7)Quintin Little #1 Little	30-15N-5E Craighead Co., Ark.	1965	8686'	sample descriptions	U.S.G.S.
				geophysical log	company files
				well sample chip log	company files

TABLE I (Cont.)

SOURCES OF KEY WELL DATA

Well Name	Location	Year of Comp.	T.D.	Type of Data Available or Analyses Performed	Sources of Data or Analyses
(8) Dow Chem. #1 Garrigan	28-15N-10E Miss. Co., Ark.	1982	12,040'	sample descriptions	company proprietary
				geophysical logs	company files
				mudlog	company proprietary
				organic geochemical analyses	company proprietary
				daily drilling reports	company proprietary
				biolithologic analyses	company proprietary
				core fracture analyses	company proprietary
				core descriptions and environmental interpretations from cores	company proprietary
				well test data	company proprietary
				gas analyses	company proprietary
				synthetic seismogram	company proprietary
				well sample examination	James Howe
				well sample chip log	James Howe
				well site geology	James Howe
(9) Dow Chem. #1 Wilson	14-12N-9E Miss. Co., Ark.	1981	14,869'	sample and core descriptions	company proprietary
				geophysical logs	company files
				mudlog	company proprietary
				organic geochemical analyses	company proprietary
				daily drilling reports	company proprietary
				drill stem test data	company proprietary
				radiometric dating	company proprietary
				biolithologic analyses	company proprietary
				insoluble residue log	Missouri Geological Survey
				velocity survey log	company proprietary
				time/depth conversion chart	company proprietary
				well sample examination	James Howe
				well sample chip log	James Howe
				well site geology	James Howe

TABLE I (Cont.)

SOURCES OF KEY WELL DATA

Well Name	Location	Year of Comp.	T.D.	Type of Data Available or Analyses Performed	Sources of Data or Analyses
(10)Houston Oil & Minerals #1 Singer	36-9N-4E Cross Co., Ark.	1979	11,158'	geophysical logs	company files
				mudlog	company files
				organic geochemical analyses	company proprietary
				insoluble residue log	Missouri Geological Survey
				synthetic seismogram	company proprietary
				well sample examination	James Howe
				well sample chip log	company files
(11)Pennzoil #1 Morris	15-8N-1W Woodruff Co., Ark.	1982	4800'	geophysical logs	company files
				mudlog	company proprietary
				daily drilling reports	company proprietary
				partial well sample examination	James Howe
(12)Pennzoil #1 Raymond	13-7N-1W Woodruff Co., Ark.	1982	6200'	geophysical logs	company files
				mudlog	company proprietary
				daily drilling reports	company proprietary
				well velocity survey	company proprietary
				synthetic seismogram	company proprietary
				partial well sample examination	James Howe
(13)Sun Explor. #1 Nichols	14-5N-4W Woodruff Co., Ark.	1981	13,800'	geophysical logs	company files
				mudlog	company proprietary
(14)Cockrell- Consolidated #1 Carter	4-4N-1E St. Francis Co., Ark.	1971	14,881'	geophysical logs	company files
				mudlog	company proprietary
				drill stem test data	company proprietary
				radiometric dating	company proprietary
				synthetic seismogram	company proprietary
				sample descriptions	company proprietary
				well lithology log constructed from well sample descriptions	James Howe

this method. The other Paleozoic units were not readily correlated regionally by using only geophysical log character.

5. Previously established stratigraphic correlations by Caplan (1954), Grohskopf (1955), and Cushing et. al. (1964) were used for the Mesozoic-Cenozoic sequence of the Reelfoot area.

6. A composite stratigraphic section (Figure 9) and a composite electric log were constructed for the Reelfoot aulacogen from segments of four key wells (numbered 8, 9, 12, and 13 in Table 1). Because of the varied structural positions occupied by these wells (some were in deep basin areas and others were on structurally positive features), it was possible to reconstruct a nearly complete stratigraphic sequence for the Reelfoot aulacogen.

7. My interpretations of depositional environments put forth in this thesis are based on lithology as determined primarily from examination of key well samples and cores, previously published well sample and core descriptions, outcrop and subsurface formation descriptions, geophysical logs, and referenced interpretations as applicable.

8. Pre-Late Cretaceous subcrop maps (such as Figure 8) were produced from well data, seismic data, and by modifying a previously published map (Glick, 1979). These maps dramatically illustrate the late

Paleozoic uplift of the Pascola arch, buried Ouachita orogen, and Axial fault.

9. Geologic cross sections contained in this thesis (Figures 2, 3 and 4) were constructed from my geologic interpretation of seismic reflection profiles and well data. Regional geologic cross sections were layed out along traverses that made optimum use of good quality seismic profiles. Interpreted formation tops and faults determined from seismic profiles were projected into the lines of traverse. Geologic data, recorded in seismic travel-time, were converted to depth by using time/depth conversion charts or by direct calculation using velocities obtained from a well velocity survey. These data were plotted on a geologic cross section in feet. The total combined length of the regional geologic cross sections is approximately 205 miles.

10. A sequential geologic reconstruction of the Axial fault (Figure 12) was made from my geologic interpretation of a seismic reflection profile that crossed the Axial fault. I first made a geologic interpretation of the seismic profile that was recorded in travel-time and then I converted it to a geologic cross section plotted in feet. The fault displacements were then sequentially undone by hand so that the depositional surfaces on both sides of the Axial fault paleoreconstructions were restored to

their estimated original depositional elevations.

11. I developed a regional tectonic map (Figure 1) by modifying a portion of a Geologic Map of the U.S. compiled by King and Beikman (1974). I interpreted the faults shown in the area of the Mississippi Embayment on the basis of well data, seismic reflection data, and regional gravity and magnetic maps. My fault interpretations, especially of the Reelfoot rift's boundaries, were aided by my interpretation of regional gravity and magnetic data obtained from the National Geophysical Data Center in Boulder, Colorado and published maps. I used the gravity and magnetic data for fault interpretation (in conjunction with seismic and well data) in manners similar to those shown by Hildenbrand et al. (1977) and Hildenbrand et al. (1982). The mapping of interpreted gravity and magnetic lineaments aided my determination of fault orientations.

12a. I gathered close-spaced gravity and magnetic data along three profile lines that crossed the Axial fault uplift. These profile lines had a combined length of 29 miles. Distances between data recording stations were maintained at approximately one thousand feet. I precisely surveyed the station positions by using a theodolite, electronic distance meter, and a self-leveling level. I made repeated gravity and magnetic readings at selected base stations that I had previously established and I corrected all readings for drift.

12b. I applied free-air, latitude, and bouguer corrections to the gravity readings. I made bouguer corrections with respect to sea level and assumed a density of 2.0 for the poorly consolidated recent sediments that lie between the surface and sea level. No terrain correction was applied to the data as the topography is nearly flat. I constructed bouguer anomaly profiles for each profile line.

12c. To remove the regional effects from the magnetic data, I obtained grid values for total magnetic intensity for the region dated 1965 and determined gradients of change for the north-south and east-west components of secular variation. I removed the regional field from the magnetic data relative to one specific point of longitude and latitude within the survey area and constructed total magnetic intensity anomaly profiles for each profile line.

12d. My integration of interpretations derived from both seismic reflection data and well data proved very useful in accomplishing the objectives of this thesis. My integration of these two sets of data allowed the interpretation of the geologic history of the Reelfoot aulacogen and its Axial fault uplift. The granting of permission to show proprietary seismic reflection profiles in this thesis has significantly aided my explanations of these histories, superceding the importance of the three local gravity and magnetic profiles. Therefore, I deleted these profiles from this thesis.

13a. I interpreted approximately 3300 miles of proprietary seismic reflection data from both structural and stratigraphic viewpoints. Proprietary seismic data, varying in coverage and quality, was available to me from twenty-seven counties in the states of Arkansas, Missouri, Kentucky, and Tennessee. Arkansas seismic data came from Clay, Greene, Craighead, Mississippi, Jackson, Poinsett, Cross, Crittenden, Woodruff, and St. Francis counties. Missouri seismic data came from Mississippi, Stoddard, New Madrid, Dunklin, and Pemiscot counties. Kentucky seismic data came from Ballard, Carlisle, Hickman, Graves, Calloway, and Fulton counties. Tennessee seismic data came from Lake, Dyer, Lauderdale, Crockett, Tipton, and Haywood counties.

13b. In addition to this seismic data, I viewed and interpreted other proprietary seismic data acquired from some adjacent areas. These areas included the Arkoma basin and its eastern extension, buried eastern extension of the Ouachita orogen, southern Illinois basin, and west-central Tennessee.

13c. I selected strong, regionally persistent seismic reflectors for regional seismic correlation. Initially, the geologic sources of the deep seismic reflectors were unknown due to the absence of deep well data from within the Reelfoot aulacogen. I used shallow and eventually deep well data to identify the geologic sources of the more prominent seismic reflectors. I used synthetic seismograms and time/depth conversion charts generated from sonic and velocity survey logs to tie well formation tops into the seismic reflection data. The main seismic reflecting horizons used for seismic correlations represent the following: the top of the Precambrian basement, top of the Middle Cambrian Bonneterre Formation, base of the Cambro-Ordovician Arbuckle-Knox carbonate sequence, top of the Mississippian-Devonian-Silurian, Boone-Chattanooga-Hunton stratigraphic sequence, and the Cretaceous-Paleozoic unconformity surface.

13d. I established a seismic correlation network first in areas of good data quality and well control and then I branched it out into poorer data areas and areas of new data as it was received from the seismic data contractor. I made seismic reflection correlations by directly tying into crossing or connecting seismic profiles whenever possible. Sometimes I made jump correlations where lines did not connect or when faults cut the profiles. Often in these cases, the character of the seismic reflection was distinctive enough to permit such correlations. I verified the seismic correlation by tying into well data whenever possible.

13e. Poor quality deep seismic data hindered correlation of pre-Mesozoic reflecting horizons in some areas. Major fault zones or near surface static problems usually were the culprits. Major faults such as the Axial fault or rift boundary faults were often difficult to correlate across because of their linear extent. Further drilling in the Reelfoot region or better seismic data or both should allow improvements to be made in the seismic correlation.

13f. My integrated use of seismic reflection profiles and well data greatly enhanced my structural and stratigraphic interpretations in the Reelfoot aulacogen. My geologic interpretation of the seismic data permitted my categorization of the varied types of fault displacements that I observed on seismic reflection profiles. I identified the following five main categories of fault movements: early Paleozoic extension stage normal fault displacements only (early Paleozoic stratigraphic thickening occurred on the downthrown side of faults that ceased moving near the end of Elvins Group time); late Paleozoic normal reactivation of early Paleozoic extension stage normal faults; late Paleozoic compressive reactivation of early Paleozoic extension stage normal faults; Cenozoic compressive reactivation of early Paleozoic extension stage normal faults that have also experienced previous late Paleozoic normal reactivation or compressive reactivation or both; and late Paleozoic normal faulting that was initiated only during the late Paleozoic (no previous stratigraphic thickening is recognized across these faults).

13g. Seismic reflection data also permitted some of my generalized stratigraphic interpretations such as stratigraphic pinchouts in the latest Precambrian-Cambrian Potsdam Megagroup, submarine fans in the Cambrian Elvins Group, and facies changes in the lower part of the Cambro-Ordovician Arbuckle-Knox Megagroup (seismic reflectors from the lower Arbuckle-Knox in deep basins are stronger and more numerous than their equivalents on adjacent platforms, suggesting intervals of increased shaliness in the deep basins).

13h. My geologic interpretation of seismic data allowed identification of potential hydrocarbon traps and permitted interpretation of their histories of formation. Potential hydrocarbon traps include primary traps (those that formed during early Paleozoic extension and subsidence) and secondary traps (those that formed during late Paleozoic, Late Cretaceous, or Tertiary compression). At a few locations, I note that both primary and secondary trap types exist together at different vertical positions due to fault reactivations. At these combination prospect locations, a single well could evaluate two different types of potential hydrocarbon traps.

14. Structural and stratigraphic data from surrounding areas together with postulated paleostress orientations based on published paleogeographic reconstructions aided my interpretation of late Paleozoic structural movements in the Reelfoot aulacogen. This was especially useful in view of the extensive pre-Late Cretaceous erosion that removed large intervals of late and middle Paleozoic strata from much of the Reelfoot area, thus making it difficult to precisely interpret the timing of late Paleozoic structural movements.

15. I evaluated potential hydrocarbon source rocks in the Reelfoot aulacogen primarily on the basis of proprietary organic geochemical analyses. Total organic carbon determinations provided the principal basis for evaluating organic richness. Organic quality and thermal maturity were determined principally from visual kerogen assessment, solid hydrocarbon reflectance, vitrinite reflectance, and types of reported hydrocarbon shows.

16. I evaluated potential hydrocarbon reservoir rocks in the Reelfoot aulacogen in terms of porosity and permeability on the basis of public and pro-

prietary well data. Principal types of data included drill stem test data, driller's logs, well samples, sample descriptions, and geophysical logs. I used seismic reflection data to anticipate potential fracture reservoir trends.

17. Through literature research, I collected published articles, reports, maps, and guidebooks and assembled, updated, and studied them during the course of my thesis research.

18. While participating in five field trips during 1980, 1981, and 1982 to Arkansas, Missouri, western Tennessee, and western Kentucky, I inspected the Paleozoic section in the Ouachita Mountains, Arkoma basin, Ozark plateaus, and St. Francois Mountains and I observed recent geomorphic features in the Mississippi Embayment that relate to earthquakes. In 1982, I coordinated a field trip to the Rio Grande rift in New Mexico for the Houston Geological Society to view well-exposed rift features.

19. Other workers familiar with the Reelfoot region were contacted in government, academia, and industry. I made visits to the Arkansas, Illinois, Missouri, and U.S. geological surveys and to the Mid-America Remote Sensing Center, Murray, Kentucky. I attended regional AAPG, GSA, AGU, and Nuclear Regulatory meetings where I listened to papers presented on the Reelfoot area. In 1984, I presented the

results of my thesis research before a group of Reelfoot rift researchers at the U.S. Geological Survey in Golden, Colorado.

REGIONAL SETTING

The Reelfoot aulacogen extends northeasterly from a junction with the eastern extension of the Ouachita orogen in east-central Arkansas. Figure 1 shows the apparent rift boundaries of the aulacogen, other major faults of the region, locations of the regional geologic cross sections (Figures 2, 3, and 4), and locations of the regional composite seismic reflection profile segments (Figure 5). Figure 6 shows this tectonic map superimposed upon a surface geologic map of the region. Both the Reelfoot aulacogen and the eastern extension of the Ouachitas lie unconformably beneath the Gulf Coastal Plain strata of the Mississippi Embayment. These late Mesozoic and Cenozoic embayment strata occupy a broad trough as shown in Figure 7 by the structure contour map of the Paleozoic-Mesozoic unconformity surface. Figure 8 shows the tectonic map superimposed upon a combined surface geologic map and generalized pre-Late Cretaceous subcrop map of the Mississippi Embayment and Figure 9 shows a composite stratigraphic section for the aulacogen compiled from parts of four wells.

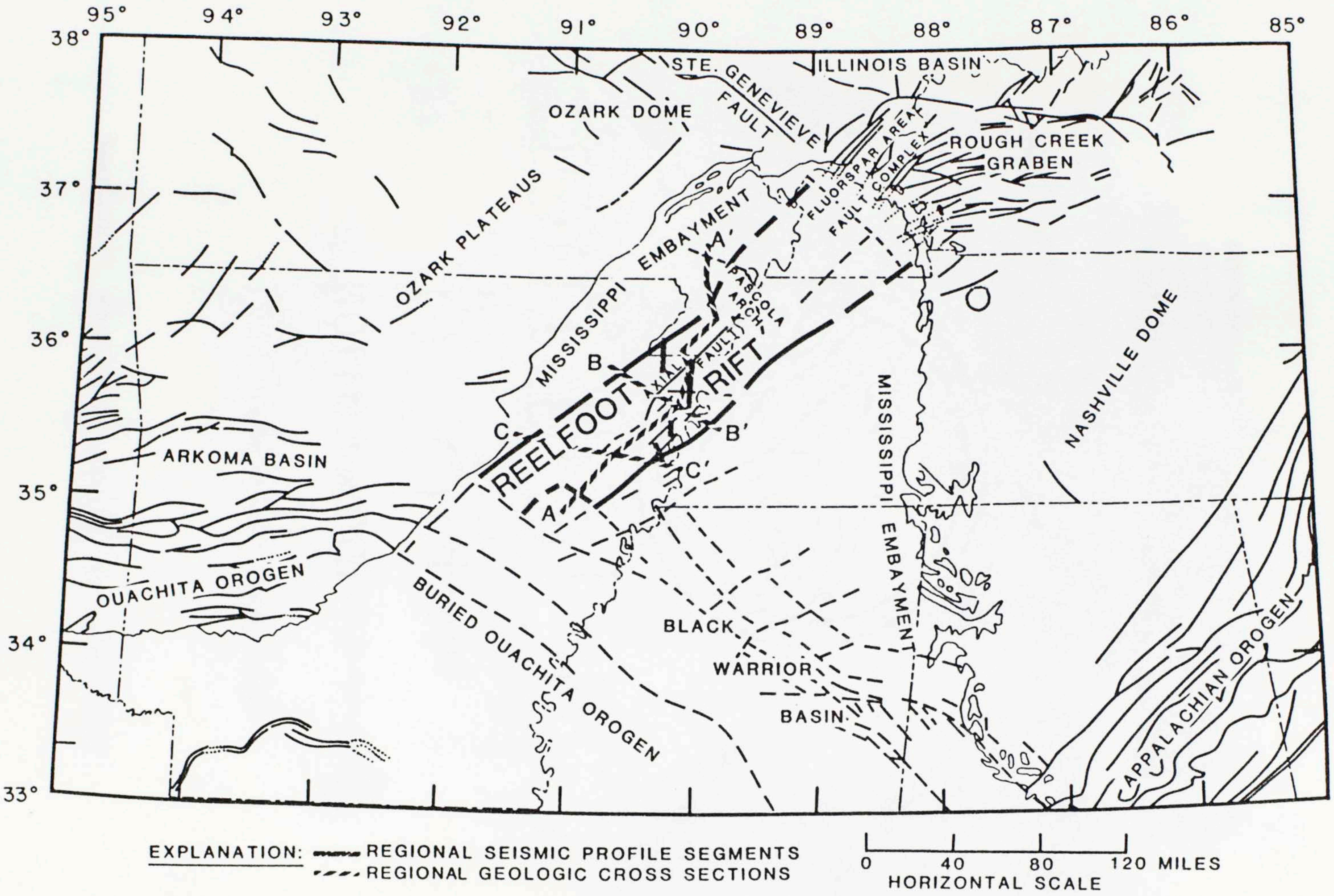


Figure 1. Regional tectonic map (modified from King and Beikman, 1974).

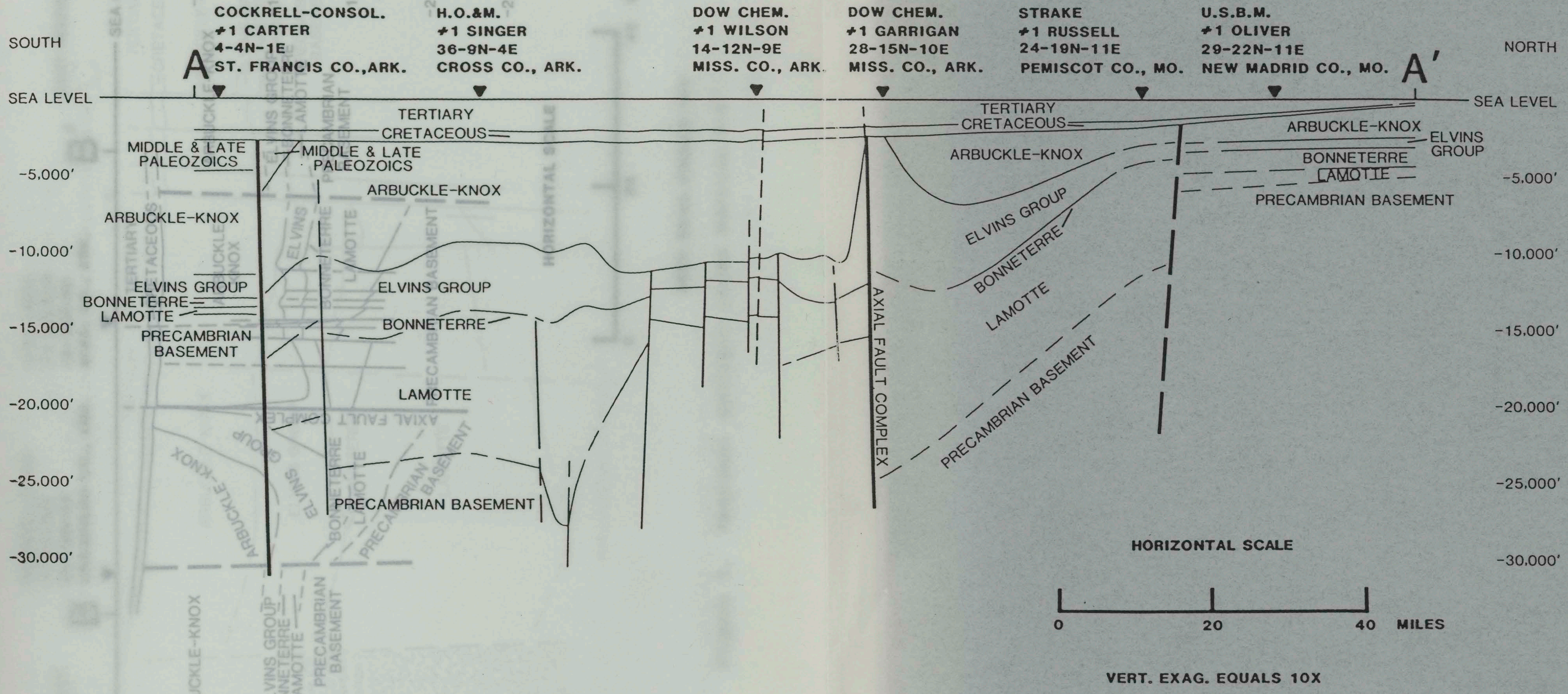


Figure 2. Regional geologic cross section A-A'.

