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A GROUND MAGNETIC SURVEY OF THE JOHNSON COUNTY AREA OF ILLINOIS

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ABSTRACT

A detailed ground magnetic survey of approximately 800 stations in Johnson, southwestern Saline, and northwestern Pope Counties in Illinois has provided new information about the crustal geology of southern Illinois. Magnetic susceptibility measurements of pertinent rock samples in and around the study area were taken in order to identify the rock types that have produced observed magnetic anomalies. Lithologic changes in the basement rocks, as indicated by the magnetic field, offer a possible explanation of the characteristics and location of observed geologic structures in the Johnson County area.

Based on the data gathered in this study, the Johnson County area of Illinois does not appear to be the site of any zone of weakness in the earth's crust that would affirm structural continuity between the Wabash Valley Fault System to the northeast and the New Madrid Seismic Zone to the southwest.

INTRODUCTION

In the past several years, earth scientists have made considerable efforts to establish or negate the structural continuity between the New Madrid Seismic Zone extending approximately from Memphis, Tennessee, to Cairo, Illinois, and, to the northeast, the Wabash Valley Fault System of southeastern Illinois and southwestern Indiana. The question of structural continuity between these tectonic features may have great significance for evaluation of seismic risk in the central Mississippi Valley.

Most work on this problem has been concentrated on the Fluorspar Area Fault Complex of the southern Illinois and western Kentucky area, which is characterized by northeast-to-southwest-trending faults, basic intrusives, and mineralized veins (pl. 1). The region just west of the Fluorspar Area Fault Complex (west of the structural lineament formed by the southwest-to-northeast-striking portion of the Shawneetown Fault and its southeastern extension, the Lusk Creek Fault Zone) has previously been given little attention. This area, the Johnson County area of Illinois, is the principal concern of this study (fig. 1, pl. 1).

Recent microearthquake studies in the New Madrid region have shown linear trends of epicenters that may be indicative of active faulting in the New Madrid Seismic Zone (Zollweg et al., 1974). The northernmost point of these trends is at approximately 37.3^{o} N. and 89.2^{o} W. near Elco in Alexander County, Illinois. A line formed by this northern epicentral trend, extended northeastward, would pass to the west of the Fluorspar Area Fault Complex. Moreover, a line connecting the epicenters of two recent sizeable earthquakes (November 9, 1968, at Broughton in Hamilton County, Illinois, and April 3, 1974, at Seminary in Richland County, Illinois) interpreted as being associated with the Wabash Valley Fault System (Stauder and Nuttli, 1920, and Nuttli, 1974)

Figure 1. The Johnson County area of Illinois.

extended southwestward, would also pass to the west of the Fluorspar Area Fault Complex.

The Johnson County area is within a structural province characterized by a northeastern and northward regional dip interrupted by few irregularities. It is bounded on the east by the Fluorspar Area Fault Complex and on the west by the Ozark structural province. In the Johnson County area these structural irregularities consist of a complex pattern of folding and faulting which appears to have been caused by regional compressive forces (Brokaw, 1916; Lamar, 1925; Weller, J. M., 1940; Stonehouse and Wilson, 1955; Weller, S., and Krey, 1939). These structural irregularities are the focus of this study.

A detailed ground magnetic survey of the Johnson County area was made in an attempt to discover additional information about the crustal geology of southern Illinois (pl. 2) and to gain some insight into the structural fabric, depth to basement, and lithologic changes in the basement of the area. We also hoped that the data might facilitate delineation of possible igneous intrusives and faulting in the sedimentary rocks.

In addition to the ground magnetic survey, precise measurements of magnetic susceptibility of pertinent rock types in and around the study area were made to determine the sources of observed magnetic anomalies. Besides aiding the interpretation of the data gathered in this study, the susceptibility measurements should be valuable in future research in the area.

GEOLOGY OF THE STUDY AREA

Background

Warren and Healy (1973), using data from reversed seismic refraction profiles, showed that extreme southern Illinois has a typical continental crust. The northeast portion of a northeast-to-southwest profile terminating at the Mississippi River near the border between Alexander and Union Counties, Illinois, showed a crustal thickness of 44 kilometers; the northeast portion of another profile terminating at the Mississippi River at Randolph County, Illinois, showed a thickness of 43 kilometers. These measurements agree with those obtained by other investigators. Stewart (1968), from a northeast-to-southwest profile terminating near Ste. Genevieve, Missouri, found on the northeast a crustal thickness of 40 kilometers, of which the upper 28 kilometers corresponded to granitic rocks. McCamy and Meyer (1966) ran a northeast-to-southwest profile terminating at Cape Girardeau, Missouri, and found a crustal thickness of 45 kilometers on the northeast; the upper 29 kilometers corresponded to the granitic layer.

The basement rocks of Illinois are part of a Precambrian granite-rhyolite terrain, relatively uniform in rock type and age, that extends from the Mississippi River eastward into Ohio (Rudman et al., 1965). The uppermost Precambrian rocks in Illinois, with one exception, are about 1100 to 1400 million years old (Lidiak et al., 1966).

Although no mafic igneous rocks have been encountered in the basement of Illinois, reports of these rock types in the Precambrian of adjacent states suggest that they may be present (Willman et al., 1975). Aeromagnetic and gravity maps of southern Illinois indicate that the portion of the state south of and including Rough Creek Lineament (pl. 1) may have a significant amount of intrusive activity.

Two recently drilled deep holes in the study area, one in sec. 27, T. 12 S., R. 3 E., Johnson County, and another in sec. 2, T. 11 S., R. 6 E., Pope County, bottomed at depths of 14,284 feet and 14,920 feet, respectively, without penetrating Precambrian igneous rocks. These wells were finished in a quartzitic rock that may be of Precambrian age.

The oldest sedimentary rocks in the study area are probably Mt. Simon Sandstone of the Croixan Series (upper Cambrian). Paleozoic rocks of the Ordovician, Silurian, Devonian, Mississippian, and Pennsylvanian Systems are also present.

The bedrock surface is composed of rocks as old as the Ste. Genevieve Limestone (Mississippian) and as young as the Carbondale Formation (Pennsylvanian) (fig. 2). Cretaceous rocks occur just south of the Cache River, which forms a common boundary between Johnson County and Pulaski and Massac Counties on the south (Weller and Krey, 1939; Ross, 1963; Willman et al., 1967; Willman et al., 1975).

Illinoian ground moraine extends into Johnson County on the north in T. 11 N., R. 2 E., and T. 11 N., R. 3 E. (fig. 2). Unconsolidated sediments in the southern part of Johnson County are Wisconsinan lake deposits and Wisconsinan and Holocene alluvium, sand dunes, and gravel terraces associated with the Cache River valley (Willman et al., 1967; Willman and Frye, 1970; and Willman et al., 1975).

Faults and Other Structures

Stonehouse and Wilson (1955) have compiled the work of a number of investigators in a map of some of the faults and other structures in southern Illinois. The complex folding and faulting in the Johnson County area, Illinois, has been mapped in some detail by Weller (1940).

