Geophysical Setting of the Wabash Valley Fault System

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ABSTRACT

Interpretation of existing regional magnetic and gravity data and new local high-resolution aeromagnetic data provides new insights on the tectonic history and structural development of the Wabash Valley Fault System in Illinois and Indiana. Enhancement of short-wavelength magnetic anomalies reveal numerous NW- to NNE-trending ultramafic dikes and six intrusive complexes (including those at Hicks Dome and Omaha Dome). Inversion models indicate that the interpreted dikes are narrow (≤3 m), lie at shallow depths (<200 m) and are steeply dipping. Some of the interpreted dikes closely follow mapped faults; their abundance suggests that the Wabash Valley Fault System contains many more faults than those mapped. Both the interpreted dike pattern and mapped Wabash Valley Fault System terminate near the Reelfoot-Rough Creek-Rome rift system.

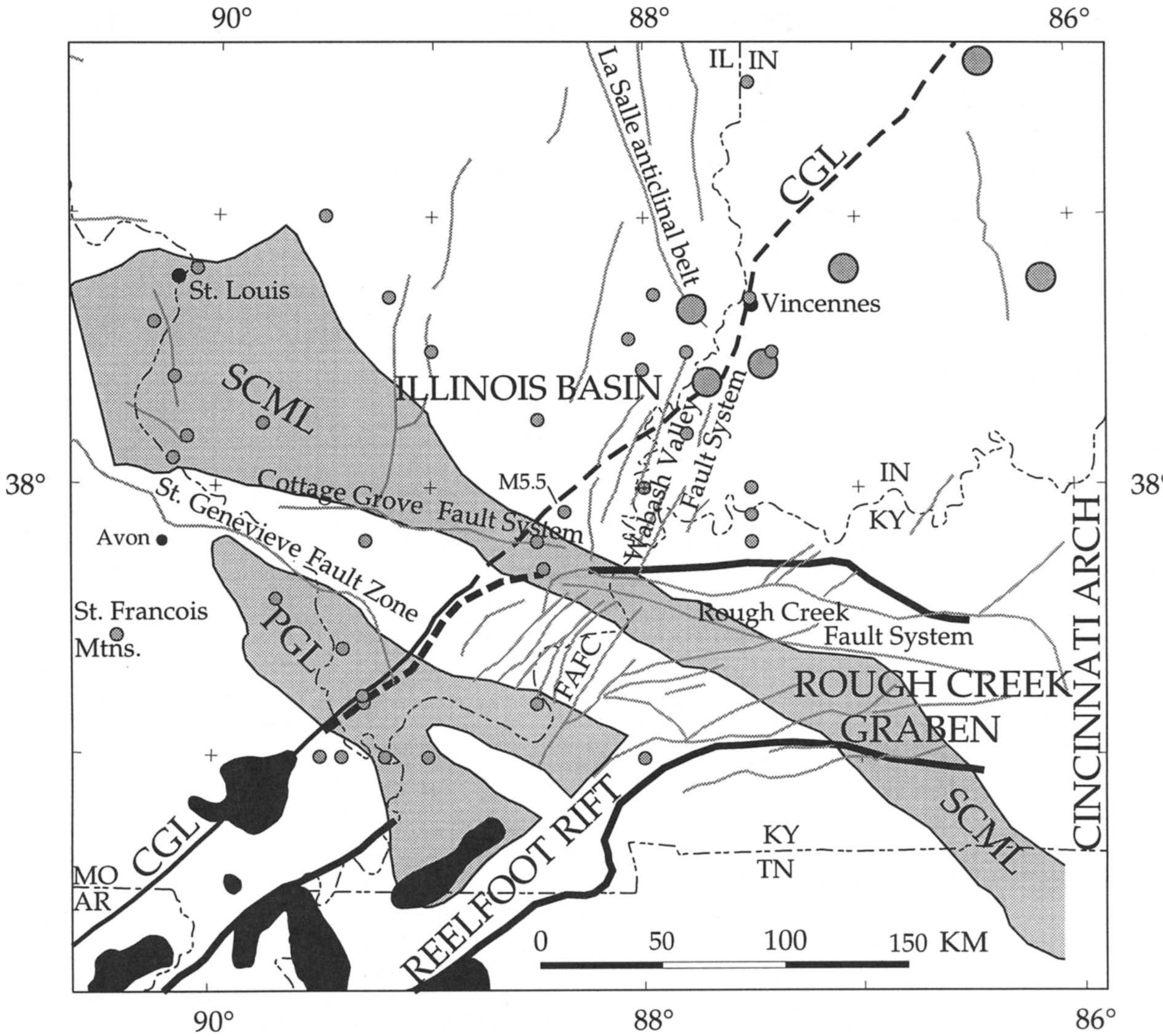
Based on the interpretation of both the regional magnetic and gravity data and the high-resolution magnetic data, we propose that the shallow faults and deep-seated rift structures in the Wabash Valley terminate at or near the Rough Creek-Shawneetown Fault System. The Grayville Graben (~20 km wide, ~700 m maximum basement relief, and <40 km long [Bear *et al.*, this volume]) underlying the Wabash Valley developed during rifting, perhaps in response to stress concentrations generated by a bend in the Reelfoot-Rough Creek-Rome rift system. We therefore hypothesize that although the Reelfoot Rift and Rough Creek Graben represent tectonic intraplate structures of large areal extent (>500 km long and generally >50 km wide) and with deep basins (locally >3 km thick), the ancestral Wabash Valley faults express, in comparison, minor tectonic structures and probably do not represent a failed rift arm.

There is a lack of any obvious relation between the Wabash Valley Fault System and the epicenters of historic and prehistoric earthquakes. Five prehistoric earthquakes lie conspicuously near structures associated with the Commerce geophysical lineament, a NE-trending magnetic and gravity lineament lying oblique to the Wabash Valley Fault System and possibly extending over 600 km from NE Arkansas to central Indiana.

INTRODUCTION

The Wabash Valley Fault System (WVFS) lies within the southern Illinois Basin (Figure 1), immediately north of the juncture of two late Precambrian-early Paleozoic rifts: the Reelfoot Rift and the Rough Creek Graben (Kolata and Nelson, 1991). This region of the juncture of two rifts is crossed by a NW-trending continental-scale crustal discontinuity, possibly representing a late Precambrian shear zone (called the south-central magnetic lineament; Hildenbrand, 1985a). Numerous igneous intrusions, some of Permian age but most of unknown age, have been emplaced in both the shallow and deep parts of the crust. The WVFS and 3 other major fault systems (Cottage Grove Fault System, Ste. Genevieve Fault Zone, Fluorspar Area Fault Complex) lie within or extend outward from the region defined as the intersection of two rifts, structurally one of the most complex regions in the Midcontinent. These structural complexities are reflected in the potential-field data, which can aid in providing a meaningful geologic picture of the subsurface. Knowledge of the crustal structures in the Wabash Valley region provides a framework for understanding the tectonic development of the craton and the seismogenic source(s) related to nearby historical and prehistoric earthquakes investigated by Munson *et al.* (this volume).

Previous regional potential-field studies have been useful in defining structures related to the Reelfoot Rift and Rough Creek Graben. Cordell (1977) suggested that the Reelfoot Rift extends northeastward into southern Illinois and western Kentucky, where broad gravity highs are interpreted as evidence for the anomalously dense zone (a fossil "rift cushion") at the crust-mantle boundary. Subsequent potential-field studies (Soderberg and Keller, 1981; Braile *et al.*, 1982, 1986; Hildenbrand *et al.*, 1982; Hildenbrand, 1985b; Hildenbrand and Hendricks, 1995) have further delineated buried rift structures in the Illinois Basin region. The E-trending Rough Creek Graben, defined with gravity, magnetic, and drill-hole data (Soderberg and Keller, 1981), meets the NE-trending Reelfoot Rift in western Kentucky and southern Illinois. Braile *et al.* (1982, 1986) used gravity, magnetic, and seismic data to interpret a quadruple rift junction, which they called the New Madrid rift complex. In



▲ **Figure 1.** Reference map of the Reelfoot Rift and Illinois Basin region. Major geophysical features include the south-central magnetic lineament (SCML) and the Paducah gravity lineament (PGL). Heavy lines represent the inferred margins of the Reelfoot-Rough Creek-Rome rift system and the source of the Commerce geophysical lineament (CGL) (dashed where uncertain). Enclosed black areas show upper crustal dense and magnetic intrusions emplaced along the margins and axis of the Reelfoot Rift (from Hildenbrand and Hendricks, 1995). The 6 large gray circles are the approximate locations of epicenters of large prehistoric earthquakes (interpreted moment magnitudes greater than 6 and estimated radial location error of less than 20 km) discussed by Munson *et al.* (this volume) and Pond and Martin (this volume). Smaller gray circles are locations of epicenters of historical (1779–1989) damaging earthquakes (Mercalli intensity of VI or greater; Stover and Coffman, 1993). *M* 5.5 identifies the epicenter of the November 1968 moment magnitude 5.5 earthquake in southern Illinois. Gray lines locate major faults. FAFC represents the Fluorspar Area Fault Complex. Mapped faults in Illinois are from digital files from the Illinois State Geological Survey (Rob Lumm, Ill. State Geol. Surv., written commun., 1996), based on the structural map of Illinois by Nelson (1993). We digitized mapped faults in Indiana and Kentucky using figures from Nelson (1991).

