# Magnetic and Gravity Study of the Paducah 1°×2° CUSMAP Quadrangle, Illinois, Indiana, Kentucky, and Missouri

U.S. GEOLOGICAL SURVEY BULLETIN 2150–C

**Cover.** Index map showing the approximate location of the Illinois Basin (shaded area) and the location of the Paducah 1°×2° CUSMAP quadrangle.

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*By* Thomas G. Hildenbrand, Robert P. Kucks, *and* Paul C. Heigold

THE PADUCAH CUSMAP QUADRANGLE: RESOURCE AND TOPICAL INVESTIGATIONS
Martin B. Goldhaber, *Project Coordinator*

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## FIGURES

# MAGNETIC AND GRAVITY STUDY OF THE PADUCAH 1°×2° CUSMAP QUADRANGLE, ILLINOIS, INDIANA, KENTUCKY, AND MISSOURI

*By* Thomas G. Hildenbrand,[1] Robert P. Kucks,[2] *and* Paul C. Heigold[3]

## ABSTRACT

Magnetic and gravity data in the Paducah 1°×2° quadrangle (the study area) provide a geologic picture of the subsurface that indicates a long and complex tectonic and magmatic history. A prominent, continental-scale magnetic lineament (called the south-central magnetic lineament) possibly delineates a Precambrian northwest-trending shear zone intruded by large, intermediate igneous bodies. Models crossing these intrusions suggest that the sources are composed of highly magnetic, intermediate rock, such as quartz diorite. Two Early Cambrian rifts (the Reelfoot and Rough Creek) trend into the study area. Interpreted structures and magnetic basement depths suggest that the Reelfoot graben bends eastward to join with the Rough Creek graben. Paralleling the south-central magnetic lineament to the southwest is a pronounced gravity lineament that may represent dense mafic intrusions emplaced along northwest-trending faults and axial faults of the Reelfoot graben. The age of these intrusions is interpreted to be Cambrian (syn-rift) or younger. Strike-slip motion along the northwest-trending faults is suggested by deflections of magnetic anomalies along the margins of the Reelfoot graben.

Post-rifting geology is characterized by thick sequences of sedimentary rocks, as evidenced by the deepening of magnetic basement (>6 km) in the Rough Creek graben in the eastern part of the Paducah quadrangle. Shallow, large magnetic intrusions of post-rift age may be present in or near the Wabash Valley fault system and in the region of tripoli (microcrystalline silica) deposits in southwestern Illinois. A high-pass magnetic anomaly map delineates as many as 14 shallow (<1 km), plug-like or laccolithic intrusions in the eastern part of the study area. Three of these shallow intrusions coincide with known or indicated shallow intrusive centers at Hicks dome, Omaha dome, and Coefield; other interpreted shallow intrusions may also have mineral potential similar to that at Hicks dome.

## INTRODUCTION

The study area (Paducah 1°×2° quadrangle, fig. 1) is surrounded by major uplifts and basins. To the west, in southeastern Missouri, Precambrian basement rises toward the crest of the Ozark uplift and crops out in the St. Francois Mountains. Basement also rises to the east along the north-south-trending Cincinnati arch in central Kentucky. To the north and southwest, basement descends beneath the Illinois Basin and Mississippi Embayment, respectively. The study area is structurally complex and includes at least seven major fault systems. Two rifts intersect or join within the quadrangle. Moreover, a continental-scale crustal discontinuity crosses the study area. Numerous igneous intrusions have been emplaced along this discontinuity. The study area is structurally one of the most complex regions in the Midcontinent. Regional potential-field studies aid in our understanding of the structures of the Paducah quadrangle and can provide a meaningful geologic picture of the subsurface.

Past potential-field studies have contributed significantly to the understanding of structures and lithologies within the study area. Ervin and McGinnis (1975) combined gravity, seismic, stratigraphic, and petrologic data to suggest that the Mississippi Embayment is the site of a northeast-trending, late Precambrian rift, which they called the Reelfoot rift. Subsequent gravity and magnetic studies (Kane and others, 1981; Hildenbrand and others, 1982; Hildenbrand, 1985b; Hildenbrand and Hendricks, 1995) have further defined the buried rift structures, some of which extend into the study area. Cordell (1977) suggested that the Reelfoot rift extends northward into southern Illinois and western Kentucky, where broad gravity highs are interpreted as evidence for a fossil rift cushion at the crust-mantle boundary. An east-west-trending rift graben (Rough Creek graben),

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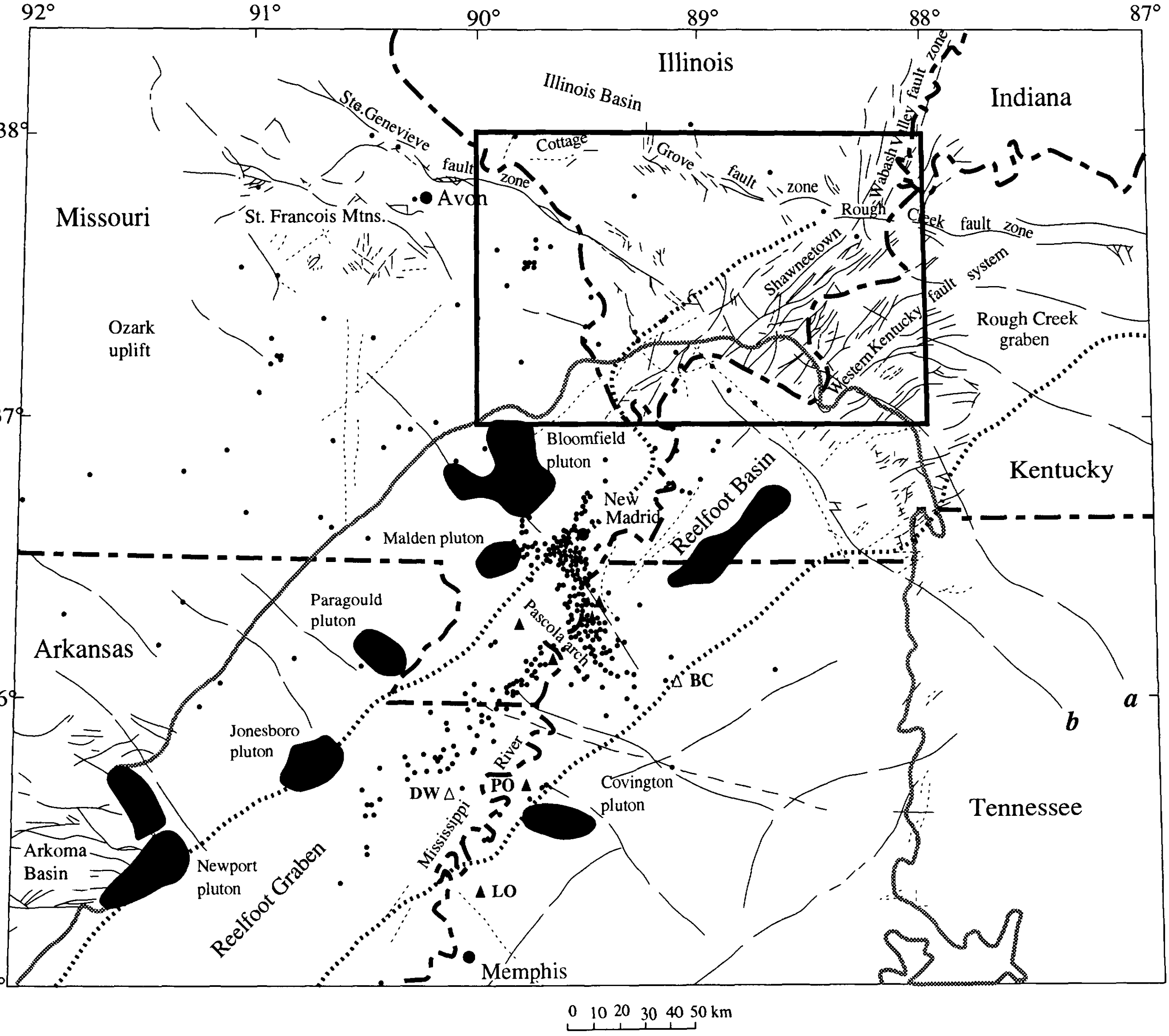



## EXPLANATION

- Northern limit of coastal-plain material of the Mississippi Embayment
- ▲ Mafic or ultramafic intrusions within the Mississippi Embayment identified in drill-hole cuttings. Intrusions labeled PO and LO are also locations of the Pure Oil McGregor No. 1 and the Lion Oil Company No. 1 wells, respectively.
- Mafic intrusion within the Mississippi Embayment interpreted from the magnetic field. Approximate boundaries of intrusions determined from zero contour of associated anomaly on a second vertical derivative map.
- ● City or town
- Long dashed lines show principal magnetic lineaments reflecting faulting and lithologic contrasts in magnetic basement. ***a*** and ***b*** are lineaments discussed in text.
- Fault- Dashed where inferred
- Possible or hypothetical fault. Locations based on subsurface data or exceptionally strong lineaments from aerial photographs.
- Approximate margins of the Reelfoot graben.
- △ Locations of the Big Chief (BC) and Dow Chemical 1 Wilson (DW) drill holes.
- • Earthquake epicenter

**Figure 1** (facing page). Reference map of the northern Mississippi Embayment region showing the study area (the Paducah 1°×2° quadrangle; heavy black line). After Hildenbrand (1985b).

defined with gravity, magnetic, and drill-hole data (Soderberg and Keller, 1981), meets the northeast-trending Reelfoot rift within the study area. Braile and others (1982, 1986) used gravity, magnetic, and seismic data to interpret a quadruple rift junction, which they called the New Madrid rift complex. In their model, the Reelfoot and Rough Creek rifts form two failed rift arms; potential-field anomalies extending northeast and northwest from the juncture of the Reelfoot and Rough Creek rifts may represent the remaining two arms.

Prominent northwest-trending magnetic and gravity anomalies cross the study area and are aligned along mapped and inferred faults (Lidiak and Zietz, 1976; Hildenbrand and others, 1982, 1983). Of particular interest is the south-central magnetic lineament (Hildenbrand and others, 1983; Hildenbrand, 1985a; Ravat, 1984), which reflects a continental-scale geologic feature that extends from eastern Tennessee to Missouri.

This paper reviews these earlier potential-field studies and considers the tectonic and magmatic development of the study area and their interrelationships. For this purpose, aeromagnetic and gravity anomaly maps (figs. 2 and 3) were prepared from available digital data. The nature of digital data allowed application of several analytical techniques to enhance and invert the anomalies and provide new interpretive information. Some geophysical anomalies correlate well with major known Precambrian and Paleozoic tectonic features and aid in delineating their lateral extent and associated structure. Although the sources of some anomalies are not completely understood, observed patterns and correlations yield new insights into the tectonic and magmatic evolution of the region.

