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A GRAVITY SURVEY OF EXTREME SOUTHEASTERN ILLINOIS

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ABSTRACT

The Illinois State Geological Survey is currently engaged in a program to cover the entire state of Illinois with a gravity survey having approximately one mile grid spacing. Several reports concerned with portions of this state-wide survey have already been published.

Included in this report is a simple Bouguer gravity anomaly map of extreme southeastern Illinois which includes the southeastern extremities of the Fairfield Basin and the fluorspar district of southern Illinois. This area possesses, perhaps, the most complex array of geologic structures to be found in Illinois. The gravity anomalies of extreme southeastern Illinois appear to be related to deep-seated basic intrusives and near-surface lateral density contrasts.

INTRODUCTION

Approximately 2000 square miles in extreme southeastern Illinois have been covered by a reconnaissance gravity survey conducted by the Illinois State Geological Survey (fig. 1). This survey is a small part of the Illinois State Geological Survey program that will ultimately cover the entire state with a gravity network of approximately one station per square mile.

Gravity stations were occupied at points where elevations were given on the topographic maps of the area (mainly at section corners). In general, the density of the gravity stations decreased toward the southeastern part of the surveyed area due to the absence of elevation data in the rough terrain of the Shawnee National Forest and areas adjacent to the Ohio River.

A World-Wide Gravimeter was used in this survey. This meter is of the null reading, temperature compensated variety and has a scale constant of approximately 0.1 milligals per scale division.

All data reduction besides the manual correction of observed gravity values for meter drift and terrain effects was performed on the IBM 360/75 computer at the University of Illinois.

