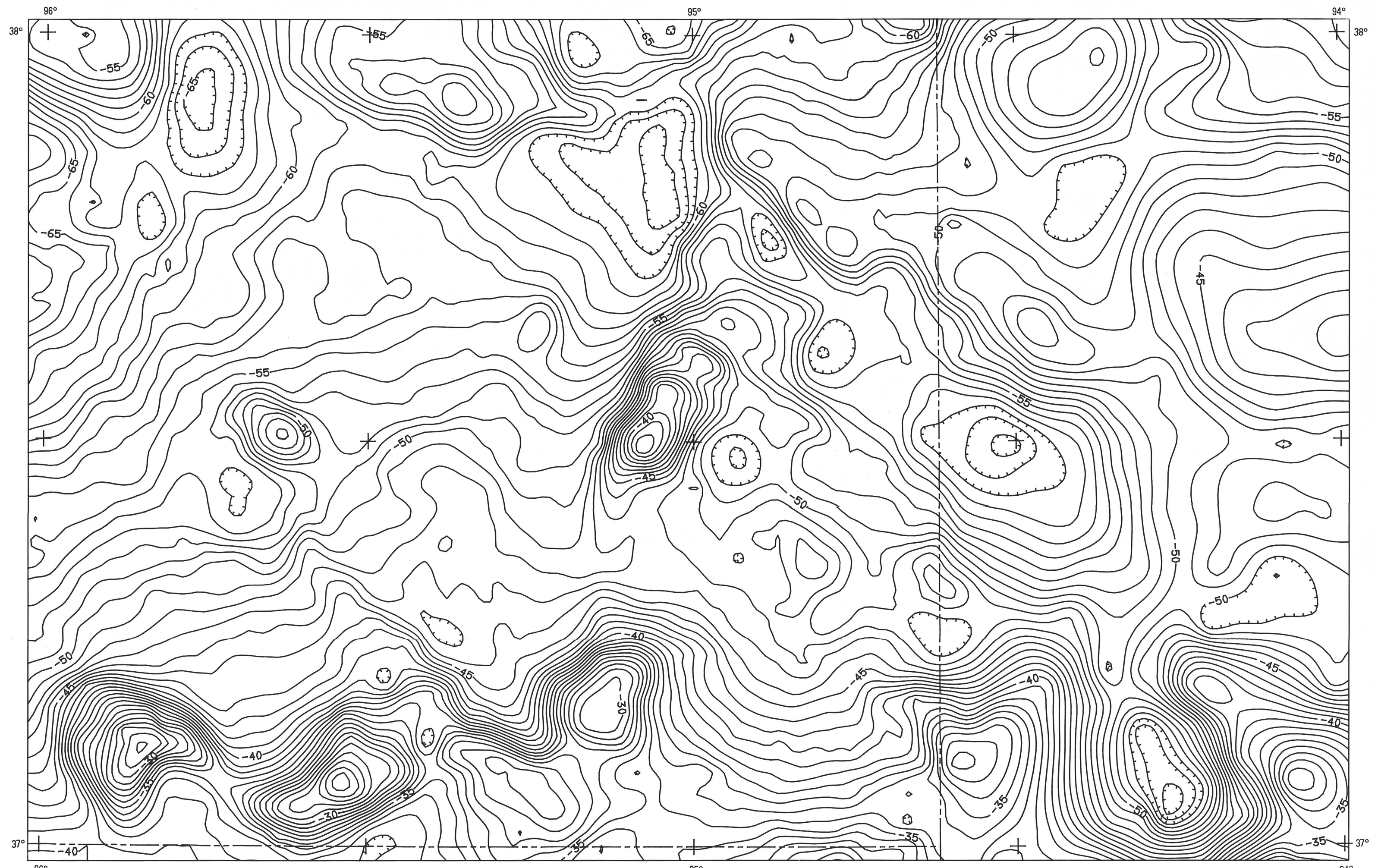
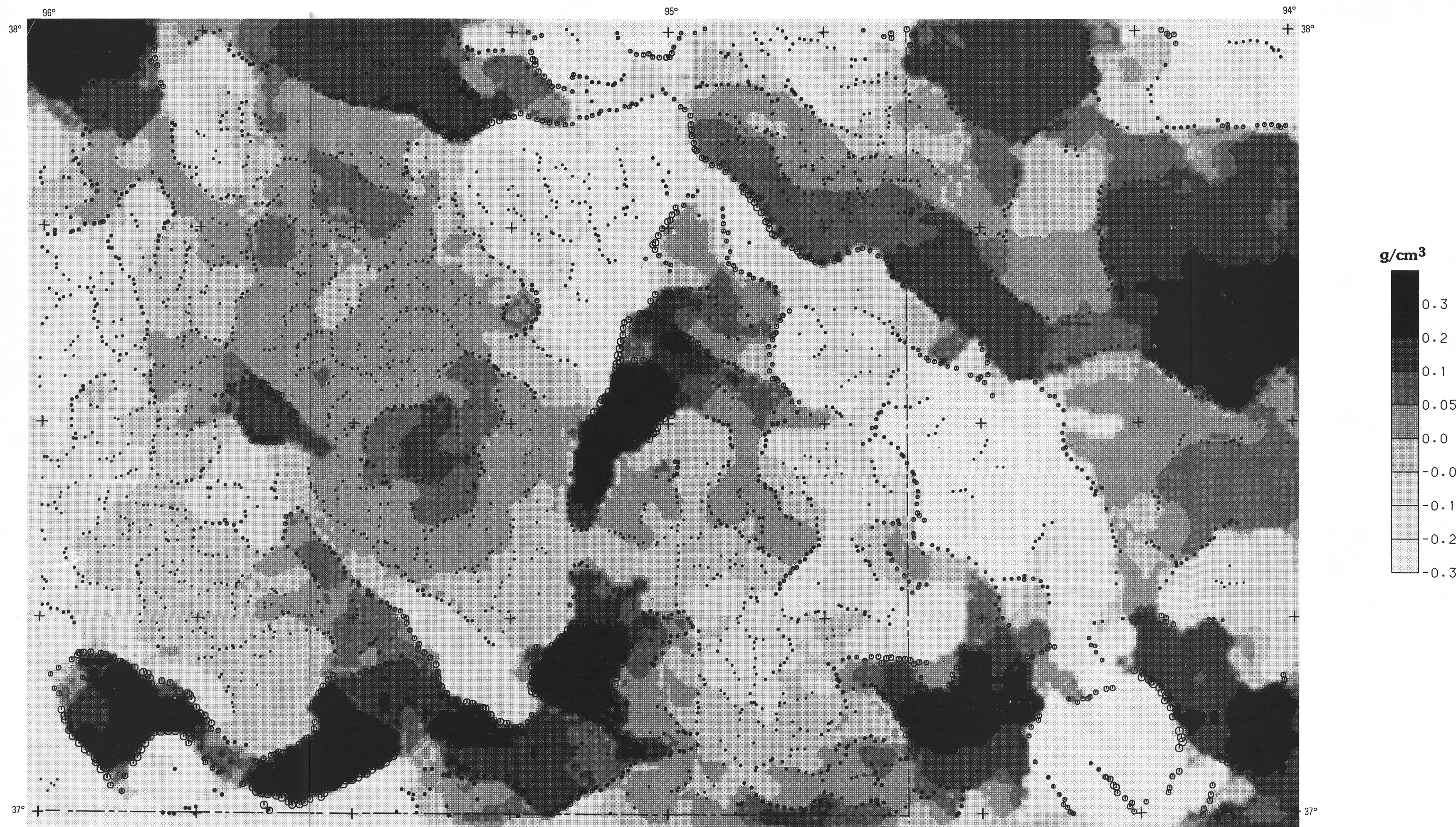
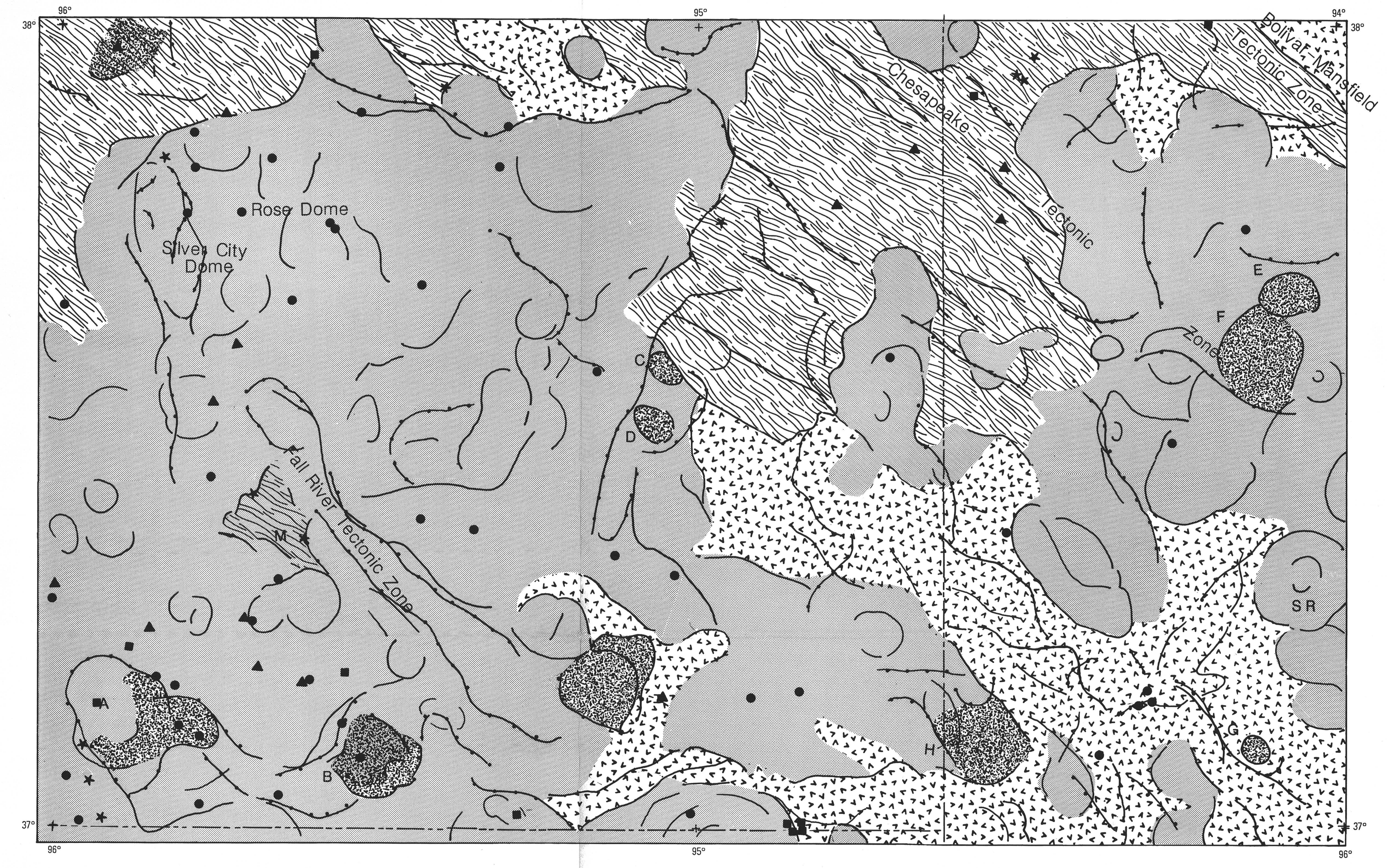
PREPARED IN COOPERATION WITH THE KANSAS GEOLOGICAL SURVEY AND THE MISSOURI DEPARTMENT OF NATURAL RESOURCES, DIVISION OF GEOLOGY AND LAND SURVEY