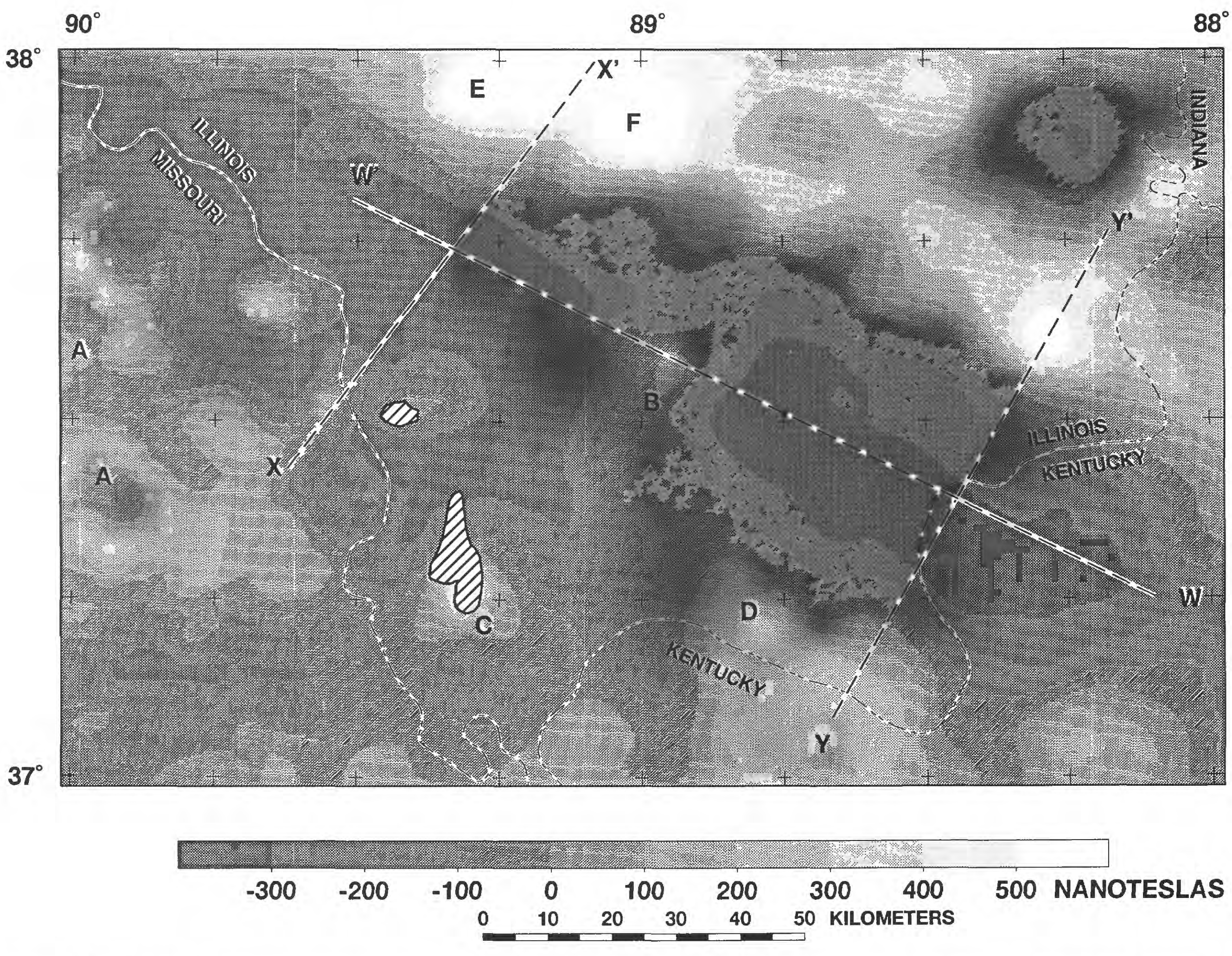



**Figure 2.** Reduced-to-pole magnetic anomaly map. Models along profiles X-X′, Y-Y′, and W-W′ are shown in figure 7. Anomalies A through F are discussed in the text. Hachure patterns depict occurrence of silica deposits in southwestern Illinois (Lamar, 1953).

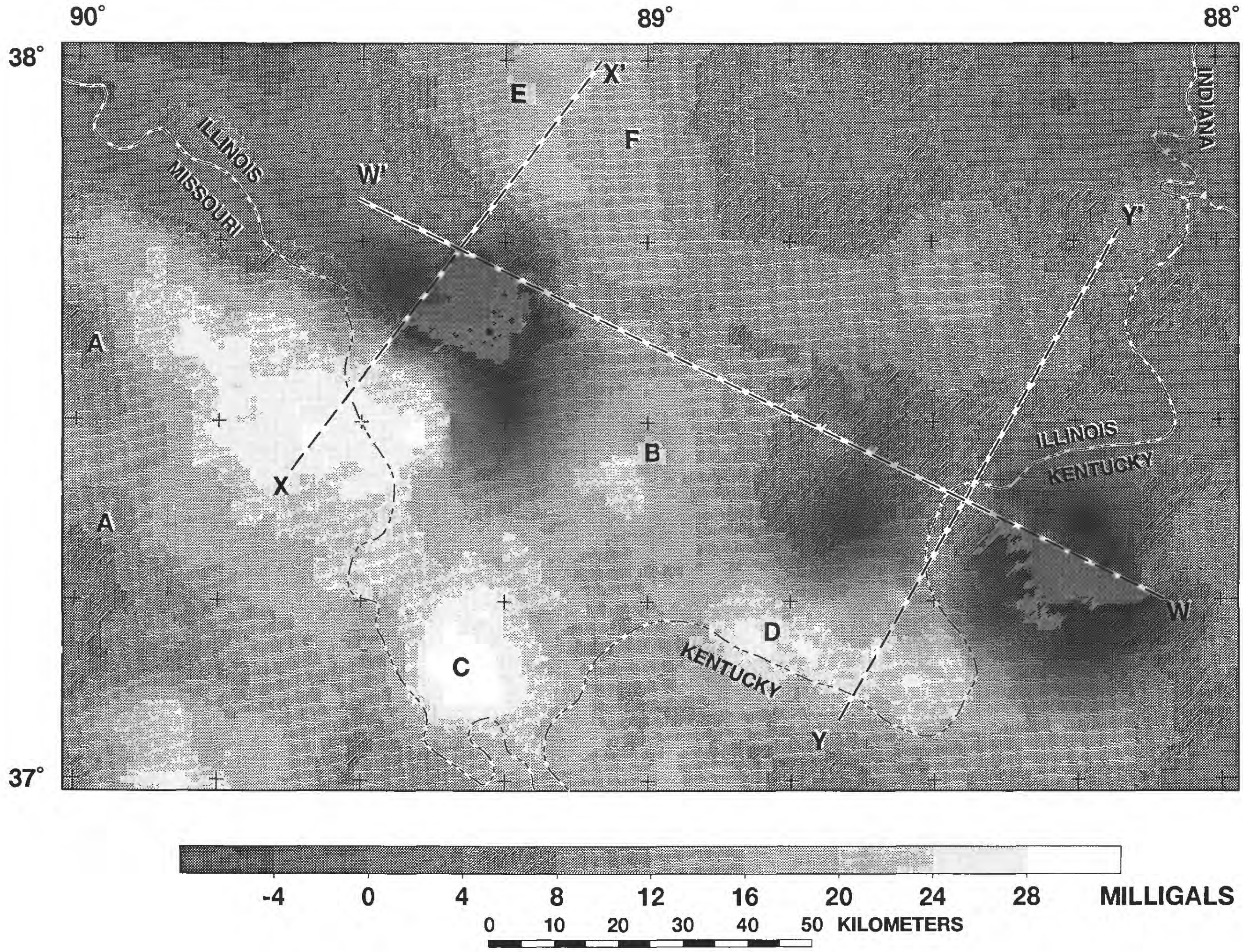



**Figure 3.** Residual gravity anomaly map produced by removing a second-order orthogonal polynomial (shown in fig. 4) from the gravity field. Models along profiles X-X′, Y-Y′, and W-W′ are shown in figure 7. Anomalies A through F are discussed in the text.

## GEOLOGIC HISTORY

Precambrian crystalline basement contains the major gravity and magnetic sources within the study area. Precambrian rocks crop out only in the St. Francois Mountains to the west near the crest of the Ozark Uplift, where unmetamorphosed volcanic and related epizonal intrusive rocks (~ 1.5 Ga) (Bickford and others, 1981; Kisvarsanyi, 1981) are exposed. This granite-rhyolite terrane is extensive in the southern and central interior of the craton (VanSchmus and others, 1993). Magnetite-trachytes and diabase dikes are also present in the St. Francois terrane, but they are not areally extensive. In Missouri, the granite-rhyolite terrane overlies a gneissic pre-volcanic basement (about 1.6 Ga), generally having a northwesterly structural grain (Kisvarsanyi, 1984). To the south within the Reelfoot graben, the Lee Wilson well (DW, fig. 1) encountered granitic gneiss, once buried as deep as 15 km (Denison, 1984). To the north in the Illinois Basin, drill holes reaching Precambrian basement have encountered granite-rhyolite rocks (Kolata and Nelson, 1991), except in Lawrence County, Indiana (lat 38°48′ N. long 86°24′ W.) where ophitic basalt was recovered (Lidiak and others, 1985). In eastern Kentucky and Tennessee, the Grenville Province rocks (1.1 Ga) developed in and adjacent to the granite-rhyolite St. Francois terrane. This province consists of a variety of rock types: among these are mafic and felsic volcanics, amphibolite, and mafic granulite (Lidiak and others, 1985).

North America was part of a larger supercontinent in Late Proterozoic time. During the Late Proterozoic to Early Cambrian, continental breakup resulted in the formation of a passive continental margin along the present southern and eastern edge of the proto-North American craton (Hendricks, 1988; Kolata and Nelson, 1991). Several aulacogens (or failed rifts) and strike-slip faults developed in conjunction with the formation of this new continental margin; the

Reelfoot rift (Ervin and McGinnis, 1975; Hildenbrand, 1985b; Hendricks, 1988) and the Rough Creek graben (Soderberg and Keller, 1981) also formed during this break-up, probably in Cambrian time (Thomas, 1991). The Reelfoot rift trends northeast from east-central Arkansas to the study area and is reflected as a 70-km-wide graben with a structural relief of about 2 km (Hildenbrand, 1985b). Large plutonic bodies (fig. 1) were emplaced along the margins of the graben probably during Cretaceous time or later. The Rough Creek graben, with a maximum structural relief of greater than 6 km, trends east-west in western Kentucky and southern Illinois (Soderberg and Keller, 1981). Kolata and Nelson (1991) suggested that the Rough Creek graben is a simple extension of the Reelfoot graben, and, thus, the quadruple junction of Braile and others (1986) does not exist.

Due to the confusion that sometimes involves the term "rift," we define "rift" here as a fundamental flaw in continental crust along which the entire lithosphere has ruptured under extension. A clear distinction is made between rift and graben, in that the graben is one near-surface manifestation of the rift.

A post-rifting phase in early Paleozoic time included thick accumulation of sediments in the Reelfoot basin of western Kentucky and southeastern Missouri (Schwalb, 1978). From early Paleozoic until Middle Pennsylvanian, regional deposition and subsidence continued intermittently throughout the region (Glick, 1975, 1982); late Paleozoic and Mesozoic uplift resulted in the formation of the Pascola arch (fig. 1). The rise of the arch created the southern margin of the Illinois Basin. Subsidence and accompanying deposition of predominantly marine clastic sediments, attaining a thickness of 1 km west of Memphis, Tenn., began in the Late Cretaceous and are preserved in, and directly adjacent to, the present Mississippi Embayment (Stearns and Marcher, 1962). The Reelfoot graben, lying beneath the Mississippi Embayment, noticeably contains the area of principal seismicity in the Midcontinent (fig. 1) and, in particular, the epicentral line of the devastating 1811–12 New Madrid earthquake series (Nuttli, 1982).

Dikes, diatremes, and plugs as young as Late Cretaceous intrude Precambrian basement and younger formations within the study area and surrounding regions. For instance, the emplacement of intrusions in the Devonian (Zartman and others, 1967) may have been accommodated by the Ste. Genevieve fault (fig. 1). In the Illinois-Kentucky fluorspar district near lat 37°30′ N. and long 88°15′ W., Permian mica peridotite dikes and diatremes are restricted to northwest-trending fractures (Watson, 1967). Permian lamprophyric dikes have been encountered in drill holes (fig. 1) in rocks of Cambrian and Ordovician age on the Pascola arch (Zartman, 1977). Late Cretaceous lamprophyre, syenite, and nepheline syenite (Moody, 1949; Kidwell, 1951) have been encountered in wells in southwest Tennessee. The Magnet Cove complex of ring dikes in east-central Arkansas (Erickson and Blade, 1963) and the syenite intrusions near Little Rock (Gordon and others, 1958) are composed of Late Cretaceous alkalic rocks (Zartman, 1977).

## AEROMAGNETIC AND GRAVITY DATA

The digital set of aeromagnetic data for the Paducah quadrangle was compiled by Kucks (1990) from several published surveys. Flight-line spacing of these surveys was 1.6 km (1 mi), except for a small survey in the southwest corner of the quadrangle where the spacing was 0.8 km (0.5 mi). A 0.5-km grid of magnetic values was prepared for each survey using minimum curvature (Briggs, 1974) and a computer algorithm developed by Webring (1982). The grids were analytically continued to a consistent 305 m (1,000 ft) above mean terrain before compositing to create a compatible data set. Data were reduced to the north magnetic pole, a procedure that shifts the anomalies to positions above their sources. The resulting map is shown in figure 2.

The gravity data were earlier compiled by Hildenbrand and others (1979) at a scale of 1:250,000. All data were tied to the IGSN-71 gravity datum (Morelli and others, 1974) and reduced to simple Bouguer anomaly values using a reduction density of 2.67 g/cm$^3$ and the 1967 formula for theoretical gravity (International Association of Geodesy, 1967). Approximately 4,800 gravity stations at an average spacing of 4 km were used to construct a 1-km grid of values.