Among the salient structures in and around the Johnson County area shown on plate 1 is the Shawneetown Fault, the westward extension of the Rough Creek Fault Zone of western Kentucky. From the Ohio River near Shawneetown the fault continues westward across Gallatin County to Equality in Saline County, where it curves sharply southwestward and enters Pope County. Displacement along this fault, down to the north and northwest, is locally as much as 3500 feet and may be even greater (Butts, 1925). Structures

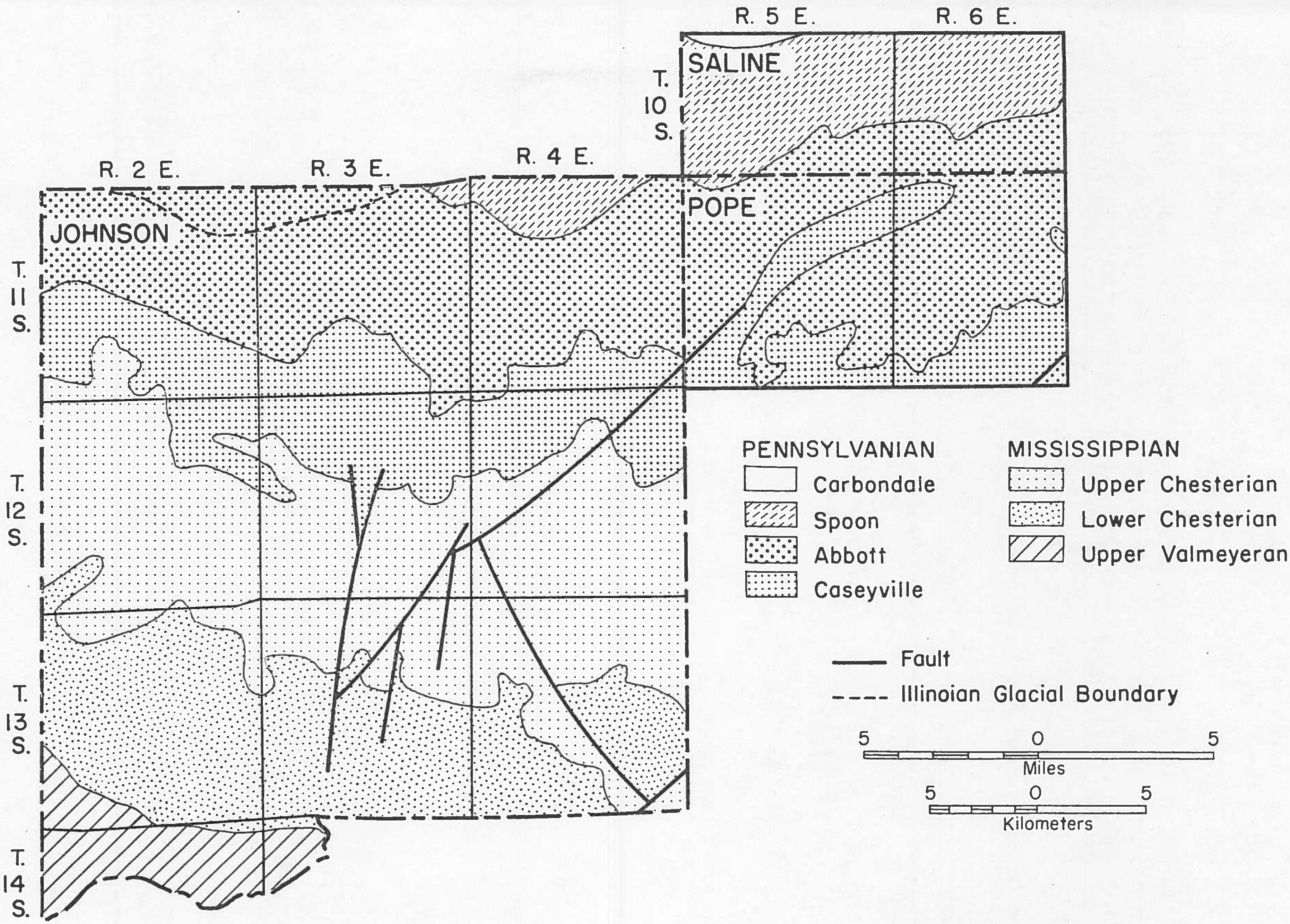


Figure 2. Geologic map of the Johnson County area, Illinois. (After Willman et al., 1967).

just to the west of where the Shawneetown Fault swings to the southwest in Saline and Pope Counties indicate that it is a high-angle thrust fault there (Weller, 1940).

The Dixon Springs Graben extends from the northeast corner of Pope County to the Bay Bottoms in Massac County, beyond which it is concealed by the Cretaceous deposits of the Embayment area. Its northwestern boundary, the Lusk Creek Fault Zone, extends southwestward from sec. 25, T. 11 S., R. 6 E., and passes just to the west of Dixon Springs. This zone is very shattered in an area 200 feet to a quarter mile wide and appears to have been produced by high-angle thrust or compression faulting (Weller, Tippie, and Grogan, 1952). North of sec. 25, T. 11 S., R. 6 E., the Lusk Creek Fault Zone splits. One part, which probably carries most of the thrust faulting, extends north and connects with thrust faulting in the Shawneetown zone. The other part appears to continue northeastward as the Herod Fault.

The New Burnside Anticline begins abruptly near the border between Johnson and Pope Counties and extends southwestward past New Burnside and Parker. It is asymmetrical in that it has much steeper dips to the northwest than to the southeast. The anticline continues southwestward beyond Parker, but the dips become much gentler; neither the form nor the location of the crest of the anticline has been accurately determined (Weller, 1940, and Brokaw, 1916).

The Stonefort Anticline is mainly in southwestern Saline County; its western extremity swings southward and terminates in Pope County. Distinctly asymmetrical, the anticline has steep dips to the north and gentle dips to the south. This structure seems to be the eastern extension of the New Burnside Anticline (Weller, 1940).

The McCormick Anticline extends westward across the northern part of T. 11 S., R. 6 E., in Pope County and then swings gently to the southwest and passes into a fault near McCormick. It is conspicuously asymmetrical, having dips as great as 30° on the north flank, but having dips rarely more than 4° or 5° on the south (Weller, 1940, and Brokaw, 1916).

The Goreville anticlinal nose is a short distance southwest of Goreville in Johnson County and plunges northeast (pls. 1 and 2). This structure is based upon elevations of the lower Pennsylvanian sandstones. It is possible that the present attitude of these sands is not entirely structural, but is partly dependent upon unequal deposition; if so, comparable structures may not occur in the underlying formations (Weller, 1940).

PREVIOUS GEOPHYSICAL WORK

A number of geophysical studies of the area in and around Johnson County, Illinois, serve as useful background. Patenaude (1964) published the results of an aeromagnetic survey of a portion of southeastern Illinois south of lat 39° N. and east of long 89° W. The survey was flown in north-to-south lines 6 miles apart at an elevation of 3000 feet above mean sea level. The map of residual total magnetic intensity was contoured on a 100-gamma interval.

McGinnis and Bradbury (1964) used aeromagnetic data to study the Hardin County area, Illinois, east of the Johnson County area. The aeromagnetic survey was flown at 2000 feet above mean sea level and included 24 north-to-south flight lines approximately one mile apart. The map of residual total magnetic intensity was contoured on a 20-gamma interval.

Lidiak and Zietz (1976) interpreted aeromagnetic anomalies between latitudes 37° N. and 38° N. in the eastern and central regions of the

United States (fig. 3). The aeromagnetic survey used in their study followed flight lines roughly parallel to the circles of latitude about 8 kilometers apart at an elevation approximating 1525 meters barometric pressure. The contours on the map of residual total magnetic intensity were at a 100-gamma interval.

In 1976 Heigold published the results of an aeromagnetic survey of an area in Illinois south of lat 39° N. and west of long 89° W. The survey followed north-to-south flight lines one mile apart at an elevation of 3000 feet above mean sea level. The map of residual total magnetic intensity was contoured at a 20-gamma interval.

McClure (1930) ran a vertical magnetic intensity survey at approximately 50 stations in the vicinity of Hicks Dome in western Hardin County. This small ground survey included no local anomalies and showed only a portion of a regional trend in the magnetic field. In 1931 McClure conducted a ground survey of the vertical magnetic intensity of several hundred stations in southwestern Illinois. Although data were sparse, McClure was able to construct a useful map of residual vertical magnetic intensity contoured partly on a 50-gamma interval and partly on a 100-gamma interval.

McGinnis and Heigold (1961) constructed regional maps of vertical magnetic intensity in Illinois based on data gathered at 118 localities (usually county seats) throughout the state. Because of the great distance between stations, these maps show only the greatest trends in the magnetic field.