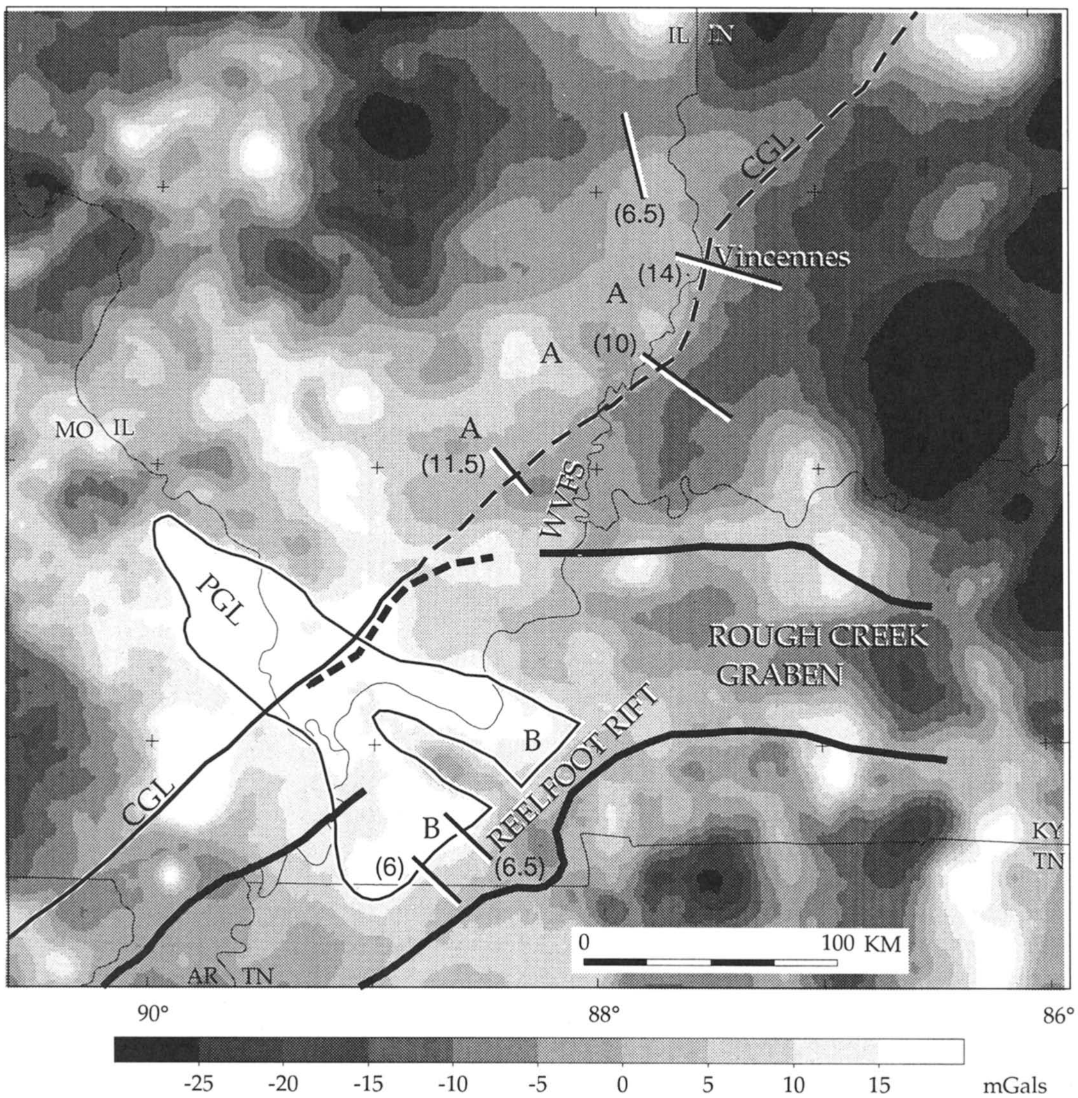
their model, the Reelfoot Rift and Rough Creek Graben form two of the failed rift arms of the quadruple junction; potential-field anomalies extending NE along the trend of the Wabash Valley and NW toward St. Louis from the juncture of the Reelfoot Rift and Rough Creek Rift may represent the remaining two arms (called, respectively, the Indiana and St. Louis rift arms). On the other hand, Hildenbrand *et al.* (1982) and Hildenbrand and Hendricks (1995) proposed that these latter two rift arms are more local features (and not rift arms) related to stress accumulations at the bend (formed by an accommodation zone or transfer zone) of the Reelfoot-Rough Creek-Rome rift system. Important here is that both interpretations suggest that although the WVFS is commonly defined as high angle normal faults outlining late-Paleozoic horsts and grabens, its time of origin extends back to late Precambrian-early Paleozoic rifting.

Here we investigate the relationship of rifting and the ancestral WVFS utilizing existing regional magnetic and gravity data. In particular, interpreted structures are sought that would aid in understanding if this fault system developed as (1) a failed rift arm with major significance to the structural development of the Illinois Basin, or (2) a local fracture system that developed due to tectonic process at a bend in the Reelfoot-Rough Creek-Rome rift system. If the ancestral WVFS is a failed rift arm, a tectonic model explaining the cause of earthquakes in the Illinois Basin would be similar to the model explaining the presence of the New Madrid seismic zone. On the other hand, if the WVFS is a local structure and not structurally connected to the New Madrid seismic zone, a seismogenic source unrelated to the WVFS may be responsible for the present seismicity and prehistoric earthquakes north of the Reelfoot-Rough Creek-Rome rift system.

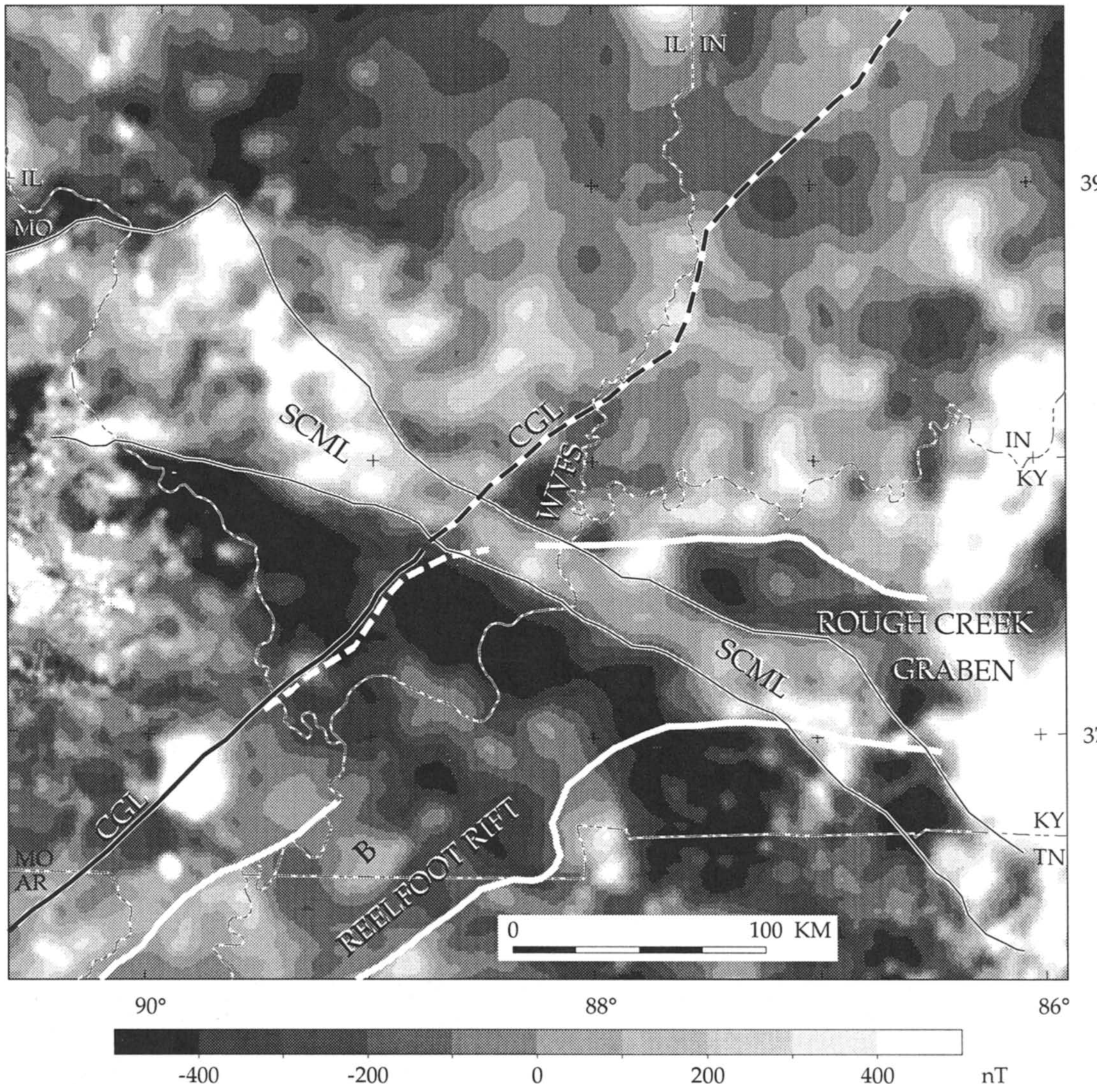
On a more local scale, new high-resolution aeromagnetic data over the southern part of the Wabash Valley are used here to define shallow magnetic sources related to faulting. These new data are important in defining the southern terminus of the WVFS. The high quality of these digital data allows application of several analytical techniques to enhance and invert the anomalies and provide new insights on the structural development of the WVFS.

GRAVITY AND MAGNETIC DATA

The gravity data (Figure 2) were taken from the Department of Defense database (85,031 stations). All data were tied to the IGSN-71 gravity datum and reduced to complete Bouguer-anomaly values using a reduction density of 2,670 kg/m^3 and the 1967 formula for the theoretical gravity (U.S.



▲ **Figure 2.** Complete Bouguer gravity. Anomalies A and B reflect dense igneous bodies with their tops lying within the upper crust, as determined from ideal body theory using the 6 profiles (heavy black/white lines; interpreted depths in km provided in parentheses). WVFS, CGL, and PGL represent the Wabash Valley Fault System, Commerce geophysical lineament, and the Paducah gravity lineament, respectively.