By the polynomial fitting method, a regional field was removed from the gravity data in an attempt to eliminate effects of deep sources and shallow, broad sources and therefore enhance the gravity signature of shallow, local features. A second-order orthogonal polynomial (SURFIT—Branch of Geophysics, 1989) was derived from a gravity field over a region extending 2° beyond the boundaries of the Paducah quadrangle. This regional field over the Paducah area is shown in figure 4 and was subtracted from the gravity field (Hildenbrand and others, 1979) to produce the residual field shown in figure 3.

## DEPTH TO MAGNETIC BASEMENT

Magnetic basement is defined here as Precambrian crystalline rocks or igneous rocks of younger age. Phanerozoic sedimentary rocks are assumed to produce little or no effect on the magnetic field.

An interpretational method developed by Vacquier and others (1951) was employed to roughly estimate the maximum depth to magnetic basement (fig. 5). In this method, we compared observed anomalies with theoretical anomalies produced by vertical prisms of various dimensions and different orientations of the Earth's ambient field. It is assumed that all magnetic sources are uniformly polarized in the same

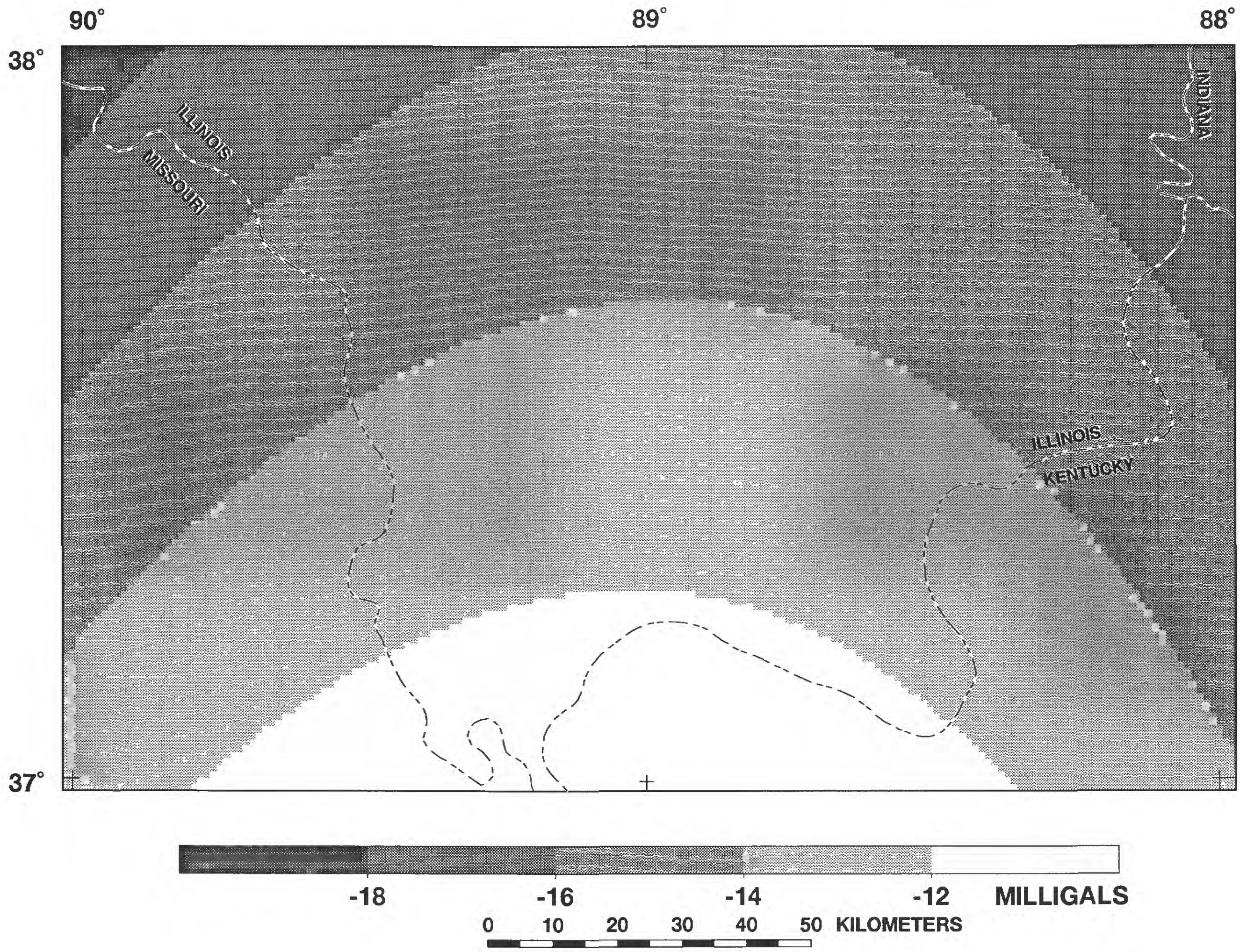



**Figure 4.** Regional gravity anomaly map generated by fitting the gravity field with a second-order orthogonal polynomial surface.

direction as the Earth's present field. When the areal shape of a theoretical anomaly closely matches that of the observed anomaly, maximum depth to the magnetic source is determined by comparing lengths of horizontal gradients associated with the two anomalies. The method yields maximum depths to magnetic sources because the theoretical models used in the curve-matching process are assumed to have vertical sides. In real geologic situations, the causative body generally has sloping sides; therefore, its actual depth of burial is shallower than the computed depth.

In the Paducah quadrangle, 90 estimates of maximum depth to magnetic basement below sea level were determined. The depths reported here must be regarded as rough estimates. It should be noted, however, that depths of magnetic basement compare reasonably well with depths of Precambrian basement, determined by seismic and drill-hole data (fig. 5). Explanations for discrepancies in depths between magnetic and Precambrian basements (e.g., southwestern Illinois and the northeast part of the study area) are offered later. Magnetic basement shallows to roughly 1 km in the west on the flanks of the Ozark uplift and descends to depths greater than 6 km in the east in the Rough Creek graben.

## MAGNETIC AND GRAVITY FEATURES

The amplitudes and wavelengths of anomalies exhibited on the compiled magnetic and gravity anomaly maps vary considerably within the study area. For example, the gravity low in the eastern part of the study area reflects the deepening of Precambrian basement to depths greater than 6 km (fig. 5). Magnetic and gravity anomalies with steeper gradients in the west depict the shallowing of basement westward across the quadrangle. Lithologic variation accounts for some of the wide variety of anomaly patterns. This is evident at the western edge of the study area, where two corresponding oval magnetic and gravity lows (A, figs.

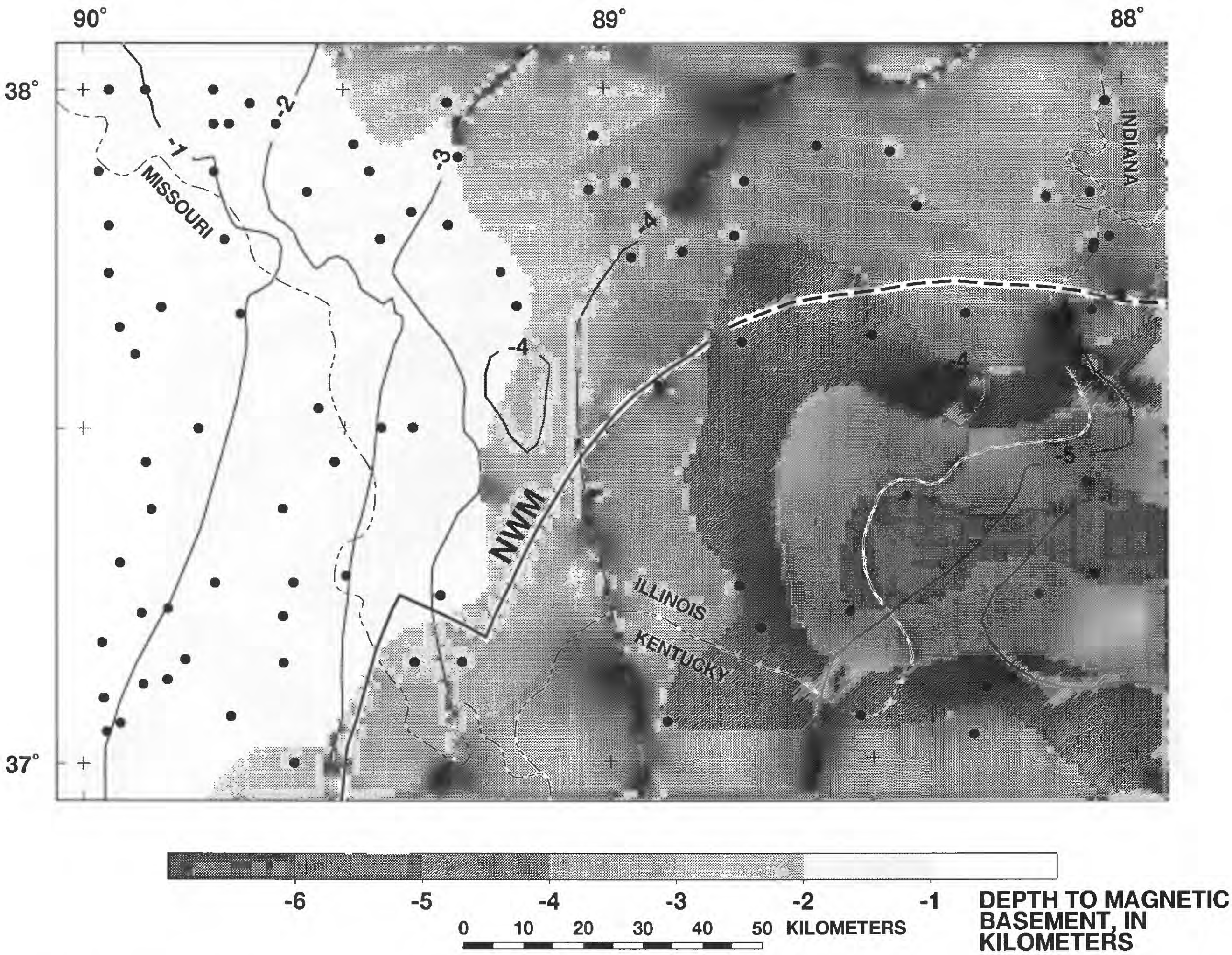



**Figure 5.** Maximum depth to magnetic basement. Dots denote locations of depth estimates. Heavy line (dashed where inferred) is the interpreted northwest margin (NWM) of the northeast-trending Reelfoot graben as it merges with the east-trending Rough Creek graben. Contours (1-km interval) are depths to Precambrian basement provided by Michael Sargent (Illinois State Geological Survey, written commun., 1991) from drill-hole and seismic data.

2 and 3) probably reflect tin-granite plutons. The magnetic lows are bounded by a distinct ring of magnetic highs. These characteristic geophysical patterns are observed over several exposed tin-granite plutons to the west in the St. Francois Mountains (Cordell and Knepper, 1987). The prominent gravity and magnetic highs to the south of these ring anomalies (in the southwest corner of the study area) express the northern edge of the Bloomfield pluton (fig. 1).

On a more regional scale, Ervin and McGinnis (1975) and Cordell (1977) proposed that a broad northeast-plunging positive gravity anomaly associated with the Mississippi Embayment is caused by an anomalously high density mass at the base of the crust. They interpreted this regional gravity high (which includes the prominent positive anomalies in the Paducah quadrangle) as the fossil Reelfoot rift cushion underlying the Mississippi Embayment. It will be shown later that, although some positive anomalies in the study area may be related to deep crustal sources, many of the high-amplitude gravity anomalies are caused by dense igneous intrusions at depths shallower than 10 km.

## PADUCAH GRAVITY LINEAMENT (PGL)

Many of the individual gravity peaks within the broad northwest-trending gravity high zone in the southwest part of the quadrangle coincide with isolated magnetic highs. Herein, this northwest-trending gravity high zone will be referred to as the Paducah gravity lineament (PGL). The presence of both magnetic and very dense sources suggest that the area of the PGL is heavily intruded by mafic rock. Within this broad zone of igneous rocks, large plutons are interpretable and are sketched in figure 8. The locations of three of these interpreted plutons appear to be reflected in drainage patterns of rivers.