In 1976 McGinnis, Heigold, Ervin, and Heidari published the results of a gravity survey of Illinois having a grid spacing of approximately one mile. The resulting simple Bouguer gravity map, based on the assumption that the surficial rocks possess a density of 2.35 gm/cm^3, was contoured on a 5-milligal interval. Data from this statewide survey have been used in studies of

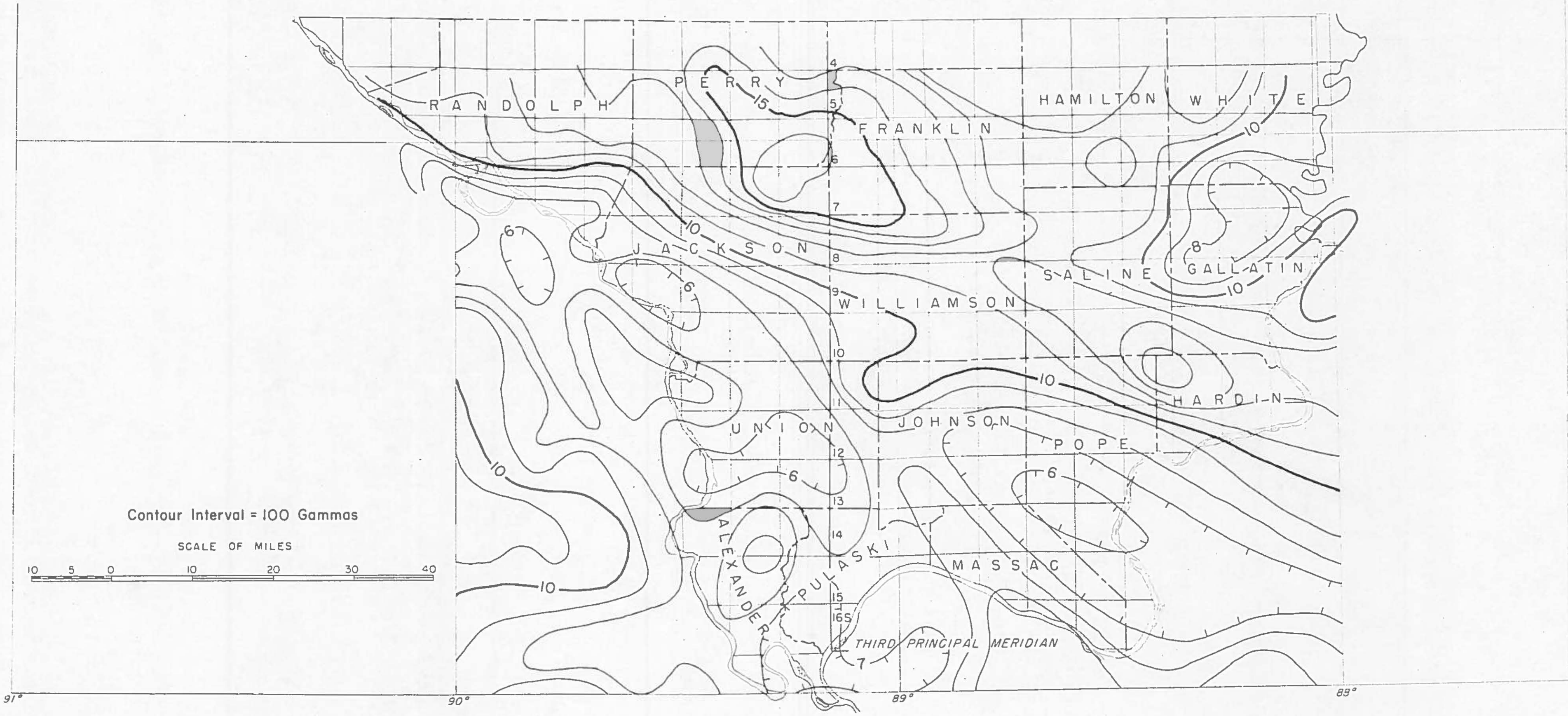


Figure 3. Residual total magnetic intensity of southern Illinois between latitudes 37° N. and 38° N. (After Lidiak and Zietz)

portions of Illinois. In 1970 Heigold studied the gravity field of extreme southeastern Illinois and presented a simple Bouguer gravity anomaly map of that area contoured on a .5-milligal interval. In 1973 Schafersman studied the crustal structure of southwestern Illinois from gravity models.

Lawrence and Reinerio (1962) covered the entire state of Illinois with gravity stations spaced approximately 10 miles apart. Their simple Bouguer gravity anomaly map of Illinois, based on the assumption that the surficial rocks possess a density of 2.67 gm/cm^3, was contoured on a 10-milligal interval and later incorporated into the simple Bouguer gravity anomaly map of the United States by Woollard and Joesting (1964).

COLLECTION AND REDUCTION OF DATA

The field work for this study was conducted with a Scintrex MF 2-100 vertical component fluxgate magnetometer. The accuracy of this instrument, according to the manufacturer, is ±1 gamma. In this survey values of vertical magnetic intensity were accurate to ±5 gammas.

Rugged terrain, swamps, and man-made structures sometimes prevented spacing stations at the intended half-mile intervals. A larger spacing was used in parts of southwestern Saline County and northwestern Pope County, where a more regional determination of the earth's magnetic field was desired. Overall, the survey included about 800 stations (pl. 2).

To correct for diurnal variations in the earth's magnetic field, base stations were occupied hourly during every field day. Observed vertical magnetic intensity data were corrected by linear interpolation of values between base stations.

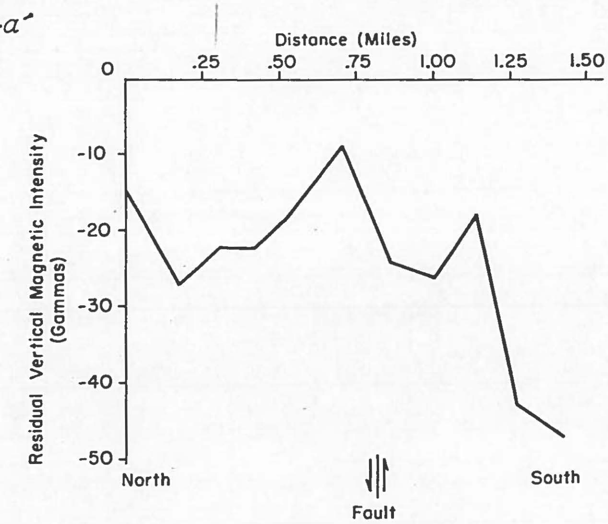
The locations of the stations, noted in the field on 7.5-minute U.S.G.S. topographic maps, were digitized and transformed into Lambert conformal conic projection coordinates used in the ILLIMAP system at the Illinois State Geological Survey.

The correction for latitude was made by systematically subtracting a theoretical plane of vertical magnetic intensity increasing 9 gammas per mile in a direction 2.5^{o} east of geographic north from the observed vertical magnetic intensity data corrected for diurnal variations in the magnetic field. The declination of 2.5^{o} east was obtained from a map of magnetic declination of the United States (Fabiano, 1975). The gradient of 9 gammas per mile was determined by fitting a least-squares plane, constrained to dip along the 2.5^{o} east azimuth, to the observed vertical magnetic intensity data corrected for diurnal variations in the magnetic field. In an earlier study involving vertical magnetic intensity data in Illinois, McClure (1931) subtracted a theoretical plane increasing 10 gammas per mile to the geographic north from the observed magnetic intensity data; in a study published in 1961, McGinnis and Heigold subtracted a theoretical plane increasing 9 gammas per mile to the geographic north.