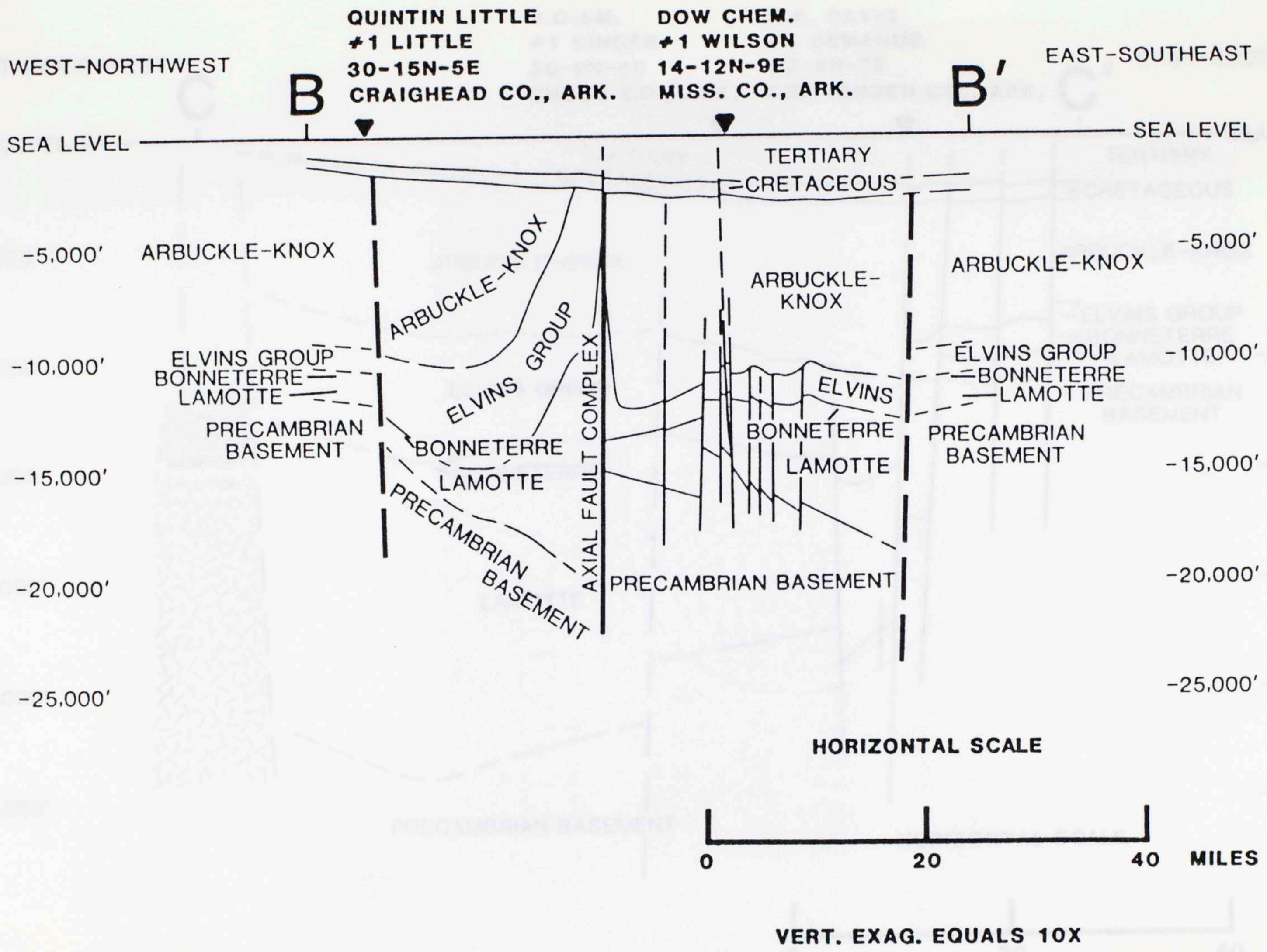


Figure 3. Regional geologic cross section B-B'.

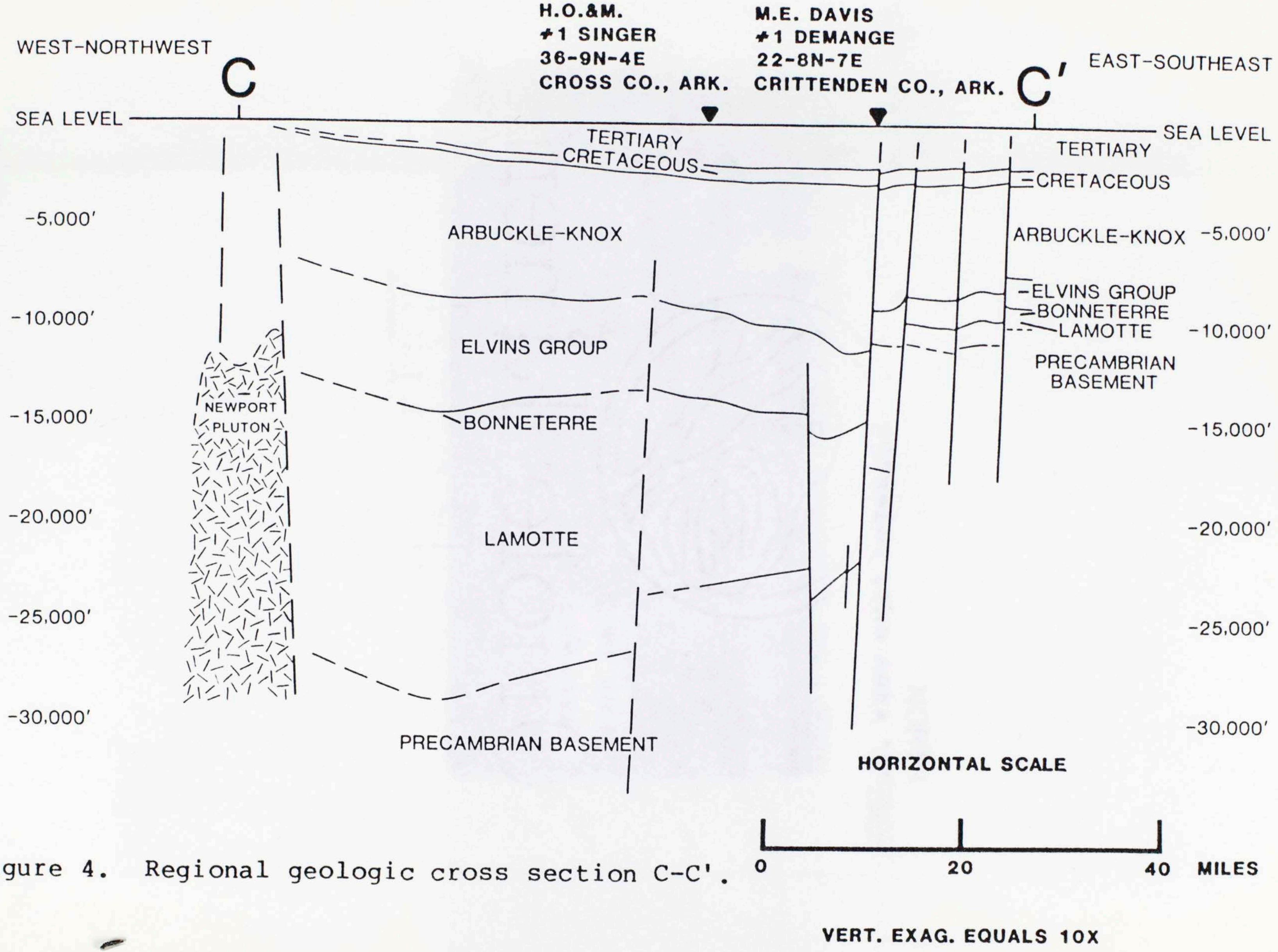


Figure 4. Regional geologic cross section C-C'.

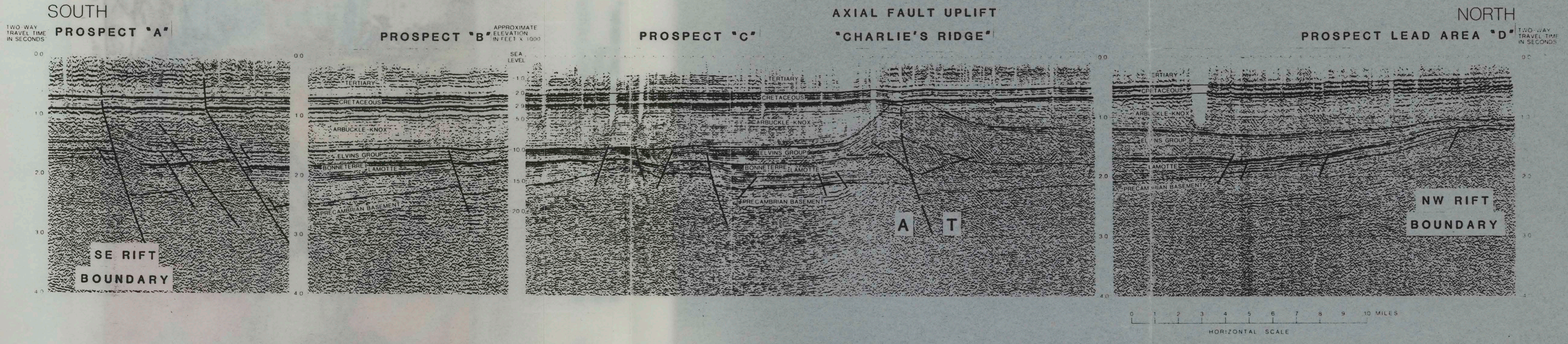


Figure 5. North-south regional composite seismic reflection profile.

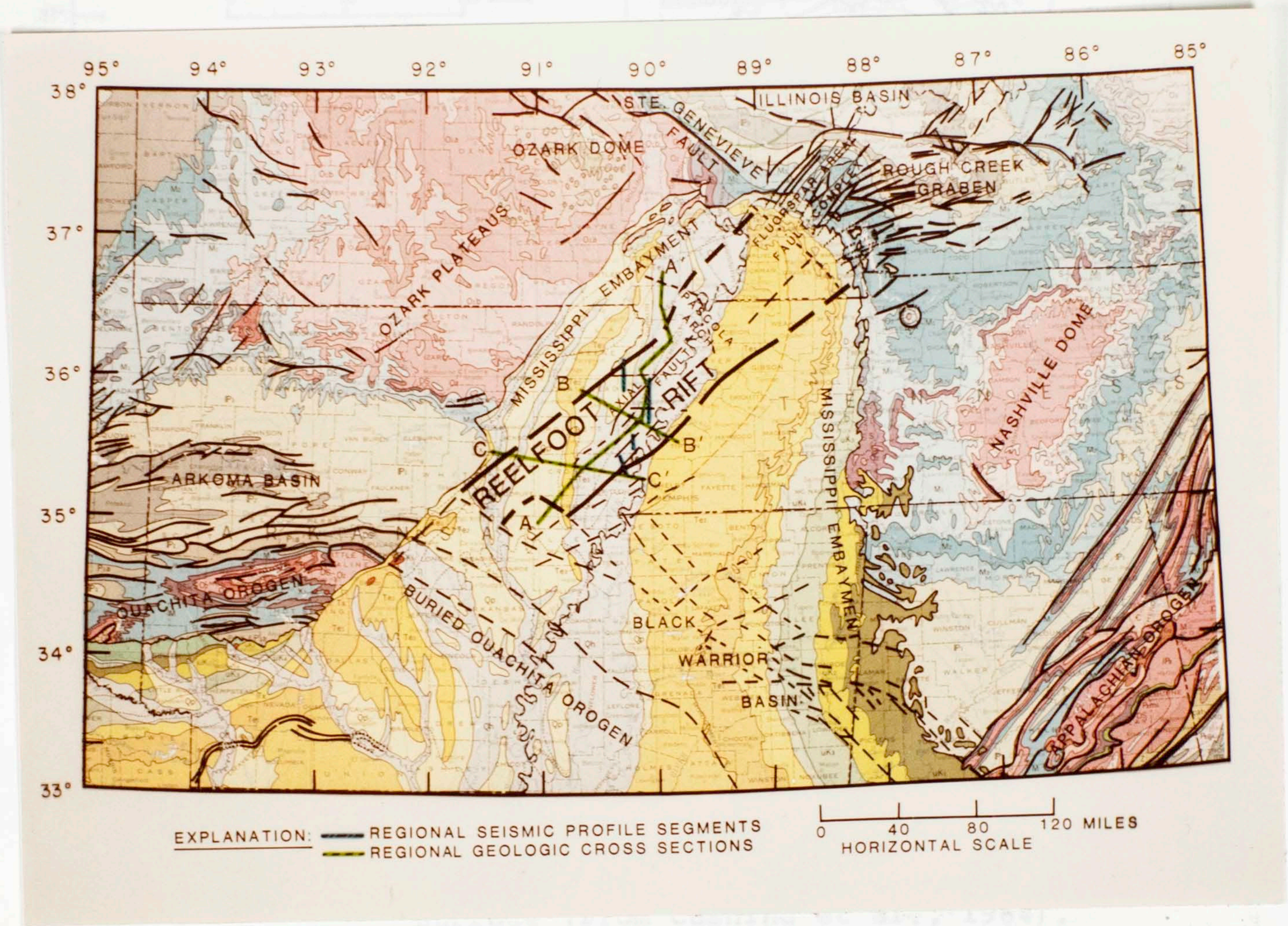


Figure 6. Regional tectonic map superimposed upon a surface geologic map (modified from King and Beikman, 1974).

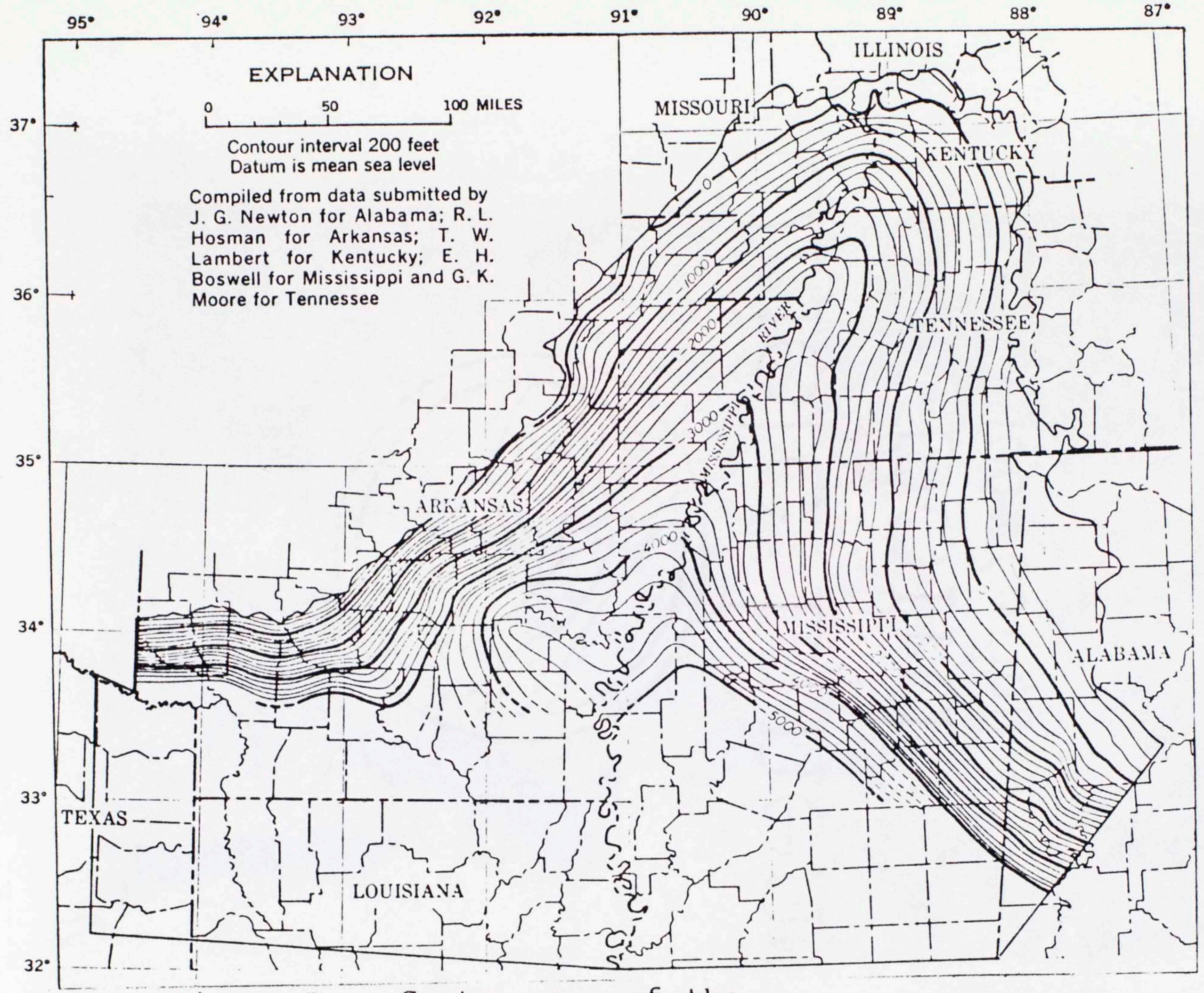


Figure 7. Contour map of the Paleozoic-Mesozoic unconformity surface (from Cushing et al., 1964).

