# State gravity map of Kansas

by *Chi-Kin Lam*[1] and *Harold L. Yarger*[2]
Kansas Geological Survey, Lawrence, Kansas 66046

## Abstract

A gravity survey of the state of Kansas has been completed with compilation of 31,000 gravity data points covering the entire state. Repeat measurements at overlap stations indicate that the data are reliable to 0.1 mgal. A steep west-dipping gravity gradient in western Kansas corresponds to thickening of the crust to the west as evidenced by seismic-refraction results. Numerous residual anomalies remain after removal of the regional trend: a northeast-trending +60 mgal high with -30 mgal flanking lows in central Kansas, which is the southern end of the Midcontinent Geophysical Anomaly (MGA) and which reflects an aborted Precambrian rift; a +5 to +15-mgal southwest-trending high which appears to extend the MGA to the Kansas–Oklahoma border; a +30-mgal high in Montgomery, Labette, and Cherokee counties, which coincides with rhyolitic basement; a northeast-trending +15-mgal high coincident with the Nemaha Ridge in southern Kansas; a triangular shaped -20-mgal low in Greenwood County, which overlaps part of the "Wichita magnetic low," which has been previously observed; +20 and +15-mgal highs over the northwest and southeast end of the Central Kansas uplift; and a +15-mgal high in the Salina basin west of the MGA. A seventh-order residual map enhances features such as the MGA, the anomaly over the Nemaha Ridge, a possible northwest-trending cross-state fault zone, and a northwest-trending fault zone near the southeast end of the Central Kansas uplift. Oblique illumination of the gravity map in eastern Kansas shows two sets of orthogonal lineaments, corresponding to the pre-rift northwest-trending fractures in the granitic basement and the northeast-trending lineaments associated with late Precambrian rifting. A difference in reflectance patterns seems to identify the east-west boundary between the two granitic basement terranes of different Precambrian age.

# Introduction

The Kansas Geological Survey (KGS) has compiled 31,000 gravity data points covering the entire state. A gravity map of the state was produced (fig. 1). Repeat measurements at overlap stations indicate that most of the Kansas gravity data are reliable to approximately 0.1 mgal. The data in northeastern Kansas are reliable to within 0.3 mgal. These high-quality data provide valuable clues to the geology, tectonics, and crustal structure of the state.

## Instrumentation

Several LaCoste & Romberg model G and D meters and a Worden gravimeter were used in collecting the data. In the early stage, a Worden gravimeter was used in northeastern Kansas. Borrowed LaCoste and Romberg model G meters 256, 111, and 56 were used in southeastern, south-central, and northwestern Kansas. KGS-owned LaCoste and Romberg D meters 71 and 72 were used in western and south-central Kansas.

## Data collection

The average north-south gravity-station spacing was 9.6 km (6 mi) in northeastern Kansas, 6.4 km (4 mi) in southeastern Kansas, and 3.2 km (2 mi) in western Kansas (fig. 2). Except for some stations spaced 3.2 km (2 mi) apart in northeastern Kansas, the average east-west station spacing was 1.6 km (1 mi) for the whole state. Almost all the stations were at 1-mi section corners which were usually road intersections or fence lines. U. S. Geological Survey 7.5-min topographic maps were used for navigation and for determining station elevations. Field procedure was similar to that described in Lam (1987). The study area was divided into blocks of 26 by 40 km (16 by 25 mi). Gravity stations within each block were tied to a KGS base station at the center of the block. Stations on the eastern and western boundaries of each block were measured twice. This 4% overlapping redundancy allowed for error checking and quality control of the data.

## Data reduction

The field data were corrected for tidal and meter drift and were tied into Department of Defense (DOD) base stations, which were referenced to the International Gravity Standardization Net 1971 (Morelli et al., 1974). Bouguer gravity was calculated using the 1967 International Gravity Formula (International Association of Geodesy, 1967), a density of 2.67 gm/cc, and a reference elevation of sea level. A 1.6 x 1.6-km (1 mi x 1 mi) grid was prepared from the Bouguer gravity values using the Surface III computer program (Sampson, 1988). A color contour map was generated from this grid (sheet 1, in back pocket).