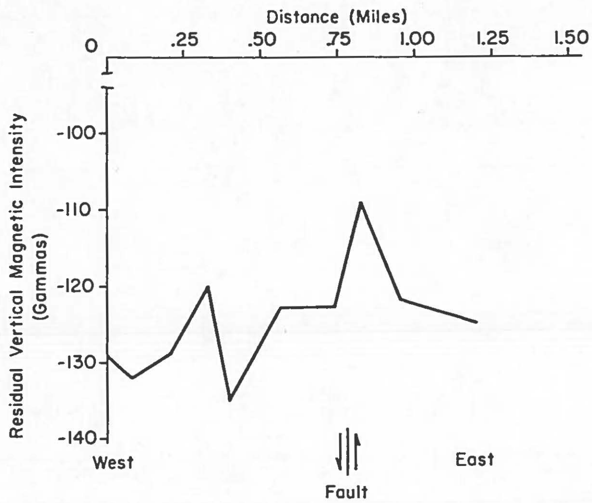
The residual vertical magnetic intensity data were plotted and contoured by computer. Isolated high or low values were checked at the study area to be sure they were not the result of errors in reading or errors caused by set-up over buried, discarded farm equipment or other man-made objects. The final residual vertical magnetic intensity data were first plotted by computer and then hand-contoured on a 20-gamma interval (pl. 2).

Included in the residual vertical magnetic intensity data are three detailed profiles across known faults mapped by Weller (1940) (pl. 2 and fig. 4). Stations along these profiles were approximately 1/8 mile apart. We hoped a lateral susceptibility contrast associated with these faults would be large enough to produce a magnetic anomaly that could be mapped with the vertical component magnetometer.

Profile *a–a'*



Profile *b–b'*



Profile *c–c'*

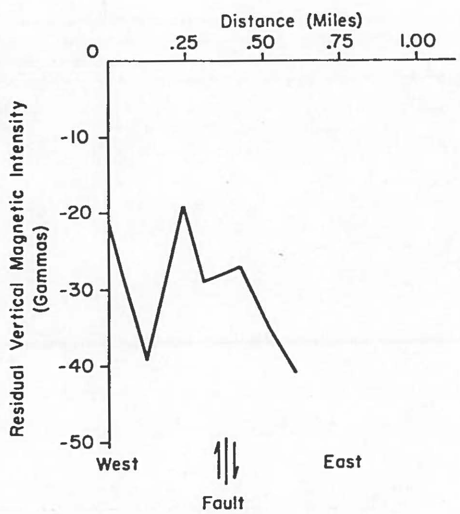


Figure 4. Some profiles of residual vertical magnetic intensity across known faults in the Johnson County area, Illinois. (See plate 2 for locations.)

MEASUREMENT OF MAGNETIC SUSCEPTIBILITY

In order to identify the rock types that produced the observed magnetic anomalies in the Johnson County area, Illinois, and to provide basic information for future research in the area, values of magnetic susceptibility were determined for pertinent rock samples in and around the study area (table 1 and fig. 5). The instrument used was a Soiltest MS-3 magnetic susceptibility bridge, which uses alternating current at an audio frequency. For low-resolution work, a set of headphones is used to balance the bridge after the rock sample has been introduced. For this study, the accuracy of the readings was enhanced by using a special analog-meter read-out attached to a variable-gain integrated circuit to balance the bridge visually. According to the manufacturer of the bridge, the range of direct calibration for the instrument extends from approximately 2×10^{-6} to $40,000 \times 10^{-6}$ cgs units and the absolute accuracy ranges approximately from 5 to 10 percent. In actual use the chief limitation on accuracy arises not from instrumentation, but from a lack of uniformity within each sample. Magnetic properties of the samples may vary considerably from point to point.

All rock samples measured were small fragments. Where enough sample was available, the fragments were placed in glass tubes of outer diameter closely approximating the diameter of the instrument's internal sample holder. When only a small amount of sample was available and it was necessary to decrease the test-tube diameter to insure that the sample extended above the internal sample holder, a hollow wooden insert was placed in the sample holder and a test tube of smaller diameter was emplaced snuggly into the auxiliary holder.

The calculation of magnetic susceptibility for each sample was made with the calibration curve provided for the instrument for solid samples with diameters of 1-3/16 inches. This curve shows magnetic susceptibility (in cgs units) as a function of the resistance change needed to balance the bridge

TABLE 1

Measurements of Magnetic Susceptibility in Southern Illinois

	Well	Location (sec.-twp.-range)	Surface elev. (ft) datum m.s.l.	Total depth (ft)	Top of basement (ft) datum m.s.l.	Elev. of samples (ft) datum m.s.l.	Rock type	Number of samples	Range of magnetic susceptibility (cgs units)	Mean magnetic susceptibility (cgs units)
1	Brehm Drlg. & Prod. Heminghaus Comm. No. 1	Clinton Co. 33-T3N-R1W	478	7040	-6402	-6472 to -6552	Rhyolite and granite porphyry	2	.000175 to .000358	.000266
2	Brehm Drlg. & Prod. Bochantin Comm. No. 1	Washington Co. 35-T3S-R2W	454	7338	-6836	-6836 to -6846	Granite	1		.000085
3	Texaco R. A. Johnson No. 1	Marion Co. 6-T1N-R2E	541	9210	-8629	-8634 to -8669	Granite	4	.000111 to .000148	.000127
4	Maryland Service Co. Kircheis No. S-1	Madison Co. 27-T3N-R6W	504	5018	-4506	-4511	Granite	1		.000216
5	Texaco E. Cuppy No. 1	Hamilton Co. 6-T6S-R7E	393	13051	-12574	-12574 to -12658	Granite	4	.000323 to .002546	.001221
6	Herndon Drlg. Campbell No. 1	Pike Co. 15-T4S-R5W (4th P.M.)	716	3207	-2488	-2488 to -2489	Rhyolite porphyry	2	.000317 to .000618	.000467
7	Mississippi River Fuel Corp. Theobald No. A-15	Monroe Co. 35-T1S-R10W	66	2768	-2093	-2093 to -2094	Granite	2	.000075	.000075
8	Humble Weaber-Horn No. 1	Fayette Co. 28-T8N-R3E	536	8616	-7676	-7676 to -8077	Rhyolite	5	.000046 to .000154	.000104
9	Union Oil of Calif. Cisne Comm. No. 1	Wayne Co. 3-T1S-R7E	504	11614	-11010	-11061 to -11110	Granite	3	.000202 to .000217	.000209
10	Panhandle Eastern Pipeline Mumford No. 1-21	Pike Co. 21-T5S-R4W (4th P.M.)	812	2226	-1409	-1409 to 1414	Granophyre	3	.000526 to .001316	.000952
11	Texas Pacific Oil Co., Inc. B. Farley et al.	Johnson Co. 34-T13S-R3E	594	14284	?	-13666 to -13686	Metasediments	3	.000029 to .000059	.000049
12	Texas Pacific Oil Co., Inc. Mary L. Streich Comm. No. 1	Pope Co. 2-T11S-R6E	804	14942	?	-14116	Metasediments	2	.000299 to .000522	.000410
13	Orrs Landing Dike (outcrop)	Hardin Co. NE SW NE 33-T12S-R8E					Lamprophyre (mostly carbonate)			.000106
14	Mix Farm Dike (outcrop)	Pope Co. NE NE 18-T13S-R7E					Mica-peridotite			.012751
15	Absher Dike (outcrop)	Williamson Co. SE SW SE 34-T9S-R4E					Mica-peridotite			.000223
16	Omaha Dome Intrusive	Gallatin Co. SE NW SW 4-T8S-R8E					Mica-peridotite			.016155
17	Downeys Bluff Sill (outcrop)	Hardin Co. NW NW SE 5-T13S-R8E					Lamprophyre (abundant carbonate)			.010132