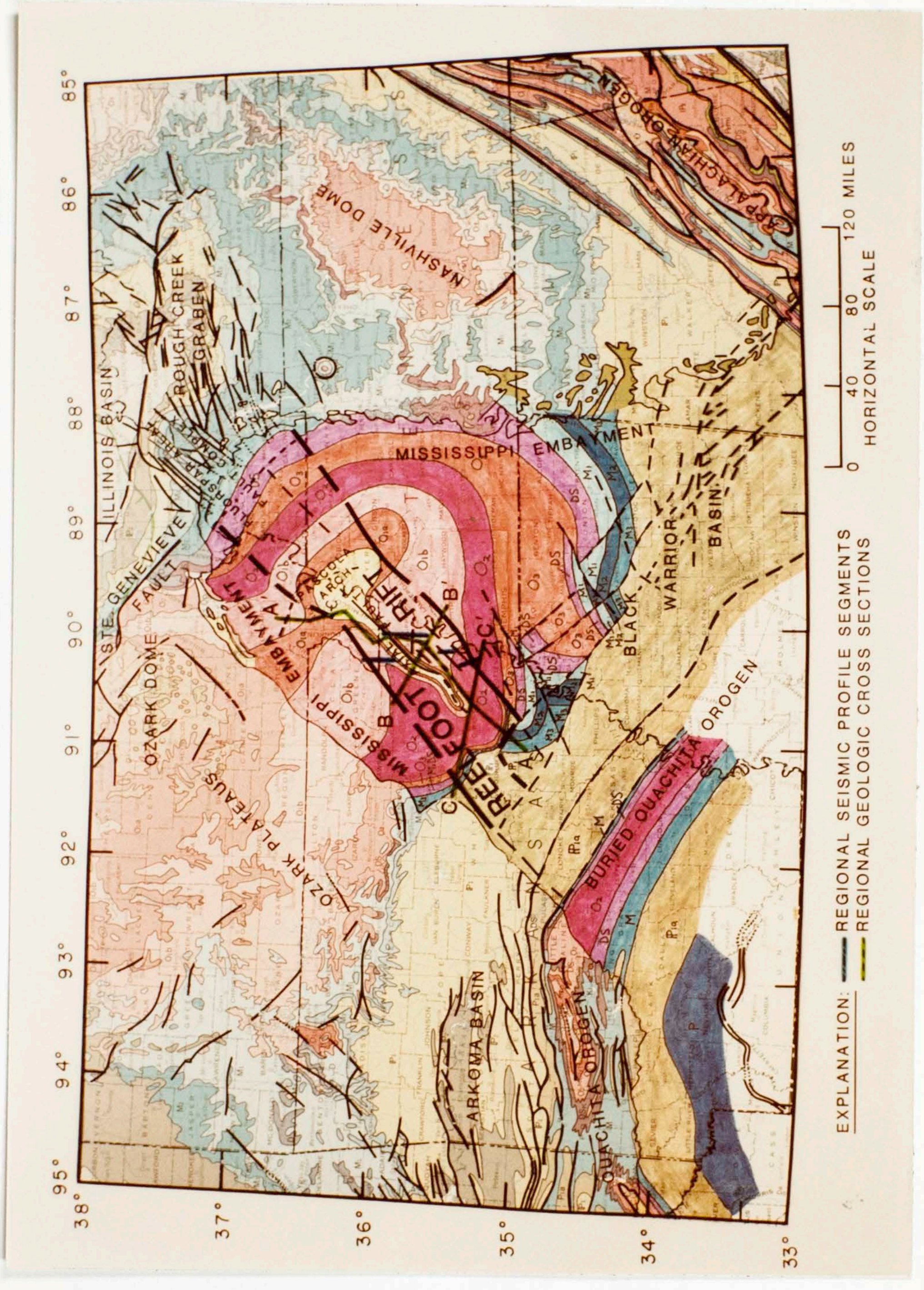
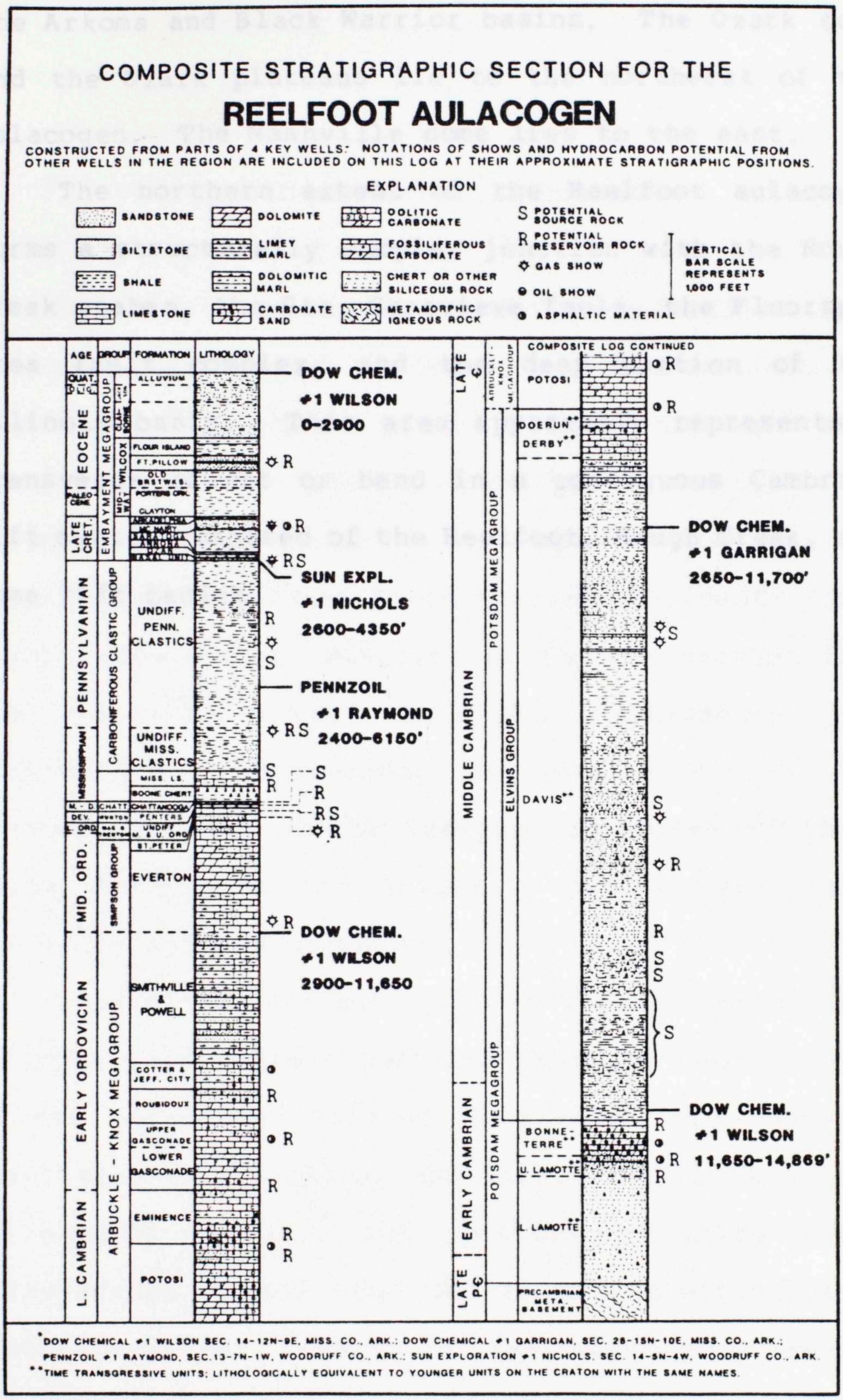


Figure 8. Regional tectonic map superimposed upon a combined surface geologic map and generalized pre-Late Cretaceous subcrop map of the Mississippi Embayment (modified from King and Beikman, 1974 and Glick, 1979).

Figure 9. Composite stratigraphic section for the Reelfoot aulacogen.



COMPOSITE STRATIGRAPHIC SECTION FOR THE REELFOOT AULACOGEN

CONSTRUCTED FROM PARTS OF 4 KEY WELLS:* NOTATIONS OF SHOWS AND HYDROCARBON POTENTIAL FROM OTHER WELLS IN THE REGION ARE INCLUDED ON THIS LOG AT THEIR APPROXIMATE STRATIGRAPHIC POSITIONS.

*DOW CHEMICAL #1 WILSON SEC. 14-12N-9E, MISS. CO., ARK.; DOW CHEMICAL #1 GARRIGAN, SEC. 28-15N-10E, MISS. CO., ARK.; PENNZOIL #1 RAYMOND, SEC.13-7N-1W, WOODRUFF CO., ARK.; SUN EXPLORATION #1 NICHOLS, SEC. 14-5N-4W, WOODRUFF CO., ARK.

**TIME TRANSGRESSIVE UNITS; LITHOLOGICALLY EQUIVALENT TO YOUNGER UNITS ON THE CRATON WITH THE SAME NAMES.

Figure 9.

The southern part of the Reelfoot aulacogen links the Arkoma and Black Warrior basins. The Ozark dome and the Ozark plateaus lie to the northwest of the aulacogen. The Nashville dome lies to the east.

The northern extent of the Reelfoot aulacogen forms a structurally complex junction with the Rough Creek graben, the Ste. Genevieve fault, the Fluorspar Area fault complex, and the deep portion of the Illinois basin. This area apparently represents a transverse offset or bend in a contiguous Cambrian rift system composed of the Reelfoot, Rough Creek, and Rome rift basins.

TECTONICS AND SEDIMENTATION

Crustal divergences and convergences have influenced structural movements and sedimentation in the Reelfoot aulacogen since at least the late Precambrian. Many similarities exist between the structural histories of the aulacogen and the adjacent continental margins of North America. Plate tectonic theory supports the division of these histories into the following stages: extension, subsidence, and compression. Subsequent sections summarize the tectonic history of the Reelfoot aulacogen in these terms along with the interplay between structural movements and sedimentation.

Interpretations put forth in these sections rely on reflection seismic profiles from the central part of the aulacogen, limited deep well data, seismic stratigraphy, structural and stratigraphic data from surrounding areas, and postulated paleo-stress orientations based on published paleogeographic reconstructions. Reliable paleogeographic reconstructions exist from the present back to the Mesozoic break-up of Pangea because of the preserved pattern of dated magnetic reversal stripes on the ocean floor. Paleozoic paleogeographic reconstructions are less certain without having a direct way to determine the longitudinal separation of continents as the oldest undeformed ocean floor is Jurassic. Paleozoic reconstructions must rely on a synthesis of paleomagnetic, paleoclimatic, paleobiogeographic, and tectonic data that are preserved only within the continents (Bambach et al., 1980; Ziegler, 1981). I use present-day directions throughout.

Late Precambrian to Late Cambrian Extension Stage

The early Paleozoic continental margins of North America formed largely by rifting that also produced several failed intracratonic rifts. These include the Reelfoot, Rome, Rough Creek, and southern Oklahoma rifts (Figure 10).

Active rifting in the Reelfoot area apparently began in the latest Precambrian and continued through the Middle Cambrian. During this time, the rift area experienced crustal stretching, extension faulting, regional subsidence, marine transgression, and sedimentary infilling. The thick Potsdam sedimentary sequence of the rift (assumed to be of latest Precambrian to Late Cambrian age) records this period, lying unconformably above a pre-rift surface of deeply eroded Precambrian metamorphic, igneous, and possibly

Figure 10. Postulated configuration of the southeastern continental margins of North America during the Cambrian with some associated intracratonic rifts (modified from Braile et al., 1982).

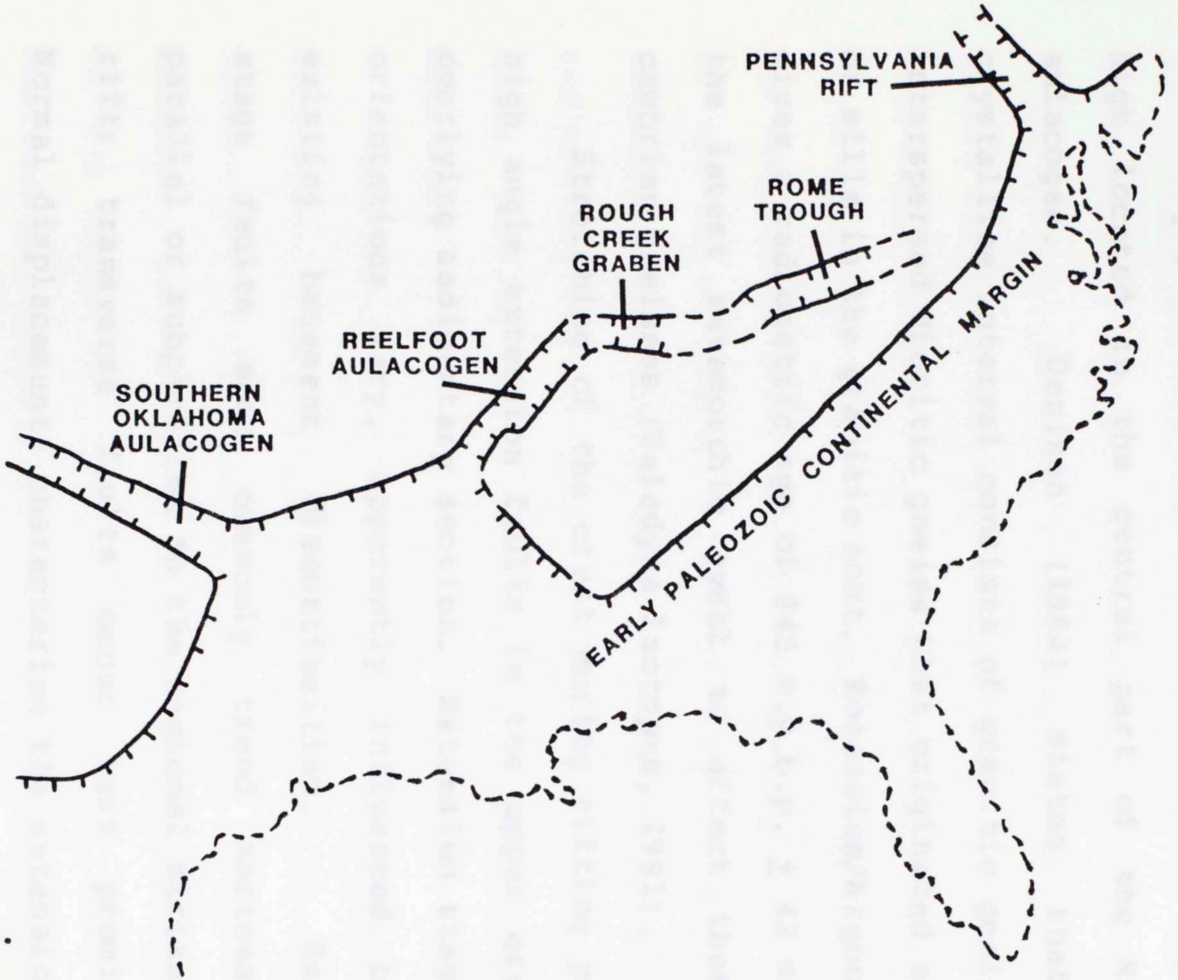

PENNSYLVANIA RIFT
ROME TROUGH
ROUGH CREEK GRABEN
REELFOOT AULACOGEN
SOUTHERN OKLAHOMA AULACOGEN
EARLY PALEOZOIC CONTINENTAL MARGIN

Figure 10.

sedimentary rocks.

The Dow Chemical #1 Wilson well, Sec. 14-12N-9E, Mississippi County, Arkansas, penetrated about 560 feet of Precambrian crystalline rocks before reaching total depth at 14,869 feet on an intra-rift platform high located in the central part of the Reelfoot aulacogen. Denison (1984) states that this crystalline interval consists of granitic gneiss with interspersed dioritic gneiss that originated as dikes or sills in the granitic host. Potassium/Argon dating gives a radiometric age of 845 m.y.b.p. ± 42 m.y. for the latest metamorphic event to affect these Precambrian gneisses (Teledyne Isotopes, 1981).

Stretching of the crust during rifting produced high angle extension faults in the upper crust and overlying sedimentary section. Extension stage fault orientations vary, apparently influenced by pre-existing basement discontinuities. Extension stage faults most commonly trend northeasterly, parallel or subparallel to the regional strike of the rift; transverse faults occur less prominently. Normal displacements characterize the extension stage faults.

Great variations in the thicknesses of the Potsdam Megagroup (2,500 to 20,000 feet) reflect relative movements across syndepositional basement normal faults that "grew" during rifting. The north-south regional seismic profile (Figure 5) contains several examples of this type of block faulting. Note the differences in Potsdam thicknesses across extension stage normal faults. The extension stage sedimentary section thickens dramatically across the south-central segment of the Axial fault (Figures 2, 3, 5, and 11), an early normal fault. Deformation and uplift later accompanied compressive reactivation of this fault to form a portion of the Axial fault uplift (also known as "Charlie's Ridge"). Figure 12 shows the sequential formation of the south-central portion of the Axial fault. Initial displacements across extension stage normal faults decreased upward in the sedimentary section from the basement and died out to drape folding at the base of the Arbuckle-Knox sequence.

Subsidence of the rift concurrent with extensional faulting allowed marine transgression and sedimentary infilling of the basin. The initial Paleozoic marine transgression (Sauk transgression) of the North American craton began at the rifted continental margins and intracratonic rifts during the latest Precambrian or Early Cambrian and covered much of the craton by the Late Cambrian. The vertical succession preserved as the Potsdam Megagroup (lower Lamotte, upper Lamotte, Bonneterre, and Elvins) represents landward shift of a persistent facies

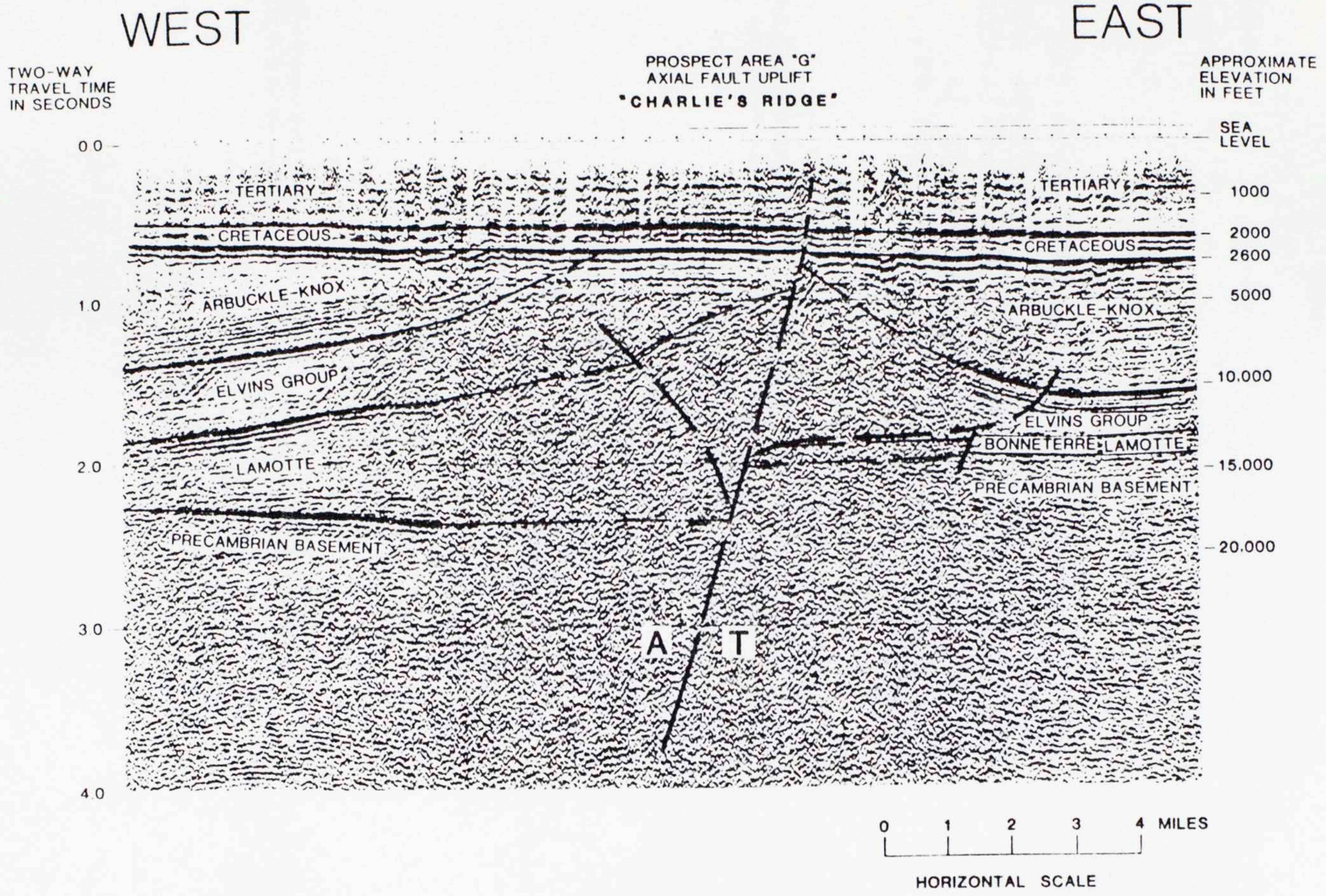


Figure 11. East-west seismic reflection profile across the Axial fault uplift (Craighead and Mississippi Counties, Arkansas).