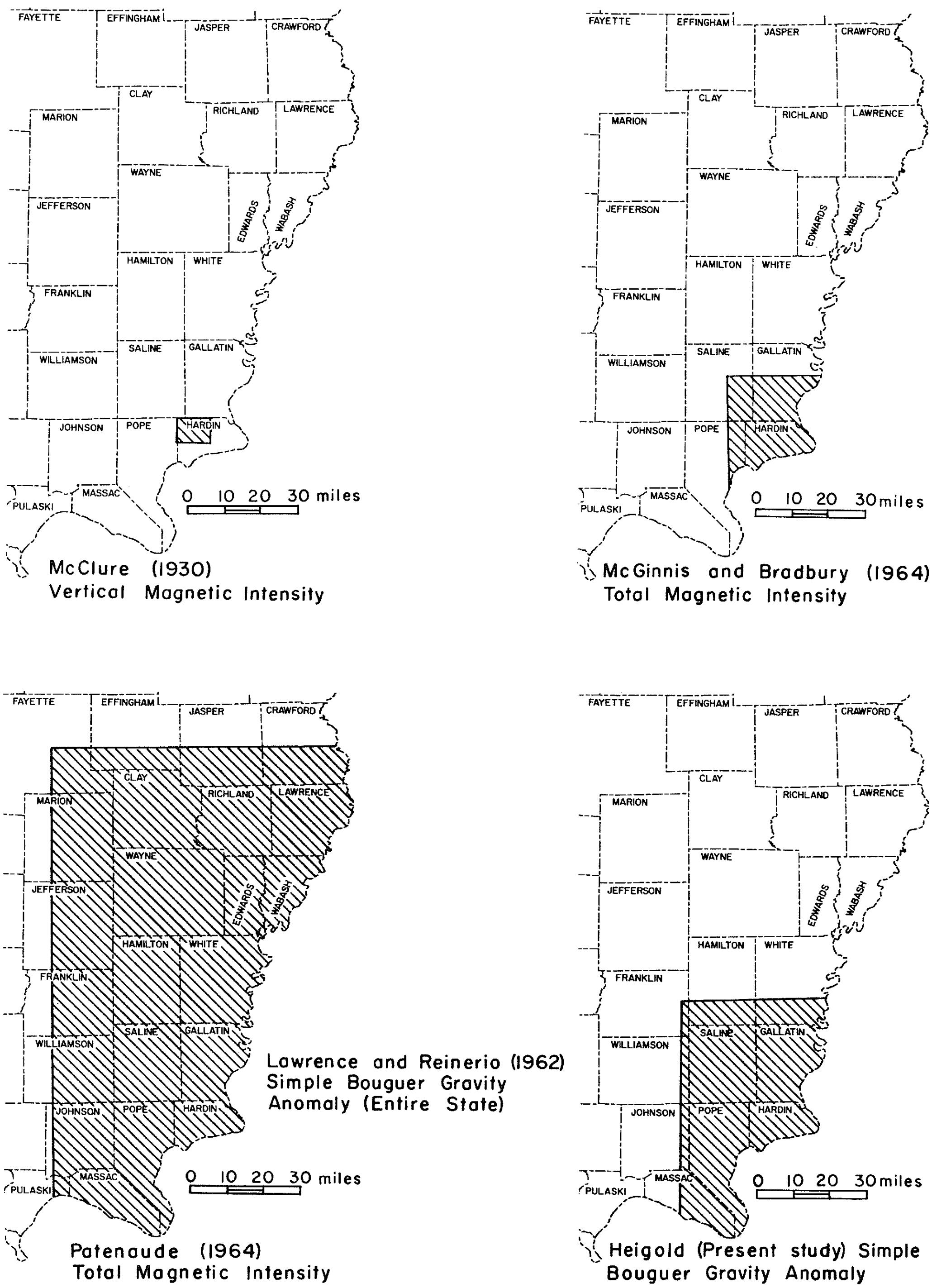


Fig. 1 - Index map showing areal extent of the present gravity survey and other geophysical studies in extreme southeastern Illinois.

Gravity Data Reduction

The gravity survey was tied to a U. S. Coast and Geodetic Survey pendulum station established at Murphysboro, Illinois, in 1941. This station was originally assigned an observed gravity value of 979.947 gals, but this value has since been adjusted to 979.9448 gals by McGinnis's statewide base station network, established in 1966. In this survey, all readings have been referred to the adjusted value.

In order to obtain Bouguer gravity values, meter drift, free-air, Bouguer, and terrain corrections were applied to the observed gravity values. Terrain corrections were applied to many readings in the southern part of the surveyed area because in many cases, the effect of terrain on the gravity field there was appreciable. Repeated readings at a base station throughout the field day determined meter drift. Free-air and Bouguer corrections, to compensate for the effects of the difference in elevation and the attraction of the material between the reference elevation (mean sea level), and that of the individual station, were combined under an assumption of 2.67 gm/cm^3 density for the surficial rocks. Terrain corrections, to compensate for the effects of local irregularities of topography, were made according to the system of zones and compartments described by Nettleton (1940), also using a density of 2.67 gm/cm^3.

Elevations given at section corners and bench marks on U. S. Geological Survey topographic maps where gravity stations were located have an accuracy of ±1 foot, which is sufficient for regional gravity surveys. The combined free-air and Bouguer corrections contributed an error of ±.059998 milligals to the values of Bouguer gravity, while the terrain corrections, where made, contributed an error of ±.1 milligals.

Theoretical gravity was based on the "1930 International Formula,"

$$g_t = 978.049\ (1. + .0052884 \sin^2\phi - .0000059 \sin^2 2\phi)$$

where g_t = theoretical gravity in gals

ϕ = latitude.

Gravity stations were located accurately to ±.1 minute of latitude, so theoretical gravity values were subject to an error of ±.075 milligals. It follows that the Bouguer gravity anomaly (Bouguer gravity minus theoretical gravity) is accurate to ±.134 milligals in those areas where no terrain corrections were made, and to ±.234 milligals where terrain corrections were included.

Previous Geophysical Work

McClure (1930) ran a vertical magnetic intensity ground survey of approximately 50 stations in the vicinity of Hicks Dome in western Hardin County (fig. 1). This small survey was devoid of local anomalies and showed only a portion of a regional trend in the magnetic field.

Lawrence and Reinerio (1962) covered the entire state 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, and contoured on a 10 milligals interval, was later incorporated into the simple Bouguer gravity anomaly map of the United States by Woollard (1965).

McGinnis and Bradbury (1964) made a study of the southeastern portion of the present study area using aeromagnetic data (fig. 1). The data were obtained from a survey flown at 2000 feet above mean sea level and included 24 north-south profiles one mile apart. From these data a total field magnetic intensity map with a contour interval of 20 gammas was constructed.