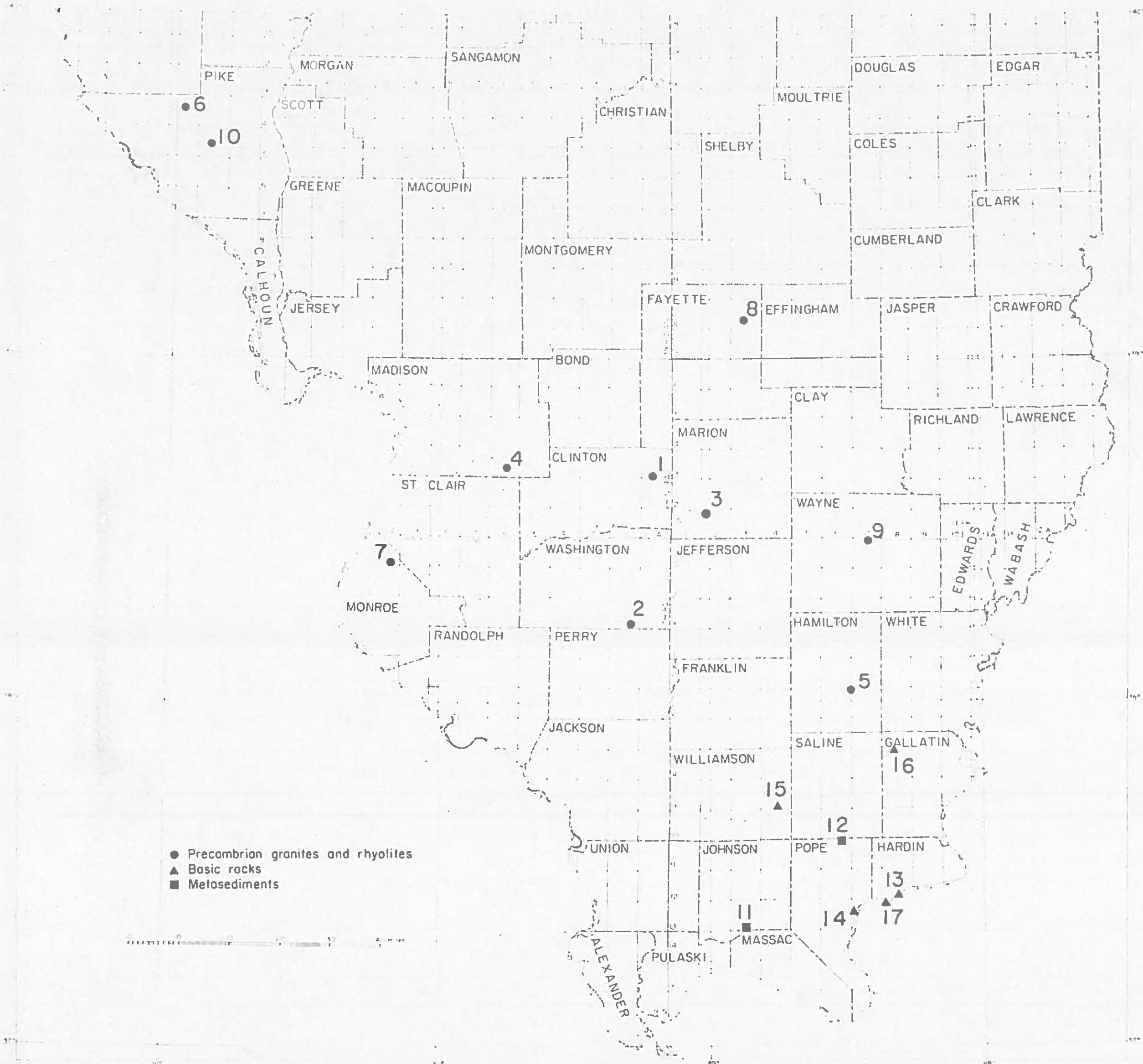


Figure 5. Locations of pertinent rock samples on which magnetic susceptibility measurements were made. (See table 1.)

once the sample is inserted. Since fragmented samples in test tubes of different inner diameters were used, corrections were made for density of the sample and the size of the holder.

The first group of rocks on which magnetic susceptibility measurements were made was composed of lower Pennsylvanian and Chesterian (Mississippian) rocks obtained from a well in sec. 30, T. 11 S., R. 3 E., near the town of Tunnel Hill in Johnson County. These rocks, some of which are ferruginous, were considered the most likely among the sedimentary rocks to have magnetic susceptibilities great enough to produce discernible vertical magnetic intensity anomalies in a ground survey (Heigold and McGinnis, 1961). This hypothesis was not confirmed, however. All of the samples tested had magnetic susceptibilities too small to be measured with the available instrument.

The second group of rocks considered was composed of acidic igneous rocks from near the basement surface (table 1 and fig. 5). These rocks were recovered from deep holes penetrating the basement surface in southern Illinois. Most were fresh-looking igneous rocks from which any deeply weathered material had been removed. The magnetic susceptibility values obtained for these rocks were about as expected. The group of samples from the Texaco E. Cuppy No. 1 well in sec. 6, T. 6 S., R. 7 E., in Hamilton County is notable because the magnetic susceptibilities of four basement samples from this well increased monotonically with depth, from .000323 cgs units at -12,574 feet (m.s.l.) to .002546 cgs units at -12,658 feet (m.s.l.). The highest value given here is comparable with those found for basic rocks.

A third group of rock samples measured was composed of basic intrusive rocks that had been collected in southern Illinois by staff members of the Illinois State Geological Survey (Bradbury, 1962) (table 1 and fig. 5).

These intrusive rocks occur as dikes, sills, and explosion breccias. Some of the samples, especially the explosion breccias, are mostly sedimentary rocks (carbonates) and therefore have low values of magnetic susceptibility. The other intrusives measured were mica peridotites or lamprophyres. The values for some of the mica peridotites were extremely high. The high value of magnetic susceptibility (.016155 cgs units) for the intrusive rock of the Omaha Dome is noteworthy.

Among the rock samples measured were the metasediments found at the bottom of the two deep tests in Johnson and Pope Counties which did not encounter igneous basement (table 1 and fig. 5). The magnetic susceptibilities determined for these rock samples were in the range of susceptibilities found for granitic basement rocks, with the Pope County samples being an order of magnitude more susceptible than those from Johnson County.

Many of the geophysical studies cited earlier in this report present, and include reference to, other geophysical studies that provide useful data on magnetic susceptibility. A particularly exhaustive study is an unpublished report by Schnepfe (1962) dealing with density and magnetic-susceptibility measurements on rocks in the St. Francois Mountain area, Missouri.

INTERPRETATION OF MAGNETIC DATA

The map of residual vertical magnetic intensity of the Johnson County area, Illinois (pl. 2), represents the algebraic sum of all vertical magnetic intensity anomalies resulting from horizontal variations in the magnetic polarization of the rocks from the surface to the Curie Point Geotherm of magnetite, the principal ferromagnetic mineral of rocks. In stable cratonic areas, this geotherm, the surface below which magnetite loses its magnetic properties, is located roughly at the interface in the lower crust that separates the upper, granitic rocks from the lower, basic rocks. Magnetic polarization is caused by induction in the earth's field, which is a function of the rock's magnetic susceptibility, and by remanent magnetism, which generally is significant as a source of magnetic anomalies only from crystalline rocks and particularly from extrusive rocks.

It is generally thought that the magnetic susceptibilities of sedimentary rocks are small (i.e., on the order of 10^{-6} cgs units) in comparison with those of igneous rocks. McGinnis and Heigold (1961) found a distinct magnetic low, measured at the surface, extending upstream from the mouth of the Illinois River. This low was attributed to the absence of Pennsylvanian sediments. McEvilly (1957) noted that several sedimentary formations in eastern Missouri have magnetic susceptibilities of about one-fourth the normal value for granite.