Figure 12. Generalized sequential formation the south-central portion of the Axial fault developed from the east-west reflection seismic profile shown in Figure 11 (Craighead and Mississippi Counties, Arkansas).

see Fig 11 Crittenden-Miss Co

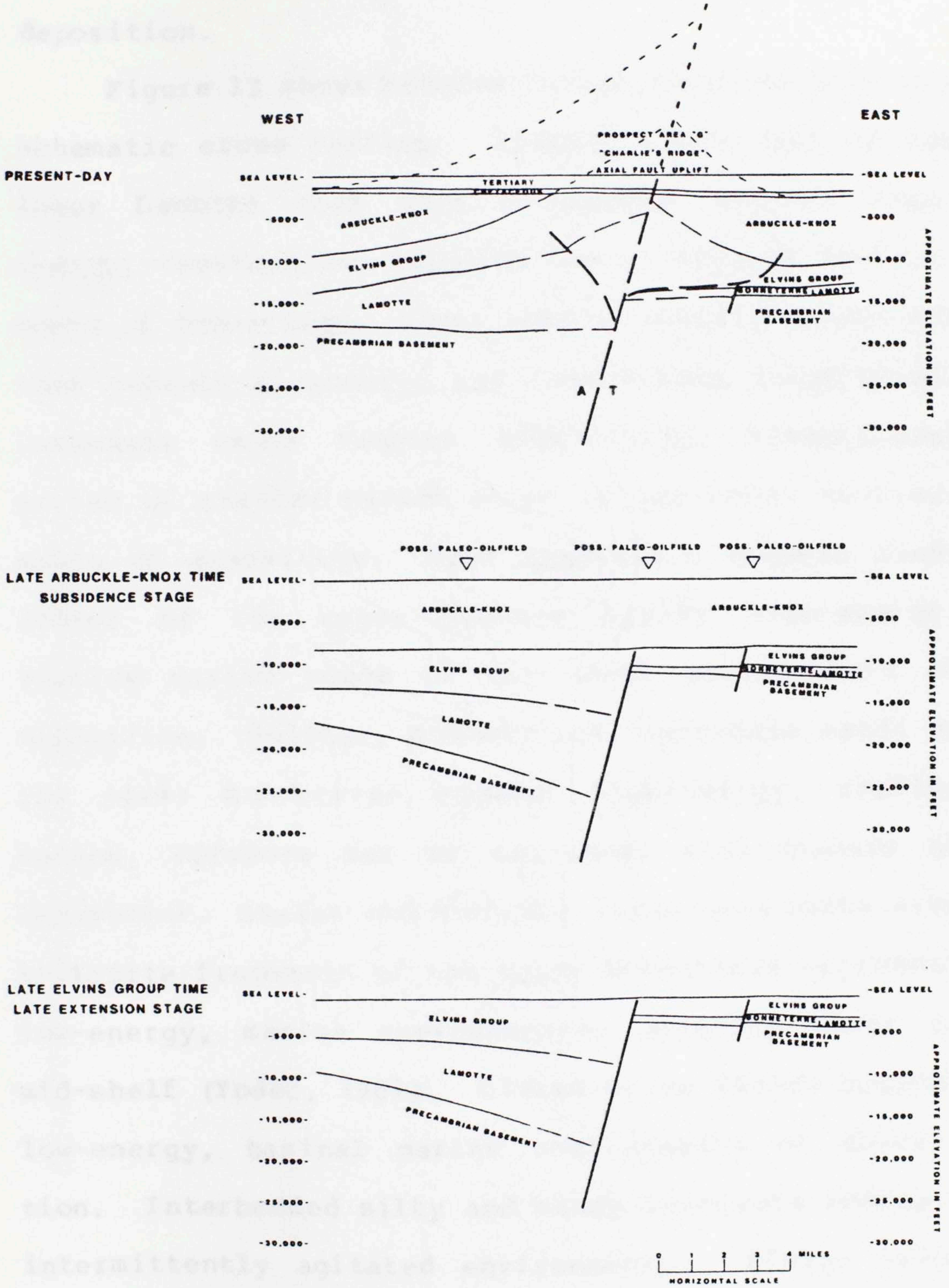


Figure 12.

pattern of continental, marginal marine, shallow marine, and basinal marine environments of deposition.

Figure 13 shows Potsdam facies relationships in a schematic cross section. Arkosic sandstones of the lower Lamotte that lack glauconite suggest high-energy, continental, alluvial fan or fluvial environments of deposition. Lower Lamotte arkosic sandstones that contain glauconite and interbedded dolomitized, carbonate sands suggest high-energy, transitional marine or shallow marine beach or bar-shoal environments of deposition. More quartzitic arkosic sandstones of the upper Lamotte typify high-energy, shallow marine beach or bar- shoal environments of deposition. Oolitic, dolomitized, carbonate sands of the lower Bonneterre suggest high-energy, shallow marine, offshore bar or bar-shoal environments of deposition. Shales and micritic limestones containing trilobite fragments of the upper Bonneterre represent low-energy, marine environments, possibly inner to mid-shelf (Yoder, 1981). Elvins Group shales suggest low-energy, basinal marine environments of deposition. Interbedded silty and sandy intervals indicate intermittently agitated environments. Elvins Group cores taken from the Dow Chemical #1 Garrigan well, Sec. 28-15N-10E, Mississippi County, Arkansas

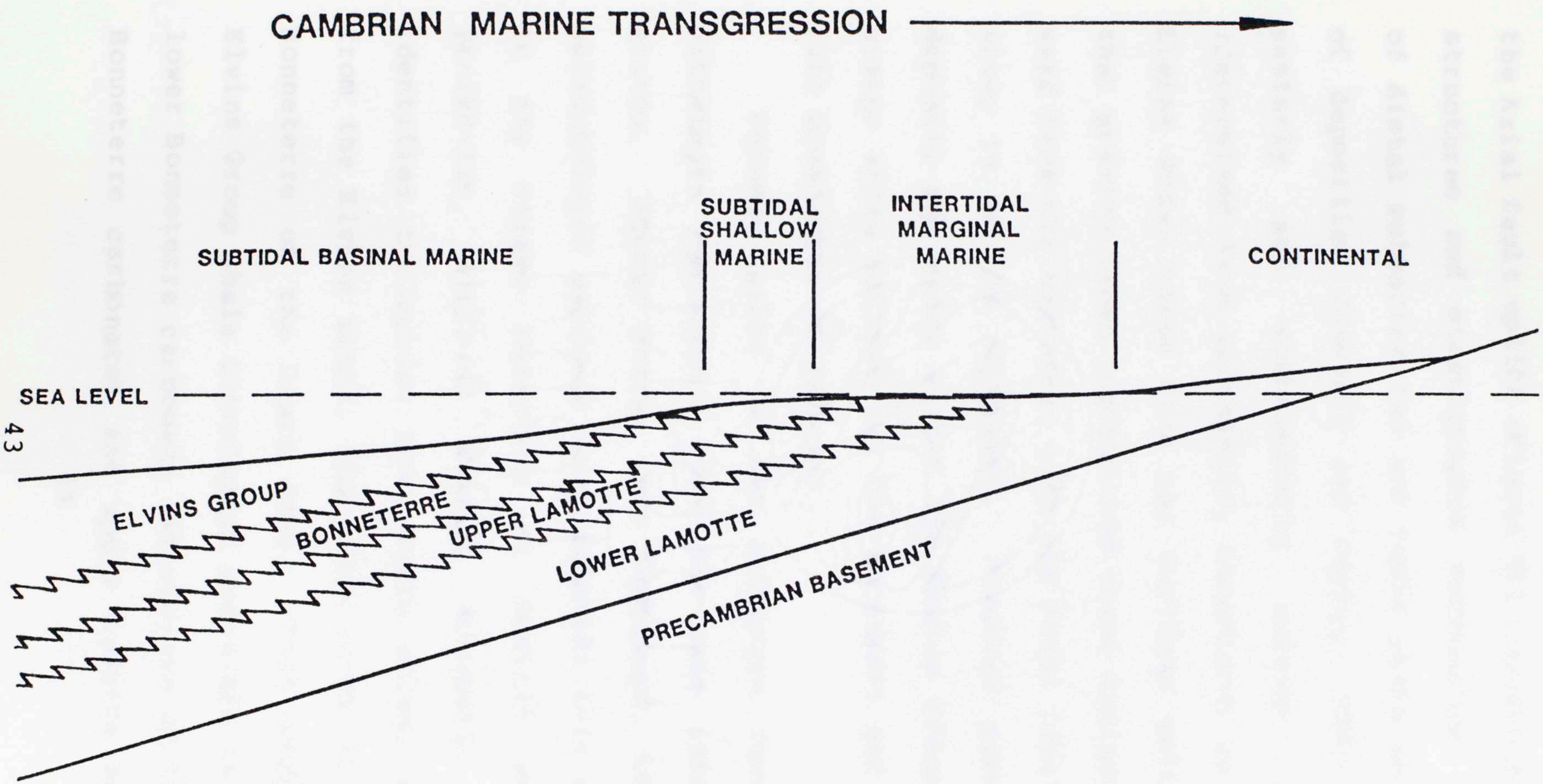


Figure 13. Schematic cross section showing Potsdam facies relationships.

[located in a deep basin area on the northwest flank of the Axial fault uplift (Figure 5)] contain sedimentary structures and stratigraphic successions indicative of distal submarine fan and basin plain environments of deposition (Vessell and Davies, 1982). Southeasterly and southwesterly current directions (determined from sedimentary structures in oriented, Elvins Group cores from the Garrigan well) suggest that gravity flows transported these sediments basinward from the northwest into the Axial fault and then along it to the southwest. Proximal submarine fan deposits may exist within the Elvins Group at fault scarps along portions of the northwest and southeast rift boundaries (Figure 14).

Potsdam units in the aulacogen have younger lithologic equivalents with the same names on the craton. Josiah Bridge (see Grohskopf, 1955) found paleontologic evidence that supports this contention in the Strake Petroleum #1 Russell well, Sec. 24-19N-11E, Pemiscot County, Missouri. Bridge identified trilobites from shale cores, apparently from the Elvins Group, that also occur in the lower Bonneterre of the Ozark dome. This suggests that Elvins Group shale lithologies correlate in time with lower Bonneterre carbonate lithologies on the craton. Bonneterre carbonates and upper Lamotte sandstones,

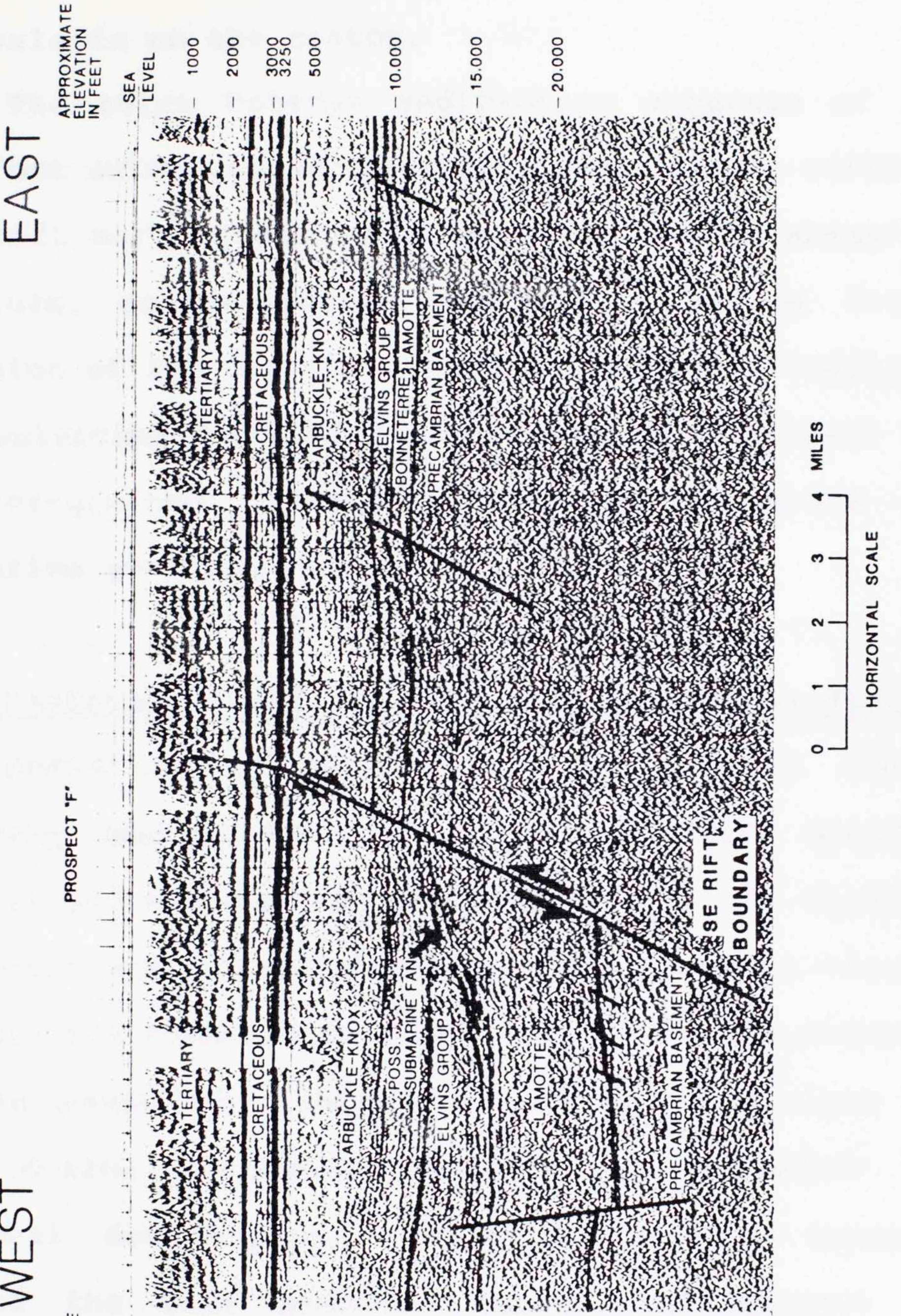


Figure 14. East-west seismic reflection profile across the southeast rift boundary in Crittenden County, Arkansas possibly showing a submarine fan complex.

penetrated beneath the Elvins Group shales in the Russell well also seem older than their lithologic equivalents on the craton.

The thick Potsdam sedimentary sequence of the Reelfoot aulacogen accumulated during active rifting. The rift margins initially provided source areas for immature, coarse-grained clastics. Marine transgression of the craton limited the sediment supply in the aulacogen to fine-grained, pelagic sediment and coarser-grained material carried basinward by submarine gravity flows.

Late Cambrian to Middle Ordovician Subsidence Stage

Cessation of major basement-involved normal faulting (except possibly along some rift bounding faults) and regional downwarping of both the Reelfoot aulacogen and its surrounding cratonic areas characterized the subsidence stage. Cooling and subsidence of the anomalous lithosphere that formed beneath the rift during extension provided the mechanism for regional downwarping. This downwarping extended beyond the rift bounding faults and allowed the formation of a broad and relatively unfaulted trough that overlies the graben. This post-extension subsidence corresponds to post-rifting, passive subsidence of the continental margins.

Post-extension subsidence began at the end of the Middle Cambrian and continued without major interruption until the Middle Ordovician. The thick Arbuckle-Knox carbonate sequence records this period in the Reelfoot area, suggesting a long period of widespread shallow marine deposition. Despite faster subsidence rates within the aulacogen, deposition generally kept pace with subsidence and shallow marine conditions prevailed across both the craton and the aulacogen. Greater subsidence rates and slightly deeper water tended to protect the trough sediments from frequent subaerial exposure, favoring limestone deposition in the aulacogen versus dolomite on the adjacent craton.

The Cambro-Ordovician Arbuckle-Knox Megagroup of the Reelfoot area is a thick time transgressive carbonate sequence composed predominately of limestones, marls, and dolomites with subordinate amounts of sandstone, shale, and chert. Regionally, the Arbuckle-Knox thins toward the shield areas by thinning of individual units and truncation at the top. Thicknesses for this megagroup within the Reelfoot aulacogen range from 5000 to 8000 feet.

Detailed studies of the Arbuckle in southern Oklahoma by Burgess (1968) and Gatewood (1978) suggest that most of the Arbuckle of that area was deposited in one of four basic shallow water marine environments. These four environments are (1) lagoonal (hypersaline, with anhydrite and dolomite), (2) lagoonal-supratidal complex (highly dolomitized with anhydrite and algalstromatolitic structures), (3) intertidal (mud flats, tidal channels, stromatolites and intertidal shoaling), and (4) subtidal (limestone, marls, with some intertidal shoaling). Lateral shifting of these four environments due to regional and local subsidence, sea level fluctuations, and sediment progradations produced a complex vertical succession.

These environmental interpretations seem applicable to the Arbuckle-Knox carbonates of the Reelfoot aulacogen. In both Oklahoma and the Reelfoot area, these four environments existed at different times in both the cratonic and trough areas; however, because of the increased subsidence rates experienced by the trough areas, the subtidal environment dominated there most often, favoring limestone deposition. The lagoonal, lagoonal-supratidal, and intertidal environments constituted a diagenetic terrain where dolomitization commonly occurred. These environments prevailed most often on the cratonic areas where slower subsidence rates favored dolomite formation.

Middle Ordovician to Late Pennsylvanian Transition Stage

The absence of middle and late Paleozoic rocks from the central portion of the Reelfoot aulacogen hinders interpretation of this period of the aulacogen's geologic history. Figure 8 shows a tectonic map of the region superimposed on top of a combined surface geologic map and generalized pre-Late Cretaceous subcrop map of the Mississippi Embayment. Interpretations for this time period are based on the stratigraphic record preserved in the southwestern and northeastern parts of the aulacogen and on data from surrounding regions. The Simpson, Trenton, Maquoketa, Hunton, Chattanooga, Mississippian chert and limestone, and Carboniferous clastic groups record this transition.

The Middle Ordovician to Late Pennsylvanian represents a period of continued regional subsidence of the aulacogen interspersed with episodes of mild deformation and uplift apparently resulting from the change from continental divergence to plate convergence and the associated plate interactions at the continental margins. Unconformities appear at the top of the Arbuckle-Knox, St. Peter, Trenton, Maquoketa, Hunton, and Mississippian clastics and may relate to this tectonic activity. The erosion of uplifts associated with the eastern orogenies (Taconic, Acadian, and Alleghanian) provided sediments for the Maquoketa Shale, Chattanooga Shale, and Carboniferous clastics respectively.

The Middle Ordovician Simpson Group records a complex regressive and transgressive marine depositional history. A major marine regression marked the end of Arbuckle-Knox deposition at the close of the Early Ordovician. This regression exposed a large portion of the previously marine area of the continent to subaerial erosion. The trough and cratonic areas that remained submerged received considerably more terrigenous clastic sediment than during Arbuckle-Knox deposition. With renewed marine transgression of the craton beginning during the Middle Ordovician (Tippecanoe transgression), units of the Simpson Group accumulated progressively further northward.

Simpson Group lithologies consist of argillaceous, silty, and sandy carbonates and quartz sandstones of the Everton Formation and well sorted, frosted, friable, quartz sandstones of the St. Peter Formation. Total thickness of the Simpson Group within the Reelfoot aulacogen may exceed 2,500 feet with the approximate thicknesses of the component formations ranging between 1,000 and 2,200 feet for the Everton and between 20 and 300 feet for the St. Peter.

Deposition of sandy and argillaceous carbonate units of the Everton occurred primarily in very shallow marine, shelf environments. Sandstones of the Everton and St. Peter formations typify shoreline and offshore bar environments of deposition. Some poorly sorted sandstones, shales, and sandy and argillaceous carbonates represent lagoonal environments of deposition that existed between some shoreline and offshore bar environments.

Second cycle sand grains within the Simpson Group have experienced considerable reworking, probably by both wind and wave action. Fluvial processes transported the sand across the craton from source areas to the north. Once in the marine environment, longshore currents carried the sand southwesterly, parallel to the ancient shoreline (Suhm, 1979). Small fluctuations in the sea level or minor vertical movements of the crust produced dramatic shifts in the shoreline and associated marginal marine environments.

The extensive Tippecanoe marine transgression of North America allowed widespread deposition of the Middle Ordovician Trenton Group carbonates. These carbonates overlie the St. Peter or Everton formations and underlie the clastics of the Maquoketa Group. Within the Reelfoot aulacogen, the Trenton Group consists of undifferentiated limestones and shaly limestones with a total thickness that may range from

75 to 1,400 feet.

Trenton Group carbonates generally represent very shallow, epeiric sea environments of deposition on the craton and possibly shallow marine environments within the aulacogen. Trenton lithologies may have been deposited directly above the Everton in areas that remained submerged during the marine regression that occurred at the end of the Early Ordovician. Those areas were not exposed to severe erosion and may not have had St. Peter Sandstone deposited on them.

The St. Peter Sandstone of the marginal areas, together with the Trenton carbonates of the shelf areas, formed a facies couplet of shoreline and off-shore, shallow shelf deposits. This facies pattern moved progressively northward during the Middle to Late Ordovician Tippecanoe transgression. Fluctuations in the relative sea level produced minor regressions; however, the main trend was toward marine transgression of the continent.

The Maquoketa Group represents a dramatic influx of fine-grained clastics that inhibited the formation of limestone over an extensive area during the Late Ordovician. Over much of the central Midcontinent, the Maquoketa Group consists of shaly units that lie unconformably between carbonates of the Trenton and Hunton groups. Where preserved in the Reelfoot aulacogen (in the northeast and southwest portions), the

Maquoketa comprises black to gray to green, fissile, calcareous, pyritic, and occasionally phosphatic shales. Some thin interbeds of shaly limestones or pyritic, glauconitic, fine-grained sandstones also occur. The thickness of the Maquoketa Group ranges from approximately 50 feet, in the southern and western parts of the Reelfoot aulacogen, up to 360 feet in the northeastern part. Erosion of cratonic uplifts associated with the Taconic orogeny provided the clastic sediment for the Maquoketa Group. The re-emergent Ozark uplands were source areas for much of the Maquoketa of the Reelfoot area.

Stable conditions prevailed across the Mid-continent during the interval between the Taconic and Acadian orogenies, allowing deposition of relatively pure carbonates and cherts. The depositionally wide-spread Hunton Group records this period (Early Silurian to Middle Devonian) lying unconformably between the Maquoketa and Chattanooga shales.