Patenaude (1964) published the results of an aeromagnetic survey of a portion of southeastern Illinois that includes the present study area (fig. 1). The survey was flown in north-south flight lines six miles apart at an elevation of 3000 feet above mean sea level. The total field magnetic intensity map was constructed with a contour interval of 100 gammas.

Structural Framework of the Surveyed Area

The area covered by this survey includes the southeastern extremities of the Fairfield Basin and the fluorspar district of southern Illinois. This area possesses, perhaps, the most complex array of geologic structures to be found in Illinois.

Stonehouse and Wilson (1955) made a compilation which summarizes known structural data in southern Illinois on one map. A portion of that map which covers the area surveyed is shown in figure 2. Most of the faults shown are steeply dipping, normal faults of small displacement, but displacements of 400 to 2000 feet are known to exist. Many of the faults are complex zones rather than simple faults. Thrust faults occur in this area, the most prominent being the Shawneetown-Rough Creek Fault Zone in southern Gallatin County and its extension in Saline and Pope Counties, where the known displacement is as much as 3500 feet.

Weller (1940) suggested that faulting in the fluorspar district and adjacent areas of southern Illinois and western Kentucky resulted from intrusion of a great mass of igneous material at considerable depth, which strongly arched the overlying strata until they ruptured. Large wedge-shaped blocks thus dropped considerably below the level of rocks on either side. The fractures served as avenues of escape for mineral-bearing solutions derived from the igneous mass. Later, this arch is believed to have collapsed somewhat, due to cooling and spreading of the intrusive material, renewing and perhaps reversing movement along some of the previously existing faults, and producing others.

Ross (1963) and Weller, Grogan, and Tippie (1952), in studies of faulting and intrusions in southern Illinois, showed that the basic igneous intrusions are of about the same composition and therefore represent a common parent body. McGinnis and Bradbury (1964) noted the similarities between the magnetic susceptibilities of the dike rocks in the area and an anomalous mass at depth which they considered the parent body.

Since intrusions both occupy fault planes and are cut by fault planes, Ross (1963) suggested that the intrusions occurred after the fault pattern was established, but before movement ceased. Heyl and Brock (1961) provided a lead-alpha date of 90 to 100 million years on monazite from an intrusive breccia from the Hicks Dome area. This suggests that there was intrusive activity in this area at least as late as middle Cretaceous time. McGinnis (1963) and Heigold (1968), in reports dealing with the seismicity of this general area, suggested that movement along deep-seated fault planes has persisted up to the present time.

Density Model of the Earth's Crust and Upper Mantle

Prior to any discussion of the earth's gravity field in the surveyed area, it is useful to consider a schematic model of that portion of the earth directly affecting the gravity field, the crust and upper mantle (fig. 3). Basically, this model describes density zones and gives representative values of density where possible. Because Bouguer gravity anomalies are the result of lateral variations in density, the model's primary function is the indication of interfaces where such lateral variations may take place.

In 1941, Walter and Birkenhauer concluded from near earthquake data that the earth's crust south of St. Louis, Missouri, is essentially composed of three layers. From top to bottom these layers are approximately 5, 20, and 15 kilometers thick (1 kilometer = .62137 miles) and correspond to the sedimentary, granitic, and basic rocks, respectively, of the typical continental crust. At the base of the basic rock layer is the Mohorovicic Discontinuity, separating the crust from the mantle.

The rocks found in a deep test drilled by Texaco, Inc., are representative of the rocks within the surveyed area. The test, E. Cuppy #1, sec. 6, T. 6 S., R. 7 E., is located in southern Hamilton County just east of Dale, immediately north of the area covered by this gravity survey (fig. 2). This well was apparently located on a Precambrian high; therefore the oldest sedimentary rocks overlying the Precambrian may be appreciably thinned or absent at the well site. The well was finished in Precambrian granodiorite and altered albite (Bradbury, personal communication) at a driller's total depth of 13,051 feet (12,659 feet below mean sea level).