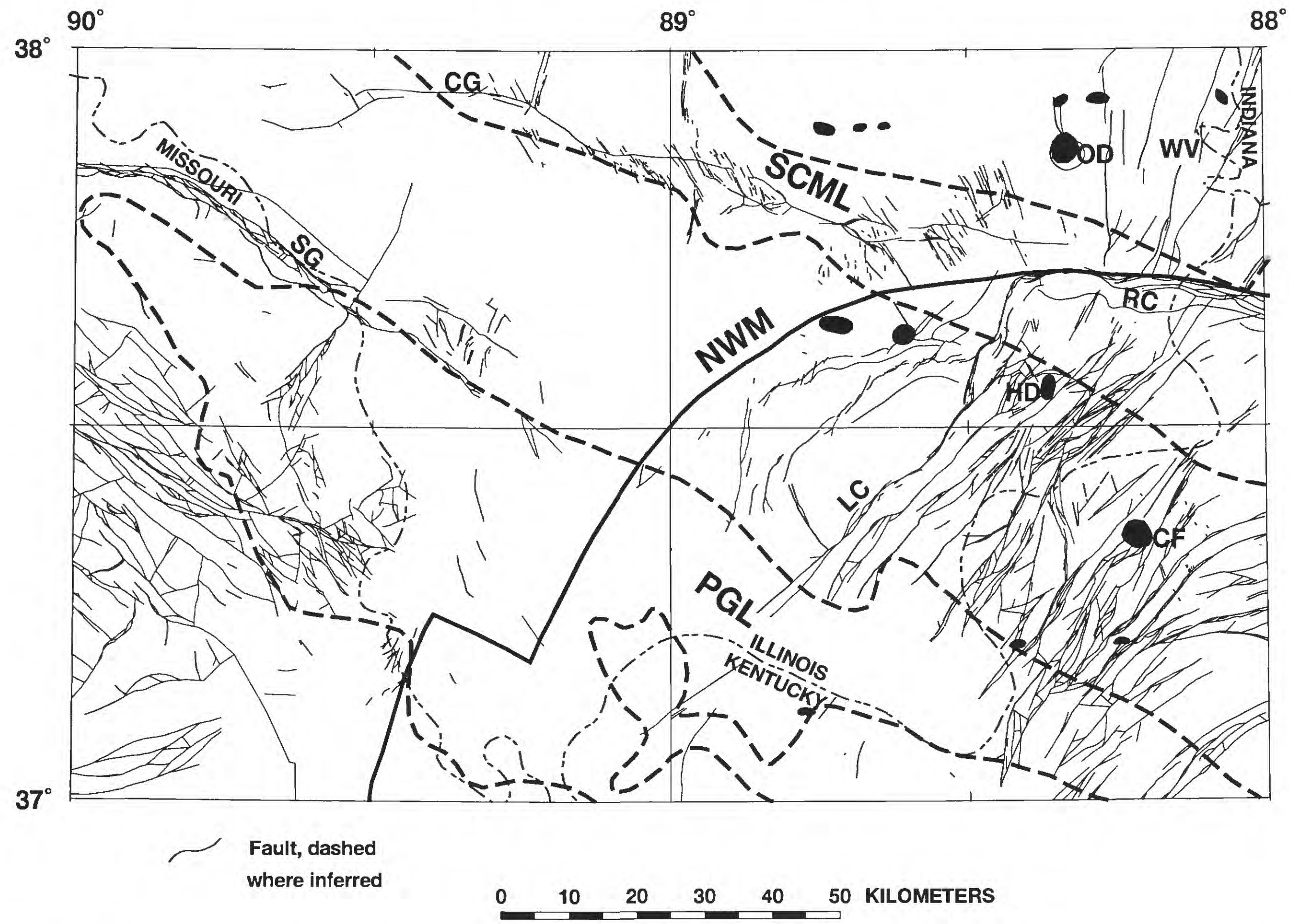



**Figure 6.** Boundaries of the Paducah gravity lineament (PGL) and the south-central magnetic lineament (SCML). Heavy line depicts the interpreted northwest margin (NWM) of the Reelfoot graben as it merges with the east-west-trending Rough Creek graben. Major fault zones include the Ste. Genevieve (SG), Cottage Grove (CG), Rough Creek (RC), Lusk Creek (LC), and Wabash Valley (WV) fault zones. Fourteen small enclosed black areas represent shallow, dike-like intrusions reflected in the high-pass magnetic anomaly map (fig. 10). Three known or indicated shallow intrusive centers (Hicks dome (HD), Omaha dome (OD), and Coefield (CF)) coincide with highs in the high-pass data shown in figure 10.

As the PGL crosses the Illinois-Missouri State boundary, the steep gradient on its northeastern edge coincides with the Ste. Genevieve fault zone (SG, fig. 6). Isopach data on sedimentary formations suggest that the oldest movement along this fault zone is Middle Ordovician (Timothy Hayes, oral commun., 1991). Kolata and Nelson (1991) suggested that deformation along the Ste. Genevieve fault zone resulted in the emplacement of Devonian diatremes of mica peridotite southwest of the fault near Avon, southeastern Missouri (fig. 1, near lat 37°45′ N. and long 90°15′ W.). About 80 plugs and dikes (Kidwell, 1947) occur here at shallow depths in a small area. Although the mappable, southeast-trending Ste. Genevieve fault terminates in Union County, Illinois, the northeastern margin of the PGL continues to the southeast. We propose that the northeastern edge of the PGL reflects a Precambrian fault zone; thus the Ste. Genevieve fault zone may represent a Paleozoic reactivation of this interpreted Precambrian fault zone. The continuation of the PGL beyond the terminus of the Ste. Genevieve fault zone suggests that the ancestral Precambrian fault zone continues southeastward in the subsurface into western Kentucky (Lidiak and Zietz, 1976; Hildenbrand and others, 1982).

The gravity high near the center of the quadrangle (B, fig. 3) disrupts the gradient related to the Ste. Genevieve fault zone. Because of the presence of a corresponding magnetic high (B, fig. 2), we interpret the source to be a large mafic intrusion.

## SOUTH-CENTRAL MAGNETIC LINEAMENT (SCML)

A prominent northwest-trending zone of magnetic highs is present in the northeastern part of the quadrangle and parallels the PGL. This magnetic anomaly is part of the south-central magnetic lineament (SCML) named by Hildenbrand and others (1983). Hildenbrand (1985a) suggested that the SCML extends northwestward from eastern Tennessee to possibly as far as southeastern Nebraska. Although some north-trending anomalies associated with Keweenawan structures in eastern Tennessee cross the SCML, other anomalies end abruptly at the SCML. This anomaly pattern prompted Hildenbrand (1985a) to propose that the sources of the SCML developed during or prior to Keweenawan time. The SCML is clearly expressed as a 40-km-wide band of magnetic highs from the Tennessee-Kentucky boundary at long 86°30′ W. (Hildenbrand and Keller, 1983) to eastern Missouri.

Near the Kentucky-Illinois border, lamprophyre and mica peridotite dikes and sills, together with intrusive breccias (Clegg and Bradbury, 1956; Koenig, 1956; Heyl and others, 1965), have been mapped and encountered in drill holes in the vicinity of the magnetic highs along the SCML; mica and amphibole from these rocks have Rb-Sr and K-Ar ages of approximately 270 Ma (Zartman and others, 1967, reconverted to the decay constants of Steiger and Jäger, 1978). Hicks dome, a structural feature of the Kentucky-Illinois fluorspar mineral district (HD, fig. 6), is on the southwestern flank of this northwest-trending magnetic feature. The dome is underlain by a body of mineralized breccia (Brown and others, 1954) that is interpreted as a diatreme formed in alkalic to carbonatitic magmatism (Bradbury and Baxter, 1992). Small lamprophyre and phlogopite peridotite dikes and plugs and intrusive breccias occur on the dome's flanks (Heyl and others, 1965).

Magnetic highs generally coincide with gravity highs along the SCML in the study area. These gravity highs are, however, lower in amplitude than those along the PGL. In contrast, the magnetic highs along the PGL have lower magnetic intensities than those along the SCML. The implication of this reverse correlation in magnetic and gravity anomaly intensities is discussed later.

## FAULT ZONES

Hildenbrand and Hendricks (1995) suggest that some fault zones correlate with geophysical features. For example, the Ste. Genevieve fault zone may be expressed as steep gravity gradients related to the northeast edge of the PGL. Also, the Cottage Grove fault system may have provided channelways for magma forming intrusions related to the SCML. On the other hand, the numerous northeast-trending faults in the eastern part of the study area have no apparent expression on the gravity and magnetic anomaly maps. Hildenbrand and Keller (1983) suggested that fault displacements here are too small to be detected by regional potential-field methods.

## PROFILE MODELING

The principal goal of potential-field studies is to detect and quantify changes in magnetic and mass properties at depth. To translate observed magnetic and gravity anomalies into a meaningful geologic picture of the subsurface requires inversion or modeling programs. We used a $2^1/_2$-dimensional modeling program, SAKI (Webring, 1985), based on generalized inverse theory to derive upper crustal models (fig. 7) along three individual profiles shown in figures 2 and 3. The program requires an initial estimate of model parameters (depth, shape, density, and magnetization of sources) and then varies selected parameters in an attempt to reduce the weighted root-mean-square error between the observed and calculated gravity and magnetic fields. Due to the lack of information on remanent magnetization, total magnetization was assumed to be in the direction of the Earth's present-day magnetic field (inclination = 66° N. and declination = 2° E.).

Knowledge of several parameters facilitated the selection of the initial estimate for the models. Several hundred measurements of physical properties of rocks from drill holes and outcrops in the St. Francois Mountains (west of the Paducah quadrangle) (Eva Kisvarsanyi, Missouri Department of Natural Resources, written commun., 1990) were used to assign a value for density and susceptibility of Precambrian basement in the western part of the study area. Statistical measurements on these laboratory results (Joseph Rosenbaum, written commun., 1991) indicate that unweathered St. Francois granite-rhyolite terrane has an apparent average density of 2.67 g/cm$^3$ and susceptibility of 0.009 SI ($4\pi$ cgs = SI).

Geophysical logs from drill holes located west, north, and east of the quadrangle suggest a wide range of densities for Paleozoic units. For example, average densities range from 2.4 g/cm$^3$ for the Cambrian Lamotte Sandstone to 2.73 g/cm$^3$ for the Cambrian Eminence Dolomite. A value of 2.65 g/cm$^3$ was obtained for the average density of the Paleozoic section (based on visual inspection of density logs) and agrees with the estimated density of similar rocks at depth in Oklahoma (based on density-depth data from drill samples—Athy, 1930; Cordell, 1977). This value was used in our models. A more detailed model for the Paleozoic is considered inappropriate due to the lack of information on depths and densities of the Paleozoic units within the broad study area. The estimated depths to magnetic basement (fig. 5) were used to approximate the base of Paleozoic sedimentary rocks.

The velocity-density relationship of Birch (1961) and velocities cited by Mooney and others (1983) were used to select a representative density for middle crust (2.75 g/cm$^3$). Middle crust susceptibilities were assigned a value of 0.006 SI, a reasonable estimate for metamorphic rocks (Carmichael, 1982).

Before inverting the data on long profiles, individual anomalies related to inferred intrusions were modeled to provide reasonable estimates of their thicknesses. Two gravity anomalies (C and D, fig. 3) were modeled along the PGL using a three-dimensional inversion algorithm (GI3, Cordell, 1968). Assuming the intrusions have mafic compositions (e.g., gabbro) and densities of about 2.9 g/cm$^3$, the modeling results suggest that the depth to the bottom of an intrusion along the PGL is about 10 km below the surface. A similar modeling exercise was carried out for two magnetic anomalies (using the algorithm SAKI) along the SCML (E and F, fig. 2). If the depth to the bottom of intrusion is placed at 10 km, some calculated susceptibilities were unreasonably high (>0.15 SI); therefore, the base of an intrusion along the SCML is assumed to lie at 15 km.

The interpretation of potential-field data yields nonunique solutions because an infinite number of geometrical models will have an associated field that closely matches the measured field. Available drill-hole information, simultaneous inversion of gravity and magnetic data, and geological reasoning have aided in deriving a suitable geophysical model to represent the geologic situation in the study area. It should be noted, however, that increasing the density and decreasing the thickness of an intrusion will generally not produce an appreciable change in the computed fields.