Map A. Complete Bouguer gravity-anomaly map of the Joplin 1° x 2° quadrangle. Contour interval is 1 mgal. Hachures show areas of gravity lows



Map C. Terrace-density map showing density domains as calculated from the gravity-anomaly data. Shading interval is 0.05 g/cm^3. Lines show the maxima of the horizontal gradient of gravity and are interpreted to be steep or near-vertical contacts



Map E. Geophysically inferred structural and lithologic map of the Precambrian basement in the Joplin 1° x 2° quadrangle

EXPLANATION

Drill-hole lithologies--Generalized after Blair and others, 1992

- ● **Granite**
- ■ **Volcanic**--Includes rhyolite, andesite, and trachyte
- ▲ **Metamorphic**--Includes quartzite ,metarhyolite, schist, and meta-arkose
- ★ **Other**--Includes arkose, sandstone, shale, and conglomerate

Geophysically inferred lithologic terranes

Granite terrane--Circular features within this terrane are inferred granite plutons. Location SR shows possible location of tin-granite pluton as described by Kisvarsanyi (1981)

Volcanic terrane

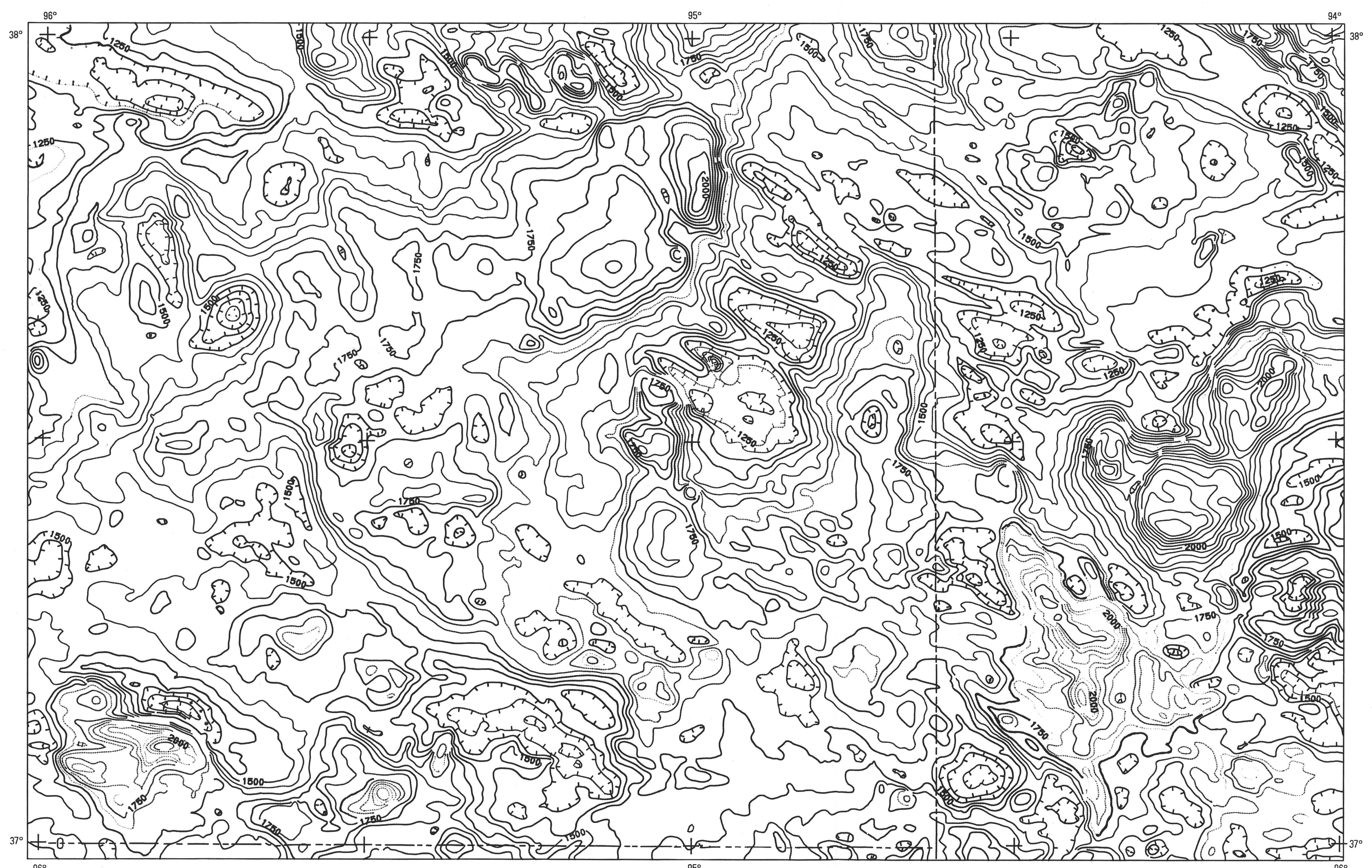
Metamorphic terrane

Intermediate to mafic intrusions--Letters A through G show locations of possible intrusive bodies characterized by high magnetization and density. Letters H and I show locations of possible intrusive bodies with high density but very low magnetization values. Features H and I could be explained by the presence of either a dense nonmagnetic body or a magnetic source with reverse polarity