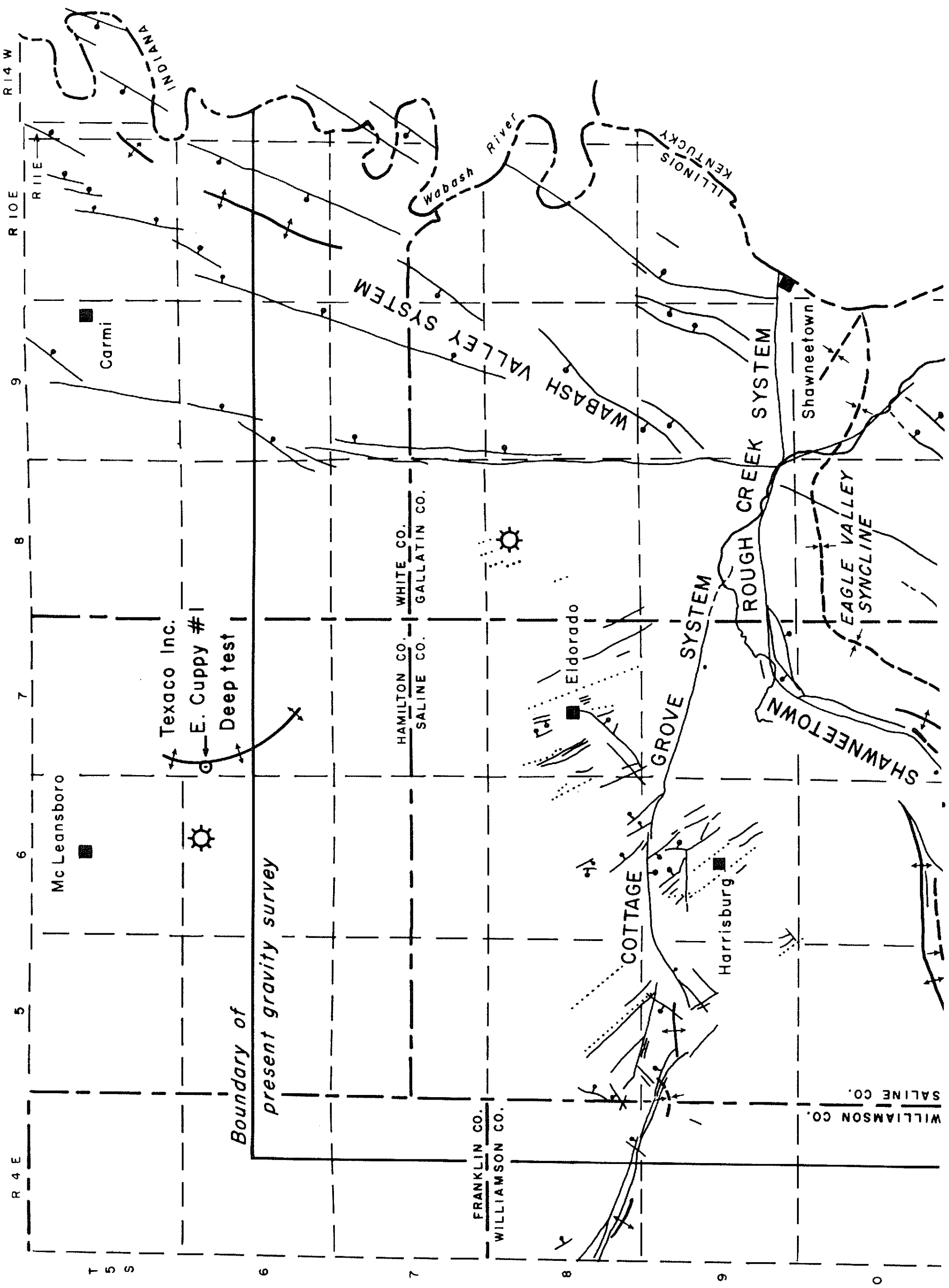
Particularly relevant to this gravity survey is the Formation Density Log. The logged interval extends from a depth of 3,165 feet (2,773 feet below mean sea level) in the Mississippian St. Louis Formation down to a depth of 13,034 feet (12,642 feet below mean sea level) into the top of the Precambrian rocks.