Profile W-W′ (figs. 2 and 3) was selected with a northwest trend that avoided the major positive anomalies related to the PGL and SCML. The magnetic low along W-W′ parallels the SCML southeastward into Tennessee. In the Midcontinent, other linear magnetic lows of similar intensity and length exist but are uncommon. The SCML may be flanked on the southwest by a trough filled with low-density, reversely magnetized rocks (e.g., an old rift filled with volcanic rocks). Ravat (1984) modeled a reversely magnetized body in the midcrust to explain the presence of this pronounced magnetic low. The existence of reversely magnetized rocks is plausible but not necessary to explain the steep gradient between the geophysical low and the SCML. We assume here that the crystalline rocks beneath the sedimentary sequence along W-W′ have negligible magnetic properties (i.e., zero susceptibilities). Associated densities of the crystalline rocks at the northwest end of profile W-W′ are assumed to be similar to those in the nearby St. Francois Mountains (2.67 g/cm$^3$).

The data along profile W-W′ were inverted first, based on the assumed physical properties at its northwestern end (density of 2.67 g/cm$^3$ and zero susceptibility). Knowledge of the resulting change in these physical properties eastward along profile W-W′ then helped to constrain Precambrian properties at the junctures of this profile with the remaining profiles. Profiles X-X′ and Y-Y′ trend northeast and are normal to the PGL and SCML.

## PROFILE W-W′

A distinct change in the gravity field occurs along profile W-W′ (fig. 7*A*). In the northwestern part of the profile, crystalline basement beneath the sedimentary rocks is assumed to have a density of 2.67 g/cm$^3$. To the southeast, the increase in the gravity field reflects a more dense (2.74 g/cm$^3$) Precambrian basement within the region of the Rough Creek graben. This change in basement density occurs across an interpreted igneous intrusion (B, fig. 3) near the center of the profile. We suggest that this change in Precambrian basement composition represents the northern extension of the faulted northwestern margin of the Reelfoot graben as it joins with the northern margin of the Rough Creek graben. An alternative explanation for the increase in gravity southeastward along profile W-W′ is that the regional field (fig. 4) does not adequately reflect deep sources. The level change in gravity along the profile may therefore be related to lateral density variations associated with a dense rift cushion at depth. We prefer the modeling results because a density increase in Precambrian basement is anticipated over areas where the low-density St. Francois terrane is absent or thin. Early Paleozoic uplift related to rifting may have resulted in substantial erosion of the St. Francois terrane, as similarly proposed by Denison (1984) for the region to the south where granitic gneiss (once buried as deep as 15 km) was encountered in a drill hole (DW, fig. 1).

## PROFILES X-X′ AND Y-Y′

Profile X-X′ (fig. 7*B*) and profile Y-Y′ (fig. 7*C*) are situated normal to the northwest-trending Paducah gravity lineament and the south-central magnetic lineament. The proposed igneous bodies producing the PGL and the SCML appear to be dense and magnetic. Computed densities and susceptibilities are reasonable for a variety of igneous rocks such as syenite, quartz diorite, gabbro, and peridotite (Daly and others, 1966; Carmichael, 1982; Coleman, 1971). Calculated densities along the PGL range from 2.78 to 2.91 g/cm$^3$, whereas, along the SCML, their range is 2.72 to 2.78 g/cm$^3$. On the other hand, calculated susceptibilities are generally greater along the SCML (0.021 to 0.103 SI) than those along the PGL (0.009 to 0.090 SI). This reverse correlation in both physical properties and anomaly intensities (figs. 7*B*, 7*C*) suggests that the igneous bodies along the PGL have different compositions and origin than those along the SCML. An alternative explanation is that the igneous intrusions have similar origins but ultramafic rocks along the SCML have been chemically altered during serpentinization, whereby Fe-rich silicates such as olivine and pyroxene were oxidized to form ferrimagnetic material. During serpentinization, magnetizations of the ultramafic rocks significantly increase, but their densities decrease (Coleman, 1971; Saad, 1969; Toft and others, 1990). We do not favor this process here, however, because the linear zone of intrusions associated with the SCML is considerably larger than the size of known serpentinized ultramafic rock bodies.

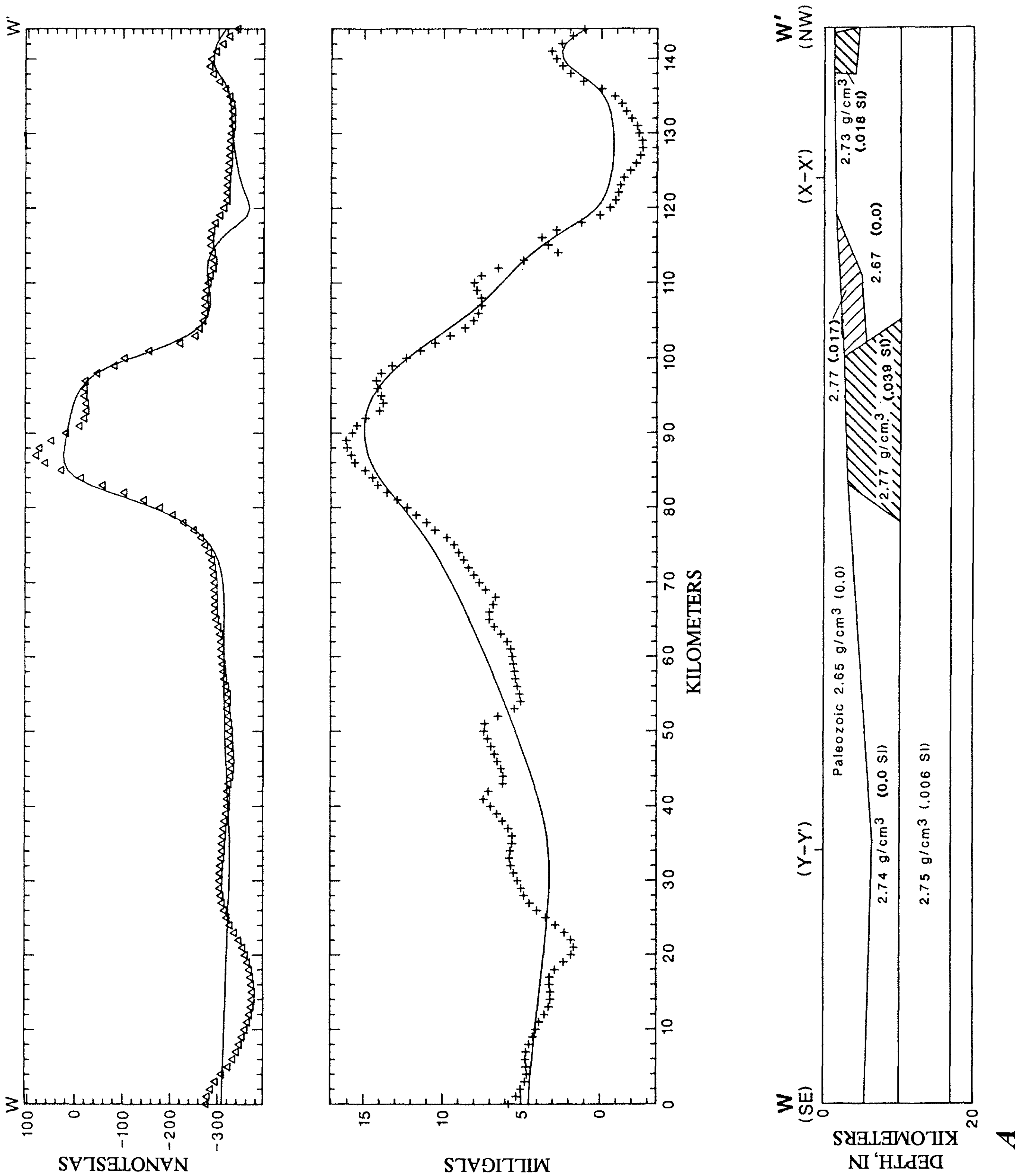
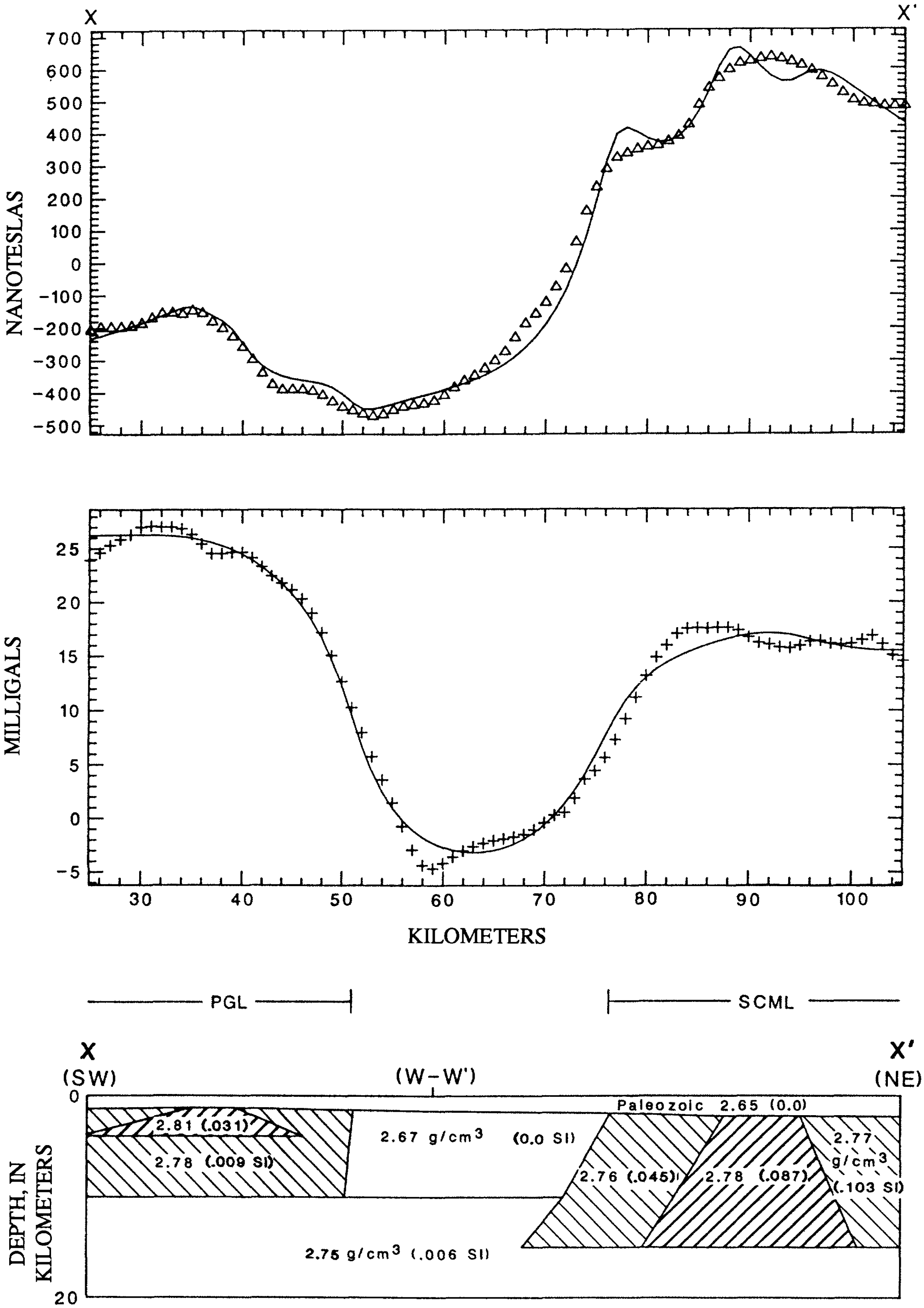
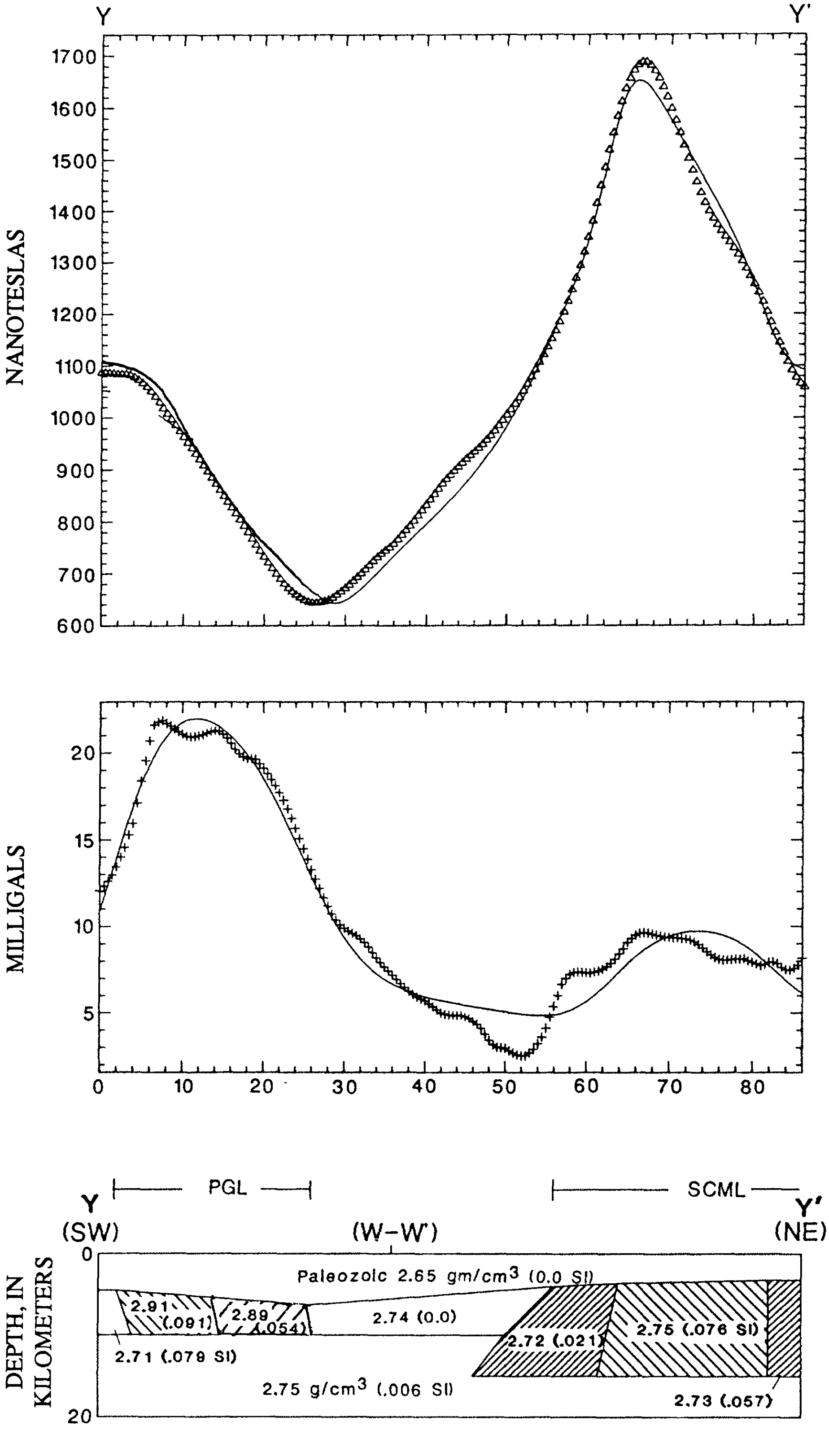