The present-day distribution and thickness of the Hunton Group varies considerably due to depositional patterns and to the occurrence of several erosional episodes during and after Hunton time. Presently, the thickness of the Hunton may range from 100 to possibly 600 feet in the southern portions of the Reelfoot aulacogen and up to 1000 feet in the northeasternmost portion where it is close to a Hunton depocenter located just to the north in the southern part of the Illinois basin. From limited data, it appears that only the Middle Devonian Penters Chert or younger Hunton units exist in the south-central part of the aulacogen. Older Hunton formations may have been removed by pre-Penters erosion; alternatively, the Penters Chert may contain thin and presently undifferentiated lower Hunton units of Early Silurian through Early Devonian age. The Penters Chert may represent a deep-water, sediment-starved environment of deposition.

Unconformities within and especially at the top of the Hunton reasonably resulted from the effects of the Acadian orogeny to the northeast. Reactivation of many local uplifts occurred at this time throughout the Midcontinent.

The areally extensive shales of the Chattanooga Group overlie the Hunton as deposited during a rapid marine transgression of North America during the Late Devonian and Early Mississippian. In the Reelfoot aulacogen, the Chattanooga Group consists of the Chattanooga Shale, a brownish-black to black, pyritic, radioactive, organic rich shale that ranges in thickness from 10 to 100 feet. The organic richness of the Chattanooga Shale indicates an oxygen-poor, stagnate, possibly coastal lagoon or deep marine environment of deposition. The erosion of highlands, produced as a result of the Acadian orogeny, supplied an influx of fine-grained sediments for deposition as Chattanooga Shale.

Clastic input diminished across the Midcontinent during the middle Mississippian. In the Reelfoot area, the Boone Chert (Osagean) lies conformably above the Chattanooga Shale and consists of calcareous to noncalcareous cherts with thin interbeds of cherty limestone and cherty shale. The total thickness of Boone Chert may reach 250 feet. The Boone Chert seems to represent a deep-water, sediment-starved environment of deposition. Shallow marine conditions existed during the Meramecian, allowing deposition of fossiliferous, argillaceous limestones, and calcareous shales conformably(?) above the Boone Chert.

A renewed influx of clastic sediments into the Reelfoot area began in the Late Mississippian and likely continued into the Permian. The Carboniferous clastic group partially records this period in the southwestern and northeastern portions of the aulacogen where it consists of shales, siltstones, and sandstones of the Chester, Morrow, and Atoka. These clastics came from elevated source areas to the northeast [possibly from the vicinity of Quebec (Sloss, 1979b)] that formed during the Alleghany orogeny. The Carboniferous clastic group in the Reelfoot aulacogen represents distal, basinal marine environments of deposition in a subsiding trough area. Deposition of younger Paleozoic rocks likely occurred in the Reelfoot area, but they have been removed by pre-Late Cretaceous erosion.

Late Paleozoic Compression Stage

Plate convergences and continental collisions associated with the assemblage of Pangea reasonably explain deformation within the Reelfoot area during the Pennsylvanian through Early Permian. The resulting regional stress patterns acted on zones of pre-existing crustal weakness in the Reelfoot region to produce various types of structural movements. This intracratonic deformation, in response to continental collision, resembles in some ways the deformation that extends deep into the Asian continent in response to its Cenozoic collision with India as discussed by Molnar and Tapponier (1975).

Extensive pre-Late Cretaceous erosion has removed large intervals of late and middle Paleozoic strata from much of the Reelfoot area making it difficult to precisely interpret the timing of late Paleozoic structural movements. Subsequent interpretations rely on structural and stratigraphic data from surrounding areas and postulated paleo-stress orientations based on published paleogeographic reconstructions.

Northwest to west-northwest oriented maximum regional compressive stresses presumably associated with the convergence between Laurentia and Gondwana (Figure 15) reasonably caused formation or reactivation of some northwest trending normal faults at the southern end of the Reelfoot aulacogen (Figures 16 and 17) and reactivation of the northeast trending Axial fault as a reverse-faulted uplift with a possible component of right wrenching (Figures 2, 3, 5, 11, 12, and 18).

The normal faulting shown in Figures 16 and 17 occurred between the Early(?) Pennsylvanian (age of the youngest preserved offset rocks) and Late Cretaceous, most likely during the Atokan. This Atokan faulting would have corresponded to a time of major normal faulting in the adjacent Arkoma and Black Warrior basins.

Formation of the Axial fault uplift took place sometime between the Early to Middle Ordovician (age of the youngest preserved deformed rocks) and Late Cretaceous, probably between Early Pennsylvanian and Late Permian, most likely during the middle Permian. The Axial fault uplift formed largely by compressive reactivation of extension stage normal faults. Figure 12 shows the sequential formation of the south-central portion of the Axial fault.

The Axial fault uplift has different charac-

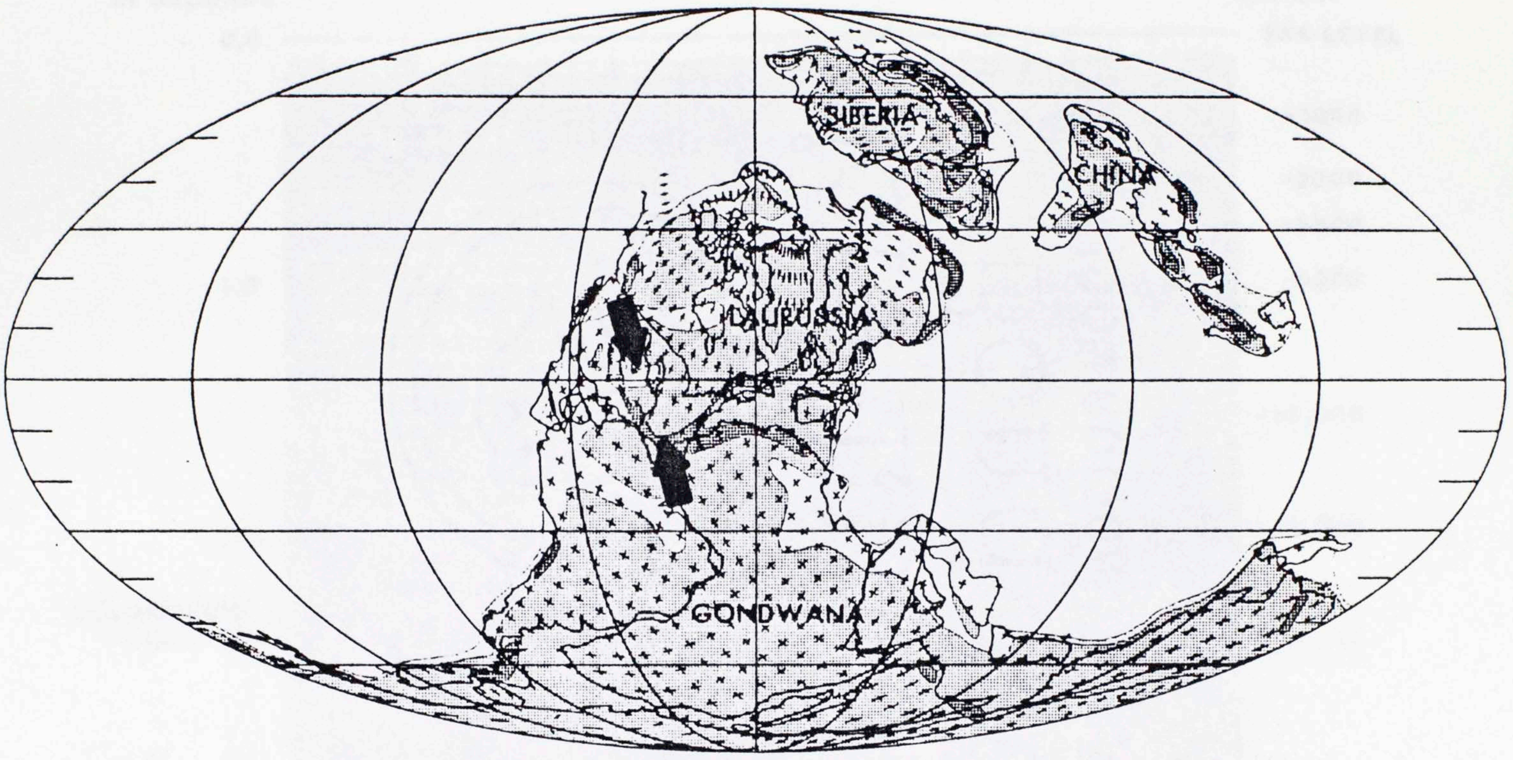


Figure 15. Middle late Carboniferous (Westphalian CD) paleogeographic reconstruction; dark stipple = mountains, medium stipple = lowlands, light stipple = shallow seas, unshaded = deeper seas, and arrows = postulated maximum regional compressive stress orientation (modified from Scotese et al., 1979 and Ziegler, 1981).

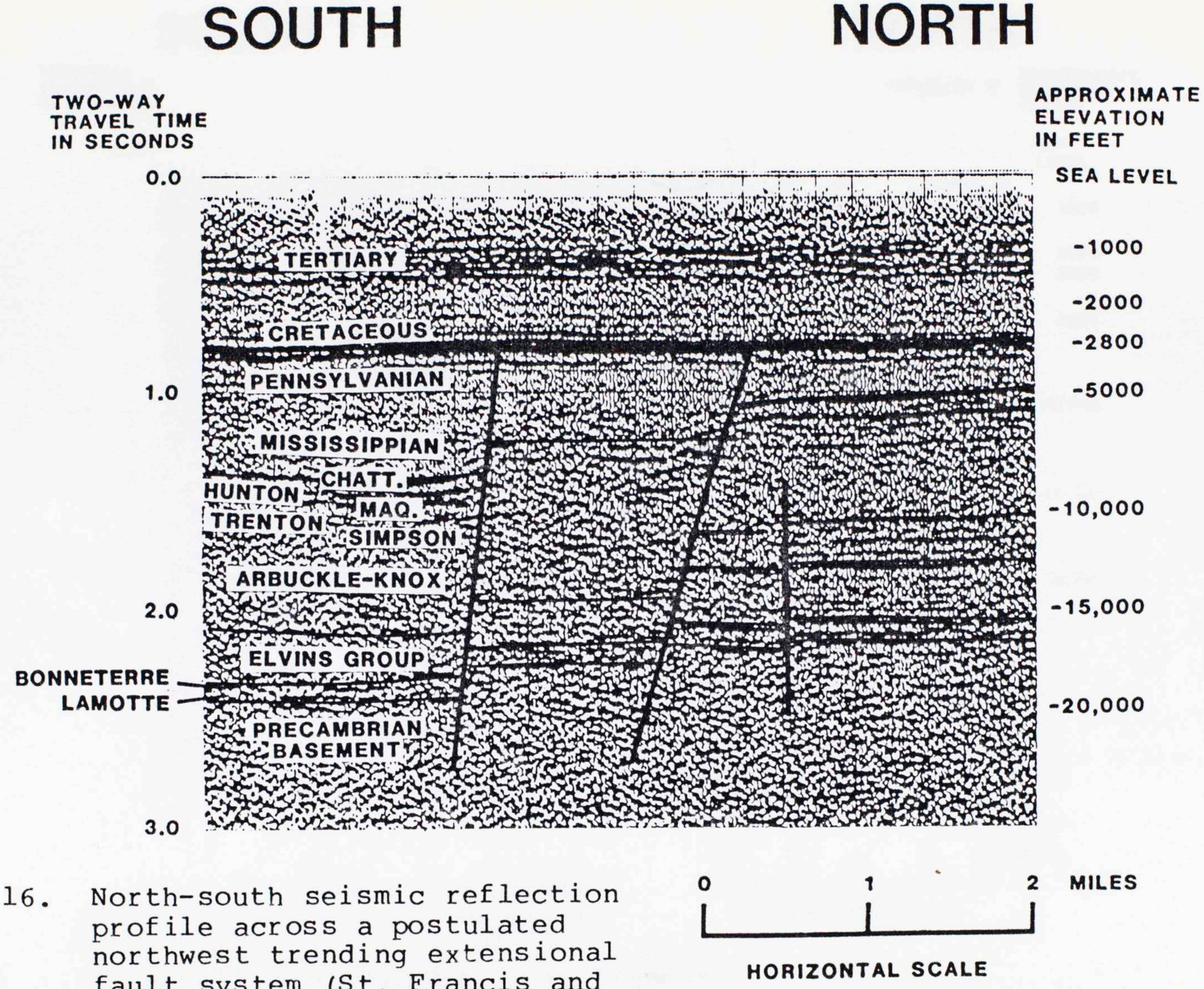


Figure 16. North-south seismic reflection profile across a postulated northwest trending extensional fault system (St. Francis and Cross Counties, Arkansas).

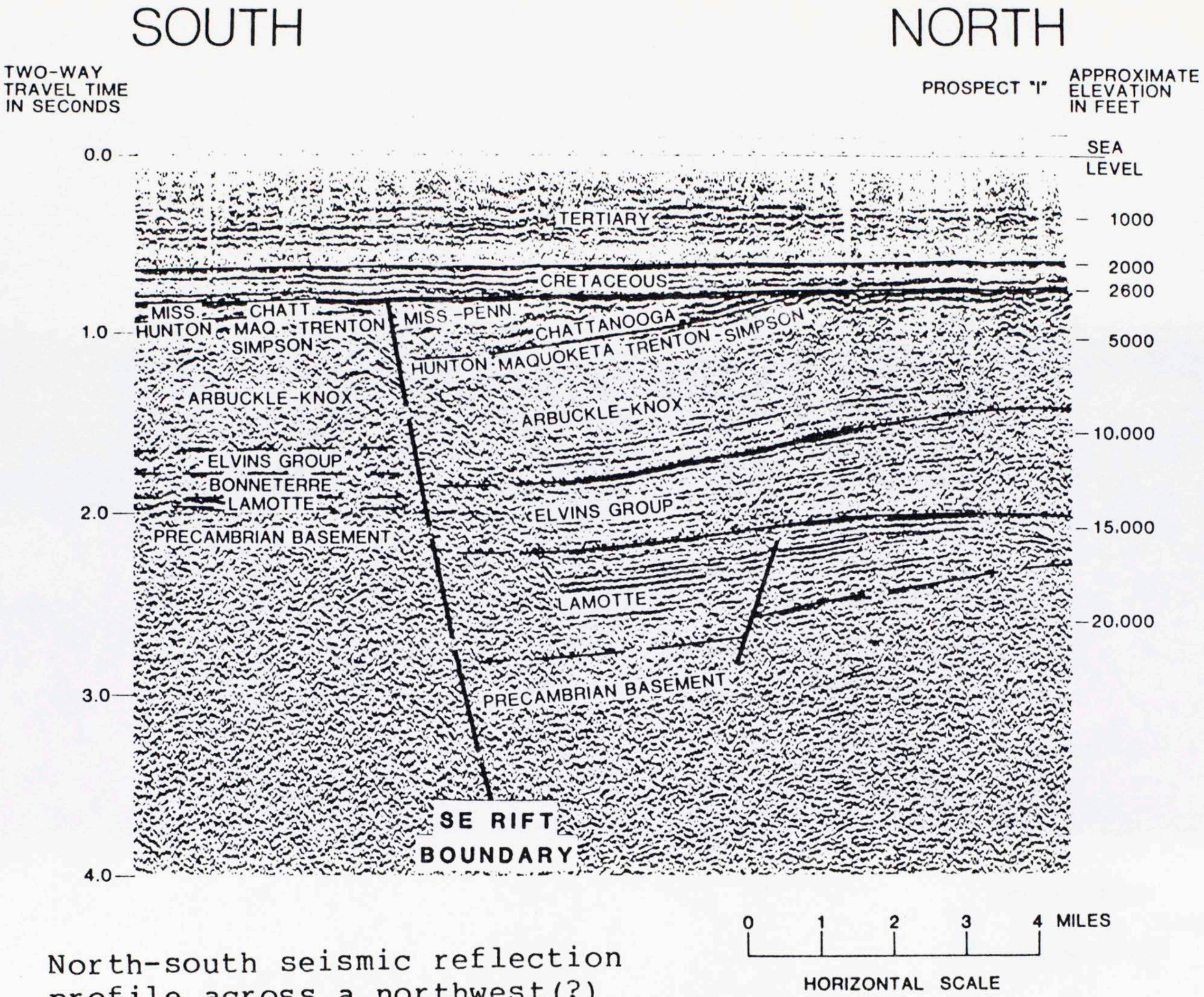


Figure 17. North-south seismic reflection profile across a northwest(?) trending segment of the southeast rift boundary (St. Francis and Cross Counties, Arkansas).

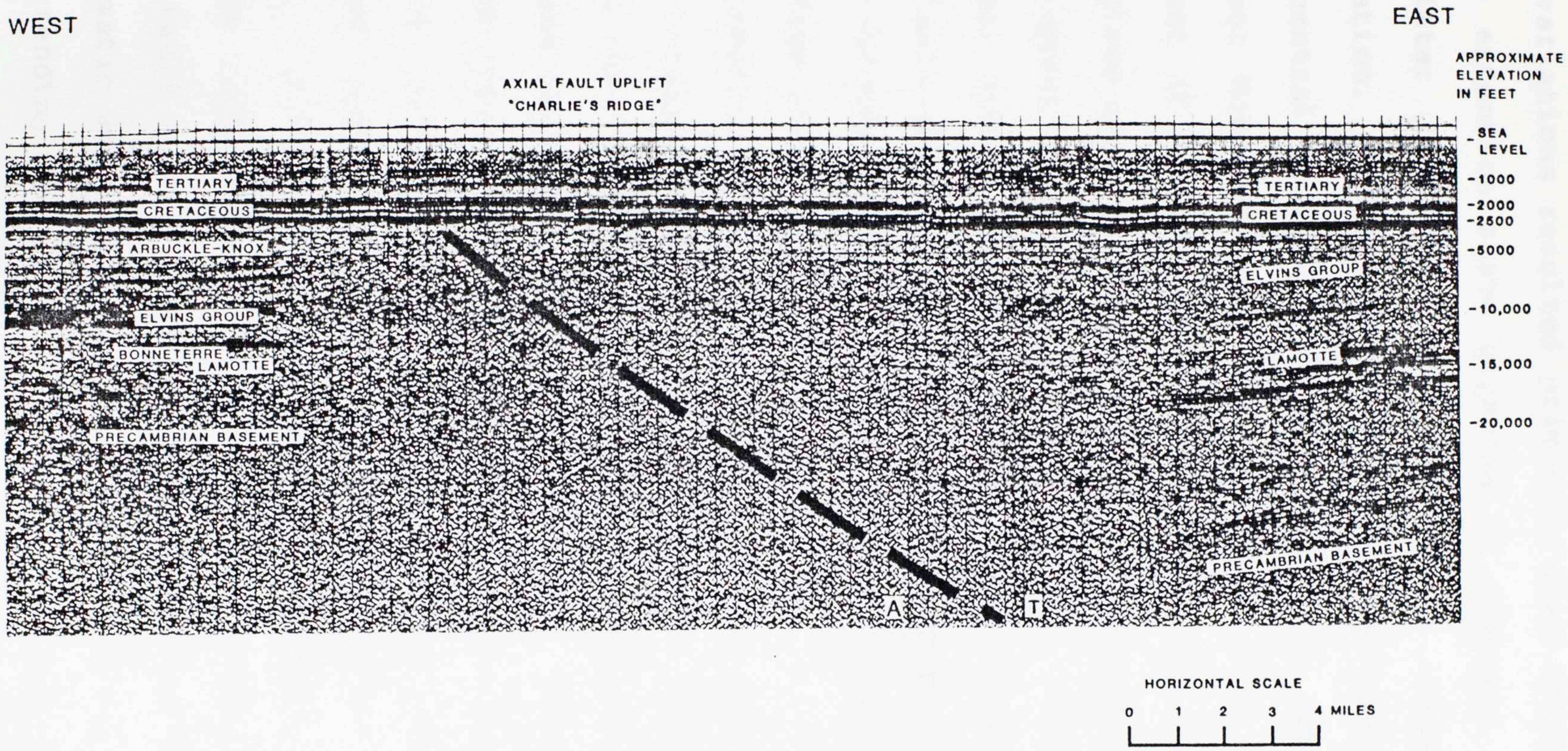


Figure 18. East-west seismic reflection profile across the Axial fault uplift (Dunklin and Pemiscot Counties, Missouri).

teristics along different segments of its length. These variations resulted primarily from differences in the extension stage geometry of basement blocks that later influenced the nature of compressive deformation. Reflection seismic profiles across the north-central portion of the Axial fault uplift in southeast Missouri show a deep basin area to the southeast of the uplift (Figure 18). The basement fault plane dips to the southeast. Compare Figure 18 with Figures 2, 3, 5, 11, and 12 that show cross sectional views of the south-central portion of the Axial fault uplift where the deepest basin areas lie to the northwest of the uplift and the basement fault plane dips to the northwest.

Formation of the Axial fault uplift during the middle Permian would have been concurrent with middle Permian structural movements in the area just to the north and east of the Reelfoot aulacogen that Nelson and Lumm (1984) described. Post-Early Permian reverse faulting (possibly due to compressive wrenching) occurred along the Rough Creek-Shawneetown fault system. Leonardian to possibly Guadalupian compressive right-wrenching occurred along the Cottage Grove fault system and Leonardian (Zartman et al., 1967) mafic dikes were emplaced along certain northwest trending fractures. These events seem interrelated and consistent with a common northwesterly oriented regional compressive stress.