Figure 4 shows the density-depth relationship throughout the logged interval where density values, calculated at every 10 feet, are averaged over 100-foot intervals. The average density of the sedimentary rocks in the logged interval was calculated to be 2.62 gm/cm^3. That portion of the sedimentary column from the top of the St. Louis Formation to the earth's surface can be expected to have an average density somewhat less than 2.62 gm/cm^3 since these younger rocks are clastic in nature.

The density of the granitic rocks in the study area was also obtained from the Formation Density Log. An average density value of 2.63 gm/cm^3 resulted from seven values calculated below the Precambrian surface. This average value is compatible with the fact that granodiorite and altered albite were encountered in the bottom of the hole. Moreover, since this deep test was drilled on a Precambrian high, one would not expect the density values to be influenced greatly by a weathering zone on the Precambrian surface.

The basic rocks of the crust are assigned a density value range of 2.70 to 3.00 gm/cm^3. This is based on the fact that most of the intrusive igneous rocks in the area occur as dikes and sills of mica peridotite and lamprophyre (Clegg and Bradbury, 1956).

Wyllie (1963) indicated that the Mohorovicic Discontinuity may be a chemical change from basalt in the lower part of the crust to peridotite (density 3.15 to 3.28 gm/cm^3) in the upper mantle, and that at appropriate depths in the mantle, eclogite (density 3.41 gm/cm^3) replaces the peridotite. The density of the ultrabasic rocks below the Mohorovicic Discontinuity likely increases with depth.


R 14 W
R 11 E
R 10 E
R 4 E
T 5 S
INDIANA
ILLINOIS
KENTUCKY
Wabash River
WABASH VALLEY SYSTEM
Carmi
Shawneetown
ROUGH CREEK SYSTEM
EAGLE VALLEY SYNCLINE
COTTAGE GROVE SYSTEM
SHAWNEETOWN
Eldorado
Harrisburg
McLeansboro
Texaco Inc.
E. Cuppy #1
Deep test
Boundary of present gravity survey
WHITE CO.
GALLATIN CO.
HAMILTON CO.
SALINE CO.
FRANKLIN CO.
WILLIAMSON CO.
SALINE CO.
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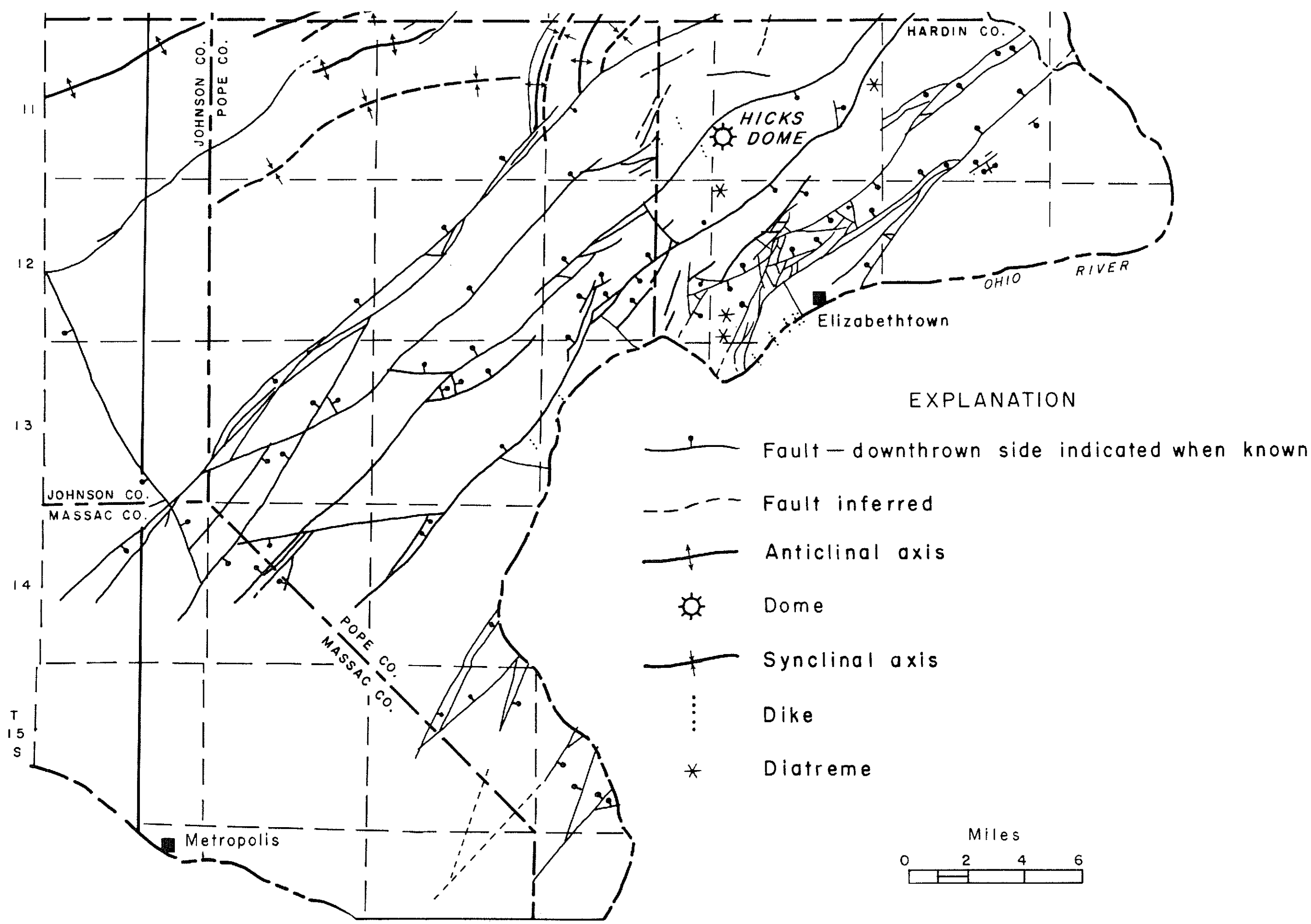