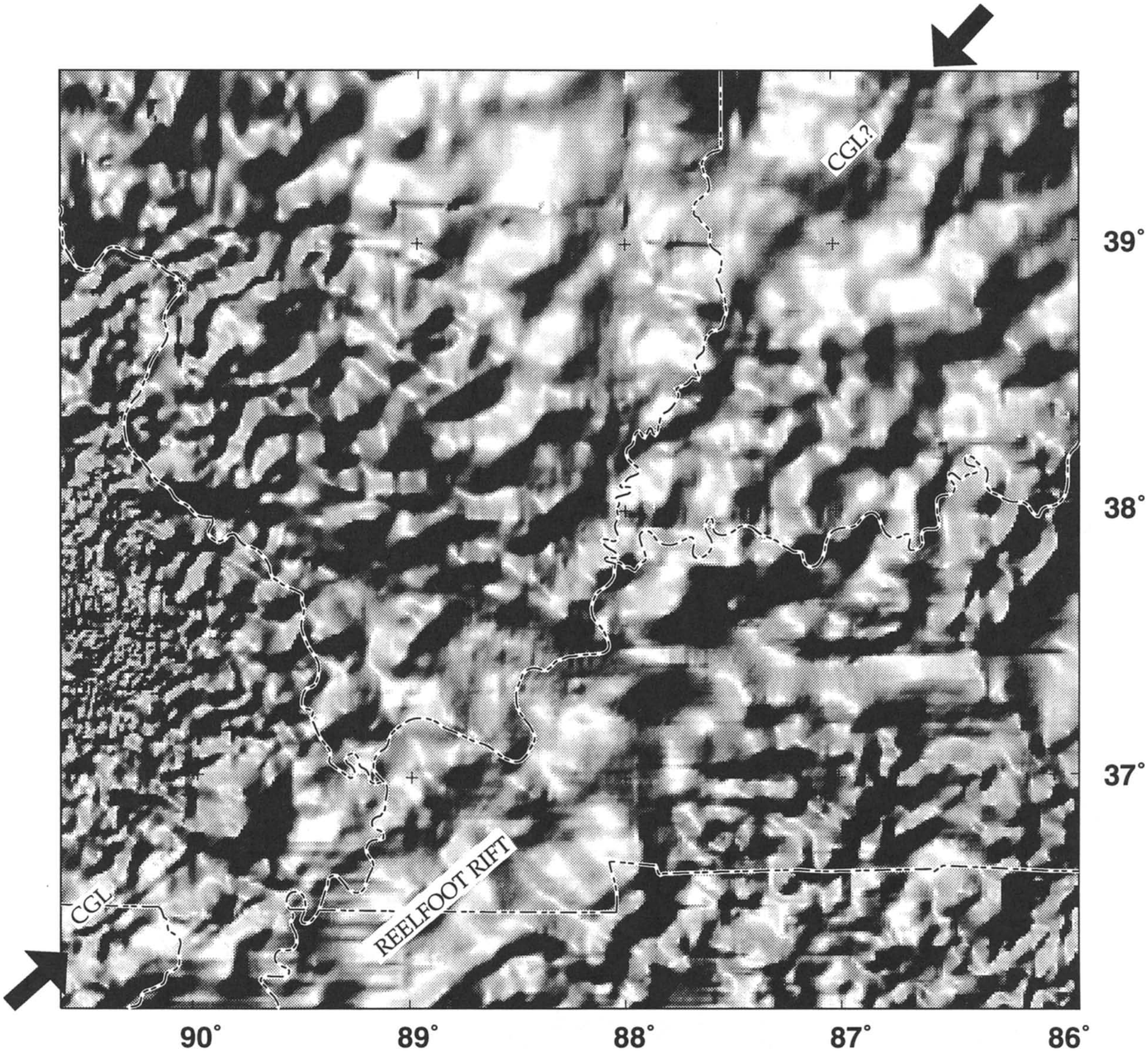


▲ **Figure 3.** Reduced-to-pole magnetic anomaly field of the Reelfoot Rift and Illinois Basin region. SCML and the CGL represent the south-central magnetic lineament and the Commerce geophysical lineament, respectively. Anomaly B represents a magnetic pluton lying along the axis of the Reelfoot Rift.

Geological Survey equations given by Cordell *et al.* [1982]). Although variable within the study area, the density of gravity stations is very good (generally one station per 3 to 6 km^2). Regions with poorer resolution include Kentucky and Tennessee where an average of one station per 10 km^2 is found, and in southern Indiana where the average station density is about one station per 40 km^2. A 1 km grid of Bouguer values (Figure 2) was prepared using a minimum curvature algorithm developed by Webring (1982).

The digital set of regional aeromagnetic data was compiled by merging two previously compiled databases of the central U.S. (Hildenbrand, unpublished data) and the Mississippi Embayment region (Hildenbrand and Hendricks, 1995). The resolution of existing magnetic data is adequate to study the regional features at the juncture of the Reelfoot Rift and Rough Creek Graben. Survey line spacing is generally 1.6 km or less in these areas, except in central Illinois, where the spacing increases to 10 km. A 1 km grid of magnetic values was prepared for each aeromagnetic survey using a minimum curvature algorithm. All data were analytically continued to a consistent 305 m above terrain. The magnetic-anomaly data shown in Figure 3 were reduced to the magnetic pole, a procedure that shifts most anomalies to positions above their sources. A shaded-relief map (Figure 4) of these data highlights the boundaries of major features intersecting the southern Illinois Basin region.

A new, high-resolution aeromagnetic survey was recently flown at 152 m above the ground along 457-m-spaced flight lines over the southern part of the WVFS. Flight direction was N62°W, roughly normal to the faults in the Wabash Valley. The resulting reduced-to-pole magnetic field is shown in Figure 5. This new magnetic anomaly data set offers the opportunity to investigate the continuity of magnetic features trending south toward the Rough Creek-

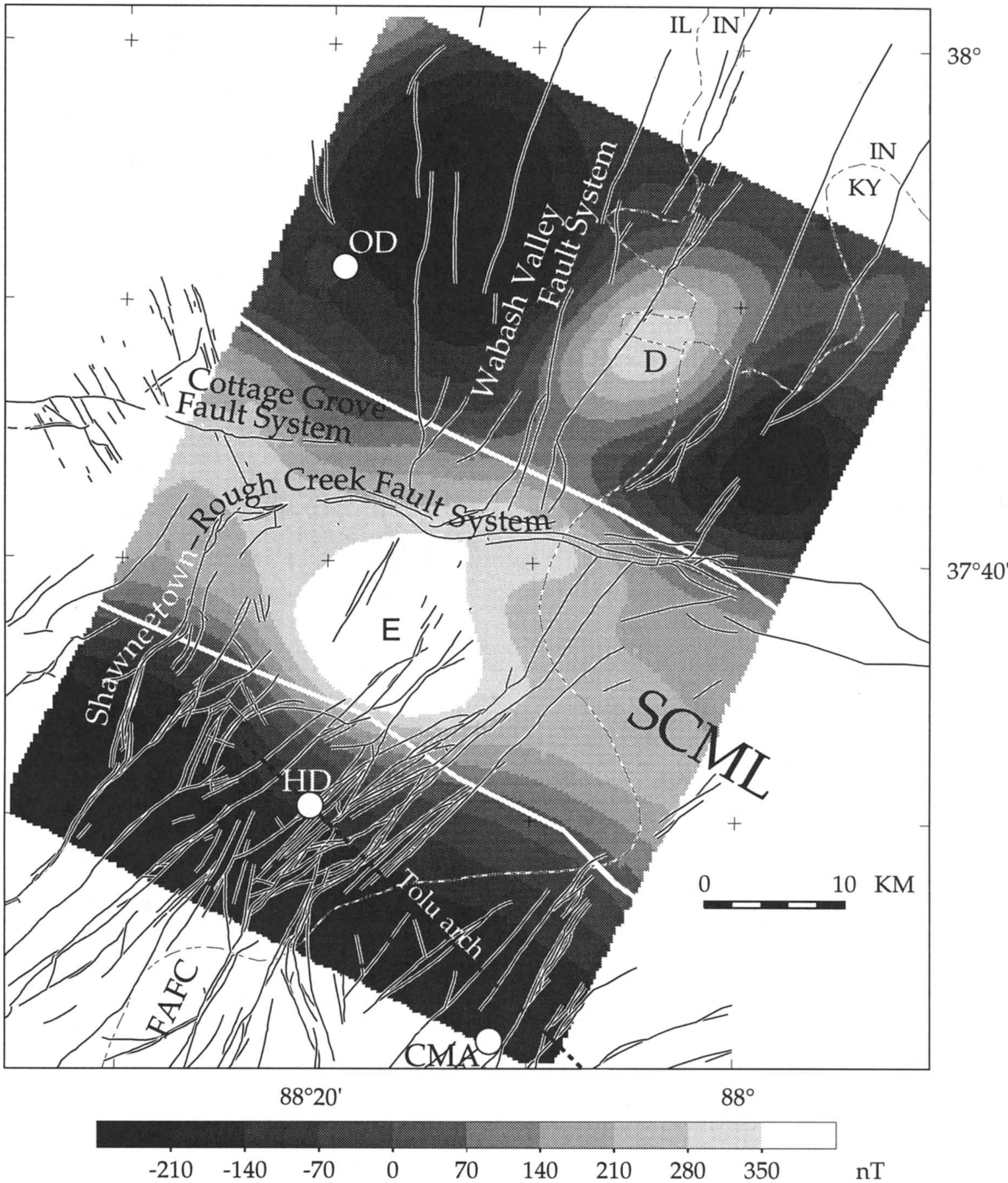


▲ **Figure 4.** Shaded relief map of the reduced-to-pole magnetic field of the Reelfoot Rift and Illinois Basin region. Arrows highlight the trend of the Commerce geophysical lineament (CGL).

Shawneetown Fault System and their relation to the Reelfoot-Rough Creek-Rome rift system.

GEOLOGICAL AND GEOPHYSICAL SETTING

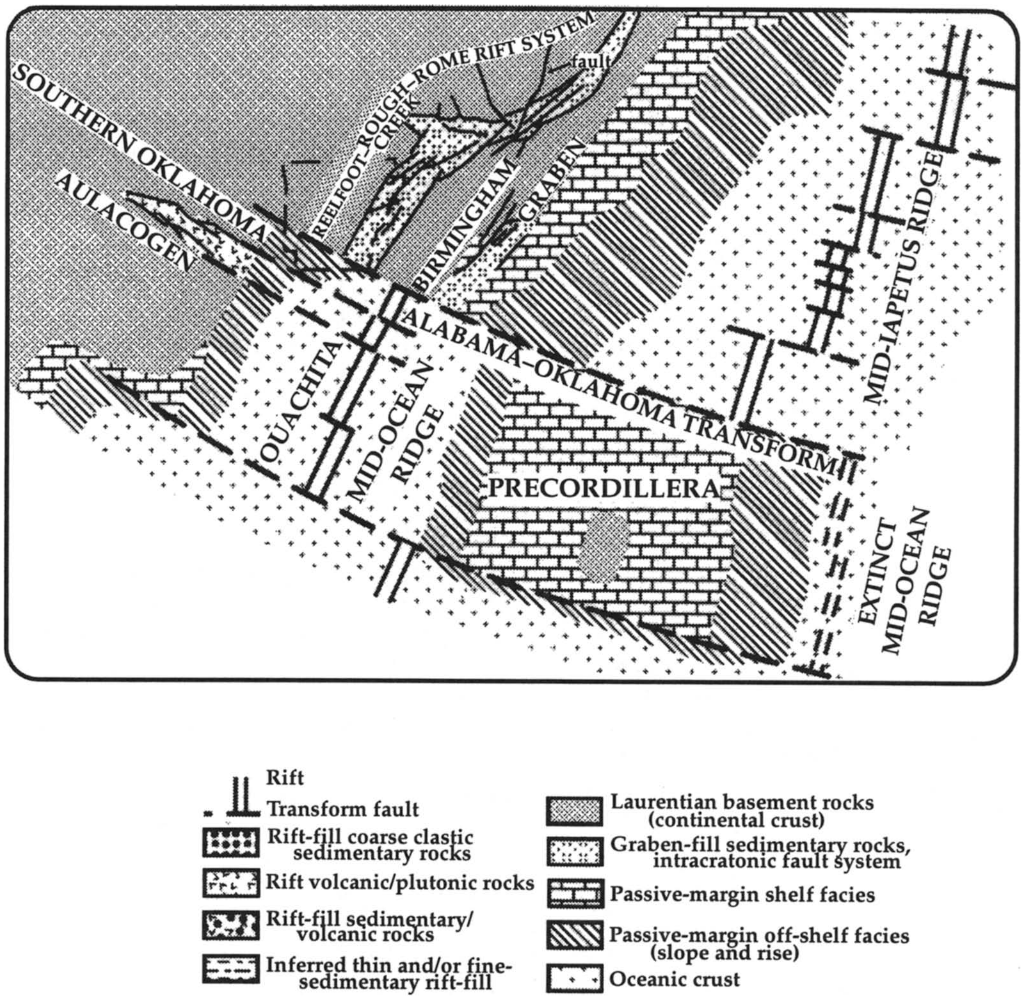
Precambrian crystalline basement contains the major gravity and magnetic sources within the Illinois Basin. Precambrian rocks crop out only in the St. Francois Mountains to the west near the crest of the Ozark Dome, where Middle Proterozoic (~1.5 Ga) plutonic and volcanic rocks consisting mainly of epizonal granite and related rhyolite (Bickford *et al.*, 1981; Kisvarsanyi, 1981) are exposed. This granite-rhyolite terrane is extensive in the southern and central interior of the craton (Van Schmus *et al.*, 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). South of the Illinois Basin within the Reelfoot Rift, a deep drill hole 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 SE of the WVFS in the Rough Creek Graben (Exxon #1 Bell) where a 0.65 Ga basalt was encountered (Larry Snee, U.S. Geol. Survey, written communication, 1993) and farther east in Lawrence County, Indiana (lat 38°48′ N long 86°24′ W) where ophitic basalt was recovered (Lidiak *et al.*, 1985). In eastern Kentucky and Tennessee, the Grenville Province rocks (1.1 Ga) developed in and adjacent