Present addresses: [1]Indiana Geological Survey, Bloomington, Indiana 47405; [2]Chevron USA Inc., Houston, Texas 77010

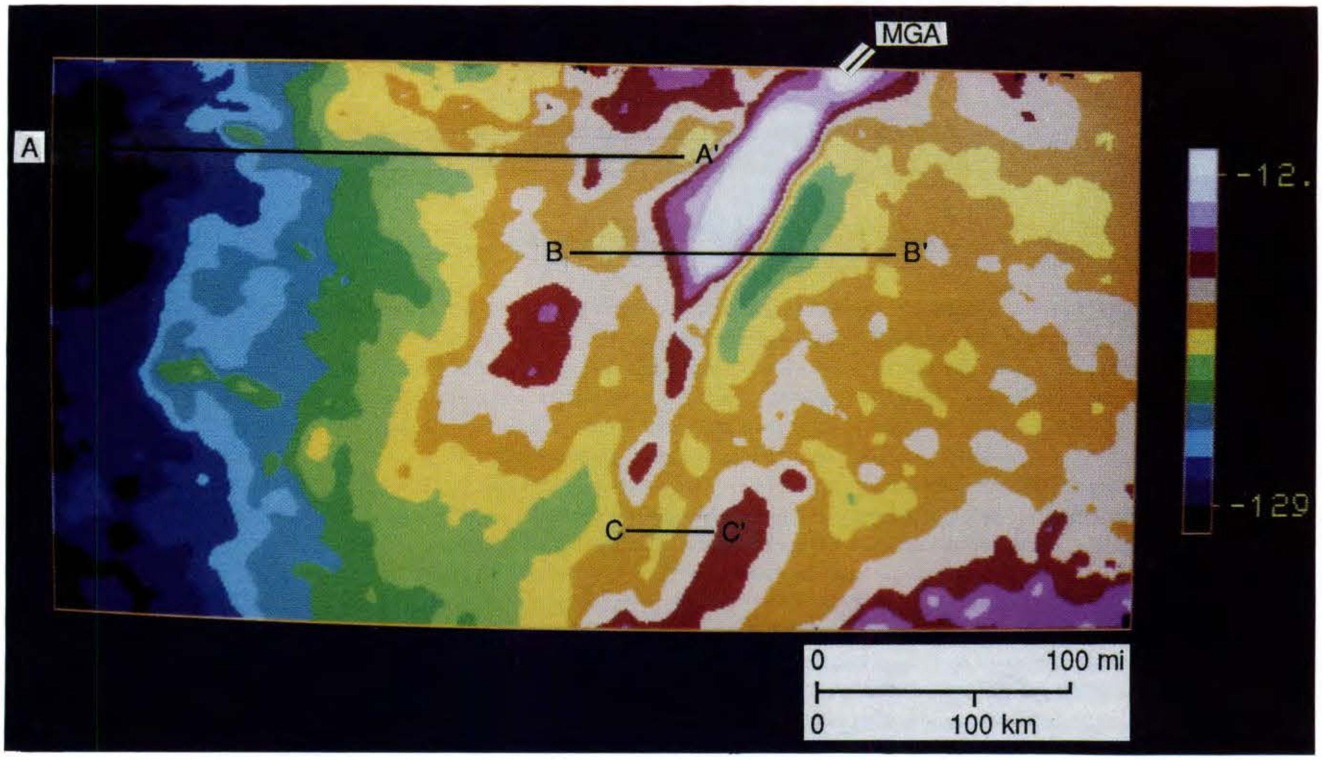


FIGURE 1—Bouguer gravity map of Kansas.