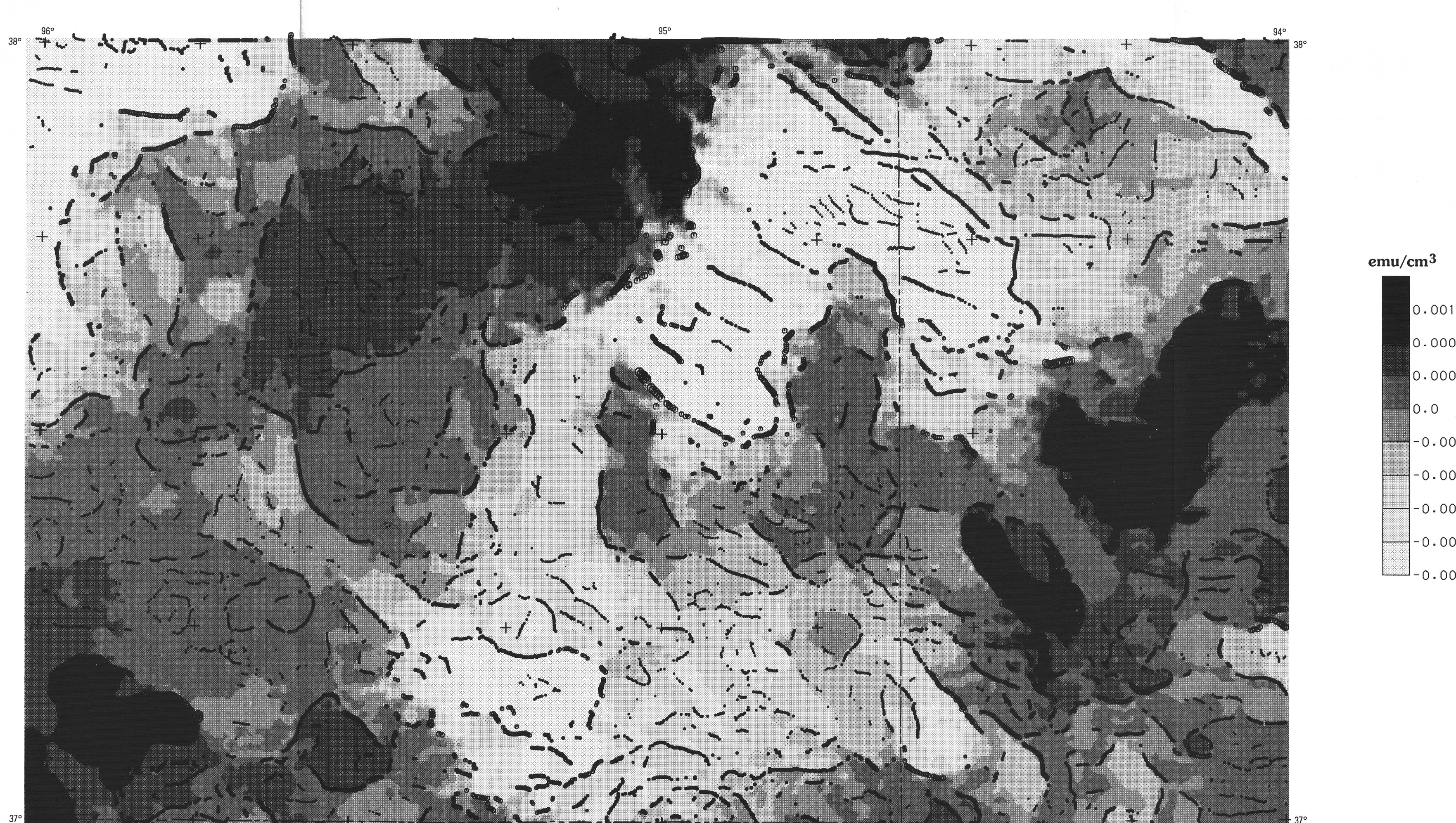
Geophysically inferred structure

Faults and lithologic contacts--Inferred from the horizontal gradient maxima of gravity

Faults and lithologic contacts--Inferred from the horizontal gradient maxima of pseudogravity



Map B. Aeromagnetic-anomaly map of the Joplin 1° x 2° quadrangle. Survey was flown in 1985 at 150 m above terrain along east-west flightlines spaced 800 m. Hachures indicate areas of aeromagnetic lows. Contour interval is 50 nanoteslas



Map D. Terrace-magnetization map showing uniform domains of magnetization as calculated from the aeromagnetic-anomaly data. Shading interval is 0.0001 emu/cm^3. Magnetization boundaries inferred from the horizontal-gradient method are shown as black lines

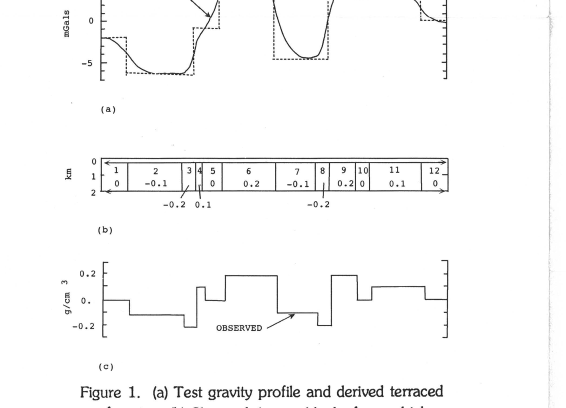
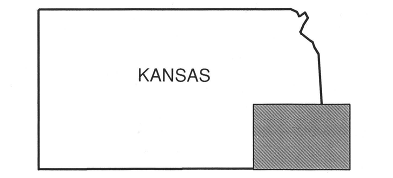


Figure 1. (a) Test gravity profile and derived terraced function. (b) Sheet of density blocks from which test gravity profile was calculated. Numerals show block number (above) and density contrast in g/cm^3 (below). Horizontal scale equals vertical scale. (c) Terrace-density contrast function for model (after Cordell and McCafferty, 1989).