▲ **Figure 5.** Reduced-to-pole, high-resolution magnetic anomaly data over a structurally complex area where several faults systems intersect (such as the Wabash Valley Fault System, Rough Creek Fault System, Fluorspar Area Fault Complex [FAFC], and Cottage Grove Fault System). Individual faults are shown by lines. Heavy white lines represent the boundaries of the NW-trending south-central magnetic lineament (SCML). White circles locate intrusive complexes at Hicks Dome (HD) and Omaha Dome (OD) and underlying the Coefield magnetic anomaly (CMA). Black short-dashed line shows the trend of the Tolu arch. Magnetic anomalies D and E are discussed in the text.

to the Eastern Granite Rhyolite Province. The Grenville Province consists of a variety of rock types: among these are mafic and felsic volcanics, amphibolite, and mafic granulite (Lidiak *et al.*, 1985).

North America was part of a larger supercontinent during Late Proterozoic time. During the Late Proterozoic to Early Cambrian, continental breakup resulted in the formation of a passive continental margin along the present south-



▲ **Figure 6.** Diagrammatic map showing Thomas's (1991, 1996) interpretation of the late Precambrian-early Paleozoic Appalachian-Ouachita rifted margin of North America as it appeared in Middle Cambrian time. In Thomas's model, the opening of the Iapetus Ocean produced an orthogonally zigzag margin outlined by NE-trending rift zones and NW-trending transform faults. Important here is the hypothesis that the NW-SE extensional forces (possibly coupled with drag on the rifted block sliding along a transform fault) resulted in the formation of the Reelfoot Rift, possibly along a preexisting weak zone. In Thomas's model, the Rough Creek Graben functioned as an oblique transfer zone connecting the offset extensional structures of the NE-trending Reelfoot Rift and Rome Trough. Note the complex structures at the two bends of the Reelfoot-Rough Creek-Rome rift system. We propose that these structures form at these bends to relieve stress concentrations arising not only during rifting but also during subsequent tectonic events. (Taken with permission from W.A. Thomas (1996), The Argentine Precordilla: A traveller from the Ouachita Embayment of North America Lauentia, *Science,* **273**, 752–757. Copyright 1996 Ammerican Association for the Advancement of Science; and taken from the Geological Society of American Bulletin, W.A. Thomas [1991]. The Appalachian-Ouachita rifted margin of southeastern North America: *Geol. Soc. Am. Bull.,* **103**, 415–431, with permission of the Geological Society of America, Boulder, Colorado, USA. Copyright 1991; note that in his figures the Reelfoot Graben is named the Mississippi Valley Graben.)

ern and eastern edge of the proto-North American craton (Keller and Cebull, 1973; Hendricks, 1988; Thomas, 1991; Kolata and Nelson, 1991). Several aulacogens (or failed rifts) and strike-slip faults developed in conjunction with the formation of this new continental margin (Figure 6) (Burke and Dewey, 1973; Thomas, 1996).

Of interest here are the anomalously-thick accumulations (roughly 1.5 km and locally >3 km) of late Precambrian or Cambrian sediments in the Reelfoot Rift, the Rough Creek Graben and Rome Trough (Ervin and McGinnis, 1975; Soderberg and Keller, 1981; Hildenbrand, 1985b; Potter and Drahovzal, 1994; Drahovzal and Noger, 1996; Drahovzal, this volume). The Reelfoot-Rough Creek-Rome rift system (Figure 6) formed during this continental breakup. The Reelfoot Rift trends northeast from east-central Arkansas to the southern Illinois Basin region and is reflected as a 70-km-wide graben (Hildenbrand, 1985b) with a maximum basement structural relief of over 4 km

(Dart, 1995). The Rough Creek Graben, with a maximum basement relief of 4 km (Potter and Drahovzal, 1994), is roughly 100 km wide and trends east-west in western Kentucky and southern Illinois (Soderberg and Keller, 1981). Basement structural relief related to the Rome Trough in eastern Kentucky and western West Virginia can locally exceed 3 km (Ammerman and Keller, 1979).

The Wabash Valley Fault System (WVFS) is characterized by high-angle normal faults that bifurcate upward and outline horsts and grabens (generally less than 800 m wide). Maximum throw on these faults is about 150 m. Kolata and Nelson (1991) suggested that NW-SE compressional stresses during continental collision during late Paleozoic time arched this region and formed the WVFS. However, seismic reflection data show a late Precambrian-early Paleozoic graben (called the Grayville Graben) underlying the Wabash Valley (Sexton *et al.*, 1986). Based on the seismic reflection data, Bear *et al.* (this volume) define the NNE-trending Grayville Graben as underlying the WVFS and extending from near lat 38° N to about lat 38° 15′ N. The older Grayville Graben may be related (*e.g.*, part of an ancestral fault system?) to the late-Paleozoic WVFS. In comparison to the Reelfoot-Rough Creek-Rome rift system, the Grayville Graben is considerably smaller in cross section (~0.7 km maximum basement structural relief; ~20 km width) (Bear *et al.*, this volume). The width of the Grayville Graben is considerably less than that of the Indiana rift arm proposed by Braile *et al.* (1986).

Igneous intrusions

Besides the massive plutons lying along the margins of the Reelfoot Rift, dikes, diatremes, and plugs as young as Permian intrude Precambrian basement and younger formations within the southern Illinois Basin region. For instance, in the Illinois-Kentucky Fluorspar district, late Paleozoic faults of the Fluorspar Area Fault Complex (FAFC, Figure 5) commonly displace Permian alkalic dikes, related to a regional dike system near Hicks Dome (Nelson, 1991). Hicks Dome is assumed to be associated with this igneous event because the dikes of peridotite, lamprophyre, and carbonatite breccia composition radiate from the dome. Reynolds *et al.* (1997) date these igneous rocks as 272 Ma years old, using $^{40}Ar/^{39}Ar$ geochronometric and paleomagnetic methods. Seismic reflection studies by Potter *et al.* (1995) reveal that the entire Phanerozoic sequence and the Precambrian basement surface are domed in this region.

North of the Rough Creek-Shawneetown Fault System (Figure 5), Permian ultramafic dikes of similar composition and age to those near Hicks Dome have been encountered in coal mines and exploratory wells at the Omaha Dome and along the Cottage Grove Fault System (Baxter *et al.*, 1989; Nelson, 1991). In comparing depths of magnetic basement and depths of Precambrian basement (based on seismic and drill-hole data), Hildenbrand *et al.* (1996) found that an interpreted intrusion (anomaly D on Figure 5) lies at a depth shallower (>1 km) than the depth of Precambrian basement. They proposed that this large shallow intrusion was emplaced during the Paleozoic in or near the WVFS.

On a more regional scale, Ervin and McGinnis (1975) and Cordell (1977) proposed that a broad NE-trending positive gravity anomaly associated with the Mississippi Embayment is caused by anomalously high-density masses at the base of the crust. They interpreted this regional gravity high (*e.g.*, anomaly A, Figure 2) as the fossil Reelfoot Rift cushion, which also appears on seismic refraction records (Mooney *et al.*, 1983). It will be shown later that, although the positive anomalies in the study area may be related to deep crustal sources, they have associated high-amplitude anomalies caused by dense igneous intrusions at shallower depths (<~10 km).

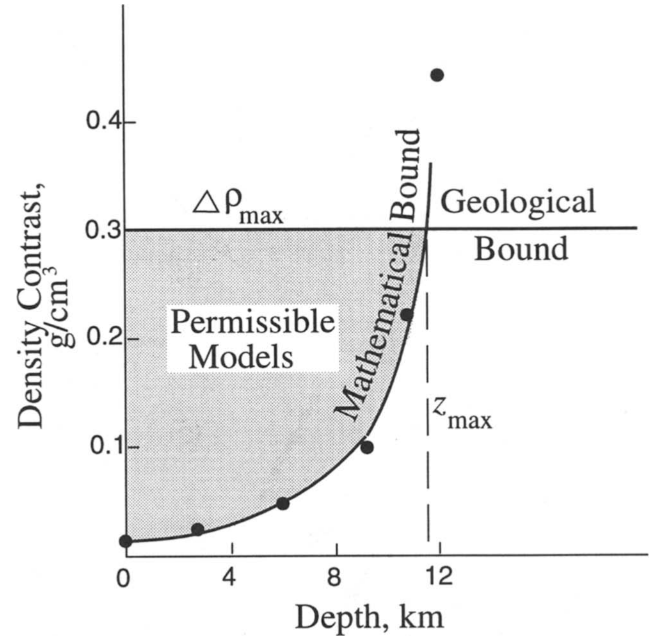
Many of the individual gravity peaks within a broad northwest-trending gravity high zone (the Paducah gravity lineament—PGL, Figure 2) coincide with isolated magnetic highs and thus suggest the presence of upper crustal mafic intrusions (Hildenbrand and Hendricks, 1995), although these anomalies may have related sources in the lower crust. Where the PGL crosses the Illinois-Missouri State boundary, the steep gradient on its northeastern edge coincides with the Ste. Genevieve Fault Zone (Figure 1). 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, Missouri. The Ste. Genevieve Fault Zone was active in Middle Devonian with normal faulting and in Pennsylvanian with reverse faulting (Weller and St. Clair, 1928; Nelson and Lumm, 1985). Hildenbrand and Hendricks (1995) proposed 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. Three other prominent NW-trending gravity gradients related to the PGL prompted Hildenbrand and Hendricks to propose that the PGL reflects a transition from a rift to a block faulted region that accommodated strain at the juncture of the Reelfoot Rift and Rough Creek Graben.