Northeast oriented maximum regional compressive stresses [perhaps associated with the combined convergence of Gondwana, Laurentia, and Siberia (Figure 19)] possibly caused renewed extension along some northeast striking extension stage normal faults in the aulacogen, upwarp of the Pascola arch, and reverse faulting at the southern end of the Reelfoot aulacogen near the junction with the buried Ouachitas. Post-Arbuckle(?) and pre-Late Cretaceous normal faulting of some northeast trending faults shown in Figures 5,14, and 20 may relate to post-Early Permian normal faulting in the Fluorspar Area fault system, located at the northern end of the Reelfoot aulacogen. Some Fluorspar Area normal faults cut across and post-date northwest trending Leonardian mafic dikes (Trace and Amos, 1984). Schwalb (1982) believes the Pascola arch relates genetically to the normal faulting in the Fluorspar Area. The reverse faulting near the junction with the Ouachitas also may be post-Early Permian or it may have occurred during the Middle and Late Pennsylvanian Ouachita orogeny.

Late Cretaceous and Tertiary Subsidence

The Reelfoot aulacogen and surrounding areas may have been emergent from the latest Paleozoic until the latest Mesozoic when renewed subsidence began forming

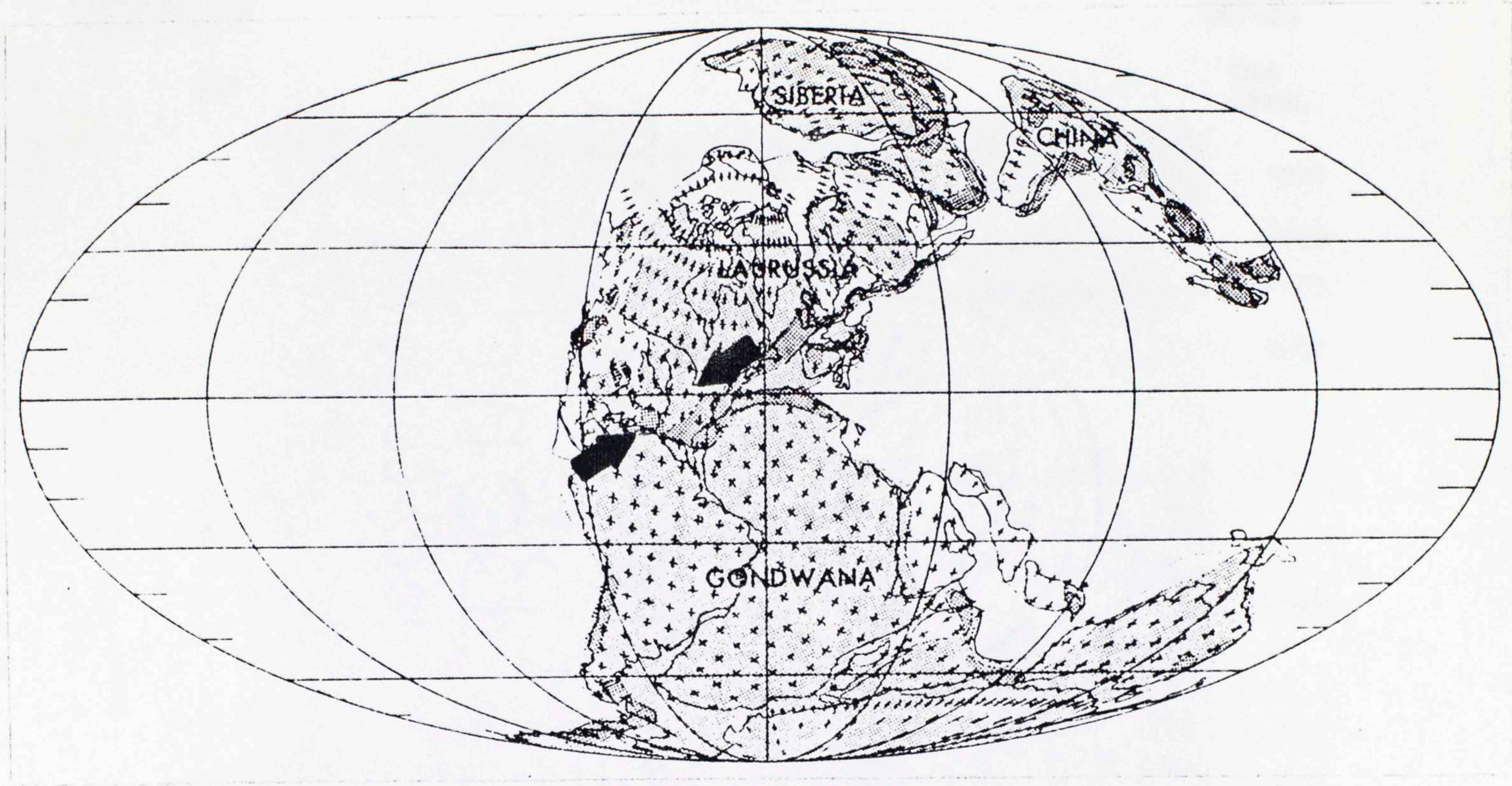


Figure 19. Early Late Permian (Kazanian) paleogeographic reconstruction; dark stipple = mountains, medium stipple = lowlands, light stipple = shallow seas, unshaded = deeper seas, and arrows = postulated maximum regional compressive stress orientation (modified from Scotese et al., 1979 and Ziegler, 1981).

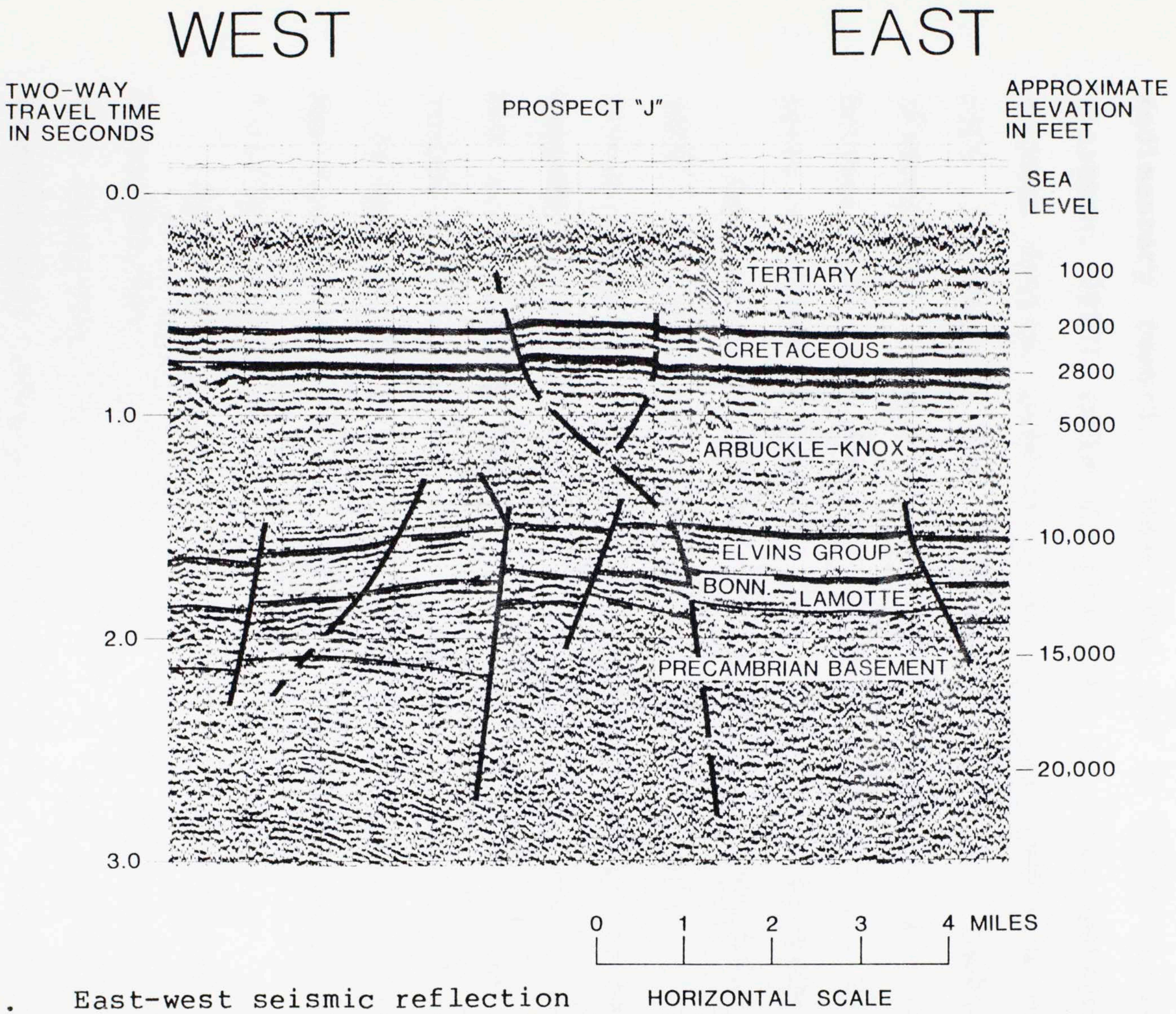


Figure 20. East-west seismic reflection profile from Mississippi County, Arkansas.

the Mississippi Embayment. A major unconformity separates the Paleozoic rocks from the overlying Late Cretaceous, Tertiary, and Quaternary strata of the Embayment Megagroup, leaving a significant gap in the sedimentary record. Near the end of this hiatus (Zartman, 1977) mafic plutons came up along certain ancient faults, especially at the intersections of rift boundaries and transverse trending faults (Figure 21). Kane et al. (1981) proposed a link between this late Mesozoic igneous activity and the onset of renewed subsidence that formed the embayment.

Coastal plain strata of the Embayment Megagroup infill the broad Mississippi Embayment trough. This trough opens to the southwest and becomes shallower towards its edges to the north, northwest, and east. Its axis roughly parallels the Mississippi River, trending south 30° west in contrast to the Reelfoot rift that trends approximately south 50° west. In the Reelfoot region, the Embayment Megagroup ranges in thickness from 0 to almost 4,000 feet.

Late Cretaceous strata of the Embayment Megagroup record a widespread marine transgression that coincided with a global rise in sea level. This transgression extended beyond the present boundaries of the embayment as demonstrated by the discovery of Late Cretaceous strata in outliers and sinkholes outside the embayment. In the upper Mississippi

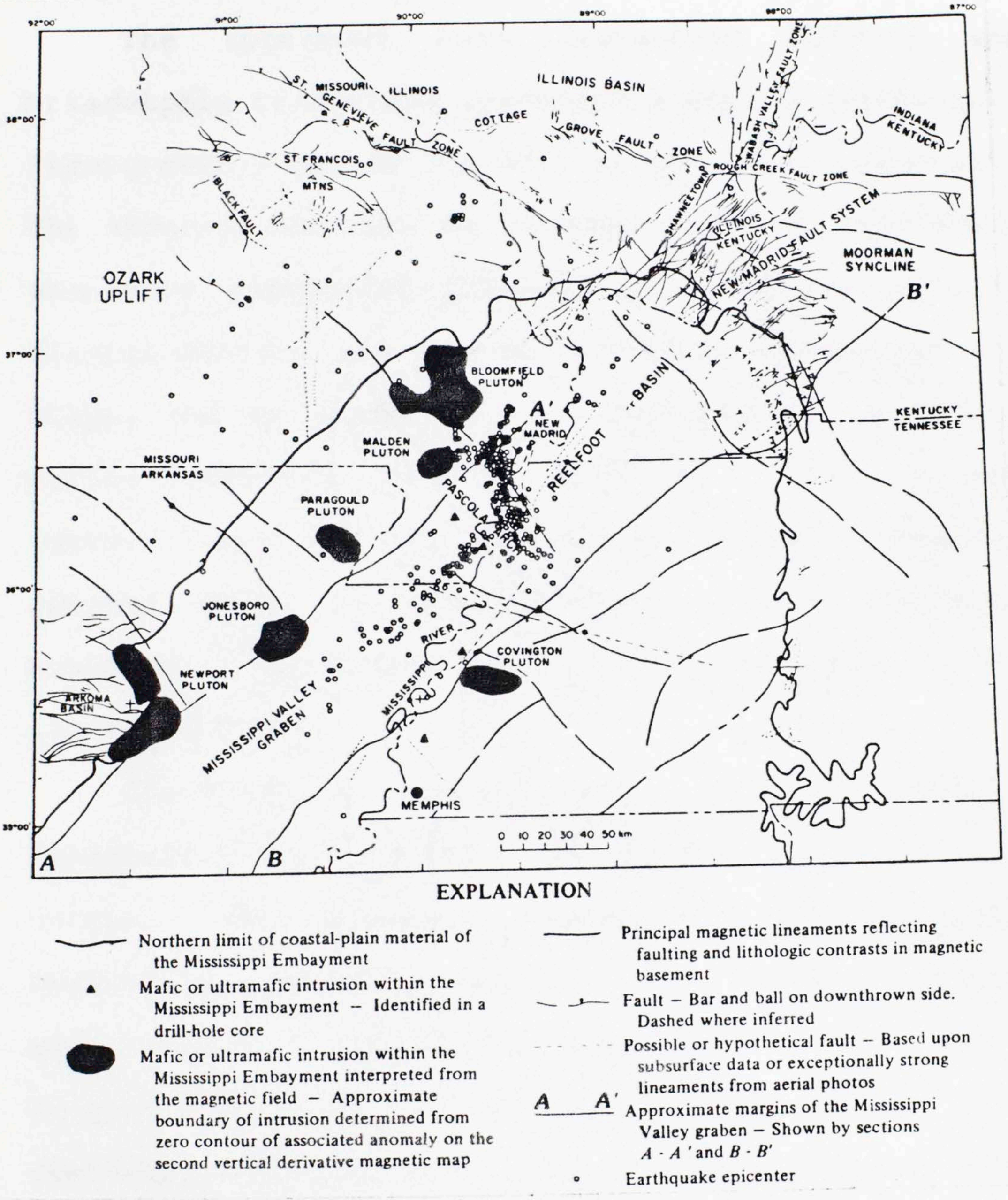


Figure 21. Seismotectonic map of the upper Mississippi Embayment (modified from Hildenbrand et al., 1982).

Embayment, Late Cretaceous marginal marine sandstones onlap a relatively smooth Paleozoic unconformity surface. Offshore marine shales, clays, and chalks overlie the basal sandstones.

The uppermost Late Cretaceous McNairy and Arkadelphia formations represent a marine regressive-transgressive period for much of the upper embayment. The McNairy consists of a lower unit of regressive nearshore sandstones overlain by a middle unit of fluvial-deltaic and partly estuarine sandstones and clays, and an upper unit of transgressive nearshore marine sandstones (Russell and Parks, 1975). At the northern end of the embayment, deltaic deposits compose most of the McNairy. The overlying Arkadelphia Formation consists of offshore marine sands and clays.

The Tertiary deposits of the upper Mississippi Embayment contain strata of both marine and non-marine origin. The Paleocene Clayton and Porters Creek formations represent marine and shallow marine environments of deposition respectively. The Eocene Wilcox, Claiborne, and Jackson groups include predominately fluvial and deltaic sediments with some interspersed marine deposits. The absence of all but earliest Oligocene and all Miocene deposits marks an unconformity between the Jackson Group and Pliocene fluvial deposits, whereas Quaternary fluvioglacial and fluvial sediments unconformably overlie the Pliocene.

Post-Paleozoic Faulting

Late Cretaceous, Tertiary, and Quaternary faulting occurred in some areas of the upper Mississippi Embayment. Generally these faults relate to reactivated extension stage basement faults that cut through overlying sedimentary strata. Some faults offset Late Cretaceous units and appear to die out into folds in the Tertiary section; whereas, others extend into or through Eocene units and indicate only post-Paleocene movements (Figures 5, 11, 14, 20, and 22).

The major post-Paleozoic compressive fault movements occurred during or after the Eocene and seem related to the post-Jackson Group unconformity. Variations in stratigraphic thickness of Late Cretaceous and Tertiary units across some faults suggest syndepositional faulting although a component of wrenching may have added complications. Late Cretaceous, Paleocene, and Eocene compressive faulting may relate to the plate tectonic forces responsible for the Laramide orogeny. Eocene compressive faulting may also relate to a worldwide plate reorganization that occurred then.

Earthquakes in the central part of the Reelfoot aulacogen (Figure 23) indicate continued faulting.

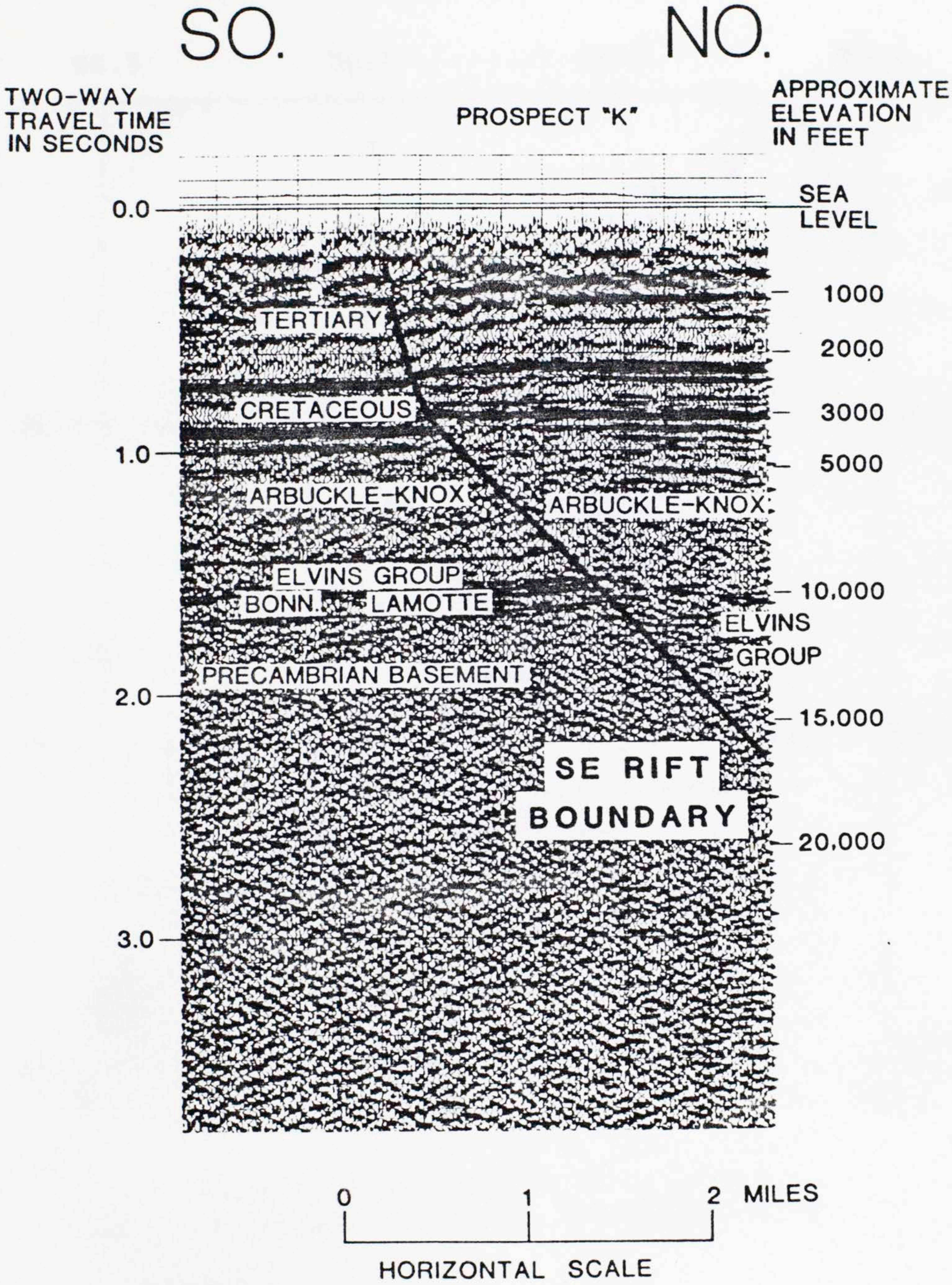


Figure 22. North-south seismic reflection profile across the southeast rift boundary (Crittenden County, Arkansas).