**Figure 7** (above and following pages). Theoretical models and potential-field anomalies along profiles *A*, W-W′; *B*, X-X′; and *C*, Y-Y′. Profile locations are shown in figures 2 and 3. Triangles and crosses in the potential-field plots are the observed data (figs. 2 and 3); solid lines are calculated fields based on the model shown at the bottom of each part of the figure. Numbers in model represent calculated densities in g/cm$^3$ and susceptibilities in SI units (in parentheses). Hachured bodies in model represent igneous intrusions. Labels PGL and SCML in *B* and *C* show lateral extent of the Paducah gravity lineament and south-central magnetic lineament along the profile. Vertical exaggeration in the models is 1.65×.


X
X'
NANOTESLAS
700
600
500
400
300
200
100
0
-100
-200
-300
-400
-500
MILLIGALS
25
20
15
10
5
0
-5
30
40
50
60
70
80
90
100
KILOMETERS
PGL
SCML
X
(SW)
(W-W')
X'
(NE)
0
Paleozoic 2.65 (0.0)
2.81 (.031)
2.78 (.009 SI)
2.67 g/cm3
(0.0 SI)
2.76 (.045)
2.78 (.087)
2.77 g/cm3 (.103 SI)
2.75 g/cm3 (.006 SI)
DEPTH, IN KILOMETERS
20

*B*


Y
Y'
NANOTESLAS
1700
1600
1500
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1300
1200
1100
1000
900
800
700
600
MILLIGALS
20
15
10
5
0
10
20
30
40
50
60
70
80
PGL
SCML
Y
(SW)
(W-W')
Y'
(NE)
DEPTH, IN KILOMETERS
0
20
Paleozoic 2.65 gm/cm3 (0.0 SI)
2.91 (.091)
2.89 (.054)
2.74 (0.0)
2.72 (.021)
2.75 (.076 SI)
2.71 (.079 SI)
2.75 g/cm3 (.006 SI)
2.73 (.057)

*C*

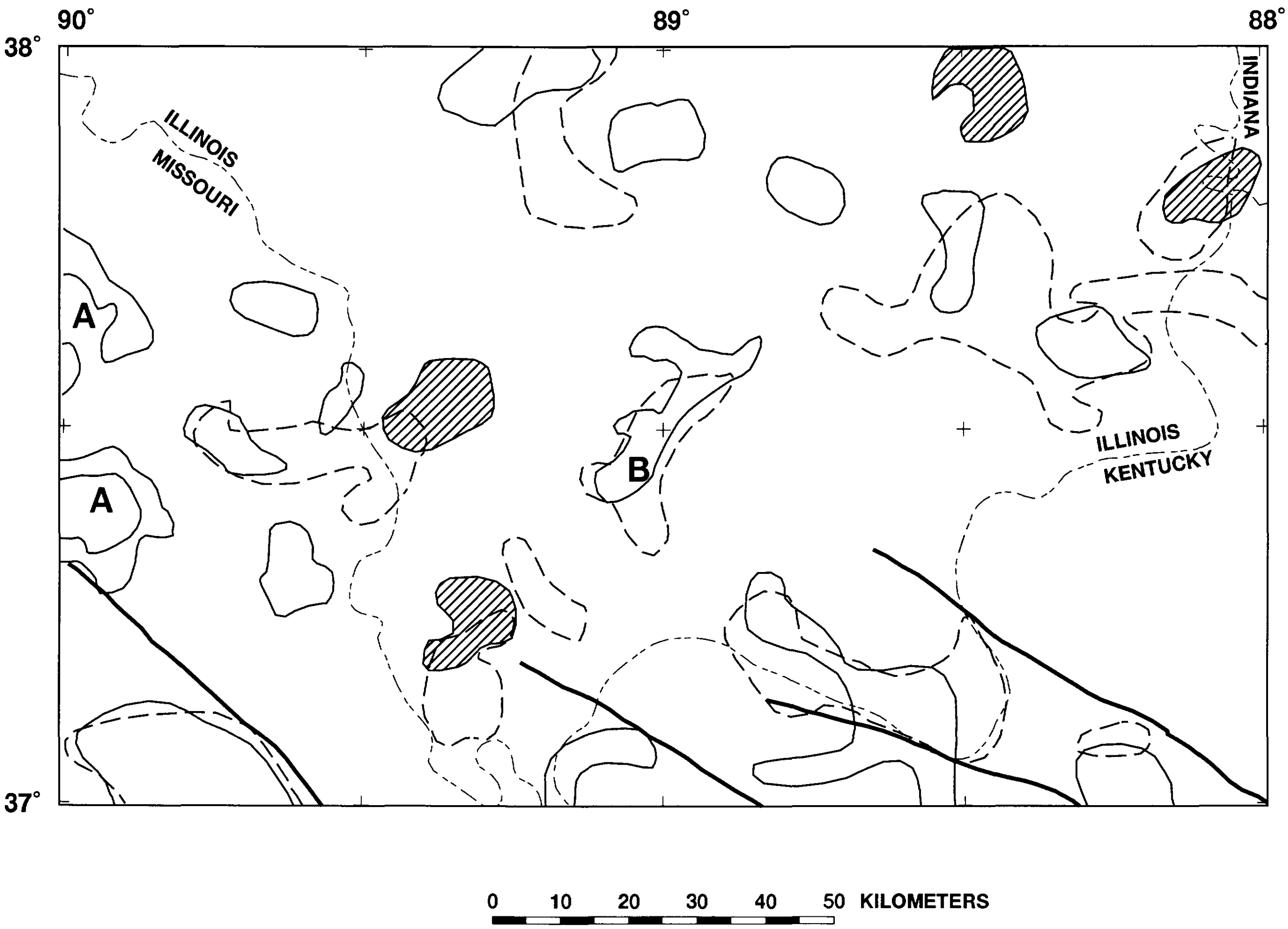


**Figure 8.** Interpreted large intrusions. Solid enclosures denote boundaries of magnetic sources. Dashed enclosures depict gravity sources. Magnetic intrusions with hachure pattern lie at depths considerably shallower (>1 km shallower) than the depth of Precambrian basement (see fig. 5). Heavy lines are interpreted faults (some with strike-slip offsets), also shown in figure 9. Intrusions A are interpreted Precambrian tin-granite plutons, similar to those to the west in the St. Francois Mountains. Intrusion B lies along the interpreted northwest margin of the Reelfoot graben.

The steep gravity gradients bounding the PGL require near-vertical intrusions lying at shallow depths. On the other hand, the intrusions along the SCML may dip about 60°. It is worth noting that the intrusions appear to be laterally differentiated (i.e., their cores may be generally more magnetic and dense).

## DISCUSSION

Four major geophysical features cross the study area: anomalies associated with the Reelfoot and Rough Creek grabens, the south-central magnetic lineament (SCML), and the Paducah gravity lineament (PGL). The physical and geologic relations among these four features and their associated structures (e.g., the many fault zones) are poorly understood and raise the following questions. Does the Reelfoot rift simply merge with the Rough Creek rift or are there more complicated rift structures involving several failed arms? What are the origins of the PGL and SCML? How do the fault zones relate to these four features? The following discussions address these and other questions.

To facilitate the discussions of igneous bodies, a map of interpreted large intrusions was prepared and is shown as figure 8. Intrusive boundaries were defined using two techniques: horizontal gradient maxima of the gravity and pseudogravity fields (Cordell and Grauch, 1982) and body edges indicated on first- and second-vertical-derivative anomaly maps.

Also shown in figure 8 (hachure pattern) are interpreted intrusions that appear to lie at depths substantially above Precambrian basement. In comparing depths of magnetic basement and Precambrian basement (fig. 5), four interpreted intrusions appear to lie at depths shallower (>1 km) than the depth of Precambrian basement. Although highly speculative, we propose the two shallow intrusions in the northeast part of the study were emplaced during late Paleozoic in or near the Wabash Valley fault zone. The late Paleozoic to early Mesozoic was a period when the craton was experiencing both compression and extension when Pangea was formed and then broke up. The other two shallow intrusions in the western part of the study area lie along the Paducah gravity lineament and are discussed later.

## RIFTS

Hildenbrand and others (1982) and Braile and others (1982) suggested that the graben related to the Reelfoot rift continues northeastward in the Mississippi Embayment where it merges with or intersects the Rough Creek graben (Soderberg and Keller, 1981) in southern Illinois and western Kentucky. Hildenbrand and others (1982) and Hildenbrand and Keller (1983) described the southeast margin of the Reelfoot graben as bending to the east along the Pennyrile fault zone east of the study area, where it becomes the southern margin of the Rough Creek graben (fig. 1); they therefore suggested that the Reelfoot graben simply terminates in the Paducah quadrangle and merges with but does not cross the Rough Creek graben.

A more complex rift structure was proposed by Braile and others (1982). Their interpretation includes a quadruple junction in the study area with the Reelfoot and Rough Creek grabens representing two failed rift arms. A third rift arm would extend northeastward along the Wabash Valley fault system, whereas the fourth arm is bounded by the SCML and PGL and extends northwest to about St. Louis, Mo. They named this entire system and its quadruple junction the New Madrid rift complex. Nelson (1990), however, suggested that there are geologic and proprietary seismic data to dispute the existence of a quadruple junction. The following discussions expand on earlier potential-field interpretations (Hildenbrand and others, 1982) of the juncture of the Reelfoot rift and Rough Creek graben in the study area.