A prominent NW-trending zone of magnetic highs parallels the PGL and has been named the south-central magnetic lineament (SCML, Figures 1 and 3) by Hildenbrand *et al.* (1983) or the Tennessee-Illinois-Kentucky lineament (TIKL; but it also includes the flanking magnetic low south of the SCML) by Ravat (1984). Seismic reflection data across the SCML in southern Illinois also indicate a major boundary interpreted by Heigold and Kolata (1993) as a Proterozoic terrane boundary. Both Ravat (1984) and Hildenbrand (1985a) suggested that the NW-trending linear zone of magnetic highs, extending NW from eastern Tennessee to Missouri, represents a Keweenawan or older geologic/tectonic boundary intruded by mafic rocks. The Cottage Grove Fault System (Figure 1) may have evolved during strike-slip reactivation of this boundary and subsequently or concurrently acted as a channelway for magma forming some intrusions related to the SCML (Figure 5). Hicks Dome lies along the

SW flank of the SCML. Geophysical interpretations by McGinnis and Bradbury (1964), Ravat (1984), and Hildenbrand and Hendricks (1995) place the top of a mafic intrusion, represented by the NW-SE elongated magnetic high north of Hicks Dome (anomaly E, Figure 5), at a depth of about 4 km (*i.e.*, near the Precambrian surface).

Another geophysical feature related to igneous rocks is the Commerce geophysical lineament (CGL). It is defined as a NE-trending magnetic and gravity lineament extending over 400 km from NE Arkansas at least to southern Illinois (Figures 1, 3, and 4). Because the CGL is generally expressed as several narrow discontinuous magnetic and gravity highs, Langenheim and Hildenbrand (1997) suggested that the source of the CGL is a mafic dike swarm of unknown age and is probably related to the paralleling Reelfoot Rift. A careful inspection of the shaded-relief map (Figure 4) suggests that the CGL extends NE into Indiana (increasing its length to >600 km) and crosses the northern region of the WVFS. The CGL along this extension is characterized as an alignment of several NE-trending, linear edges of local magnetic anomalies probably reflecting crustal plugs, sills, or plutons at depths roughly shallower than 6 km (*e.g.*, refer to interpreted depths of magnetic sources along the CGL; Hildenbrand et. al, 1996). The CGL also follows the SE boundary of a NE-trending, broad gravity high zone (anomaly A in Figure 2). Near Vincennes, Indiana, the CGL seems to be offset about 30 km to the NW (Figure 1).

If the northeast extension of the CGL is viable, then its relation to the Reelfoot Rift becomes more enigmatic, as the Reelfoot Rift bends eastward in western Kentucky along the Rough Creek Graben. This difference in trend can be explained in two ways: (1) the CGL is related to structures older than the Reelfoot-Rough Creek rift system and it was reactivated during rifting in the sense that some of its structures provided channel ways for magma, or (2) the CGL developed during rifting but it only parallels known rift structures south of the Rough Creek Fault System (~lat 38° N) and oblique to rift structures north of lat 38° N. The relation between the CGL and rifting warrants additional study.



▲ **Figure 7.** Tradeoff curve for ideal body analysis. The curve represents the greatest lower bound on density contrast. The horizontal line denotes the maximum density contrast permitted by geologic constraints. The intersection of the curve and line leads to the maximum depth to the body. The data shown here are related to the southernmost profile associated with anomaly A in Figure 2. Black dots represent calculated minimum density contrasts for a given depth to the ideal body.

INTERPRETIVE TECHNIQUES

The gravity and magnetic data were filtered and inverted to provide geographical, geometrical, and physical constraints for the magnetic and mass sources in the Wabash Valley region. We discuss interpretations based on (1) ideal body theory to determine the maximum depth to gravity sources, (2) regional field removal to isolate the anomalies related to near-surface sources, (3) horizontal gradient analysis to locate lateral changes in magnetization, and (4) 2½-dimensional modeling to characterize crustal magnetic sources.

Ideal body theory

For any given depth to the top of a gravity source, ideal body theory mathematically leads to the smallest density contrast compatible with the data (Parker, 1975). Any source located at a particular depth must have a density contrast at least as large as the density contrast on the mathematical bound curve in Figure 7 (showing the results of one profile discussed below). With additional geologic information or reasonable assumptions on rock types, the range of permitted sources can be further constrained. Applying this geological bound to limit the maximum permissible density contrast for the geologic setting of the source leads to a limited number of possible models compatible with the data. Moreover, the intersection of the mathematical bound and geological bound determines the maximum depth of the geologically reasonable sources. In summary, with only an *a priori* assumption for the maximum reasonable density contrast, ideal body theory leads to a unique solution of maximum possible depth to the source.

An upper geological bound of 300 kg/m^3 was selected for the density contrast used to determine the permissible models for the gravity sources. This hypothetical maximum density contrast is partly based on 355 density measurements of Middle Proterozoic rocks in the St. Francois Mountains (written communication, Eva Kisvarsanyi, Missouri Department of Natural Resources, 1990). For the Eastern Granite and Rhyolite Province, densities range from 2,500 kg/m^3 (rhyolite) to 2,980 kg/m^3 (diabase) with a mean of about 2,670 kg/m^3 (note: 10 measurements on highly weathered rocks, iron ores, and specularite from this data set were not considered here). Precambrian upper crust in the study area probably has an average regional density between 2,670 and 2,750 kg/m^3. Assuming a maximum average density of about 3,000 kg/m^3 for dense igneous rocks in the upper crust (Daly *et al.*, 1966), the anticipated maximum density contrast is 300 kg/gm^3.

Six profiles crossing gravity gradients of the positive anomalies A and B (Figure 2) were used to define the maximum depth to the associated dense sources. The computed maximum depths for the source of anomaly A are 6.5, 10, 11.5 and 14 km. Figure 7 shows the results of the southernmost profile related to anomaly A. The results for anomaly B are 6 and 6.5 km. Thus the tops of the sources of anomaly A and B lie within the upper crust, although these anomalies may have related sources in the lower crust.

Linear feature analysis

To locate near-surface magnetic sources, regional magnetic anomalies were first removed to isolate the short wavelength anomalies of interest, and then horizontal-gradient analysis aided in locating the edges of these sources. The data were first reduced to the North Pole, assuming a total magnetization vector with an inclination of 56° N and declination of 36° E based on rock magnetic studies (discussed below). These reduced-to-pole data were upward continued analytically a small interval (25 m) to generate a regional field. The regional field was then subtracted from the original reduced-to-pole data to derive a residual field. However, with this approach, anomalies of wavelengths greater than 10 km remained that masked or reduced the expression of short-wavelength anomalies of interest in some areas. To remove these remaining longer wavelength anomalies, a high-pass filter (wavelength cutoff of 10 km) was applied to the residual field to create the short wavelength anomaly map shown in Figure 8). Several linear magnetic features are now apparent. Because their average length is roughly 4 km, these linear features are detected on many flight lines (an average of about 9 flight lines), providing some confidence in their existence. Moreover, the existence of similar linear short-wavelength magnetic anomalies observed from a New Madrid aeromagnetic survey (Hildenbrand *et al.*, 1992) has been established by ground magnetic profiles. (Note that errors associated with data acquired during a windy, rainy day are too large for this study of short wavelength anomalies. These poor-resolution data collected in the southern part of the survey have been removed from Figure 8. Also note that clustering of intense short-wavelength magnetic highs and lows delineate towns or oil fields. Several anomaly clusters expressing towns occur along the Ohio River and Wabash River and are highlighted in Figure 8.)

Horizontal gradient analysis is a lithologic and structural mapping tool that defines interpreted rock-unit boundaries on the basis of local curvature of the magnetic potential field (Cordell and Grauch, 1982). Maxima in the horizontal gradient of the potential field occur near steep or vertical boundaries separating contrasting magnetizations. In our study, the application of horizontal gradient analysis to the magnetic potential of the residual data aided in defining the location of linear features shown in Figure 9.

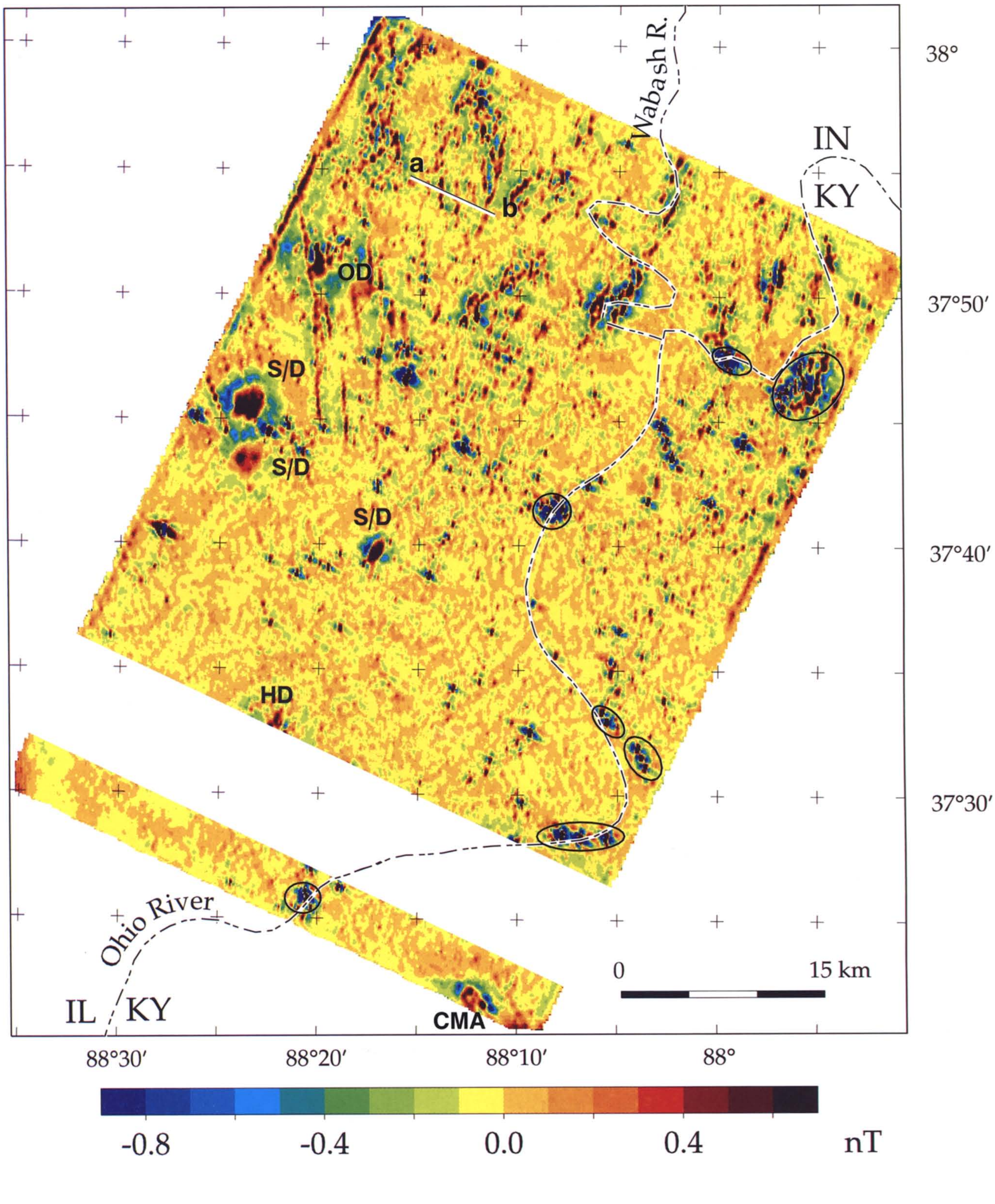
The majority of the linear features cluster in the NW corner of the survey area. Models of these linear features (below) suggest that their sources lie near the ground surface and have magnetic properties highly indicative of igneous rock. Thus, the linear features probably reflect dikes. There seems to be a correspondence between some mapped faults and interpreted dikes, which generally have similar trends. Moreover, both the faults and dikes related to the WVFS terminate near the Rough Creek-Shawneetown Fault System (Figure 9).