Even though magnetic susceptibility measurements of near-surface lower Pennsylvanian and Chesterian (Mississippian) sediments in the Johnson County area showed extremely low values, vertical magnetic intensity profiles were run across three surficial faults mapped by Weller (1940) (pl. 2 and fig. 4). The first profile *(aa')* was run north to south in sections 30 and 31, T. 11 S., R. 5 E., Pope County, across a northeast-to-southwest-trending fault. This fault, which is probably a high-angle reverse fault, has a displacement of about 150 feet up to the southeast. Rocks forming the bedrock surface on the northwest belong to the Abbott Formation (lower Pennsylvanian), whereas those to the southeast are older Caseyville (lower Pennsylvanian) rocks (Willman et al., 1967). This fault appears to be the southwest extension of the McCormick Anticline. The second profile *(bb')* was run east to west in secs. 31 and 32, T. 12 S., R. 4 E., Johnson County, across a northwest-to-southeast-trending fault that approximates the axis of the sizable magnetic low entering Johnson County from the southeast. This normal fault has a displacement of about 50 feet down to the southwest; upper Chesterian (Mississippian) rocks form the bedrock surface on both sides of the fault (Willman et al., 1967). The third profile *(cc')* was run east to west in sec. 33, T. 12 S., R. 3 E., Johnson County, across a small normal fault (displacement less than 50 feet) that forms the western boundary of a small graben (about a half mile wide). Chesterian (Mississippian) rocks also form the bedrock surface on both sides of this fault. The north-to-south-trending faults in this area tend to parallel the contours on the map of residual vertical magnetic intensity (pl. 2).

In view of the extremely low values of magnetic susceptibility obtained for the lower Pennsylvanian and Chesterian rocks in this area, it is not surprising that vertical magnetic intensity profiles across these faults do not delineate the fault traces. These results seem to discourage the further use of ground magnetic surveys as an aid in mapping faulting of Paleozoic strata in this area.

The map of residual vertical magnetic intensity (pl. 2) seems to rule out the possibility that basic intrusives of any considerable extent approach the earth's surface. The type of anomaly expected from such features is simply not exhibited. The existence of small basic intrusives between stations cannot be ruled out, however.

The great depths to igneous basement rock in the study area and the values of magnetic susceptibility obtained for igneous basement rocks in southern Illinois make isolation of magnetic anomalies difficult because lateral susceptibility contrasts at the sediment-basement interface are too small. Theoretical calculations show that even considerable relief on a granitic-rhyolitic basement surface in the study area would produce rather small (on the order of 10 gammas) vertical magnetic intensity anomalies at the earth's surface.

Several interpretive techniques were applied to the residual vertical magnetic intensity data in attempts to filter out regional trends or to isolate and sharpen anomalies. A third-order least-squares polynomial surface was found to be the "best" low-order polynomial to fit the regional magnetic field. The determination of "best" was based on the smallest average residual squared. Removal of the regional magnetic field from the residual vertical magnetic intensity data did filter the data, but the portion of the field that remained was of questionable interpretive value. In an area as compact as the Johnson County area, the regional magnetic anomalies are the ones important enough to merit further analysis. Downward continuations and derivatives of the magnetic field were calculated in an effort to better define the extent of the magnetic anomalies observed and to relate these anomalies to their geologic source (Henderson, 1960, and Rudman and Blakely, 1975). These techniques, especially the downward continuations, showed that the map of residual vertical magnetic intensity of the Johnson County area owed its configuration mainly to lithologic changes in the basement rocks.

The sizable magnetic low entering Johnson County on the southeast (pl. 2) is actually a portion of a long magnetic low that persists across southern Illinois from Kentucky on the southeast to Missouri on the west (fig. 3) (Patenaude, 1964; Heigold, 1976; and Lidiak and Zietz, 1976). This low separates two equally persistent bands of magnetic highs. Lidiak and

Zietz (1976) have correlated the line separating this low and the high magnetic band on the south with the southeastern part of the Ste. Genevieve Fault Zone and have indicated that this zone may continue to the southeast without any surface expression. The high magnetic gradient band separating this low and the magnetic highs on the north is very pronounced (fig. 3). A portion of this band in southwestern Saline and northwestern Pope Counties is shown in plate 2. Heigold (1976) and Lidiak and Zietz (1976) have indicated that this gradient presumably represents the juxtaposition of different basement rock types along a buried fault zone. The large positive anomaly of residual magnetic intensity extending into Johnson County from the northeast is a nose or spur off the band of magnetic highs to the north. It terminates in west-central Johnson County or east-central Union County without transecting the magnetic low.

In order to obtain estimates of the depth, configuration, and magnetic susceptibility contrast of the source of this positive magnetic anomaly, a profile (*AA´*) of vertical magnetic intensity extending from the highest point on the nose in sec. 12, T. 11 S., R. 2 E., to the low in sec. 22, T. 13 S., R. 4 E., was constructed (pl. 2 and fig. 6). The total relief on this profile was 480 gammas. Using equations derived by Heiland (1940) for two-dimensional dikelike bodies (of infinite and finite depth) and published components of the earth's magnetic field in Johnson County (McGinnis and Heigold, 1961, and Fabiano, 1975), families of curves obtained by varying depth, width, and magnetic susceptibility contrast for these dikelike bodies were calculated. The results indicated that the source of the anomaly was a dikelike body that extended to great depth, was approximately 4 miles wide, and whose top was about 3 miles below the earth's surface. The contrast between the magnetic susceptibility of the anomaly-causing body and that of the surrounding basement rock is approximately .004 cgs units.

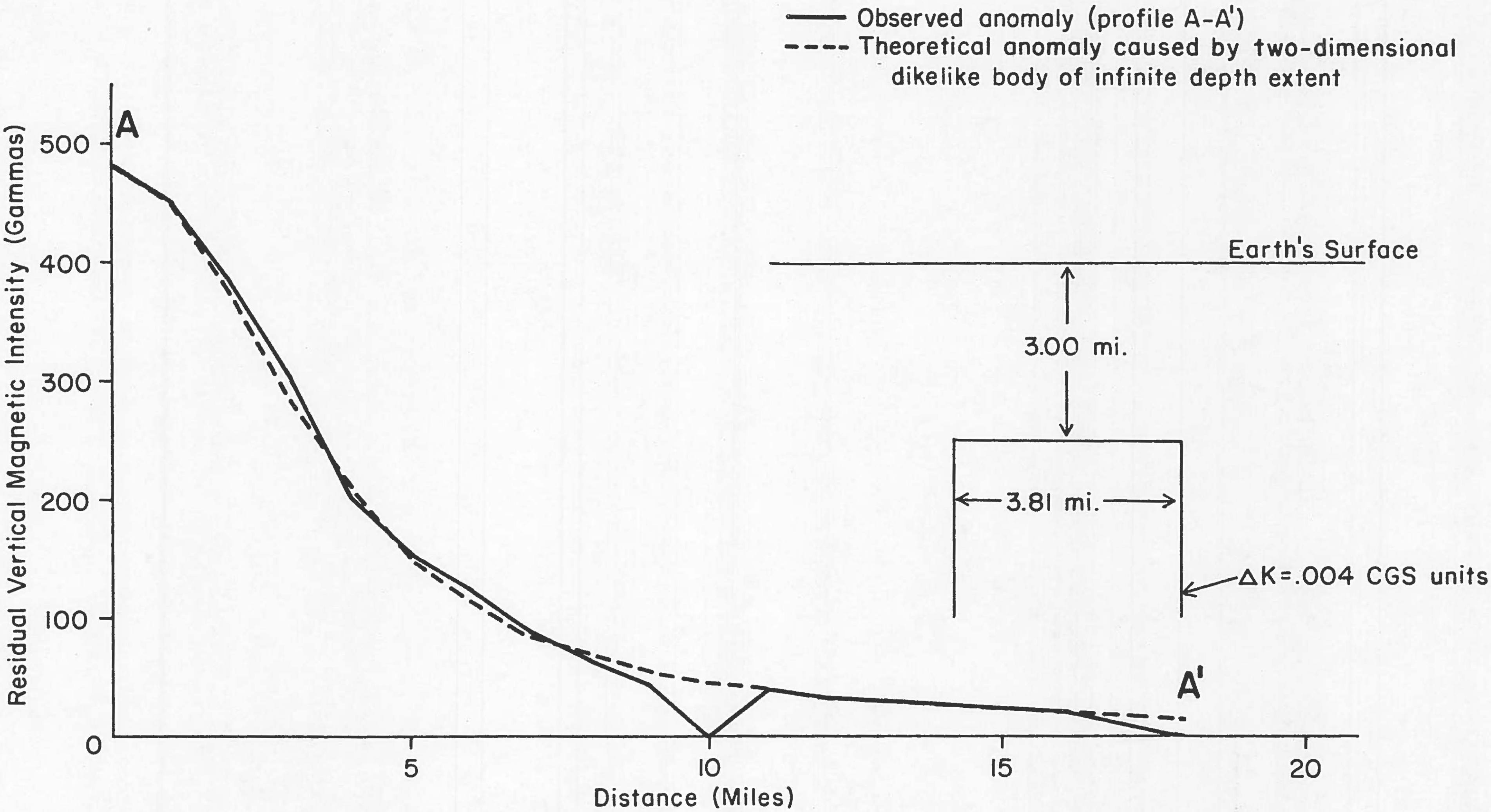


Figure 6. Theoretical model of the positive residual vertical magnetic intensity anomaly in northwestern Johnson County. (See plate 1 for location.)