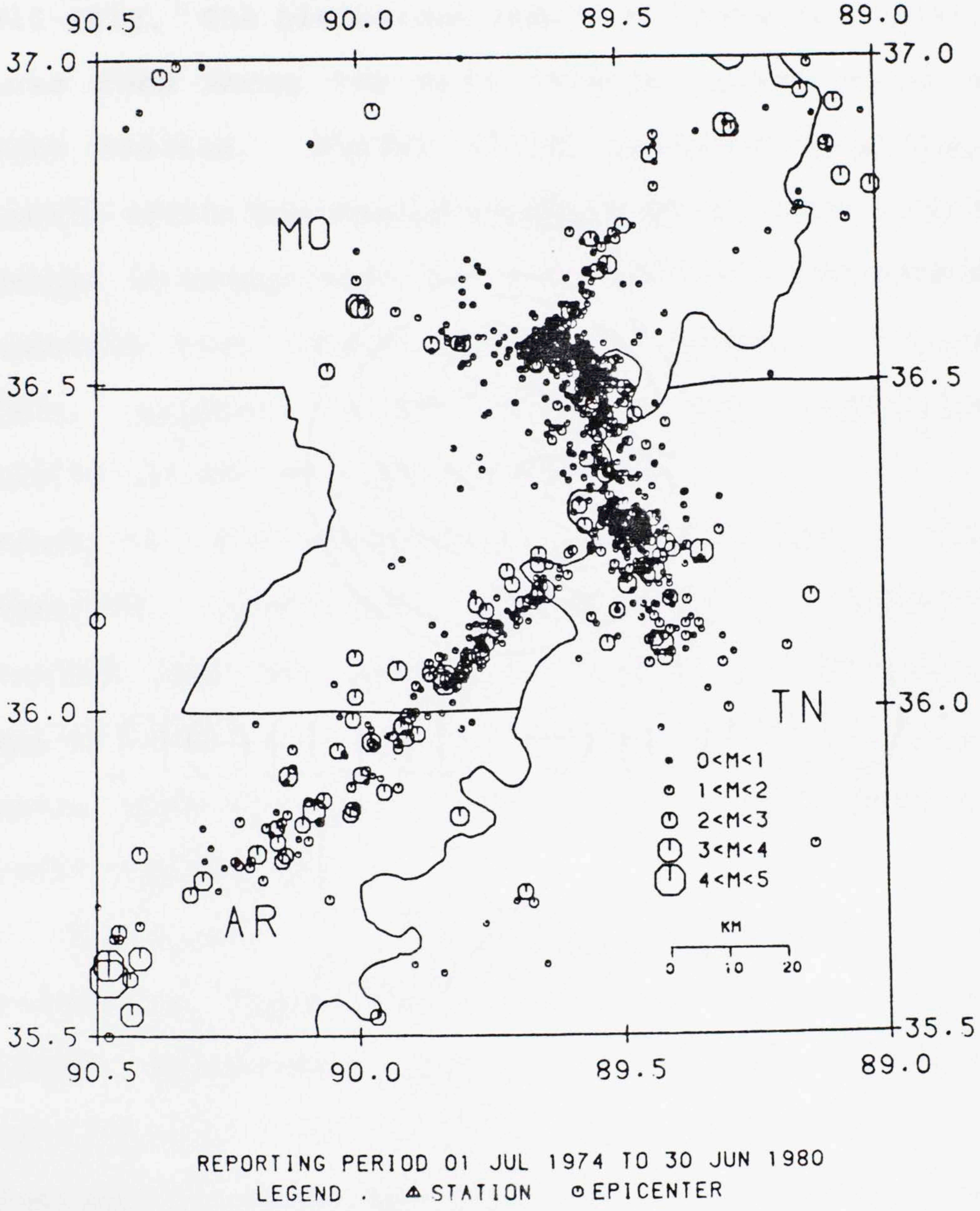


Figure 23. Plot of earthquakes located during a 6-year period (from Herrmann, 1981).

This seismically active area (named the New Madrid seismic zone after the settlement of New Madrid, Missouri) experienced a series of three major earthquakes and associated aftershocks during the winter of 1811-1812. The historical record of these earthquakes ranks them among the most intense quakes known to North America. Fuller (1912) compiled a geologic account of the New Madrid earthquakes and made note of changes in topographic features and the occurrence of sandblows that formed during the quakes. Stearns (1979) studied Recent faulting and topographic uplifts in the New Madrid area and related them to trends of microearthquake epicenters and gravity anomalies. Russ (1979) observed Holocene faults in trenches near New Madrid and Zoback (1979) related some of these movements to the reactivation of ancient faults (post-Paleozoic offsets) seen on seismic reflection profiles.

Earthquakes in the aulacogen result from the present-day stress field acting on certain ancient crustal weaknesses, usually reactivated extension stage faults. For example, earthquakes along the prominent northeast trending segment of the New Madrid seismic zone (Figure 23) relate to the northeast trending Axial fault uplift.

The south-central portion of the Axial fault uplift (Figures 2, 3, 5, 11, and 12) originated as a large extension stage normal fault with a deep basin to the northwest. Compressive reactivation of this segment of the Axial fault formed a reverse-faulted uplift in the late Paleozoic that continues to be seismically active today. Earthquakes along the south-central portion of the northeast trending segment of the New Madrid seismic zone occur in the basement on the northwest side of the Axial fault uplift since the basement fault plane dips to the northwest.

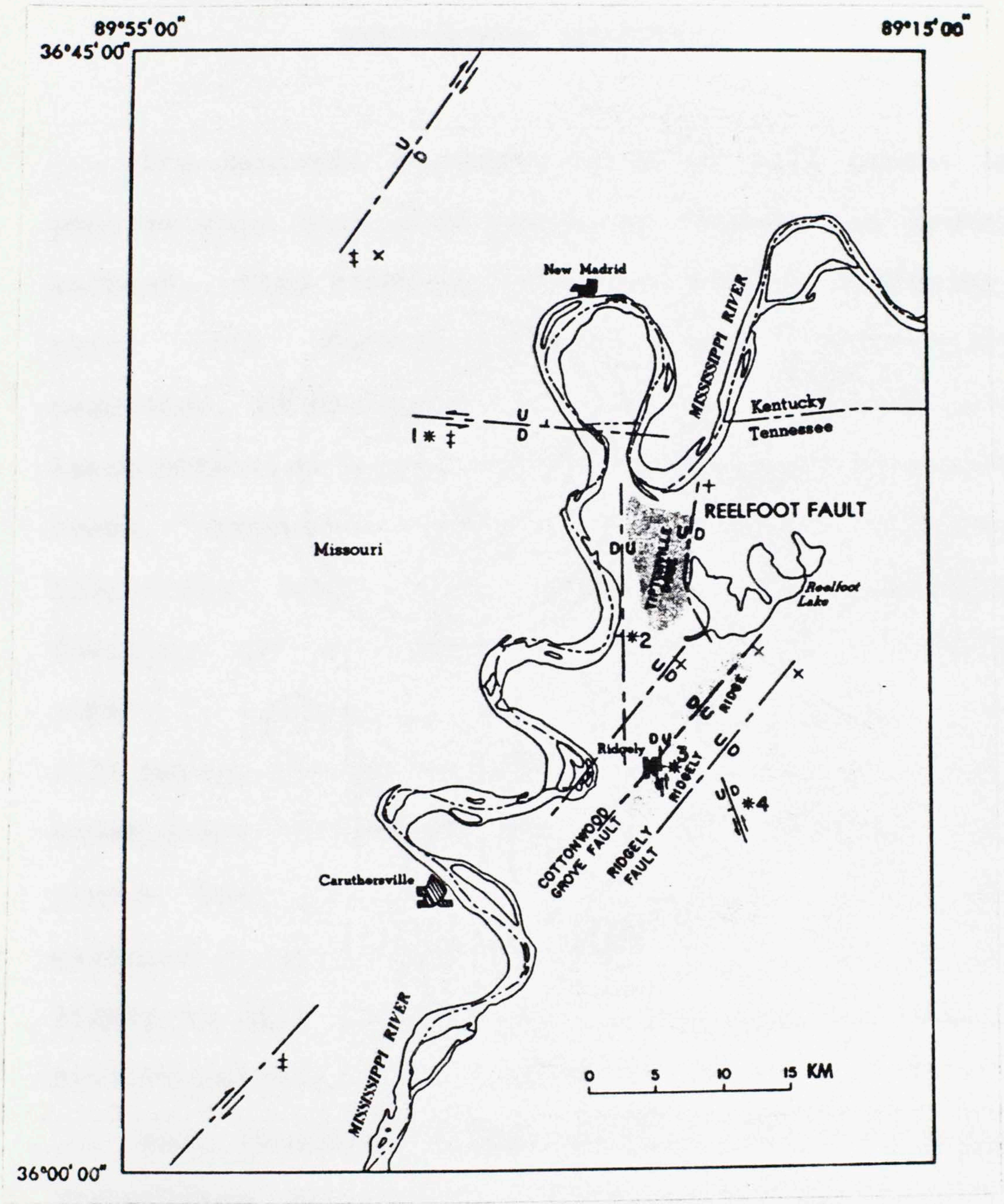
The north-central portion of the Axial fault uplift (Figure 18) apparently originated as a large extension stage normal fault with a deep basin to the southeast. Compressive reactivation of this segment of the Axial fault also formed a reverse-faulted uplift in the late Paleozoic that remains seismically active today. Earthquakes along the north-central portion of the northeast trending segment of the New Madrid seismic zone occur in the basement on the southeast side of the Axial fault uplift since the basement fault plane dips to the southeast.

Earthquake focal-mechanism solutions by Herrman and Canas (1978) show that right-lateral motion occurs along the northeast oriented seismic trend. Some apparent offsets (down to the southeast) or folding or both appear on some seismic profiles across the Axial fault in Cretaceous and Tertiary strata.

Figure 24 shows a generalized fault map with interpreted displacements for the central portion of the New Madrid fault complex. O'Connell et al. (1982) made this map on the basis of composite earthquake focal mechanism solutions and seismic reflection profiles (Zoback et al., 1980). They suggest that deformation in this region results from right-slip motion on two prominent northeast striking faults with an intervening area of complex deformation. I interpret these two northeast trending faults to be the Axial fault and possibly a reactivated segment of the northwest rift boundary.

Focal mechanism solutions (Herrmann and Canas, 1978; Herrman, 1979; and O'Connell et al., 1982) indicate a present-day regional maximum compressive stress oriented nearly east-west. Solutions for earthquakes near New Madrid, Missouri (located along the northwest trending segment of seismicity that links the two prominent northeast trends) indicate a local, northeasterly oriented maximum compressive stress. O'Connell et al. (1982) suggest that the local northeast oriented maximum compressive stress direction near New Madrid results from left-stepping offset of the major northeast trending, right-slip fault system.

Figure 24. Interpretive map of structures relating to seismicity in the central portion of the New Madrid fault complex. Long dashed lines represent faults inferred by focal plane solutions, and long and short dashed lines represent faults inferred from seismic reflection profiles; U, upthrown side; D, downthrown side; arrows indicate relative motion. A short dash perpendicular to the line indicates the direction of fault plane dip. Surface projections of the designated fault planes: *, from mechanisms 1, 2, 3, and 4 of O'Connell et al. (1982); ‡ inferred from Herrman and Canas (1978); X, inferred from the seismic reflection profiles of Zoback et al. (1980), and; +, inferred from the seismic reflection profiles of Zoback (1979). (from O'Connell et al., 1982).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TIPTONVILLE
Reelfoot Lake
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Ridgely
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RIDGELY
U
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U
D
4
COTTONWOOD GROVE FAULT
RIDGELY FAULT
Caruthersville
MISSISSIPPI RIVER
0
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Figure 24.

HYDROCARBON POTENTIAL

The geologic characteristics of rift basins in general make them good places to explore for hydrocarbons. They commonly have high thermal histories, thick and lithologically varied sedimentary sequences, an abundance of structural anomalies, and large potential traps. Diverse combinations of source rocks, reservoirs, seals, and structural features frequently occur over short lateral distances favoring the entrapment of hydrocarbons. Klemme (1980) states that 35% of all rift basins and 50% of productive rift basins contain known giant hydrocarbon fields. Nehring (1978) concludes that 25% of all moderately to extensively explored large grabens or failed rifts have or are likely to have ultimate oil recoveries of at least 3 billion barrels.

Many potential traps in the Reelfoot aulacogen (identified by seismic surveys) strongly resemble large productive traps found in other rift basins. Very few seismically located wells have tested this aulacogen. The Reelfoot aulacogen warrants further drilling in view of the large number of seismically defined, untested structural and stratigraphic anomalies, indications of source and reservoir potential from sparsely drilled deep wells, and reported hydrocarbon shows.

Source Rocks

Several possible hydrocarbon source rocks have been identified within the Reelfoot aulacogen, based on previously published information, standard organic geochemical references, and interpretations of analytical data obtained from limited well control. The following paragraphs discuss units with source potential denoted with an "S" in Figure 9.

Shaly units of the Middle Cambrian Elvins Group have good source rock potential in the deep, depositionally-thick basin areas. The Elvins Group extends in the subsurface over almost the entire region and its untruncated thicknesses may range from 500 to 10,000 feet. Elvins Group shales apparently have the highest levels of organic carbon in the deep basinal areas of the aulacogen where more rapid rates of sedimentation allowed better preservation of organic material. Deep water may have contributed to an oxygen-poor, restricted environment of deposition.

The Dow Chemical #1 Garrigan well, Sec. 28-15N-10E, Mississippi County, Arkansas, penetrated approximately 9,000 feet of Elvins Group shales, siltstones, and sandstones. This included shaly intervals totaling more than 2,400 feet that had total organic carbon levels greater than 0.5%, with some shales averaging as high as 1.82% T.O.C. Gas shows in the Elvins Group were recorded during the drilling of the Garrigan well and noncommercial quantities of combustible gas were tested through casing from 2 zones (near 4,300 and 7,900 feet), both associated with fractured intervals.

In Pemiscot County, Missouri, the Killiam #1 Pattinson well, Sec. 33-18N-13E, penetrated approximately 600 feet of Elvins Group basinal shales before reaching T.D. These shales contained an average of 0.57% total organic carbon with a high value of .94%.

Other Paleozoic units with source potential include the Late Ordovician Maquoketa shales, Devono-Mississippian Chattanooga Shale, and Mississippian and Pennsylvanian shales. The Chattanooga Shale showed an average richness of 2.58% T.O.C. in the Cockrell-Consolidated #1 Bunch well, Sec. 36-2N-1E, Lee County, Arkansas. Mississippian and Pennsylvanian shales in the Reelfoot area reasonably have source rock potential by analogy with source rocks of the same age in the adjacent Arkoma and Black Warrior basins.

The generally high heat history of the Paleozoic rocks of the aulacogen suggests gas potential; however, some areas might contain oil as well. Paleotemperatures appear highest in the south near the junction with the buried Ouachitas and locally near plutons. Cooler areas with better oil preservation potential possibly exist in some sub-basins and along segments of the rift's margins between plutons.

A Late Cretaceous shale found within the Basal Detrital Unit in the Dow Chemical #1 Wilson well, Sec. 14-12N-9E, Mississippi County, Arkansas, exhibited good oil source potential. This brownish-gray and coaly shale has good humic-lipid source character and extremely high levels of total organic carbon at 35.6%. The shale's level of maturity is in the oil window indicating capability for previous oil and gas generation.

Reservoir Rocks

The thick stratigraphic section preserved in the Reelfoot aulacogen has numerous and varied types of potential hydrocarbon reservoirs. Figure 9 shows units with matrix reservoir potential denoted with an "R". Additional possibilities exist for fracture enhanced reservoirs throughout the geologic section. The following paragraphs discuss the reservoir potential of specific formations by group or megagroup in chronological order.

Potential reservoirs in the Cambrian Potsdam Megagroup include the Lamotte Sandstone, Bonneterre dolomitic carbonate sands, and sandstones within the Elvins Group. Well data indicates that originally good porosities and permeabilities in the Lamotte Sandstone were lost by cementation in at least some areas; however, early oil accumulations may have prevented cementation in early formed traps. Secondary dissolution and fracturing may have recreated favorable reservoir conditions in some areas.

Dolomitized, carbonate sands of the Bonneterre Formation have good reservoir potential. The Bonneterre had intercrystalline and secondary leached dolomitic porosities of up to 10% in the Dow Chemical #1 Wilson well, Sec. 14-12N-9E, Mississippi County, Arkansas. Asphaltic material infilled some preexisting porosity. Circulation was lost in several zones in the Bonneterre during drilling of the U.S.B.M. #1 Oliver well, Sec. 29-22N-11E, New Madrid County, Missouri.

Elvins Group sandstones have the best reservoir potential in submarine fan complexes that apparently formed along some rift bounding fault scarps. Seismic techniques allow identification and mapping of these postulated fans that extend basinward up to 6 miles and attain thicknesses of up to approximately 5,000 feet (see seismic profile in Figure 14). The proximal portions of the fans should have the coarsest clastic material and the best porosities and permeabilities.

The thick Cambro-Ordovician Arbuckle-Knox Megagroup contains many different types of potential reservoirs. Matrix porosity types include intergranular, intercrystalline, and leached vugular porosity in carbonates, and intergranular porosity in quartz sandstones. Asphaltic material infilled some pre-existing porosity in the lower Arbuckle-Knox of the Benedum Trees #1 Mack well, Sec. 3-15N-12E, Mississippi County, Arkansas and the Dow Chemical #1 Wilson well, Sec. 14-12N-9E, Mississippi County, Arkansas. Unconformities often separate individual formations within the Arbuckle-Knox carbonate sequence and these unconformities have reservoir potential where the underlying surface experienced dissolution and leaching and where basal sandstones overlie the unconformities. The shelf and hingeline areas reasonably contain more pronounced unconformities than do the deep basins.

When drill stem tested, permeable units near the base of the Potosi Formation in the Dow Chemical #1 Wilson well yielded saltwater at a rate of 148 bbls./day. Yoder (1981) found intercrystalline and leached vugular porosities ranging from 5 to 10% in carbonates of the upper Potosi in the Wilson well.

Quartz sandstones and oolitic, carbonate sand limestones near the Potosi-Eminence boundary exhibited porosities of 10 to 20%. The Potosi-Eminence carbonates include one interval that experienced lost circulation and one interval that flowed water at a rate of 5,000 bbls./day during the drilling of the Strake #1 Russell well, Sec. 24-19N-11E, Pemiscot County, Missouri.

A permeable interval in the Eminence Formation of the Big Chief #1 Taylor well, Sec. 19-5S-7E, Gibson County, Tennessee, took water from an undetermined lower source. Salt water flowed from Eminence carbonates in the Benedum Trees #1 Mack well, Sec. 3-15N-12E, Mississippi County, Arkansas, at a rate of 2,400 bbls./day. The Eminence in the Mack well also contained asphaltic material that accumulated on the cable tool line.

Water flowed from the basal Gunter Sandstone Member of the lower Gasconade in the Big Chief #1 Taylor well, Gibson County, Tennessee. Yoder (1981) found intercrystalline porosities of 10% in lower Gasconade dolomites in the Dow #1 Wilson well, Mississippi County, Arkansas. The Wilson well also had intergranular porosities of 5 to 15% in quartz sandstones of the Roubidoux Formation. Drill stem testing of the Shell #1 Davis well, Sec. 17-L-16, Crittenden County, Kentucky, recovered salt water from permeable intervals in the Gasconade and in undifferentiated upper Arbuckle-Knox carbonates at rates of 1,500 and 950 bbls./day respectively. Circulation was lost in a permeable zone of the upper Arbuckle-Knox during drilling of the South Central #1 Cherry well, Sec. 8-B-14, Calloway County, Kentucky.

Potential reservoirs within the Middle Ordovician Simpson Group include Everton dolomites with intercrystalline or vugular porosity and Everton and St. Peter sandstones. Everton gas production was discovered in the Moran #1 Reaper well, Sec. 12-8N-8W, White County, Arkansas with an approximate flow rate of 500,000 cu. ft./day through a 1/4 inch choke. The Pennzoil #1 Morris well, Sec. 15-8N-1W, Woodruff County, Arkansas, encountered drilling breaks, lost circulation, and a gas show while drilling through a 300 foot thick interval of St. Peter Sandstone.

Other possible Paleozoic reservoirs include porous Middle Ordovician Trenton carbonates, Devonian Hunton carbonates and cherts, Mississippian carbonates and cherts, and Mississippian and Pennsylvanian sandstones. Equivalents of these units produce elsewhere in the Midcontinent and Pennsylvanian and Mississippian sandstones produce in the adjacent Arkoma and Black Warrior basins.

The best potential reservoirs in the Embayment Megagroup include the Late Cretaceous Basal Detrital

Unit and the McNairy Formation, both dominately composed of porous and permeable sandstones overlain by shaly units. Tertiary Wilcox sandstones also have reservoir potential and hydrocarbon shows have been reported from the Wilcox in some wells.

Drilling Prospects

The Reelfoot aulacogen contains numerous prospective structural and stratigraphic anomalies comprising features formed during early Paleozoic crustal extension and subsidence as well as late Paleozoic, Late Cretaceous, and Tertiary compression. Many of these anomalies relate directly to basement faults.