Fig. 2 - Faults and other structures in extreme southeastern Illinois (after Stonehouse and Wilson, 1955).

In light of this density model one can note those interfaces where large density contrasts exist, and therefore, where lateral variations in density are likely to occur. From the density-depth relationship shown in figure 4, it is apparent that there are many such interfaces in the sedimentary column. The sediments-granitic contact in this area does not appear to be an interface where lateral variations in density are large enough to appreciably influence the earth's gravity field. Anywhere rocks from an originally deeper zone (e.g. the basic rock zone) have assumed a position closer to the earth's surface than those of an originally shallower zone (e.g. the granitic rock zone), large lateral variations in density are possible.

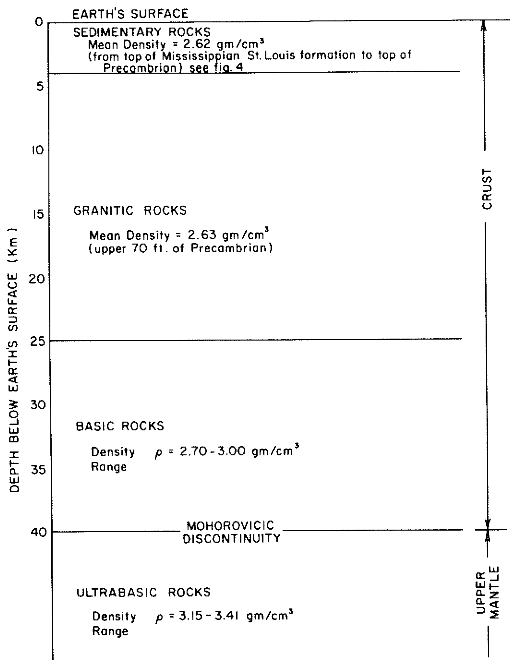

Fig. 3 - Schematic density model of the earth's crust and upper mantle in extreme southeastern Illinois.

Bouguer Gravity Anomaly Map

The bouguer gravity anomaly map (plate 1) shows the deviation of the Bouguer gravity from the theoretical gravity. Usually this deviation is caused by some combination of three major factors:

(1) structure, unconformities, and lithologic changes in the sedimentary column; (2) relief on the crystalline basement surface; and (3) lateral density changes in the crystalline portion of the earth's crust and upper mantle.

As previously noted, factor 2 is not very significant where the basement rock is predominantly granitic rock; however, it is important where the basement rock consists mainly of basic rocks. The latter case may be the result of removal of the overlying granitic rocks by erosion or intrusion of the basic rocks from below.