Three-dimensional models constructed by grouping long prismatic elements with the magnetic susceptibility contrast of .004 cgs units yielded essentially the same result as the simpler two-dimensional models (Bhattacharyya, 1964, and Whitehill, 1973). Since the recent deep tests in Johnson and Pope Counties did not encounter igneous basement rock at depths of 14,284 feet and 14,920 feet, respectively, the top of the theoretical body may not be far from the igneous basement surface here.

DISCUSSION

The intricate faulting in the Johnson County area cuts lower Pennsylvanian strata. It has generally been assumed that most of this faulting occurred at the close of the Permian when the Appalachian Mountains were folded (Weller, 1940). Ross (1963), on the basis of limited surface and subsurface data in southernmost Illinois, has suggested recurrent displacement along faults cutting Paleozoic rocks may have displaced Cretaceous and younger strata of the Mississippi Embayment to the south and that earthquake activity in the upper part of the Mississippi Embayment indicates that these faults may still be active. Studies that apply new field and subsurface data in order to better evaluate those hypotheses are underway in the area.

The New Burnside Anticline and its apparent eastward extension, the Stonefort Anticline, are offset from the McCormick Anticline in an en echelon manner. These asymmetrical structures have their steeper flanks to the northwest and north. The southeast end of the McCormick Anticline passes laterally into a fault which is upthrown on the southeast. These structures were formed by compressive forces exerted from the south and southeast (Weller, 1940, and Brokaw, 1916).

Superposition of known faults and axes of positive structures in the study area onto the map of residual vertical magnetic intensity reveals some interesting relationships (pls. 1 and 2). The faults striking north to south and northeast to southwest in Johnson County and the New Burnside, Stonefort, and McCormick Anticlines, form a system of en echelon folds and faults that is closely aligned with the magnetic contours. The basement rock hypothesized to lie north of the steep magnetic gradient band that persists across southern Illinois is also the apparent source material for the positive magnetic anomaly that noses into northwestern Johnson County from the northeast. The basement seems to have imposed a constraint on an ancient stress field, thereby determining the characteristics and location of these geologic structures. Link (1928) has shown experimentally that arcuate structural systems can be formed without introducing other constraints by unidirectional compressional forces in horizontal planes where rigid materials have adjacent incompetent beds or by application of arcuate compressional forces in the horizontal plane against homogeneous material. Where unidirectional compressional forces are applied in the horizontal plane against homogeneous material, however, other constraints would have to be introduced to cause the system to be arcuate. The geographical relationship between the structures of eastern Johnson, southwestern Saline, and northwestern Pope Counties and the magnetic anomalies bordering them appears to be significant. If the basement rock responsible for these observed magnetic anomalies imposed a constraint on an ancient stress field in this region, the character of the basement rock would have to have been established prior to this folding and faulting.

The northeast-to-southwest-trending faults so evident in the sediments of the Fluorspar Area Fault Complex east of the study area cut across the large magnetic low traversing southern Illinois (fig. 3) without a discernible effect on the magnetic field (Lidiak and Zietz, 1976), suggesting that these faults do not exist, or are poorly defined, in the basement. The magnetic high nosing into northwestern Johnson County from the northeast does not completely transect the large magnetic low, suggesting that any basement faulting that may be associated with this positive anomaly likewise is nonexistent or poorly defined.

The relationship between the predominant folding and faulting in the Johnson County area and the basement rock associated with the magnetic high on the northwest and the east-to-west-trending high magnetic gradient found in the northeast portion of the study area implies that these structures have expression in the basement since that is where the hypothesized constraint is located. There are no such compelling constraints to be found in the sedimentary column. Because there are no magnetic anomalies directly associated with these structures, an appreciable magnetic susceptibility contrast in the sedimentary column or in the basement rocks is unlikely. If a structural constraint in the basement exists and this constraint is evidenced in the magnetic field, the existence of a significant structural trend in the basement extending to the northeast from the study area is doubtful.

Stauder, Kramer, Fischer, Schaffer, and Morrissey (1976) have studied the continuity of the seismic features of the Mississippi Embayment region and those of central and southeastern Illinois. They cite the following as indications that the New Madrid Seismic Zone is probably distinct from the Wabash Valley Fault System: (1) the well-defined zones of limited dimension of seismic activity in southeast Missouri, (2) the manner in which this activity diminishes as one approaches the Cairo, Illinois, area, (3) a probable relation of the seismicity to the Pascola Arch structure, (4) extensional faulting in the New Madrid Zone in contrast with a horizontal compressional stress system in southern Illinois (Street, Herrmann, and Nuttli, 1974), and (5) the existence of possible bounding features between the two zones such as Hicks Dome and the Rough Creek Lineament.

Based on the data gathered in this study, the Johnson County area, Illinois, does not appear to be the site of any weak zone in the earth's crust that would affirm structural continuity between the Wabash Valley Fault System to the northeast and the New Madrid Seismic Zone to the southwest.

CONCLUSION

The detail of the ground magnetic survey of the Johnson County area, Illinois, has provided a view of the magnetic field of this rather compact area while allowing study of important regional aspects of the field. Extremely small contrasts of lateral magnetic susceptibility in the sedimentary column did not allow delineation of faulting in the sedimentary rocks. Moreover, there was no substantial magnetic evidence of igneous intrusives in the sediments. The combination of great depth to, and the rather small lateral susceptibility contrast at, the basement surface prevented attempts to determine basement topography. Nevertheless, the survey did provide considerable information about the crustal geology of the area. Lithologic changes in the basement rocks, as indicated by the magnetic field, offer a possible explanation of the nature and location of the more important geologic structures in the Johnson County area. Mafic rocks in the upper crust appear to have imposed a constraint on an ancient stress field that resulted in the observed arcuate system of faults and en echelon folds.

The configuration of the magnetic field would seem to negate any structural continuity, at least in the Johnson County area, between the Wabash Valley Fault System to the northeast and the New Madrid Seismic Zone to the southwest.

The results of this study indicate that detailed ground magnetic surveys are warranted in well-chosen areas to provide better understanding of the crustal geology.

REFERENCES

Bhattacharyya, B. K., 1964, Magnetic anomalies due to prism-shaped bodies with arbitrary polarization: Geophysics, vol. 29, no. 4, p. 517-531.

Bradbury, J. C., 1962, Trace elements, rare earths, and chemical composition of southern Illinois igneous rocks: Illinois State Geological Survey Circular 330, 12 p.

Bradbury, J. C., and E. Atherton, 1965, The Precambrian basement of Illinois: Illinois State Geological Survey Circular 382, 13 p.

Bristol, H. M., 1971, Selected deep tests in Illinois, in Background materials for Symposium on Future Petroleum Potential of NPC Region 9 (Illinois Basin, Cincinnati Arch, and Northern Part of Mississippi Embayment): Illinois State Geological Survey, Illinois Petroleum 96, p. 45-46.