INDEX MAP SHOWING LOCATION OF JOPLIN 1° X 2° QUADRANGLE

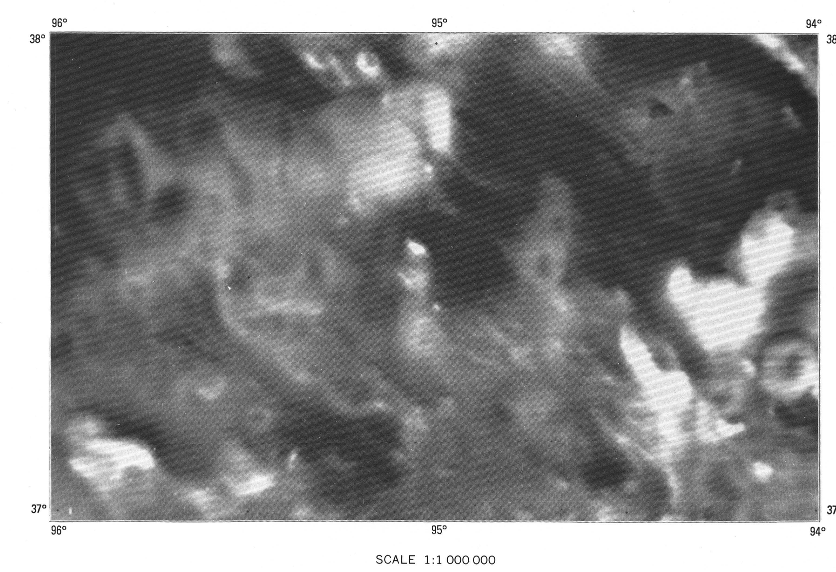


Figure 2. Grey-scale image of the aeromagnetic-anomaly data.

INTRODUCTION

This report is an analysis of regional gravity and aeromagnetic data that was carried out as part of a Conterminous United States Mineral Assessment Program (CUSMAP) study of the Joplin 1° x 2° quadrangle, Kansas and Missouri. It is one in a series of reports representing a cooperative effort between the U.S. Geological Survey, Kansas Geological Survey, and Missouri Department of Natural Resources, Division of Geology and Land Survey. The work presented here is part of a larger project whose goal is to assess the mineral resource potential of the Paleozoic sedimentary section and crystalline basement within the quadrangle. Reports discussing geochemical, geological, and various other aspects of the study area are included in this Miscellaneous Field Studies Map series as MF-2125-A through MF-2125-E. Geophysical interpretation of Precambrian crystalline basement lithology and structure is the focus of this report.

The study of the crystalline basement is complicated by the lack of exposures due to the presence of a thick sequence of Phanerozoic sedimentary cover. In areas where there are no outcrops, the geologist must turn to other indirect methods to assist in an understanding of the basement. Previous investigations of the buried basement in this region used available drill hole data, isotope age information, and regional geophysical data (Sims, 1990; Denison and others, 1984; Bickford and others, 1986). These studies were regional in scope and were presented at state and multistate scales. The work documented here used recently collected detailed gravity and aeromagnetic data to enhance the regional geologic knowledge of the area. Terrace-density and terrace-magnetization maps were calculated from the gravity and aeromagnetic data, leading directly to inferred physical-property (density and magnetization) maps. Once these maps were produced, the known geology and drill-hole data were reconciled with the physical-property maps to form a refined structural and lithologic map of the crystalline basement.

GEOLOGY OF THE CRYSTALLINE BASEMENT

The Joplin quadrangle consists of generally flat-lying Paleozoic sedimentary strata overlying Proterozoic crystalline basement. Basement rocks are primarily the 1.35-1.40 Ga "western granite-rhyolite" terrane of Bickford and others (1986). Older metasupracrustal rocks of higher metamorphic grade have been drilled locally within the Joplin quadrangle. Only a few mafic rocks have been drilled. Mafic rocks are uncommon within the granites and rhyolites, which is also typical of the immediate area surrounding the Joplin quadrangle. Precambrian rocks are found in outcrops as granitic xenoliths in peridotites located in a small area of Woodson County and in two Precambrian knobs known as the Rose Dome and Silver City Dome (Bickford and others, 1971). Elsewhere in the quadrangle, the basement is approximately 1,000 m deep, (determined from drill-hole data and stratigraphic projection) and has no more than 300 m of buried local relief.

GRAVITY AND AEROMAGNETIC MAPS

Regional gravity data collected by the Kansas Geological Survey (McCafferty and others, 1989; Lam, 1986a, 1986b) and aeromagnetic data (U.S.Geological Survey, 1989) are available for the entire quadrangle. These data are shown as contour maps in maps A and B at a scale of 1:500,000. Gravity-station spacing is a fairly uniform 1.6 km in the Kansas part of the quadrangle; in Missouri, station spacing ranges from 1 to 7 km.

The aeromagnetic data was obtained during a survey flown across the quadrangle with east-west flight lines spaced 800 m apart and an average ground clearance of 150 m. For a complete description of the gravity and aeromagnetic data, see McCafferty and others (1989) and U.S. Geological Survey (1989).

TERRACE-DENSITY AND TERRACE-MAGNETIZATION MAPS

Terracing (Cordell and McCafferty, 1989) is a new data-processing technique that recasts gridded gravity or magnetic data (transformed to pseudogravity) into inferred physical-property maps. The resulting maps emphasize large, sharply bounded domains of rock density (in the case of gravity data) or magnetization (in the case of magnetic data). The inferred physical-property boundaries often delineate known geologic features, such as faults, contacts, and intrusive igneous bodies. In this study, we used the terracing technique to define physical-property domains and (or) geologic structures within the Precambrian basement and to infer rock type based on the density or magnetization values within the domain boundaries.