The gravity phenomena related to factors 2 and 3 are generally regional in scale. Certain aspects of factor 1 may be large enought to influence the gravity field on a regional scale, but are most influential on a local scale.

The great amount of intrusive activity that has influenced the structural framework of southern Illinois must have influenced the gravity field of the area on a regional scale. Past investigators of the magnetic field of the area have postulated lateral magnetic susceptibility contrasts at great depths due to basic intrusions as a cause of regional total magnetic intensity anomalies. One may similarly look to lateral density contrasts due to these intrusions as a cause of regional Bouguer gravity anomalies. The investigators of the earth's magnetic field were limited in their search for causes of regional total magnetic intensity anomalies by the Curie Point Geotherm (the temperature dependent surface below which all rocks lose their magnetism). But examinations of the regional gravity field show the possibility that large anomalous masses and accompanying large lateral density contrasts, capable of influencing the gravity field on a regional scale, may exist below the Curie Point Geotherm.

There are positive regional Bouguer gravity anomalies along the upthrown sides of the three major fault zones bounding the Fairfield Basin on the south and southeast, the Shawneetown-Rough Creek, the Cottage Grove, and the Wabash River Fault Zones (plate 1). These Bouguer anomalies are in part correlative with the total magnetic intensity anomalies pointed out by Patenaude (1964) and McGinnis and Bradbury (1964), and are related to basic intrusions at considerable depth. Further interpretation of these and other regional Bouguer gravity anomalies must be postponed until they can be examined and evaluated with additional data covering all of southern Illinois.

On a local scale, the Bouguer gravity anomaly map (plate 1) provides evidence of near-surface lateral density contrasts. The anomalies caused by near-surface phenomena are often masked by the large-scale regional anomalies upon which they are superimposed. If needed, these small local anomalies can be brought into sharper focus by eliminating the regional portion of the gravity field by means of some ring or least square polynomial method for obtaining residual anomalies (Heigold, McGinnis, and Howard, 1964).

Examples of two of the more discernible local Bouguer gravity anomalies in the surveyed area are those associated with the Eagle Valley Syncline in southern Gallatin County and Hicks Dome in western Hardin County (fig. 2). These two examples are representative of the sort of anomalies expected from near-surface lateral density contrasts.

The Eagle Valley Syncline is a deep, asymmetric trough with steep northern and western flanks, formed by beds adjacent to the Shawneetown-Rough Creek Fault Zone, and a southern flank, formed by beds dipping much more gently to the north and northeast of Hicks Dome. The syncline deepens eastward where it contains strata of the late Pennsylvanian McLeansboro Group, the youngest consolidated rocks in the immediate area of the Shawneetown-Rough Creek Fault Zone. The expected gravity low caused by the younger, less dense, predominantly clastic rocks within the syncline, surrounded by more dense rocks on the flanks of the syncline, is evidenced by the lower Bouguer gravity anomaly contours nosing into the syncline from the east (plate 1).

Hicks Dome is a structural and physiographic high covering approximately 100 square miles in western Hardin County. Quaquaversal dips up to 25 degrees have been noted in some 4000 feet of sediments from the Devonian core to the Pennsylvanian flanks. The axis of the dome strikes approximately N50°W. Several igneous exposures, including mafic dikes and intrusive breccias, occur within a two-mile radius of the apex. Brown, Emery, and Meyer (1954) have