Circular or elliptical intense magnetic highs may delineate areas with greater volumes of near-surface ultramafic intrusions. For example, the magnetic sills related to the Omaha Dome, the Coefield magnetic anomaly (Anderson, 1992), and the northern parts of Hicks Dome are apparent in Figure 8. Three other highs (highlighted with S/D on Figure 8) may also reflect underlying intrusive centers of sills and dikes. These three magnetic highs are named here the Cottage, Saline, and Eagle magnetic anomalies (Figure 9).

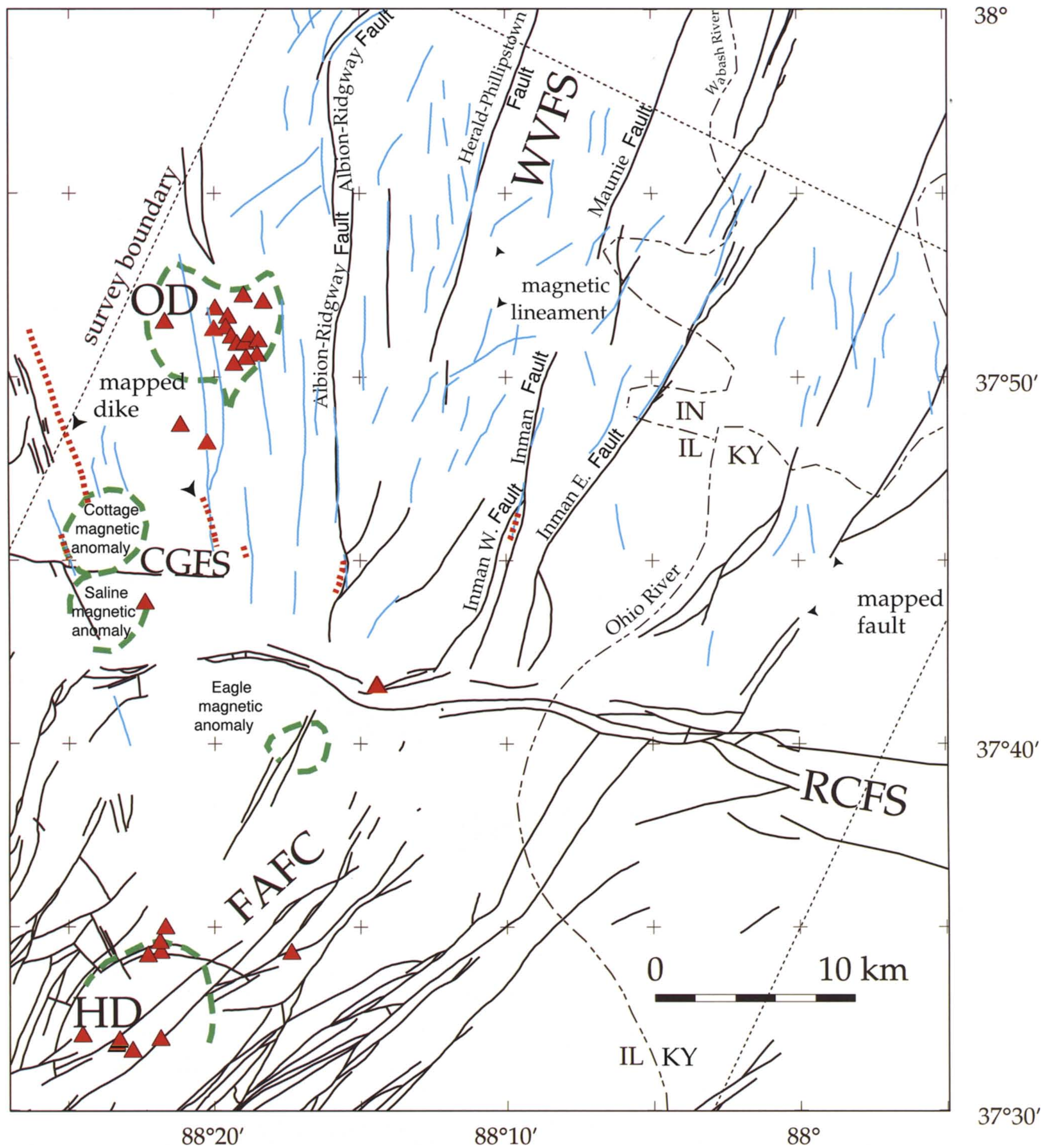
Inversion models

The principal goal of gravity and magnetic studies is to detect and quantify changes in magnetic and mass properties at depth and to make reasonable geologic inferences based on these interpreted property changes. To translate observed magnetic and gravity anomalies into a meaningful geologic picture of the subsurface requires inverse or forward modeling of the data. We used a 2½-dimensional modeling program called GMSYS (names of private products are for descriptive purposes only and do not imply endorsement by the U.S. Geological Survey), which is a mouse-driven and more elaborate version of SAKI (Webring, 1985). SAKI is based on generalized inverse theory. The program requires an initial estimate of model parameters (depth, shape, and magnetization of suspected sources) and then varies selected parameters in an attempt to reduce the weighted root-mean-square error between the observed and calculated magnetic fields. One profile (ab, Figure 8) was selected to explore the depth and magnetization of five interpreted dikes. (Adhering to the usage of SI units, the magnetic induction is expressed in nanoTesla (nT), where a SI induction of 1 T corresponds to a cgs field [induction] of 10^4 [gauss]. The induction in the study area is about 5.4×10^4 nT, so that a volume susceptibility of 2.3×10^{-2} [1.85×10^{-3} emu/cm^3] generates an induced magnetization of 1 A/m).

The interpretation of magnetic data yields nonunique solutions because an infinite number of geometrical models will have an associated field that closely matches the measured field. For example, increasing the magnetization while decreasing the depth to the bottom of a proposed intrusion will generally not produce an appreciable change in the computed field. Available drill-hole information and geological reasoning aid in deriving a suitable magnetic model to describe the buried dikes.



▲ **Figure 8.** Residual magnetic field after removing long wavelength anomalies from the new high-resolution aeromagnetic data shown in Figure 5. Several linear features interpreted as magnetic dikes are apparent in the northern part of the survey. Anomalies with roughly circular shapes, delineating inferred intrusive complexes (mainly dikes and sills), are labeled S/D. Known intrusive complexes are associated with Hicks Dome (HD), Omaha Dome (OD), and the Coefield magnetic anomaly (CMA) (Figure 5). Along the Ohio River, elliptical black lines highlight a few anomaly clusters related to cultural noise (*e.g.*, towns), each characterized by numerous intense magnetic highs and lows.



▲ **Figure 9.** Interpreted dikes (blue dashed lines) and mapped faults (solid black lines) in the Wabash Valley region. Heavy green dashed lines delineate interpreted magnetization boundaries related to intrusive complexes at Hicks Dome (HD) and Omaha Dome (OD) and at three other proposed locations (labeled S/D in Figure 8). Heavy dotted red lines locate mapped dikes. Red triangles are known locations of mafic or ultramafic igneous rocks. Both the interpreted dikes and Wabash Valley Fault System (WVFS) terminate near the Rough Creek Fault System (RCFS). Cottage Grove Fault System-CGFS. Mapped dikes and faults are from digital files provided by Rob Lumm (Ill. State Geol. Surv., written commun., 1996), based on the structural map of Illinois by Nelson (1993).

Drill-hole data of rock magnetic properties aid in constraining the magnetic properties of the dikes. A drill hole near the apex of Omaha Dome encountered ultramafic rocks in a sill containing 9 percent by volume magnetite (Sparlin and Lewis, 1994). Sparlin and Lewis successively modeled the magnetic data over the Omaha Dome using a susceptibility of 0.1 SI (0.008 cgs) for the sills. Reynolds *et al.* (1997) analyzed 10 rock samples from the Downeys Bluff sill (12 km south of Hicks Dome) and found a susceptibility of 0.052 ± 0.039 volume SI and a natural remanent magnetization of 3.3 ± 3 A/m with an inclination of $33.2 \pm 24.8°$ and declination of $107.8 \pm 23.7°$. Using the Earth's ambient field strength of 0.54 Oersteds, inclination of 67° and declination of 0°, the resulting total magnetization vector has an amplitude of 4.8 A/m, inclination of 56° N, and declination of 36° E.

These rock magnetic data indicate both a strong induced component and remanent component of magnetization. For our models of the Permian ultramafic dikes, we selected a susceptibility of 0.06 volume SI and a remanent magnetization of 5 A/m with an inclination of 24° N and declination of 108°. It should be noted that this direction of remanent magnetization leads to a virtual geomagnetic pole near the late Paleozoic part of North American apparent pole wander path (Reynolds *et al.*, 1997).

Profile ab

The unfiltered total magnetic-field data in Figure 10a show a broad low with superimposed short-wavelength magnetic highs reflecting shallow magnetic dikes. To remove this long wavelength low and thus isolate the expressions of the dikes, a model was generated by varying the magnetization of Precambrian basement until a suitable fit between the observed and measured fields was achieved (as shown in Figure 10a). The exact source for the regional field is unimportant in this analysis of the short wavelength anomalies. The regional field was subtracted from the original data to produce the residual field shown in Figure 10b.

The modeling approach was to extend vertical dikes to a depth of 10 km (however, extending the bottom of a dike to depths below 3 km had little effect on the amplitude of the calculated field). The initial depth to the top was placed at 500 m. Mapped dikes have widths that rarely exceed 5 m (Nelson and Lumm, 1984; Baxter *et al.*, 1989). We assumed an initial width of 2 m for the dikes. The width and depth to top of each dike were adjusted until a fit between the observed and calculated fields was achieved. The dike width was always adjusted first before shallowing the depth of the dike. Thereby, the resulting depths of the dikes represent approximate maximum depths. It should also be noted that the dike lying at the extreme left in Figure 10b is present only to raise the level of magnetic field, and thus the model of this dike is not intended to be an accurate description of the geologic situation.

The resulting five dikes lie at shallow depths (<200 m). The dikes are thin (1 to 3 m) and are steeply dipping.