To emphasize the physical-property boundaries, the lines tracking the horizontal-gradient maxima of the gravity field or, with magnetic data, the magnetic field transformed to pseudogravity, were overlayed on the terrace maps. These lines delimit abrupt lateral changes in the gravity or magnetic field and, by inference, are interpreted as steep or near-vertical lithologic contacts (Cordell and Grauch, 1985). The positions of the boundary lines are offset downdip if the contact is gradational or not steeply dipping. Location may also be inexact if data sampling is insufficient or if there are a number of sources located near each other (Grauch and Cordell, 1987).

Terracing Procedure

The steps followed when applying the terracing technique to either gravity or aeromagnetic data are briefly summarized herein. See Cordell and McCafferty (1989) and Phillips (1991) for a complete description of the theory and data-processing steps.

The initial step involves a mathematical calculation to remove a second-order polynomial surface from the gridded data. This step results in a second-order residual magnetic or gravity field. The removal of the regional field decreases the dynamic range of the data without degrading the short-wavelength features. This step improves the resolution of the shallow crustal sources represented by the short-wavelength anomalies.

With aeromagnetic data, we take an additional step that involves a transformation of the second-order residual magnetic field to pseudo-gravity anomalies (Hildenbrand, 1983). The positions of magnetic anomalies depend on the geomagnetic latitude of the source and the dipolar nature of the bodies causing the anomalies; the actual positions of the anomalies are displaced from their correct locations. The pseudo-gravity transformation corrects for this shift.

The gridded pseudogravity and gravity data are then "terraced"; the smoothly varying anomalies are transformed into step-like functions, with the vertical segments of the steps marking the steepest parts (or the inflection points) of the anomalies. At this point, the amplitude range of the terrace function is identical to that of the range of the input anomalies (fig. 1a).

A more complicated aspect of the terracing procedure involves converting units used on the terrace maps to units of density or magnetization within each domain. We do this by referring each terrace function to a model represented by a slab of rock with a constant thickness and flat top (fig. 1b illustrates this concept for gravity data in two dimensions). The tops of the slabs for both models were defined to be 1 km beneath the topographic surface, which represents the mean depth to the top of the crystalline basement. Depth to crystalline basement in the eastern third of the quadrangle is estimated to average 1,000 m and diminishes to less than 700 m in the west, as determined from drillhole and stratigraphic information (Sims, 1990). Basement relief is only about 200 m and, therefore, a flat surface was used in the forward calculation as an average estimate of basement relief.

A slab thickness is chosen for each model that will yield a best fit between the second-order residual fields and the forward-calculated fields together with plausible density or magnetization values. The thicknesses of the slabs used in the models for this study were allowed to vary until these conditions were reached (fig. 1c). We experimented with several slab thicknesses for both the density and magnetization terrace models. For the density model, it was determined that a slab with a thickness of 1 km would be used to calculate density-contrast values. For the terrace-magnetization model, a slab with a thickness of 10 km was used to determine the magnetization values of individual domains.

Terrace-density map

Map C shows the terrace-density map overlain by small circles that trace the horizontal-gradient maxima of the gravity. As described above, the terrace map represents densities varying laterally, but not vertically, and distributed in a 1-km-thick slab buried 1 km beneath the topographic surface. The terrace-density domains can be visualized as jigsaw pieces, each 1 km thick, having a flat top and bottom, with vertical sides. Strictly speaking, "density contrast with the regional average density" is meant, but we refer to "density" for brevity. The gravity-anomaly field resulting from this model for the Kansas part of the quadrangle was calculated for another study (Cordell and McCafferty, 1989). Because of the close fit between the forward-calculated anomaly field and the observed gravity field, we infer that the terrace-density map depicts geologically reasonable densities under the following assumptions: (1) the density sources are in the basement and (2) the sources are relatively close to the basement surface.

Variations in densities caused by overlying sedimentary rocks were not considered during compilation of the terrace-density map. Therefore, some density effects caused by the sedimentary sequence may be erroneously incorporated in the terrace-density map, but at the scale used in this report these effects are probably relatively insignificant.

We assumed that the background density of country rock in the quadrangle is equal to the standard crustal density, 2.67 g/cm^3. The values assigned to the grey-scale bar in map C reflect the addition of 2.67 g/cm^3 to the calculated density-contrast values that originally ranged from -0.40 g/cm^3 to +0.37g/cm^3. With the addition of 2.67 g/cm^3, the calculated densities range from a high of 3.04 g/cm^3 to a low of 2.27 g/cm^3.

Terrace-magnetization map

Map D shows the magnetization model calculated by the terrace method from the aeromagnetic data after the data were transformed to pseudogravity. Lines of small circles (shown in black) tracking the amplitude of the horizontal gradient of pseudogravity, which are inferred to be steep or near-vertical geologic and lithologic contacts (Cordell and Grauch, 1985). As with the density model, the magnetization model is that of a slab buried 1 km beneath the topographic surface, which also corresponds to 1.15 km beneath flight-line elevation and the average depth to crystalline basement. A slab thickness of 10 km produced the best fit (of several thicknesses tried) between the observed magnetic field and the forward-calculated field shown in Cordell and McCafferty (1989). The overlying sedimentary sequence is considered effectively non-magnetic, and therefore (in contrast to the gravity map) the magnetization map reflects changes in the lithology and structure related to the changes in magnetic properties of rocks contained within the crystalline basement.

The values shown on the grey-scale bar in map D are not as straightforward as the labeled density values because there is no useful crustal-magnetization norm comparable to the 2.67 g/cm^3 density value. Determining an acceptable background-magnetization value against which to contrast the calculated values becomes difficult without measured samples. Such samples were not available and so we tacitly assumed that the magnetization of the rocks was entirely induced in the direction of the present magnetic field and contrasted the values against a magnetization of 0.00 emu/cm^3. This datum is arbitrary and for this reason "negative" magnetization values related either to relatively weak magnetization or to predominant remanent magnetizations are admissible. The range of magnetization values is from -0.001 to +0.002 emu/cm^3.