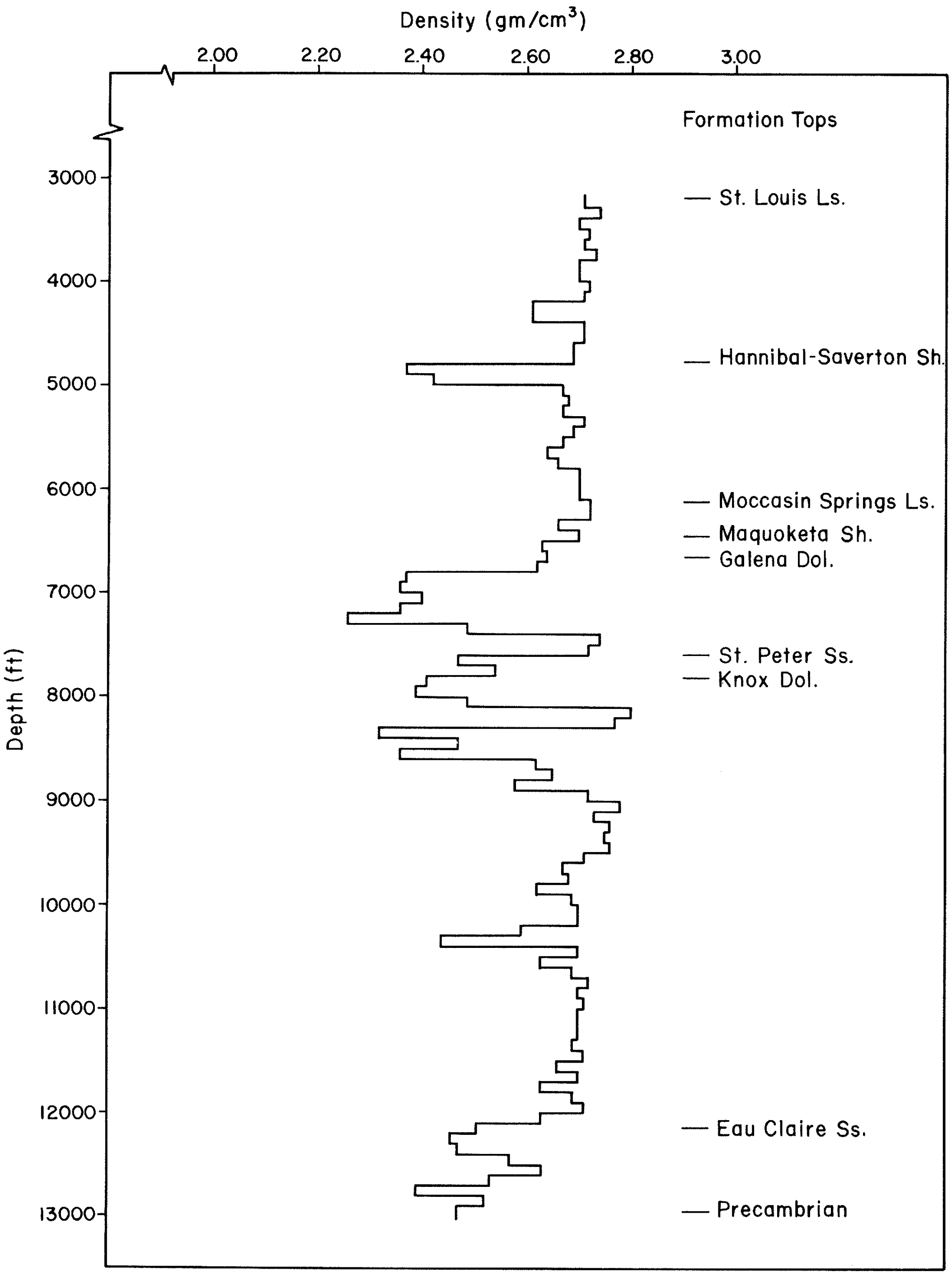

Fig. 4 - Density-depth relationship from the top of the Mississippian St. Louis Formation to the Precambrian, based on the Formation Density Log from a deep test in southern Hamilton County.

suggested that this is an uncompleted cryptovolcanic structure caused by the generation of steam in water-bearing sedimentary formations transected by basic intrusions. This explanation is consistent with McGinnis and Bradbury's (1964) finding that no magnetic anomaly can be related directly to Hicks Dome. The dense Middle Devonian cherty limestones which form the central core appear as a local Bouguer gravity anomaly high, whereas the less dense, younger sediments surrounding the dome provide an encircling low (plate 1).

SUMMARY

The gravity anomalies of extreme southeastern Illinois appear to be related to deep-seated basic intrusives and to near-surface lateral density contrasts. The former, which are regional, tend to mask the latter, which are local. Positive regional gravity anomalies thought to be related to basic intrusives are associated with the upthrown sides of major fault zones in the area. Local anomalies are associated with such structures as the Eagle Valley Syncline and Hicks Dome.

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