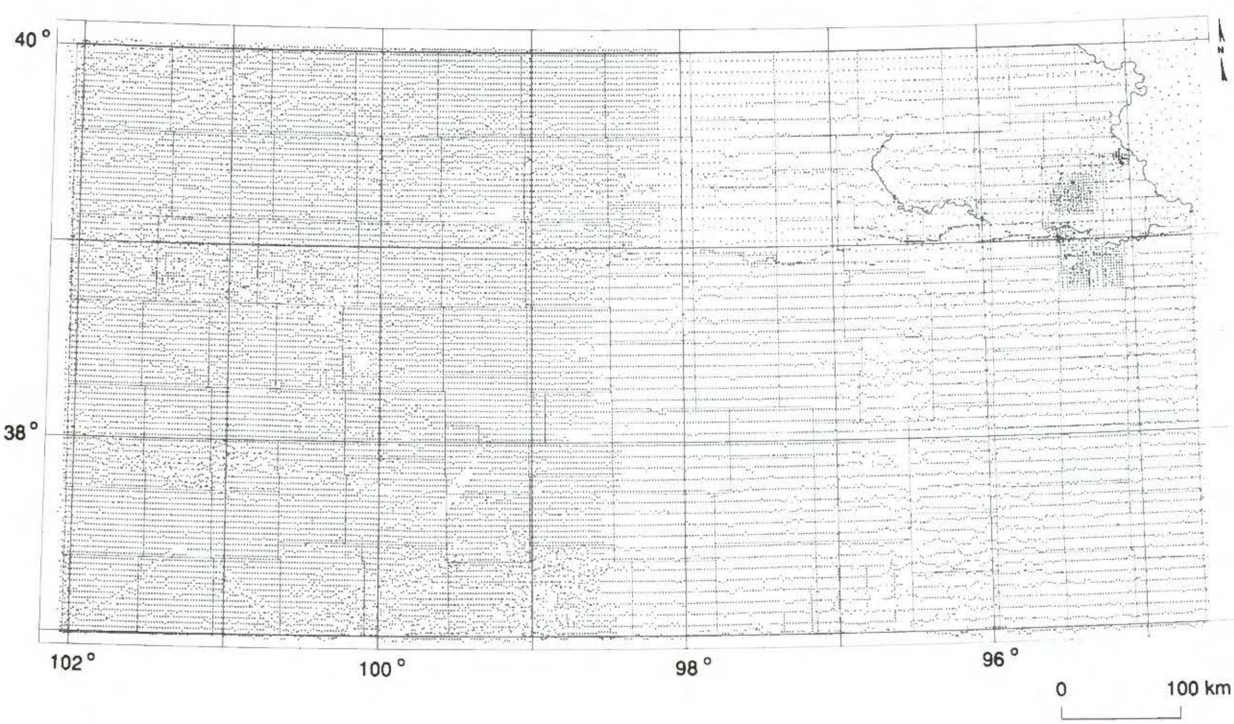


FIGURE 2—Gravity stations in Kansas.

# Regional trend analysis

A second-order trend-surface fit (fig. 3) to the gravity map (fig. 1) is a good representation of the regional trend within the state. This was judged by visually inspecting the first- through ninth-order residual gravity map, as well as examining their closeness of fit via the root mean square (RMS) values. RMS values for the first- through seventh-order fit were 16.59, 11.01, 10.01, 9.36, 9.13, 8.93, and 8.82 mgals. Raising the order of fit from the first to second improved the fit by more than 5 mgals, while successively higher orders only gave a moderately better fit. The second-order trend surface shows a steep west-dipping gradient in western Kansas and almost no gradient in eastern Kansas. To model this gravity gradient, a first-order trend surface was fitted to the western Kansas Bouguer gravity map. A west-dipping gradient of 0.255 mgals/km was obtained (fig. 4). Steeples (1976) evaluated a refraction profile shot by the U.S. Geological Survey between Agate, Colorado, and Concordia, Kansas, and derived a crustal thickness of 48 km (30 mi) at Agate and 38 km (24 mi) at Concordia. We used this seismically determined dipping Moho to model the regional gravity gradient in western Kansas (see profile A–A′, fig. 1). Since a small part of the Bouguer gravity gradient is due to the thickening (about 600 m [1,970 ft]) of the sedimentary cover to the west (Cole, 1976; Zeller, 1968; Merriam, 1963), a correction for lower-density Phanerozoic rocks is needed. From Vargas (1983), the average density of shale and limestone in a normal Pennsylvanian formation was calculated to be 2.27 and 2.51 gm/cc, respectively. If we assume these densities are representative of the entire Phanerozoic section, the average density is estimated to be 2.43 gm/cc. This assumes that the Phanerozoic section consists of approximately one-third shale and two-thirds limestone. This is 0.24 gm/cc less than the density of 2.67 gm/cc used in the Bouguer correction and corresponds to a 6-mgal difference in the gravity gradient on profile A-A′. Woollard (1959) obtained a similar value in his "geologic correction," which assumes a lateral density change on profile A-A′. This correction was applied to the Bouguer gravity gradient in western Kansas and is shown in fig. 4. The density contrast at the Moho (between the crust and mantle) was varied until the modeled gradient matched the corrected Bouguer gravity gradient. A density contrast of -0.45 gm/cc was found to give the best fit. This result is consistent with density values of 2.9 gm/cc in the lower crust and 3.35 gm/cc in the upper mantle, which are normal values for continental crust in stable cratons (see, e.g., Fleitout and Froidevaux, 1983; and Hinze et al., 1982).

This 10-km (6-mi) crustal thickening to the west, as indicated by gravity and seismic data, is not predicted by the Airy hypothesis of isostasy. Using elevations of 0.48 km (1,600 ft) at Concordia, 1.09 km (3,600 ft) at Agate, an upper


FIGURE 3—GRAVITY MAP OF KANSAS, SECOND-ORDER TREND SURFACE.