GREY-SCALE IMAGE OF THE AEROMAGNETIC DATA

A monochromatic grey-scale image of the aeromagnetic data is shown in figure 2. Grey-scale imaging is a technique that emphasizes subtle structural and lithologic features related to the magnetic properties of rocks that may not be readily recognized in the contour representation of the magnetic data. This imaging technique emphasizes high-frequency information and as a consequence, flight-line leveling problems are also emphasized (for example, the east-west stripes in the southwest quadrant of figure 2).

Grey-scale imaging is scale dependent. The optimum scale is tightly constrained by the frequency content of the data (Cordell and Knepper, 1987). In order to preserve the image's quality, the data are presented at a scale of 1:1,000,000 with no overlays other than tic marks for ease of reference. Magnetically low areas correspond to the dark shades of grey and magnetic highs appear as the bright white areas.

GEOPHYSICALLY DERIVED STRUCTURAL AND LITHOLOGIC MAP OF THE BASEMENT

Map E shows an interpretation of the structure and lithology of the Precambrian basement rocks in the Joplin quadrangle as inferred from the synthesis of terrace maps, the aeromagnetic image, and the gravity- and pseudogravity-gradient maxima.

Basement lithologies that were encountered in drill holes can be grouped into three categories: granitic, volcanic (predominantly rhyolite, but some minor occurrences of trachyte and andesite are also present), and low-grade metamorphic rocks. A few of the drill holes penetrate arkose and other sedimentary rock, and for this report are labeled as "other". Eighty-two drill holes penetrate Precambrian rock and are indicated on map E by symbols that correspond to each particular lithology.

The terranes in map E have been divided into the same general lithologic units. A fourth category, labeled "mafic", was added to the units on the basis of coincident high density and magnetization values. The traces of the gradient maxima and terrace-domain boundaries have been used as convenient breaks to indicate changes from one lithologic terrane to another. Where terrane boundaries are obscure and no gradient maxima exists, terrane patterns are adjoined subjectively. Although we use the magnetic-image and physical-property maps to distinguish between different lithologic terranes, we cannot discriminate different age terranes. For example, no attempt has been made to separate granite of the Spavinaw terrane from granite of the St. Francois terrane (see Kisvarsanyi, 1984). Multiple patterns are overlain in map E where there appears to be a magnetic texture overprinting another, possibly deeper, texture.

The following description summarizes the geophysical criteria used to characterize the lithologic terranes and basement structures from features shown on the terrace maps.

Metamorphic Terrane

This terrane is represented, as in the north-central area of the image, by the marbled, "wavy" texture in the areas with lowest magnetic values. Densities tend to be greater than 2.67 g/cm^3. Magnetization values are near or less than 0.0 emu/cm^3.

Granite Terrane

This terrane is extensive in the quadrangle, forming the greater part of the area and is represented by the broad, cloudy, middle- to dark-grey-tone areas in the image. In these areas, circular features were outlined primarily by the pseudogravity-gradient method and are inferred to be granite plutons. Throughout the image are "smoke ring-like" features reminiscent of ring structures characterized by Kisvarsanyi (1981) as tin-granite or two-mica granite plutons. The best example of this feature is the circular magnetic low ringed by a magnetic high near the east edge of the quadrangle (labeled SR on map E). Also present, but not as striking as the smoke rings, are magnetically low circular to oval features not surrounded by such a distinct magnetic high. Many circular features, while not always coincident with the location of geophysically mapped granite plutons, have been mapped on the topographic surface from Landsat and SLAR images by J.R. McCauley (Kansas Geological Survey, written commun., 1989). The terrace models indicate that these rocks have generally low densities (2.5-2.6 g/cm^3), but they possess no characteristic magnetizations.

Volcanic Terrane

The rocks of this terrane are rhyolitic in composition, based on drill-hole analysis, and are characterized by high-frequency anomalies causing a "cobblestone-like" pattern in the aeromagnetic image. Densitiy values tend to range from 2.55 g/cm^3 to 2.7 g/cm^3, seemingly higher than the granite to which the volcanic rocks are undoubtedly related. Magnetization values vary, but tend to range from 0.0008 emu/cm^3 to 0.0015 emu/cm^3.

Intermediate to Mafic Intrusions

These are circular features (labeled A through G) and are characterized by high density values greater than 2.88 g/cm^3 and magnetization values greater than 0.001 emu/cm^3.

Nongranite Intrusions

There are two intrusions included in this category (labeled H and I on map E) that correspond to areas that have high density values (more than 2.88 g/cm^3) but low magnetization values (less than -0.0008 emu/cm^3. These two features could be explained by the presence of either a dense nonmagnetic body or a magnetic body with reverse polarity.

Faults

These features are represented by long, linear segments mapped from both gravity- and pseudogravity-gradient maxima taken from maps C and D. Some mapped surface faults and tectonic zones correspond to the inferred basement faults and are labeled (map E).

DISCUSSION

For the most part, the drill-hole data and geophysically inferred lithologies agree. But some discrepancies exist between drill-hole lithologies and lithologic terranes shown on map E. Drill holes sample a very small area of the basement and the lithology encountered may represent only a local feature. Conversely, flight-line spacing is 800 m and local features smaller than this that are located between flight-lines would likely not be resolved. Similarly, features less than about 1.6 km in width would not be detected in the gravity data. The interpretation presented in map E is based on the assumption that the geophysical data reflect the more predominant lithologies.