Potential traps, identified seismically, that formed during early Paleozoic extension and subsidence include horst-block highs, compaction folds over block edges, structural and stratigraphic traps closed against faults, stratigraphic traps over block edges and along hingelines, and alluvial and submarine fans located along some fault scarps. Some specific examples of these types of prospects in the Reelfoot rift include the following: Prospect A (Figure 5), a faulted, rift-bounding, block-edge structure covered by Arbuckle-Knox carbonates and possibly associated with depositional buildups along a hingeline; Prospect B (Figure 5), a faulted, block-edge structure covered by Arbuckle-Knox carbonates; Prospect C (Figure 5), a fault-bounded, horst-block high covered by Arbuckle-Knox carbonates; Prospect Lead Area D (Figure 5), possibly a closed structural high located along a rift-bounding hingeline, updip from a deep, hydrocarbon source basin (note also the possibilities for stratigraphic pinchouts within the Elvins Group and facies changes within the Arbuckle-Knox carbonates); Prospect E (Figure 25), a broad anticline in a deep basin area, apparently folded over faults in the basement; and Prospect F (Figure 14), a seismically interpreted submarine fan complex in the Elvins Group that lies along a portion of a southeast rift-bounding fault scarp. Many of these potential traps strongly resemble productive traps found in other rift basins such as the well illustrated examples given by Harding (1984) for the Sirte basin, Libya; Gulf of Suez, Egypt; and Viking graben, North Sea.

Potential traps, identified seismically, that formed during late Paleozoic compression include forced-folds, reverse-faulted anticlines, wrench-generated uplifts, horst-block highs, and traps closed against faults. Some specific examples of these types of prospects in the Reelfoot rift include the following: Prospect Area G (Figures 5, 11, and 18 of the Axial fault uplift or "Charlie's Ridge"), a large reverse-faulted uplift, possibly right wrench-

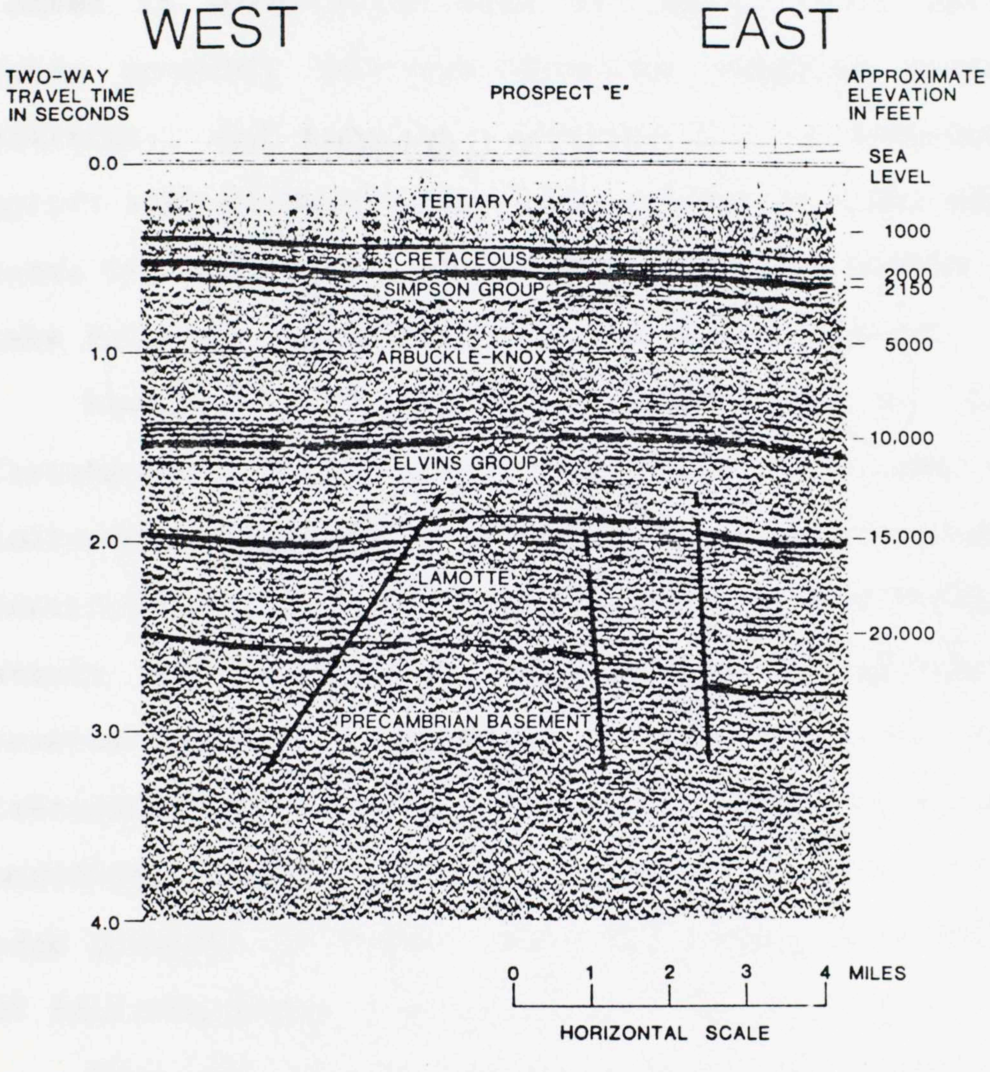

Figure 25. East-west seismic reflection profile from Poinsett County, Arkansas.

related, that formed in part by the compressive reactivation of a major extension stage normal fault (probably contains fracture enhanced permeabilities in the flanks and core of the uplift); Prospect H (Figure 26), a deep-basin, faulted anticline that formed in association with the Axial fault uplift (also probably contains fracture enhanced permeabilities); and Prospect I (Figure 17), a deep-basin uplift that formed during local tilting of a sub-basin (note the truncation trap possibilities for middle and late Paleozoic units on the flank of the uplift).

Potential traps that formed during Late Cretaceous and Tertiary compression include the following: Prospect J (Figure 20), a fault-bounded, forced-fold anticline in Late Cretaceous and Tertiary strata and Prospect K (Figure 22), an apparently reverse-faulted, forced-fold anticline in Late Cretaceous and Tertiary strata that overlies a rift-bounding, normal-faulted, structurally high, block-edge prospect at depth. Note the reactivated aspect of faulting associated with these two prospects.

Many of the potential traps that formed by compression look similar to inverted extensional basin features shown by Davis (1983) for the Gippsland basin and by Harding (1983) for the South Sumatra basin. The Axial fault uplift resembles compressive

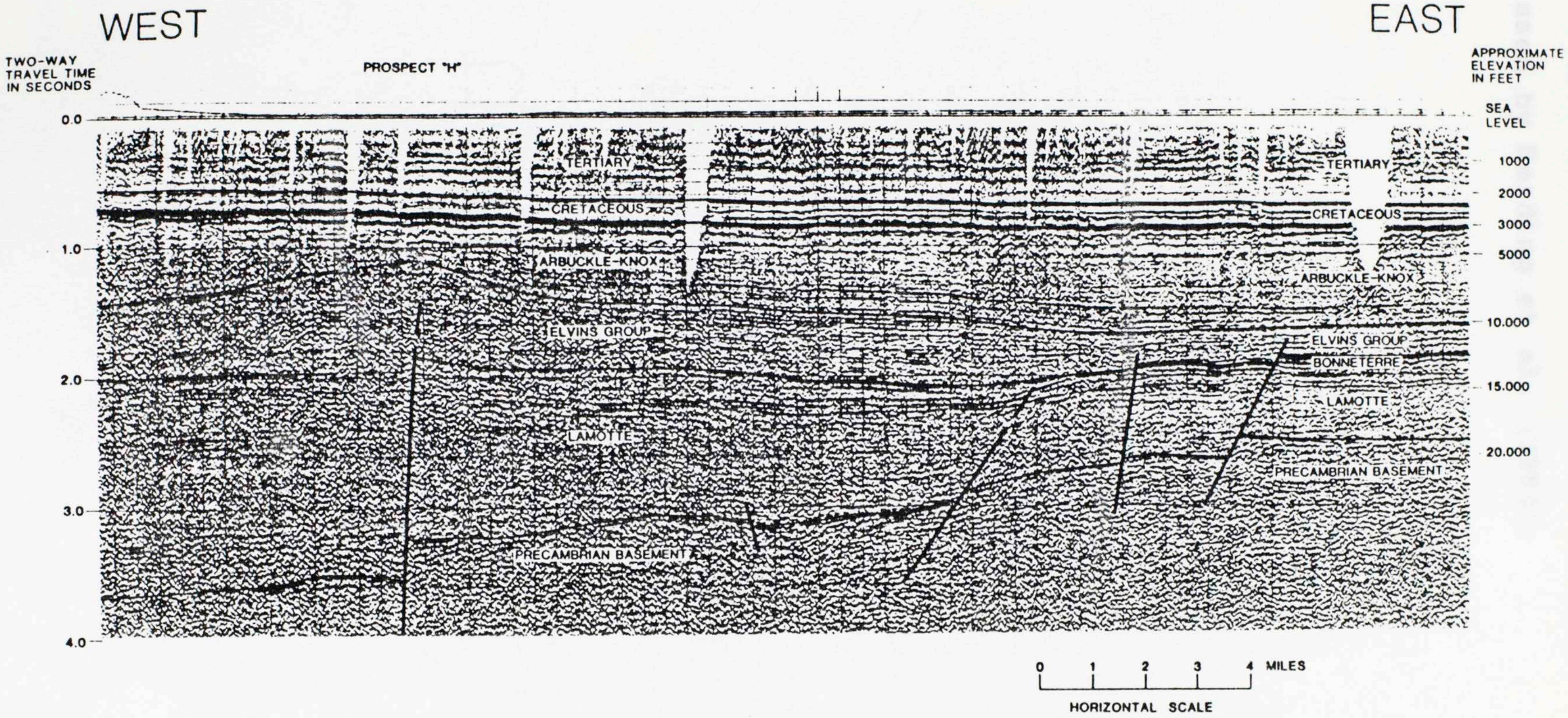

Figure 26. East-west seismic reflection profile from Crittenden and Poinsett Counties, Arkansas.

wrench uplifts of the Ardmore basin, Oklahoma, discussed by Harding et al. (1983)

CONCLUSIONS

Subsequent numbered paragraphs summarize the conclusions drawn from this thesis research.

1. Seismic reflection data, tied to deep well data, confirm the presence of a deep, early Paleozoic failed-rift basin (Reelfoot aulacogen) concealed beneath the gently dipping coastal plain strata of the Mississippi Embayment.

2. The Reelfoot aulacogen contains a sedimentary section thicker than 30,000 feet in places.

3. Regional lithospheric plate movements affect the interiors of continents as well as their exteriors, especially along lines of pre-existing crustal weakness.

4. Many similarities exist between the geologic history of the Reelfoot aulacogen and the coeval histories of the Paleozoic continental margins of North America.

5. The geologic history of the Reelfoot aulacogen lends itself to subdivision into stages of extension, subsidence, and compression that closely parallel similar stages of tectonic activity at the

continental margins.

6. Latest Precambrian to Late Cambrian extension initiated rifting to form the early Paleozoic continental margins of North America along with several failed-rift basins including the Reelfoot, Rome, Rough Creek, and southern Oklahoma rifts.

7. Active rifting in the Reelfoot area reasonably began in the latest Precambrian and continued through the Middle Cambrian. During this time, the rift area experienced crustal stretching, extension faulting, regional subsidence, marine transgression, and sedimentary infilling.

8. The thick Potsdam Megagroup of the Reelfoot aulacogen records graben infilling and great variations in its thickness reflect relative movements across syndepositional basement normal faults that "grew" during rifting.

9. The vertical succession preserved as the Potsdam Megagroup (lower Lamotte, upper Lamotte, Bonneterre, and Elvins) represents landward shift of a persistent facies pattern of continental, marginal marine, shallow marine, and basinal marine environments of deposition.

10. Potsdam units in the Reelfoot aulacogen have younger lithologic equivalents with the same names on the craton.

11. Cessation of major basement-involved normal faulting (except possibly along some rift bounding faults) and regional downwarping of both the Reelfoot aulacogen and its surrounding cratonic areas characterize a Late Cambrian to Middle Ordovician subsidence stage.

12. The Late Cambrian to Middle Ordovician subsidence stage produced downwarping that extended beyond the rift bounding faults and allowed the formation of a broad and relatively unfaulted trough that overlies the graben. This post-extension subsidence corresponds to post-rifting, passive subsidence of the continental margins.

13. The thick Arbuckle-Knox carbonate sequence records the Late Cambrian to Middle Ordovician subsidence stage in the Reelfoot area, representing widespread shallow water marine deposition. Greater subsidence rates and slightly deeper water tended to protect the trough sediments from frequent subaerial exposure, favoring limestone deposition in the aulacogen versus dolomite formation on the craton.

14. The Middle Ordovician to Late Pennsylvanian represents a transition stage of continued regional subsidence interspersed with episodes of mild deformation and uplift apparently resulting from the change from continental divergence to plate convergence and the associated plate interactions at the

continental margins. Unconformities appear at the top of the Arbuckle-Knox, St. Peter, Trenton, Maquoketa, Hunton, and Mississippian clastics and may relate to this tectonic activity. The erosion of uplifts associated with the eastern orogenies (Taconic, Acadian, and Alleghanian) provided sediments for the Maquoketa Shale, Chattanooga Shale, and Carboniferous clastics respectively.

15. Late Cretaceous and Tertiary subsidence allowed deposition and preservation of strata of the Embayment Megagroup in the Mississippi Embayment.

16. Late Cretaceous, Tertiary, and Quaternary faulting occurred in some areas of the Reelfoot aulacogen. Generally, these faults relate to reactivated extension stage basement faults that cut through overlying sedimentary strata.

17. Some post-Paleozoic faults offset Late Cretaceous units and appear to die out into folds in the Tertiary section; whereas, others extend into or through Eocene units and indicate only post-Paleocene movements.

18. The major post-Paleozoic compressive fault movements occurred during or after the Eocene and seem related to the post-Jackson Group unconformity.

19. Earthquakes in the Reelfoot aulacogen result from the present-day stress field acting on certain ancient crustal weaknesses, usually re-

activated extension stage faults.

20. Earthquakes along the prominent northeast trending segment of the New Madrid seismic zone occur in the basement along the fault planes of the northeast trending Axial fault system. The Axial fault uplift formed largely by compressive reactivation of extension stage normal faults to form a reverse-faulted uplift (possibly wrench-generated) in the late Paleozoic. This fault system continues to be seismically active today.

21. The Reelfoot aulacogen contains excellent examples of reactivated ancient basement faults that have experienced multiple periods of movement, both extensional and compressive in nature.

22. The geologic characteristics of rift basins in general make them good places to explore for hydrocarbons.

23. Potential hydrocarbon source rocks in the Reelfoot aulacogen include shaly units of the Cambrian Elvins Group, Late Ordovician Maquoketa shales, Devono-Mississippian Chattanooga Shale, Mississippian and Pennsylvanian shales, and Late Cretaceous organic rich shales.

24. Potential hydrocarbon reservoirs in the Cambrian Potsdam Megagroup include the Lamotte Sandstone, Bonneterre dolomitized, carbonate sands and Elvins Group sandstones in proximal submarine fan

complexes.

25. Potential hydrocarbon reservoirs in the Cambro-Ordovician Arbuckle-Knox Megagroup include carbonates with intergranular, intercrystalline, or leached vugular porosity and quartz sandstones with intergranular porosity. Unconformities often separate individual formations within the Arbuckle-Knox and these unconformities have reservoir potential where the underlying surface experienced dissolution and leaching and where basal sandstones overlie the unconformities.

26. Potential reservoirs within the Middle Ordovician Simpson Group include Everton dolomites with intercrystalline or vugular porosity and Everton and St. Peter sandstones.

27. Other possible Paleozoic reservoirs include porous Middle Ordovician Trenton carbonates, Devonian Hunton carbonates and cherts, Mississippian carbonates and cherts, and Mississippian and Pennsylvanian sandstones.

28. The best potential reservoirs in the Embayment Megagroup include the Late Cretaceous Basal Detrital Unit and the McNairy Formation and Tertiary Wilcox sandstones.

29. Additional possibilities exist for fracture enhanced reservoirs throughout the geologic section.

30. The Reelfoot aulacogen contains numerous

hydrocarbon prospects comprising features formed during early Paleozoic crustal extension and subsidence as well as late Paleozoic, Late Cretaceous, or Tertiary compression. Many of these anomalies relate directly to basement faults.

31. Potential hydrocarbon traps, identified seismically, that formed during early Paleozoic extension or subsidence or both include horst-block highs, compaction folds over block edges, structural and stratigraphic traps closed against faults, stratigraphic traps over block edges and along hingelines, and alluvial and submarine fans located along some fault scarps.

32. Potential hydrocarbon traps, identified seismically, that formed during late Paleozoic, Late Cretaceous, or Tertiary compression include forced-folds, reverse-faulted anticlines, wrench-generated uplifts, horst-block highs, and traps closed against faults.

33. The Reelfoot aulacogen warrants further exploration for hydrocarbons in view of the reported hydrocarbon shows, indications of hydrocarbon source and reservoir potential from sparsely drilled deep wells, and numerous structural and stratigraphic anomalies revealed by extensive seismic reflection surveys.

Possible Tectonic Associations

1a. Plate convergences and continental collisions associated with assemblage of Pangea reasonably explain deformation within the Reelfoot area during a late Paleozoic compression stage that extended from the Pennsylvanian through Early Permian. The resulting regional stress patterns acted on zones of pre-existing crustal weakness in the Reelfoot area to produce various types of structural movements.

1b. Northwest ~~North~~ to west-northwest oriented maximum regional compressive stresses presumably associated with the convergence between Laurentia and Gondwana reasonably caused formation or normal reactivation of some northwest trending normal faults at the southern end of the Reelfoot aulacogen and reactivation of the northeast trending Axial fault as a reverse-faulted uplift with a possible component of right wrenching.

1c. Northeast oriented maximum regional compressive stresses (perhaps associated with the combined convergence of Gondwana, Laurentia, and Siberia) possibly caused renewed extension along some northeast striking, extension stage, normal faults in the aulacogen, upwarp of the Pascola arch, and reverse faulting at the southern end of the aulacogen near the junction with the buried Ouachitas.

2. Late Cretaceous, Paleocene, and Eocene compressive faulting may relate to the plate tectonic forces responsible for the Laramide orogeny. Eocene compressive faulting may also relate to a worldwide plate reorganization that occurred then.

SUGGESTIONS FOR FUTURE WORK

Future work in the Reelfoot area will produce new observations, information, and interpretations. Some suggestions for future research are given in the following numbered paragraphs:

1. Use reflection seismic profiles, microearthquake data, and published aeromagnetic and gravity maps to construct a basement fault/structure map of the Reelfoot area and compare it with linear features mapped from remote sensing images, high altitude photography, surface geology, topography, and geomorphology. Basement faults have influenced sedimentation and structural movements in the Reelfoot area throughout much of the Phanerozoic and there seem to be many present-day surface expressions of basement faults in the region.

2. Use reflection seismic data and well information to construct isopach maps of the late Precambrian-Cambrian rift fill (Lamotte, Bonneterre, and Elvins) and units of the overlying Cambro-Ordovician Arbuckle-Knox. Compare these isopach maps to see if relationships exist between the amount of rift fill

and the amount of post-extension stage subsidence. Compare these isopach maps with a pre-Late Cretaceous subcrop map of the region to see if any relationships exist between the isopachs and structural uplifts, especially the broad upwarp called the Pascola arch. I suspect that the Pascola arch area experienced great subsidence during the extension and subsidence stages.

3. Use the isopach maps described above to analyze relative subsidence rates and directions of paleo-regional tilt.

4. Construct isopach maps of units within the Mississippi Embayment fill to determine what influence the Reelfoot aulacogen and related Mesozoic plutons may have had on the embayment's subsidence.

5. Make paleontological examination of Paleozoic well samples and cores from the Reelfoot aulacogen to aid in stratigraphic correlations.

6. Use well data and seismic stratigraphy to analyze Paleozoic facies changes within the Reelfoot aulacogen.

7. Analyze facies changes between Paleozoic rocks within the Reelfoot aulacogen and those of adjacent cratonic areas.

8. Model Precambrian basement discontinuities and igneous plutons by utilizing gravity, magnetic, and reflection seismic data.

9. Study northwest-trending lineaments that appear on regional gravity and magnetic maps and consider their influence on the transverse segmentation of the Reelfoot aulacogen, locations of Mesozoic plutons, and occurrence of earthquakes.

10. Investigate the tectonic interplay between the Reelfoot aulacogen and the Ouachita Mountains at their junction and the significance of the corresponding kink in the Ouachita system.

11. Compare detailed basement structure in the Reelfoot aulacogen (determined from seismic reflection profiles) with deep crustal structure (determined from published refraction data) to see what relationships might exist.

12. Investigate further the influence of basement structure and deep crustal structure on the occurrence of earthquakes in the Reelfoot region.

13. Use reflection seismic data to structurally analyze late Paleozoic and post-Paleozoic compression stage fold orientations.

14. Investigate more fully the thermal history of the Reelfoot area by using a variety of paleogeothermal indicators.

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