DISCUSSION

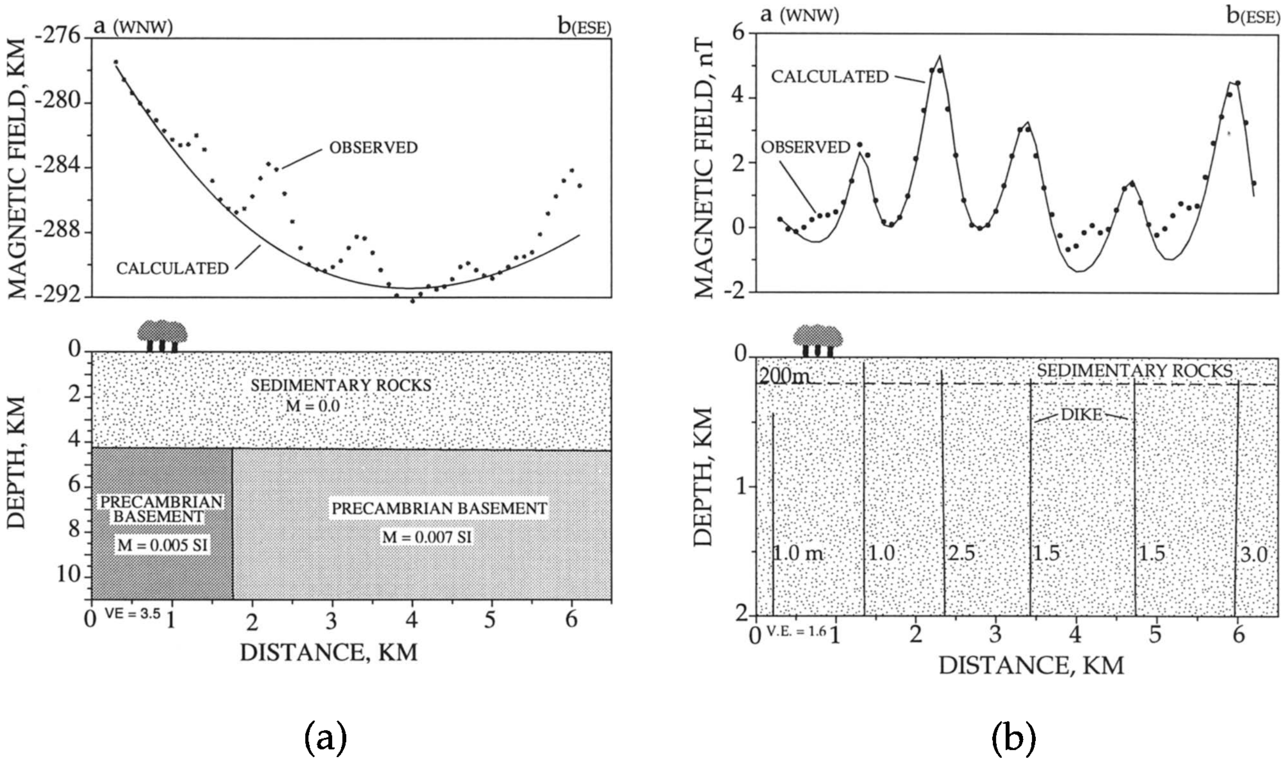
The new high-resolution magnetic data provide new insights on the tectonic and magmatic history of the Wabash Valley region. Enhancement of the short wavelength magnetic anomalies reveals the presence of numerous dikes and sills. For example, the mapped dikes and sills at Hicks Dome and Omaha Dome are clearly expressed in the magnetic field. Three similar intrusive complexes, which were previously unknown, are also expressed (S/D, in Figure 8) as intense magnetic highs, named here the Cottage, Saline, and Eagle magnetic anomalies (Figure 9). The anomalies associated with Hicks Dome and the three new intrusive complexes were not observable on earlier low-resolution aeromagnetic maps (Hildenbrand *et al.*, 1996). Hicks Dome and the igneous complex expressed as the Coefield magnetic anomaly (Anderson, 1992) lie along or near the NW-trending, block-faulted Tolu arch (Figure 5), which terminates NW of Hicks Dome (Trace, 1974).

Modeling five linear magnetic features (Figure 10b) indicated that the associated narrow dikes (≤3 m wide) lie at shallow depths (<200 m) and are steeply dipping. Because some of the interpreted dikes closely follow mapped faults, we propose that the Wabash Valley faults acted as channelways for ascending magma, similar to the mapped dikes of similar age and composition that intruded the Cottage Grove Fault System (Nelson, 1991). The interpreted locations of a few dikes indicate that mapped faults can be laterally extended (*e.g.*, the 2 faults west of the Inman West Fault, Figure 9). Are the interpreted dikes related to faults or to tension fractures? Because some mapped faults spatially correlate with interpreted dikes and because the age of the dikes and faults are similar, we suggest that the interpreted dikes delineate faults. Thus, the abundance of interpreted dikes indicates that the WVFS contains many more faults than those mapped. Both the interpreted dikes and mapped faults have trends ranging from NW to NNE.

The dike pattern and the WVFS (Figures 8 and 9) terminate at or north of the Rough Creek-Shawneetown Fault System. There is also no clear expression of any regional potential-field anomaly or anomaly offset patterns (Figures 2 to 4) to suggest that structures cross the Rough Creek-Shawneetown Fault System to connect the WVFS and the New Madrid seismic zone. Based on drill-hole data and exposures in underground coal mines, Nelson and Lumm (1984) also concluded that the WVFS does not cross the Rough Creek-Shawneetown Fault System.

Geophysical Setting of the Wabash Valley Fault System

With these additional insights from the interpretation of geophysical data, we can address the tectonic development of the WVFS. As proposed by Kolata and Nelson (1991), magmas in late Paleozoic time were injected into NNW- to NE-trending faults that formed as tension fractures during the creation of the dome and its subsequent collapse. Magma also entered the Cottage Grove Fault System (Nelson and



▲ **Figure 10.** (a) Unfiltered magnetic anomaly field (circles in upper diagram) and theoretical model of the long wavelength regional field (lower diagram) along profile ab shown in Figure 8. Line represents calculated field values. Total magnetization amplitudes (*M*) for model layers are shown. (b) Residual magnetic field (circles in upper diagram) obtained by subtracting the computed regional field (Figure 10a) from the total magnetic field. Line represents calculated field values. Theoretical model of the dikes is shown in the lower diagram. Interpreted dike widths range from 1 to 3 m.

Lumm, 1984). Three interpreted complexes and the known intrusive complexes at Hicks Dome and Omaha Dome and underlying the Coefield magnetic anomaly define upper crustal areas where larger quantities of magma were emplaced. Unlike Hicks Dome and Omaha Dome, these three new intrusive complexes seem to lack associated doming of the sedimentary strata (W.J. Nelson, Ill. State Geol. Surv., pers. commun., 1996).

Dike origin

Nelson and Lumm (1984) and Bradbury and Baxter (1992) reported that the composition and age of the dikes in the region of the Cottage Grove Fault System and those along the Tolu arch (Figure 5) appear to be identical. Dikes have not been encountered at the Earth's surface or in mines in the region immediately south of the Rough Creek-Shawneetown Fault System (W.J. Nelson, Ill. State Geol. Surv., pers. commun., 1996). These geologic data and the geophysical evidence that the south-trending Wabash Valley dikes terminate at the Rough Creek-Shawneetown Fault System cannot distinguish between models based on different intrusive events or a single event. In the first case, because there appears to be no structural connection between the Wabash Valley intrusions and those lying along the Tolu arch, two separate igneous events, one north and the other south of the Rough Creek-Shawneetown Fault System, may have occurred during late Paleozoic.

The second case of a single igneous event is appealing because of the similarities in the ages and compositions associated with the two intrusion centers. Shaw (1980) pointed out that the transportation of magma from its source to the surface is highly dependent on fracture mechanisms. According to Shaw, the ascent of magma is influenced "by the relationships between the internal pressure of magma, rock stresses, and the ability of extensional fracture to produce flow paths." In other words, the magma conduits represent paths of less resistance. The reason for the absence of dikes in the region immediately south of the Rough Creek Fault System (the intervening zone) may simply be that the effective stress in this crustal zone may be different than the crustal stresses on its flanks (*i.e.*, in the Wabash Valley and Hicks Dome regions). For example, this difference in effective stress may be related to a pluton emplaced within the intervening zone. A large pluton is clearly defined by the prominent NW-trending magnetic high lying along the SCML (anomaly E, Figure 5). On the other hand, the Wabash Valley and Hicks Dome regions may possess conduit paths of less resistance if, for example, crust beneath these regions are more extensively fractured than that underlying the intervening zone.

In short, the absence of dikes in the region immediately south of the Rough Creek Fault System can be reasonably accommodated by considering 2 separate igneous events or a single event with limited dike emplacement.

Ancestral Wabash Valley Fault System

Basement offsets resulting in the thickening of the late Precambrian-early Paleozoic sedimentary rocks in the Grayville Graben, observed in seismic reflection data (Bear *et al.*, this volume), strongly suggest deformation north of the Rough Creek-Shawneetown Fault System during extension related to the Reelfoot-Rough Creek-Rome rift system. We further suggest that magma, related to the Permian dikes emplaced along the shallow Wabash Valley faults, ascended along preexisting basement faults formed during late Precambrian-early Paleozoic rifting. Thus, some of these channelways would be related to the normal faults bounding the Grayville Graben.

There are no published mechanical models of the ancestral WVFS that account for the location of the Grayville Graben at the bend of the Reelfoot-Rough Creek-Rome rift system. Until such mechanical studies are carried out, we can only speculate on the tectonic evolution of the ancestral WVFS. Two hypotheses are found in the literature. The first hypothesis by Braile *et al.* (1982, 1986) suggests that the ancestral WVFS is a failed rift arm related to a complex quadruple rift system. The second hypothesis proposed by Hildenbrand *et al.* (1982), Kolata and Nelson (1991), Thomas (1993), and Hildenbrand and Hendricks (1995) involves tectonic models with the ancestral WVFS representing a structural feature (not a failed rift arm) formed near a bend (accommodation or transfer zones) of the Reelfoot-Rough Creek-Rome rift system. We emphasize here that the two rift hypotheses are very similar and differ only in the definition of rift structures. This difference, however, may be important when studying seismogenic sources, as discussed later.

Braile *et al.* (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 of the failed rift arms of the quadruple junction; potential-field anomalies extending NE along the trend of the Wabash Valley and NW toward St. Louis from the juncture of the Reelfoot and Rough Creek rifts may represent the remaining two arms. Hildenbrand and Hendricks (1995) also interpreted structures extending NW from the Reelfoot Rift toward St. Louis (the PGL, Figure 1), a heavily intruded block faulted region. However, the lateral extent and width of this block-faulted region is considerably smaller than that of the proposed failed rift arm of Braile *et al.* (1986). We suggest that the usage of "failed rift arm" is inappropriate if it assumes graben formation, as there is no geologic evidence for the thickening of late Precambrian-early Paleozoic sediments (Nelson, 1991). On the other hand, if the definition of a failed rift arm includes a system of crustal fractures (Bates and Jackson, 1987) and accompanying intrusions (possibly some emplaced in lower crust), then the terminology of a failed rift arm is appropriate. In other words, we do agree with Braile *et al.* (1986) and Hildenbrand and Hendricks (1995) that perhaps rift structures other than grabens (*e.g.*, dense igneous plutons) formed along the trend of the PGL during rifting and rift reactivation.