The older metamorphic terrane can be now fairly confidently mapped and extends farther south than previously supposed (Sims, 1990), a conclusion based primarily on the distinct magnetic texture seen in the magnetic image (fig. 2). This terrane can be extended even farther south if a thin veneer of granite and rhyolite encountered during drilling covers the rocks of the metamorphic terrane. For example, see locality "M" on map E, where the marbled quality of the magnetic data (characteristic of the metamorphic terrane) appears to overprint circular magnetic anomalies mapped as granite plutons. The shallow penetration of the majority of drill holes would make it difficult to estimate the thickness of a granitic or rhyolitic veneer without further model studies.

The lack of correspondence between some drill-hole data and the inferred terranes could also be accounted for by the fact that the drill holes penetrate only the basement surface, whereas the geophysical data integrates effects throughout the crust, although the effects of deep sources are attenuated. Of the 82 drill holes that penetrate the crystalline rock, 44 penetrate less than 6 m, 19 penetrate less than 150 m, and only 6 penetrate more than 150 m (Blair and others, 1992).

In this context, we point out that a geologic map (or subcrop geologic map) is referred to a specific surface (normally a time-related surface such as Cambrian, for example), whereas a geophysically inferred "lithologic" map integrates effects of sources that can be, but are often not, time related. We hope this distinction will be clear when using the term "geophysically inferred" lithologic map.

Approximately 30 new candidate granite plutons were identified using the above criteria, as were 7 major candidate mafic bodies (possibly 9 if the 2 nongranite intrusions are included in this category). Because the mafic bodies are identified primarily by their high density, an alternate hypothesis for the dense sources would be a thinner body of ultramafic rock, or, locally, an even thinner massive hematitic body similar to that observed at the Olympic Dam rare-earth-element deposit in Australia. The gravity anomaly at Olympic Dam is attributed to the presence of a dense hematite-rich breccia associated with the mineralization. The magnetic anomaly associated with the Olympic Dam deposit is still largely unexplained but presumably results from a large magnetic body located deeper than the current depth of drilling (Roberts and Hudson, 1983).

Similarities in age and lithology between basement terranes hosting the Olympic Dam deposit and the extensive mid-Proterozoic anorogenic granite-rhyolite terrane of the U.S. midcontinent allows for the possibility of a similar world class deposit in the midcontinent (Pratt and Sims, 1990). The USGS is currently studying regional gravity and aeromagnetic data together with petrologic data in an attempt to define criteria necessary for identification of such a deposit in anorogenic Proterozoic terranes of Missouri, Arkansas, Oklahoma, Kansas, and Wisconsin. In light of the evolving criteria used to develop an exploration model for an Olympic Dam-type deposit (Day and others, 1991), we tentatively suggest locations A through I (map E) may contain such deposits, although the evidence for this conclusion is weak.

A problem in defining locations A through I as Olympic Dam-type deposits is that the amplitude of the gravity anomalies over these areas is approximately 17 mgal over a distance of 15 km (1.1 mgal/km gravity gradient). By contrast, the amplitude of the Olympic Dam anomaly is 10 mgal over a distance of 3 km, equivalent to a gradient of 3.3 mgal/km (Rutter and Esdale, 1985), suggesting that a much denser body is required than that depicted by the density-terrace model. If we do not limit our analysis to the present density model presented in map C, which is referred to a slab thickness of 1 km, we could thin the slab to less than this, resulting in a density greater than that yielded by the current model. Geochemical analysis of Cambrian and Precambrian rock samples from drill core over areas A and B on map E (Erickson and others, 1990) do not indicate the presence of geochemical anomalies that might make, at least these two areas, favorable for mineral deposits. No drill holes are located near or on bodies C through I, so no geochemical or petrographic data are available to support a possible mineral association.

Overall, geochemical analysis of Paleozoic rocks for base metals in this study showed low concentrations in comparison with previous USGS studies in the Springfield, Rolla, Joplin, and Harrison quadrangles (Erickson and others, 1990). Data obtained in this study indicate that there is no apparent correlation between the geophysical and geochemical anomalies.

A few faults, mapped at the surface, are coincident with geophysical-gradient boundary lines. Of these, some gradient-boundary lines extend much farther than faults mapped at the surface; others are not as continuous as mapped faults. The Bolivar-Mansfield fault zone is evident in the extreme northeast corner of the quadrangle (map D) as a magnetic-gradient boundary. Geophysical expression of the Miami trough or the Tri-state district is not apparent. The Chesapeake fault zone is partly visible but is not as continuous as inferred by previous studies (Kisvarsanyi, 1984). The Fall River fault zone is evident as a set of parallel northwest-trending gravity gradients. This fault zone could be projected to the southeast when one considers both the magnetic and gravity gradients.

SUMMARY

The geophysical data presented in this report provide additional information on the crystalline basement not available from drill-hole data alone because the drill holes are spaced so far apart. Some of this detail can be characterized in geologic terms, while some cannot. The widely spaced drill-hole data and the closely spaced geophysical data supplement each other in interpreting basement geology for the study area.

The uniform coverage of the aeromagnetic data and gravity data (in Kansas), and subsequent derivative products has allowed a more continuous representation of basement features than the drill-hole data permits. Numerous linear features, calculated from the gravity and pseudogravity gradient maxima, and interpreted as basement faults, appear to a greater extent than previously mapped. At least forty candidate intrusive bodies have been identified and tentatively classified as granitic or mafic in composition based on geophysically inferred physical properties. The least constrained element of the basement-geology map is the magnetic texture thought to define volcanic terrane. The metamorphic terrane magnetic texture, by contrast, is more obvious and clearly defines a tract of rock that extends much farther southward than previously thought. No attempt has been made to estimate depth to superimposed sources. Rather, the assumption is made that the gravity and aeromagnetic anomalies and their causative bodies lie relatively close to the basement surface at an estimated depth of 1 km.

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By
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