South of the study area, magnetic anomaly maps clearly define the Reelfoot graben (fig. 1), which contains about 2 km of low-density fill and is flanked by dense and highly magnetic plutons. A second-vertical-derivative magnetic anomaly map (Hildenbrand, 1985b) clearly shows the southeast margin of this graben trending northeast into Kentucky, where the southeast margin gently bends eastward (lat 37° N. and long 87°45′ W.) along the southern margin of the Rough Creek graben. The sharp change in the magnetic field reflects crossing the edge of the deep graben floor to the shallowing terrane of the dipping and possibly wide graben margin. It should be noted that we cannot determine the outer edge of the graben margins due the complex magnetic signatures related to the magnetic intrusions emplaced along the margins.

On the other hand, the nature of the northern extension of the northwest margin of the Reelfoot graben beyond the Bloomfield pluton (fig. 1) is equivocal. Here northwest-trending geophysical features (mainly the SCML and PGL) may mask the more subdued gradients of the graben's northwest margin. Indirect evidence for its northward continuation into the study area is seen in the geophysical model of profile W-W′ (fig. 7*A*). A change in basement composition may occur at about lat 37°30′ N. and long 89° W., where an intrusion may also have been emplaced along the curved margin in this region (B, figs. 2, 3, and 8). Extending the graben's northwest margin to this area does not imply a widening of the graben northward from the Bloomfield pluton; rather our definition of the line representing the margin is changed. Because the expression of the edge of the graben floor is not obvious here, the line representing the northwest margin is based on subtle anomalies of northeast-trending features lying within the broad region of the graben margin. Close inspection of regional magnetic and gravity anomaly maps suggests that this northwest margin does not continue northeastward beyond the central area of the Paducah quadrangle (i.e., beyond the SCML). This margin may therefore bend to the east and merge with the northern margin of the Rough Creek graben, roughly paralleling its southern margin. Such an interpretation is easily visualized in the depth to magnetic basement map (fig. 5). A sketch of the juncture of the two grabens in the study area is shown in figures 1, 5, and 6. The offset in the margin (lat 37°10′ N. and long 89°15′ W.) is based on magnetic basement depths (fig. 5) and interpreted strike-slip faults related to the PGL (discussed later). It is worth noting that the zone of northeast-trending faults in southern Illinois and western Kentucky is largely bounded between the interpreted margins of the Reelfoot graben (figs. 1 and 6).

Hildenbrand and Hendricks (1995) suggest that the abrupt change in the trend of the Reelfoot rift (northeast) to the trend of the Rough Creek graben (east) is due to either:

1. A preferred strain direction—Rifting may have propagated northeastward and then followed existing east-west structures in western Kentucky that represented a path of less resistance; or
2. An obstacle—The competent, homogeneous batholithic rocks deep beneath the eastern flank of the Ozark uplift may have represented a crustal obstacle, diverting rift propagation to the east.

Alternatively, they propose that rifting may have originated in the east and propagated westward along the trend of the Rough Creek graben before being diverted to the southwest along the trend of the Reelfoot graben.

## PADUCAH GRAVITY LINEAMENT

Figure 9 shows the gravity field for a region larger than the study area. Four prominent gravity gradients (A–D, fig. 9) trend northwest into the study area. These gradients probably represent strike-slip faults. Evidence for strike-slip

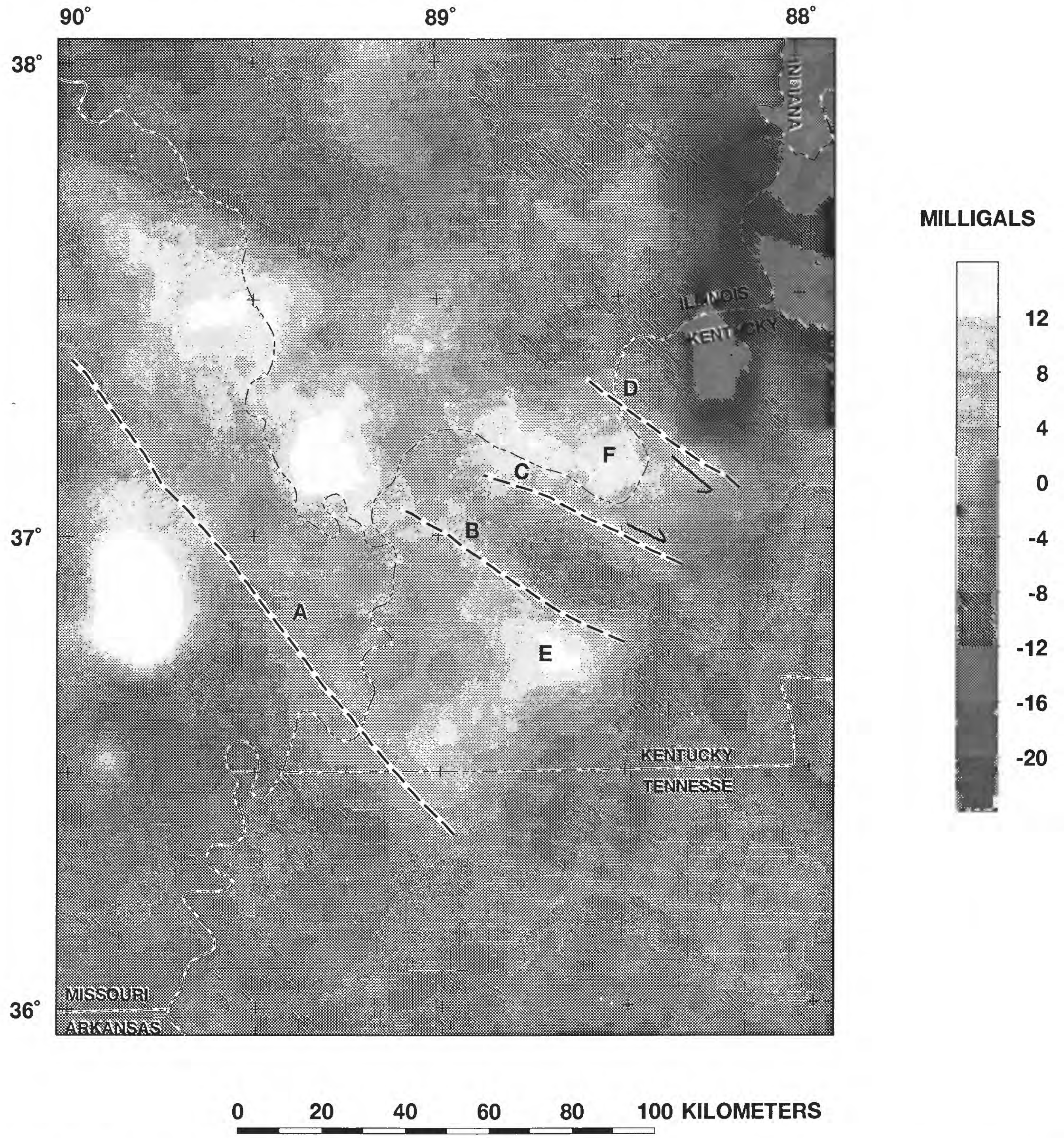


**Figure 9.** Gravity anomaly map of the northern Mississippi Embayment region. Dashed lines A–D are interpreted faults located at the junction of the Reelfoot graben and Rough Creek graben. Positive gravity anomalies E and F are discussed in the text. The intrusion related to anomaly E lies along the axis of the Reelfoot graben (see fig. 1). A southeast displacement of the block between faults C and D is inferred from a bend in the southeast margin of the Reelfoot graben (Hildenbrand, 1985b, and fig. 1).

motion is based largely on a noticeable southeastward deflection in the southeast margin of the Reelfoot graben (between magnetic lineaments a and b, fig. 1). The region between gravity lineaments C and D (fig. 9) also appears to be offset southeastward by about 12 km (Hildenbrand and others, 1982). The inferred Precambrian fault, along which the Ste. Genevieve fault developed, may extend into Kentucky either along lineament C (Hildenbrand and others,

1982) or lineament D (Lidiak and Zietz, 1976). Analysis of magnetic data indicates that gravity lineaments C and D continue southeast into Tennessee (a and b, fig. 1). Hildenbrand and others (1982) proposed that this faulted region represented a transition from a rift structure to a block-faulted region.

Of particular interest is that anomalies E and F (fig. 9) have sharp corners on their southeastern edges. Hildenbrand and others (1982) suggested that the source of anomaly E is an intrusion emplaced along axial faults of the Reelfoot graben (see intrusion located on the Kentucky-Tennessee border, fig. 1). We propose here that the intrusions associated with anomaly E and those along the PGL were emplaced along both the Reelfoot axial faults and the proposed northwest-trending faults shown in figure 9. The sharp corners of anomalies E and F indicate that the associated edges of the intrusions are structurally controlled by the intersecting northwest-trending Precambrian faults and the early Paleozoic axial faults of the Reelfoot graben. The age of the intrusions should therefore be early Paleozoic or younger.

The coincidence of magnetic highs (fig. 2) and microcrystalline silica (tripoli) argues for a post-rift igneous event along the PGL. Berg and Masters (1994) recognized this correlation and proposed that intrusions provided the heat source to drive hydrothermal waters that deposited silica in southwestern Illinois. The age of these deposits is unknown, although they are hosted by Early Devonian sedimentary rocks. The magnetic intrusions in the region of the silica deposits (figs. 2 and 8) lie at depths substantially above (>1 km) Precambrian basement. Nearby interpreted magnetic intrusions (fig. 8) may have also been heat sources with associated silica deposits. The strong correlation between silica deposits and shallow magnetic intrusions infers that some of the igneous bodies along the PGL are of Early Devonian or younger age. To the northwest, Early to Middle Devonian igneous rocks lie along the trend of the PGL near Avon, Mo. (fig. 1). Without additional data, it is difficult to speculate on the age(s) of the intrusions that produce the PGL. Intrusions of different ages may be present. Probable ages based on the age of nearby igneous rocks and structures include Cambrian (syn-rift), Devonian, late Paleozoic, and (or) Cretaceous.

Does the PGL represent a third rift arm? The lateral extent of PGL (about 80 km beyond the northwest margin of the Reelfoot graben) is considerably smaller than the length of either the Reelfoot rift or Rough Creek graben. If a third rift arm is expressed by the PGL, it has a lateral extent uncharacteristic of other rifts. There are also no data to support the existence of an associated graben or rift-related sedimentary rocks along the PGL (Kolata and Nelson, 1991). Hildenbrand and Hendricks (1995) provide an alternative interpretation for the structures related to the PGL: a strike-slip fault zone that accommodated strain at the juncture of the Reelfoot rift and Rough Creek graben.

The calculated densities of the intrusions along the PGL suggest a mafic source rock, such as gabbro or diorite. Many of the steep gradients and small widths of large-amplitude gravity anomalies along the PGL (fig. 7) clearly require that these mafic intrusions lie at relatively shallow depths (<10 km). Some of the anomalous mass producing the prominent gravity highs in the study area, therefore, resides in the upper crust. An anomalously high density mass at the base of the crust may also be present, as previously proposed by Cordell (1977). The regional gravity field in figure 4 may reflect, in part, anomalous crust immediately above the mantle.

## SOUTH-CENTRAL MAGNETIC LINEAMENT

In the study area, the SCML reflects an igneous event that emplaced large volumes of high-susceptibility rocks along a 40-km-wide northwest-trending zone (figs. 6 and 8). Occurrence of Permian alkalic, ultramafic dikes along the SCML (Baxter and others, 1989) suggests that the SCML developed during Early Permian as the supercontinent Pangea was assembled. Kolata and Nelson (1991) proposed that this major tectonic event resulted in Permian deformation and associated igneous activity in the southern part of the Illinois Basin. There are, however, reasons to propose that the source of the SCML developed earlier than Permian time:

- In east-central Tennessee, the lineament appears to reflect contrasts in magnetic properties in Keweenawan rocks (Hildenbrand, 1985a).
- Seismic lines crossing the region of magnetic anomalies E and F (fig. 2) indicate horizontal layering in the Phanerozoic sedimentary rocks, with no indication of massive invasion of magma, except possibly for dipping horizons in the Precambrian (Heigold and Kolata, 1993).