Brokaw, A. D., 1916, Preliminary oil report on southern Illinois—Parts of Saline, Williamson, Pope, and Johnson Counties: Illinois State Geological Survey Bulletin 35, p. 19-37.

Butts, Charles, 1925, Geology and mineral resources of the Equality-Shawneetown area: Illinois State Geological Survey Bulletin 47, 76 p.

Fabiano, E. B., 1975, Magnetic declination in the United States—Epoch 1975: United States Geological Survey Map I-911, 1:5,000,000.

Heigold, P. C., 1970, A gravity survey of extreme southeastern Illinois: Illinois State Geological Survey Circular 450, 12 p.

Heigold, P. C., 1976, An aeromagnetic survey of southwestern Illinois: Illinois State Geological Survey Circular 495, 28 p.

Heiland, C. A., 1940, Geophysical exploration: Prentice Hall, New York, p. 395-400.

Henderson, R. G., 1960, A comprehensive system of automatic computation in magnetic and gravity interpretation: Geophysics, vol. 25, p. 569-585.

Lamar, J. E., 1925, Geology and mineral resources of the Carbondale quadrangle: Illinois State Geological Survey Bulletin 48, 172 p.

Lawrence, J., and E. Reinerie, 1962, Illinois gravity stations: University of Wisconsin Geology Department.

Lidiak, E. G., R. F. Marvin, H. N. Thomas, and M. N. Bass, 1966, Geochronology of the midcontinent region, part 4, eastern area: Journal of Geophysical Research, vol. 71, p. 5427-5438.

Lidiak, E. G., and I. Zietz, 1976, Interpretation of aeromagnetic anomalies between 37° N. and 38° N. in the eastern and central United States: Geological Society of America, Special Paper 167, 37 p.

Link, T. A., 1928, En echelon folds and arcuate mountains: Journal of Geology, vol. 36, p. 526-538.

McCamy, K., and R. P. Meyer, 1966, Crustal results of fixed multiple shots in the Mississippi Embayment, in The Earth Beneath the Continents: American Geophysical Union Monograph 10, p. 370-381.

McClure, P. S., 1930, Vertical magnetic intensity map of western Hardin County: Illinois State Geological Survey Open-File Map.

McClure, P. S., 1931, Vertical magnetic anomaly map of southern Illinois: Illinois State Geological Survey Open-File Map, 1 in = 4 mi.

McEvilly, T. V., 1957, Abnormal sedimentary susceptibilities in eastern Missouri: Proceedings of the Geophysical Society of Tulsa, vol. 4, p. 60-69.

McGinnis, L. D., and J. C. Bradbury, 1964, Aeromagnetic survey of the Hardin County area, Illinois: Illinois State Geological Survey Circular 363, 12 p.

McGinnis, L. D., and P. C. Heigold, 1961, Regional maps of vertical magnetic intensity in Illinois: Illinois State Geological Survey Circular 324, 12 p.

McGinnis, L. D., P. C. Heigold, C. P. Ervin, and M. Heidari, 1976, The Gravity field and tectonics of Illinois: Illinois State Geological Survey Circular 494, 28 p.

Nuttli, Otto W., 1974, personal communication.

Patenaude, R. W., 1964, Results of regional aeromagnetic surveys of eastern Upper Michigan, central Lower Michigan, and southeastern Illinois: University of Wisconsin Geophysical and Polar Research Center, Department of Geology Research Report 64-2, April, 51 p.

Ross, C. A., 1963, Structural framework of southernmost Illinois: Illinois State Geological Survey Circular 351, 28 p.

Rudman, A. J., and R. F. Blakely, 1965, A geophysical study of a basement anomaly in Indiana: Geophysics, vol. 30, no. 5, p. 740-761.

Rudman, A. J., and R. F. Blakely, 1975, Fortran program for the upward and downward continuation and derivatives of potential fields: Indiana Department of Natural Resources, Geological Survey, Occasional Paper 10, 23 p.

Rudman, A. J., C. H. Summerson, and W. J. Hinze, 1965, Geology of basement in midwestern United States: American Association of Petroleum Geologists Bulletin 49, p. 894-904.

Schafersman, J. S., 1973, Crustal structure from gravity models in southwest Illinois: Unpublished M. S. thesis, Northern Illinois University, De Kalb, Illinois, 48 p.

Schnepfe, R. N., 1962, Density and susceptibility measurements, St. Francois Mountain area, Missouri: Unpublished report, Missouri Geological Survey file no. 41, 39 p.

Stauder, W., M. Kramer, G. Fischer, S. Schaffer, and S. T. Morrissey, 1976, Seismic characteristics of southeast Missouri as indicated by a regional telemetered microearthquake array: Bulletin of the Seismological Society of America, vol. 66, no. 6, p. 1953-1964.

Stauder, William, and Otto W. Nuttli, 1970, Seismic studies: South-Central Illinois earthquake of November 9, 1968: Bulletin of the Seismological Society of America, vol. 60, no. 3, p. 973-981.

Stewart, S. W., 1968, Crustal structure in Missouri by seismic refraction methods: Bulletin of the Seismological Society of America, vol. 58, p. 291-324.

Stonehouse, H. B., and G. M. Wilson, 1955, Faults and other structures in southern Illinois—A compilation: Illinois State Geological Survey Circular 195, 4 p.

Street, R. L., R. B. Herrmann, and O. W. Nuttli, 1974, Earthquake mechanics in the central United States: Science, 184, p. 1285-1287.

Warren, D. H., and J. H. Healey, 1973, Structure of the crust in the conterminous United States: Tectonophysics, vol. 20, 1-4, p. 203-213.

Warren, J. R., 1956, A study of magnetic anomalies associated with ultramafic dikes in the western Kentucky fluorspar district: Kentucky Geological Survey, Series IX, Bulletin 19, 38 p.

Weller, J. M., 1940, Geology and oil possibilities of extreme southern Illinois: Illinois State Geological Survey Report of Investigations 71, 71 p.

Weller, J. M., F. E. Tippie, and R. M. Grogan, 1952, Geology of the fluorspar deposits of Illinois: Illinois State Geological Survey Bulletin 76, 147 p.

Weller, S., and F. Krey, 1939, Preliminary geologic map of the Mississippian formations in the Dongola, Vienna, and Brownfield quadrangles: Illinois State Geological Survey Report of Investigations 60, 11 p.

Whitehill, D. E., 1973, Automated interpretation of magnetic anomalies using the vertical prism model: Geophysics, vol. 38, no. 6, p. 1070-1087.

Willman, H. B., 1967, Geologic map of Illinois: Illinois State Geological Survey, 1:500,000.

Willman, H. B., E. Atherton, T. C. Buschbach, C. Collinson, J. C. Frye, and J. A. Simon, 1975, Handbook of Illinois stratigraphy: Illinois State Geological Survey Bulletin 95, 261 p.

Willman, H. B., and J. C. Frye, 1970, Pleistocene stratigraphy of Illinois: Illinois State Geological Survey Bulletin 94, 204 p.

Woollard, G. P., and H. R. Joesting, 1964, Bouguer gravity anomaly map of the United States: American Geophysical Union and United States Geological Survey, Washington, D.C.

Zollweg, J., M. Kramer, S. T. Morrissey, and W. Stauder, 1974, Some preliminary results from a seismograph network in the New Madrid, Missouri, region: Paper presented at the 46th Annual Meeting of the Eastern Section of the Seismological Society of America, October 10-11.

PLATE I

A COMPILATION OF FAULTS AND SOME OTHER STRUCTURES IN SOUTHERN ILLINOIS

(After Stonehouse and Wilson 1955; J M Weller, 1940)

PLATE 2

RESIDUAL VERTICAL MAGNETIC INTENSITY OF THE JOHNSON COUNTY AREA, ILLINOIS

With Known Faults and Some Positive Structures Superimposed