Braile *et al.* (1986) also defined a failed rift arm extending NE along the Wabash Valley and into central Indiana. The existence of the Grayville Graben supports their interpretation. However, like the structures trending toward St. Louis, the rift structures in Wabash Valley are more limited in length and also in width than described by Braile *et al.* (1986). The Grayville Graben defined by Bear *et al.* (this volume) is very small in cross section (<25 km wide, ~0.7 km basement structural relief).

Hildenbrand and Hendricks (1995), however, argue that careful inspection of magnetic maps shows that the Reelfoot Rift simply bends eastward to merge with the Rough Creek Graben. In viewing the shaded-relief magnetic map (Figure 4) and other derivative magnetic-anomaly maps (not shown here), features extending NE from the Mississippi Embayment appear to either terminate at the junction of the Reelfoot Rift and Rough Creek Graben or bend eastward along the southern boundary of the Rough Creek Graben. For example, NE-trending magnetic highs, which have corresponding gravity highs (anomaly B in Figures 2 and 3), lie along the axis of the Reelfoot Rift. Ideal body theory indicates that the associated igneous bodies lie at a maximum depth of about 6 km. The magnetic data (Figure 4) show that this linear geophysical feature terminates near lat 37° N and long 88° W.

One may argue that NW-trending structures, apparent on the magnetic maps, mask any structural links between the WVFS and the New Madrid seismic zone. However, these NW-trending magnetic features do not mask the only NE-trending magnetic feature that we identify extending from the Reelfoot Rift region to the Wabash Valley region, the Commerce geophysical lineament (CGL in Figures 1 to 4). An alignment of several short NE-trending linear magnetic features in southern Indiana (Figure 4) appears to delineate a major structure extending from the bend in the rift system. However, such a NE-trending magnetic feature is not apparent on the unfiltered magnetic anomaly map (Figure 3), nor do the gravity data or geological data support its existence.

Thus, based on the interpretation of the regional magnetic and gravity data and the high-resolution magnetic data, we propose that both the shallow faults and the deep-seated rift structures in the Wabash Valley terminate at or north of the Rough Creek-Shawneetown Fault System. We therefore propose that the ancestral Wabash Valley faults are local rift structures that developed at the bend of the Reelfoot-Rough Creek-Rome rift system (Figure 6). In other words, Braile *et al.* (1986) correctly hypothesized the existence of rift-related structures in the Wabash Valley, but due to the inferred limited size and extent of these structures (particularly, the lack of any clear structural connection to the Reelfoot-Rough Creek-Rome rift system), they may not represent a failed rift arm in the classical sense.

A plausible explanation for the origin of the rift structures in the Wabash Valley and in the region of the PGL is that they developed during late Precambrian-early Paleozoic rifting in response to stress concentration generated by the bend in the Reelfoot-Rough Creek-Rome rift system. According to Thomas (1993), the bend may have evolved at the juncture of the Reelfoot Rift and an oblique transfer zone that formed the Rough Creek Graben. In fracture mechanics terms, bends in shear or tensile cracks create a dislocation stress that can exceed the strength of the surrounding material. Thus the lithosphere near the bend in the rift (*e.g.*, in the Wabash Valley region) would fail by secondary faults. Similar structural complexities are commonly observed at fault junctions (Andrew, 1989), for example, at tectonic plate boundaries. Moreover, the bend in the rift system, once established, probably persisted as a crustal flaw and continued to concentrate stress episodically during the Phanerozoic. Evidence for recurring structural development includes deformation or intrusive events during the Devonian, Mississippian, Pennsylvanian, and Permian (Kolata and Nelson, 1991). Like the late Paleozoic Wabash Fault System, the Cottage Grove Fault System and Ste. Genevieve Fault Zone may have developed along preexisting older and deeper rift structures (*e.g.*, faults) at the bend of the rift system. Nelson and Lumm (1984) provide considerable evidence that the ancestral Cottage Grove Fault System is continuous with the late Precambrian-early Paleozoic Rough Creek Fault System.

Similar rift structures may exist at the bend of the rift system in eastern Kentucky (Drahovzal and Noger, 1995). Although the Rome Trough terminates against the Grenville front and Cincinnati Arch (Figures 1 and 6), an east-trending magnetic lineament and a few faults trending roughly east-west prompted Heyl (1972) and Lidiak and Zietz (1976) to propose that the Rough Creek Graben and the Rome Trough are structurally connected. The source of this lineament may be related to basement as both the Cincinnati Arch and Grenville front cross the lineament (Lidiak and Zietz, 1976). A new structural map of the unconformity surface on Precambrian basement by Drahovzal and Noger (1995) clearly reveals faults extending outward at high angles from the bend of the Rome Trough. One fault-bounded structure, the Floyd County channel (Drahovzal and Noger, 1995), is very similar in width (~25 km) and offset (~700 m) to the width (~20 km) and offset (~700 m) associated with the Grayville Graben underlying the Wabash Valley (Bear *et al.*, this volume).

Seismogenic source

At least eight prehistoric earthquakes strong enough to induce widespread liquefaction (*i.e.*, $M_w \geq 6$; see cover photo) occurred north of the bend in the rift system, but only three of these earthquakes (large grey circles, Figure 1) occurred within 25 km of the 80 km long WVFS. Moreover, the relation between geologic structures and damaging historical earthquakes is equivocal (small gray circles, Figure 1). On the other hand, five epicenters related to major prehistoric earthquakes lie near the Commerce geophysical lineament (CGL). The CGL, which may extend over 600 km from Arkansas to Indiana, thus warrants additional study as a possible seismogenic source of large magnitude earthquakes.

In southern Illinois and central Indiana, the CGL is described as an alignment of linear edges of local magnetic highs reflecting shallow igneous bodies. The CGL follows the SE boundary of a NE-trending, broad gravity high zone (anomaly A in Figure 2), which appears to have corresponding local magnetic highs (Figure 3). Ideal body analysis places the tops of the dense rocks associated with this gravity high in the upper crust (maximum depth to top ranging from 6.5 to 14 km). The west-dipping basement seismic reflectors discussed by McBride *et al.* (this volume) lie interestingly in the region of the SE boundary of this gravity high. Thus, seismic data (the west-dipping reflectors in the midcrust), gravity data (the SE boundary of a regional NE-trending dense body), and magnetic data (the CGL) spatially correlate to suggest a major crustal boundary trending NE in southern Illinois. McBride *et al.* (this volume) relate their west-dipping seismic reflectors to the 1968 moment magnitude 5.5 earthquake in southern Illinois (labeled M 5.5 on Figure 1). Thus, epicenters of a damaging historic earthquake and four large prehistoric earthquakes lie near or within structures associated with the CGL. Moreover, geologic mapping by Harrison and Schultz (1994) near the Missouri-Illinois state boundary shows that a fault possibly related to the source of the CGL was active less than 15,000 years ago.

Because the CGL trends oblique to the faults in the Wabash Valley, it appears to have no relation to WVFS. The linear trend of the CGL is maintained in the region of the bend of the rift system and thus may have no relation to the bend. In NE Arkansas and SE Missouri, the source of the CGL probably expresses a shallow dike swarm (Langenheim and Hildenbrand, 1997). On the other hand, in SE Illinois and central Indiana, the CGL seems to represent the SE edge of a zone of dense and magnetic igneous intrusions, which may have been emplaced within a basement structure defined on the basis of west-dipping seismic reflectors. Of particular interest is that the apparent 30 km left-step offset in the CGL in the area of Vincennes, Indiana, occurs near a cluster of three prehistoric earthquakes. In this same area, the SE projection of SSE-trending La Salle anticlinal belt (Nelson, 1991) intersects the CGL (Figure 1). Straight segments of the Wabash River and the White River in Indiana follow the CGL (Langenheim and Hildenbrand, 1997). In short, the source of the CGL may be a major crustal feature intimately related to both surface and deep structures and to earthquake occurrences.

SUMMARY

Magnetic and gravity data have provided additional insights on the tectonic history and structural development of the Wabash Valley region. New high-resolution aeromagnetic data clearly define numerous dikes intruding mapped Wabash Valley faults and possibly delineate many new faults. Three previously unrecognized intrusive complexes, similar to those at Hicks Dome and Omaha Dome and the one underlying the Coefield magnetic anomaly, are also apparent in this magnetic data set. Probably the most significant contribution of the high-resolution aeromagnetic data is that the interpreted dike pattern and thus related faults of the Wabash Valley Fault System (WVFS) terminate at or north of the Rough Creek-Shawneetown Fault System. This conclusion and the lack of any regional potential-field feature extending south from the Wabash Valley prompt us to propose that the WVFS and the New Madrid seismic zone are not structurally connected. Legitimate arguments opposing this conclusion can be stated, due to the impossibility of proving that something does not exist (*e.g.*, cross-cutting NW-trending features may mask the more subtle expression of a structural connection). However, based on the available data, structures in the Wabash Valley appear to terminate at or north of the Rough Creek-Shawneetown Fault System.

We thus suggest that although rift structures (*e.g.*, the small Grayville Graben) underlie part of the Wabash Valley Fault System, they are related to local rift features formed in response to stress concentrations generated by the bend of the Reelfoot-Rough Creek-Rome rift system. This hypothesis may explain the lack of any obvious relation between the ancestral WVFS and the epicenters of historic and prehistoric earthquakes. Five of the eight prehistoric epicenters lie near the NE-trending Commerce geophysical lineament (CGL), which may extend over 600 km from Arkansas to Indiana (Figure 1). The CGL obliquely crosses the northern part of the WVFS. The CGL, defined largely on magnetic anomaly maps (Figure 4), spatially correlates with deep west-dipping seismic basement reflectors (McBride *et al.*, this volume) and an edge of a regional, dense igneous body (A, Figure 2). Geomorphic features also coincide with the CGL (Langenheim and Hildenbrand, 1997). We therefore suggest that the source of the CGL is a major crustal feature related to both surface and deep crustal structures and, more importantly, may be intimately related to the seismic hazards of the region north of the Reelfoot-Rough Creek-Rome rift system. A particularly important area to concentrate earthquake hazards reduction studies is near Vincennes, Indiana, where prehistoric earthquakes cluster, where the CGL is offset by about 30 km, and where the projection of the SSE-trending La Salle anticline intersects the CGL.

The new high-resolution magnetic data improved our understanding of the structural development of the Wabash Valley region. However, the information gained from these data has direct application to many related socioeconomic issues. For example, the magnetic method aided in delineating new faults and thus may be helpful in concentrating exploration in search of oil structural traps related to faulting. The high-resolution magnetic survey also proved to be a cost-effective way to locate igneous dikes that interfere with coal mining operations or that locate possible mineralized areas.

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