Thus, the SCML possibly delineates a Precambrian basement feature that developed along a northwest-trending structure of the old (1.6 Ga) metamorphic basement, similar to that underlying Missouri. The exceptional linearity of the SCML suggests that the source is a shear zone. Because Keweenawan (1.1 Ga) features may be structurally related to this proposed shear zone, its possible origin spans a period of time from about 1.6 to 1.1 Ga. The age of the igneous intrusions along the SCML may be 1.6 Ga or younger. Moreover, because the SCML appears linear (Hildenbrand, 1985a) in the region where the Reelfoot graben and Rough Creek graben merge, the source of the SCML would have been minimally affected by deformation during rifting or rift reactivation.

The calculated physical properties (figs. 7*B*, 7*C*) indicate an unusual rock type for the SCML intrusions. Densities (2.72 to 2.78 g/cm$^3$) suggest an intermediate rock such as granodiorite or quartz diorite. The high susceptibilities (0.021 to 0.103 SI), however, are typical of more mafic and denser rock types such as diorite, gabbro, or peridotite. As previously discussed, the intrusive thickness has a major effect on the calculated values of the physical properties. For example, if their thickness is reduced from 12 km to 6 km, density increases but susceptibility also increases to about 0.15 SI. This high susceptibility value is uncommon in the Precambrian rocks in the Midcontinent (except for iron-formations). On the other hand, rocks can acquire additional magnetic properties during their formation while cooling. The resulting natural remanent magnetization can be much greater than the induced magnetization (susceptibility × geomagnetic field intensity). Because there is no evidence to support large remanent magnetizations, we prefer an intermediate composition for the intrusions along the SCML

Paralleling the SCML to the southwest is a magnetic and gravity low. We assume that the geophysical low depicts a zone lying between zones heavily intruded by dense and magnetic rocks along the PGL and SCML. In a model (W-W′, fig. 7*A*) along the axis of this geophysical low, it was assumed that crystalline basement underlying the sedimentary rocks has negligible magnetic properties to a 10-km depth. This assumption is based on the intensity of the magnetic low, which is uncharacteristic in the magnetic field of the Midcontinent. Additional investigations are needed to establish whether the magnetic low is associated with a thick basin of nonmagnetic sediments or reversely magnetized rocks.

### SHALLOW DIKES

Permian ultramafic alkalic dikes and sills crop out or are encountered in drill holes at very shallow depths (<1 km) within the study area (Koenig, 1956; Clegg and Bradbury, 1956). These occurrences are much shallower than the computed depths to magnetic basement (2–6 km, figs. 5 and 7). The dimensions of these very shallow dikes (generally less than 7 m wide; Clegg and Bradbury, 1956) are too small to produce anomalies of sufficient amplitude to be observed on figures 2 and 3.

To enhance short-wavelength anomalies and delineate slightly larger igneous masses of economic interest such as Omaha dome, a high-pass filter (removing wavelengths greater than 10 km) was applied to the magnetic data east of long 89° W. (fig. 10). The data west of long 89° W. were not included because shallow Precambrian magnetic basement here can produce high-passed anomalies that are similar to those produced by shallow Permian igneous masses. Interpreted shallow intrusions are shown in figure 6. It should be noted that, because high-frequency anomalies can be generated by the deeper intrusions along the PGL and the SCML, only small intrusions offset from these lineaments are shown in figure 6. Gravity anomalies could not be used to delineate shallow intrusions due to the coarse station spacing (average spacing of about 4 km).

Of particular importance is that shallow intrusions (fig. 6) correlate well geographically with the known or indicated shallow intrusive centers near Omaha dome, Coefield, and Hicks dome. Other short-wavelength magnetic highs may delineate shallow Permian intrusions. Two intriguing possibilities would be the interpreted shallow magnetic bodies lying west-northwest of Hicks dome (intrusive-related mineralization occurs at Hicks dome) (Bradbury and Baxter, 1992).

## SUMMARY AND CONCLUSIONS

The potential-field data have provided a geologic picture of the subsurface that indicates that the study area experienced a long and complex tectonic and magmatic history. In Middle Proterozoic time (about 1.6 Ga), basement consisted of gneissic rocks with a pervasive northwesterly structural grain (Kisvarsanyi, 1984). Some of these structures may have been zones of weakness along which later structures developed, such as the proposed shear zone expressed as the SCML. The SCML is a prominent, linear magnetic feature that trends northwest from eastern Tennessee into Missouri. In the study area, the SCML is clearly expressed as a 40-km-wide band of magnetic highs that, on the basis of modeling, may reflect large plutons emplaced along the shear zone. Calculated susceptibilities and densities indicate a highly magnetic intermediate source rock, such as quartz diorite. Because Keweenawan (1.1 Ga) features to the east of the Paducah quadrangle may be structurally related to this shear zone, emplacement of the intrusions may span an interval from 1.6 to 1.1 Ga. The age of the intrusions along the SCML, however, has yet to be determined because they may have been emplaced after the development of the shear zone. Although highly speculative, we base our interpretation of an intruded Precambrian shear zone on the exceptional linearity of the SCML. The relation of the shear zone to the tectonic evolution of interior craton has yet to be determined.

To the west of the Paducah quadrangle, volcanic activity formed the St. Francois Mountains at about 1.5 Ga and laid down a granite-rhyolite terrane over, at least, the western parts of the study area (Bickford and others, 1981). Two oval magnetic and gravity lows on the western edge of the Paducah quadrangle probably represent subcropping tin-granite plutons that were emplaced during this igneous event.

In early Paleozoic time (about 570 Ma), the breakup of the North American supercontinent resulted in the formation of several aulacogens (Thomas, 1991), which included the Reelfoot and Rough Creek rifts. Our preferred interpretation of the relation between these two rifts is that the Reelfoot graben simply bends eastward to merge with the Rough Creek graben. This interpretation is based on the lack of geophysical features trending northeast across the SCML. Instead, interpreted lineaments and depressions in magnetic

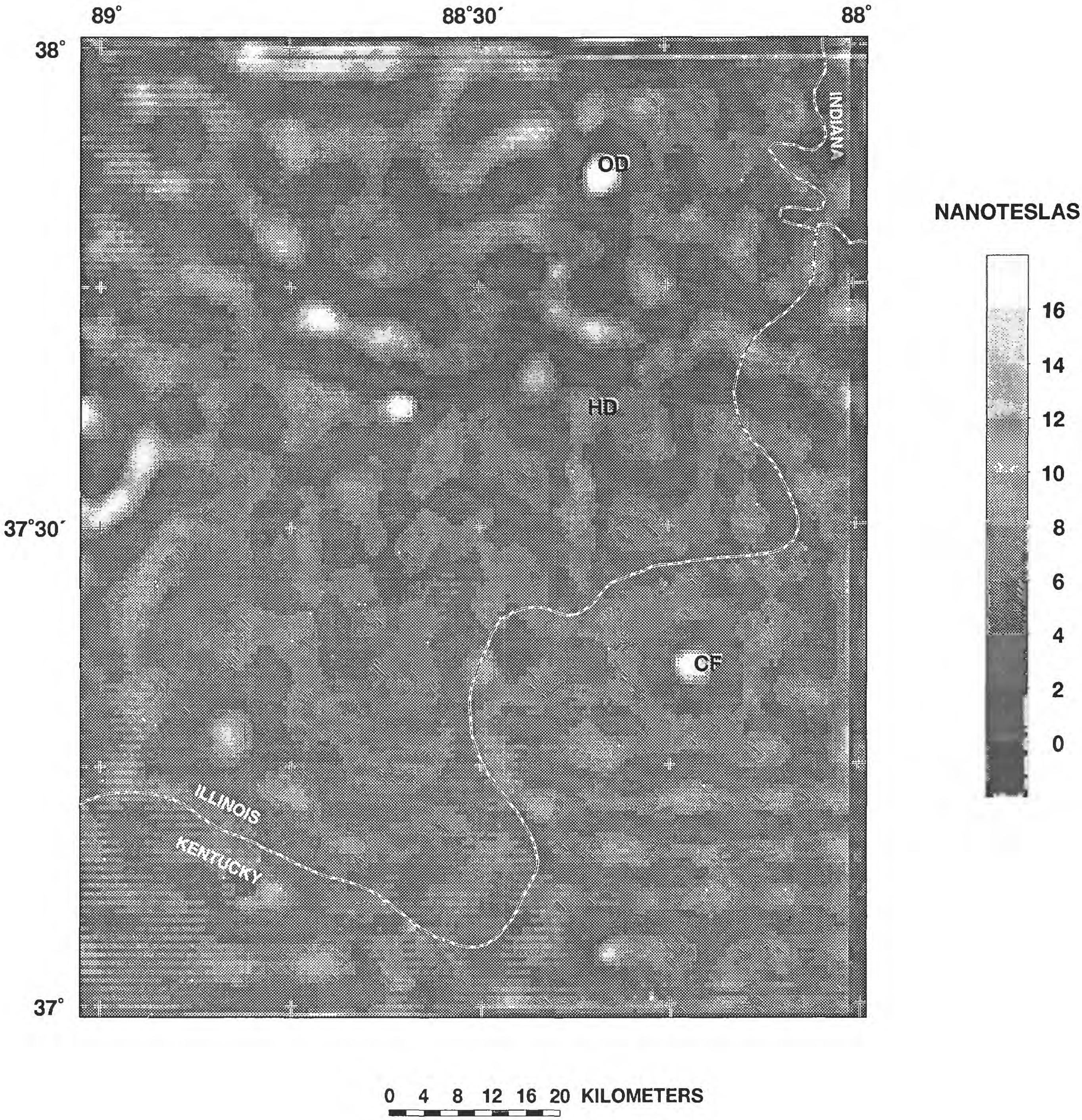


**Figure 10.** High-pass magnetic anomaly map. Wavelengths greater than approximately 10 km have been removed from the magnetic data in figure 2. Three known or indicated shallow intrusive centers (Hicks dome (HD), Omaha dome (OD), and Coefield (CF)) coincide with positive magnetic anomalies.

basement trend northwest or bend eastward at the juncture of the rifts. This interpreted bend in the rift may be related to a preferred strain direction or to an obstacle such as competent, homogeneous batholithic rocks of the St. Francois Mountains.

At the juncture of the rifts, northwest- and northeast-trending faults along the axis of the Reelfoot rift may have provided channelways for magma. Prominent gravity highs parallel these faults and form the PGL. Of particular interest is that these anomalies have sharp edges at the intersections of the faults. This geophysical pattern suggests that large intrusions were emplaced in a block-faulted region. Strike-slip motion along the northwest-trending faults is indicated by deflections in the southeast margin of the Reelfoot rift. Because the axial faults of the Reelfoot graben also appear to have been channelways for the magma, the igneous event(s) probably occurred during rifting (Cambrian) or later. Because Devonian-hosted silica deposits correlate with some of the magnetic highs along the PGL, the age of the associated intrusions appear to be Devonian or younger. One could argue, however, that nearby igneous bodies and structures indicate a late Paleozoic or Cretaceous age for these intrusions. In summary, the age or ages of the mafic intrusions along the PGL have yet to be determined, but likely possibilities include Cambrian, Devonian, late Paleozoic, and (or) Cretaceous.

These mafic intrusions form a 100-km-wide zone near the axis of the Reelfoot graben and trend northwest for 180 km into eastern Missouri where the zone narrows to 30 km. This nose extends northwest about 80 km beyond the interpreted bend of the northwestern margin of the Reelfoot graben. The PGL probably does not represent a failed rift arm due to its short lateral extent and absence of rift-related early Paleozoic sedimentary rocks (Kolata and Nelson, 1991). The heavily intruded zone is interpreted here to be the result of reactivation of old faults during rifting (Cambrian) or subsequent tectonism.

The post-rifting phase included thick accumulations of sediments, as evidenced by the deepening of magnetic basement (>6 km) in the eastern part of the study area. Because magnetic basement is considerably shallower than Precambrian basement in two areas, post-rifting igneous activity may have emplaced large intrusions along northwest-trending faults in southwestern Illinois and along or near the north-northeast-trending Wabash Valley fault system in the northeastern part of the study area (fig. 8).

Other evidence for post-rifting intrusions are the subtle, local magnetic highs, enhanced by a high-pass filter. These magnetic highs probably delineate Permian ultramafic alkalic plugs or laccoliths at shallow depths (<1 km). Of particular importance is that positive anomalies coincide with known or indicated shallow intrusive centers near Omaha dome, Coefield, and Hicks dome. Perhaps some of the other 11 positive anomalies delineate shallow intrusions with mineral potential, similar to that at Hicks dome.

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