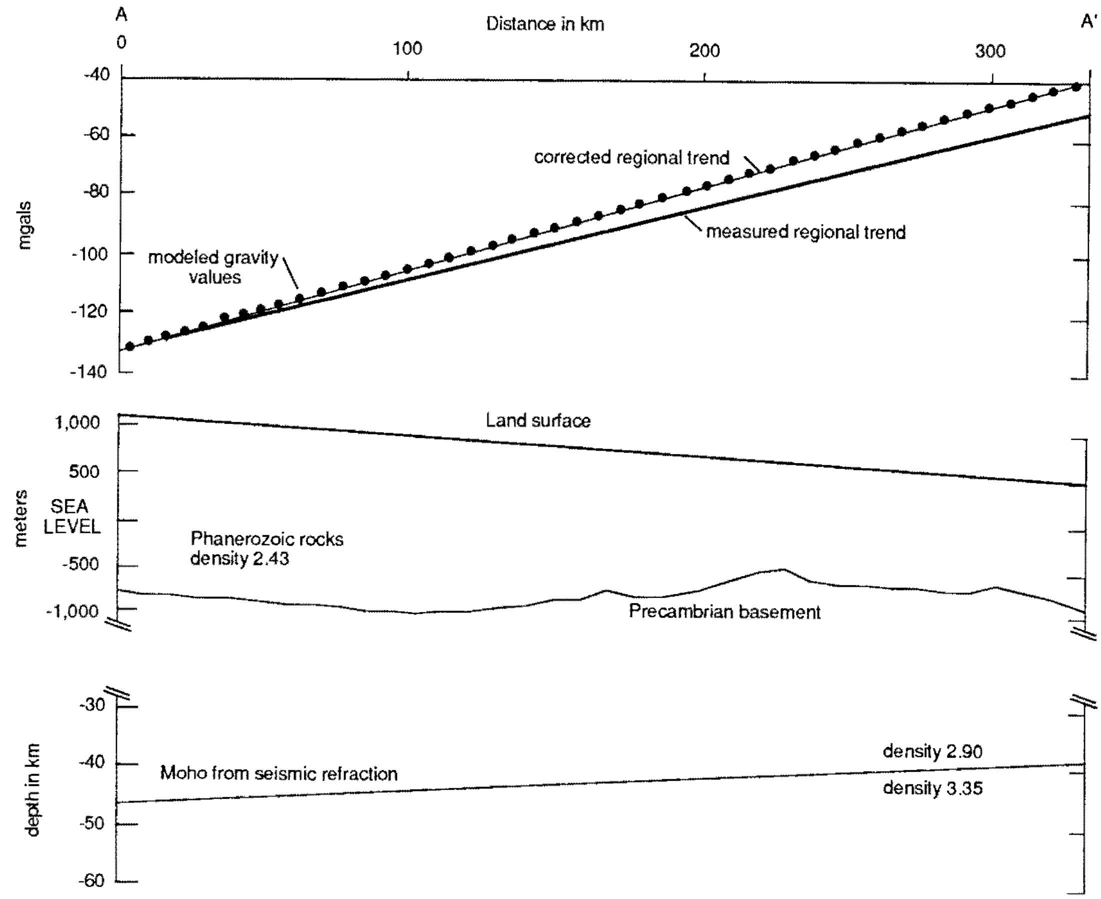


FIGURE 4—Gravity model of Moho in western Kansas (profile A–A′), basement surface adapted from Cole (1976).

crustal density of 2.67 gm/cc, and a crust-mantle density contrast of 0.45 gm/cc (as derived earlier), the predicted Airy crustal thickening is approximately 4 km (2.5 mi).

Bird (1984) suggests that this anomalous crustal thickening to the west, which is characteristic of the western Great Plains, may be related to the Laramide orogeny in early Tertiary time. According to this hypothesis, the subducting Farallon plate between 75 and 40 m.y. B.P. extended horizontally under the western half of the North American plate and then descended underneath the Great Plains region. Shear stresses between the two plates resulted in differential strain and thickening of the crust in the western Great Plains.

# Local anomalies

To emphasize the local anomalies, a residual map (fig. 5) was obtained by removing the regional field, which is best represented by a second-order trend surface. The most prominent feature on this map, which we call the Midcontinent Geophysical Anomaly (MGA), is a gravity high with flanking lows, that trends southwest through the state from Marshall County (see fig. 9 for county locations) at the Kansas–Nebraska border, to Harper County at the Kansas–Oklahoma border. Numerous previous investigators (see, e.g., Van Schmus and Hinze, 1985, for a good source of references) have interpreted this feature, which also has a magnetic expression and extends northeasterly to the Great Lakes region, as an aborted late Precambrian rift. The central gravity high and flanking lows are due, at least in part, to a rift basin filled with Precambrian arkosic sandstone and including a central trough of basalt.

Previous investigators have developed a variety of cross sectional models for the MGA. King and Zietz (1971), based on simultaneous gravity and magnetic modeling across the Iowa portion of the MGA, suggest a fairly shallow basin (8 km [5 mi] deep) filled with basalt that subcrops at the present Precambrian surface. Ocola and Meyer (1973), based on gravity modeling controlled by seismic-refraction results, suggest that a large part of the gravity high is due to

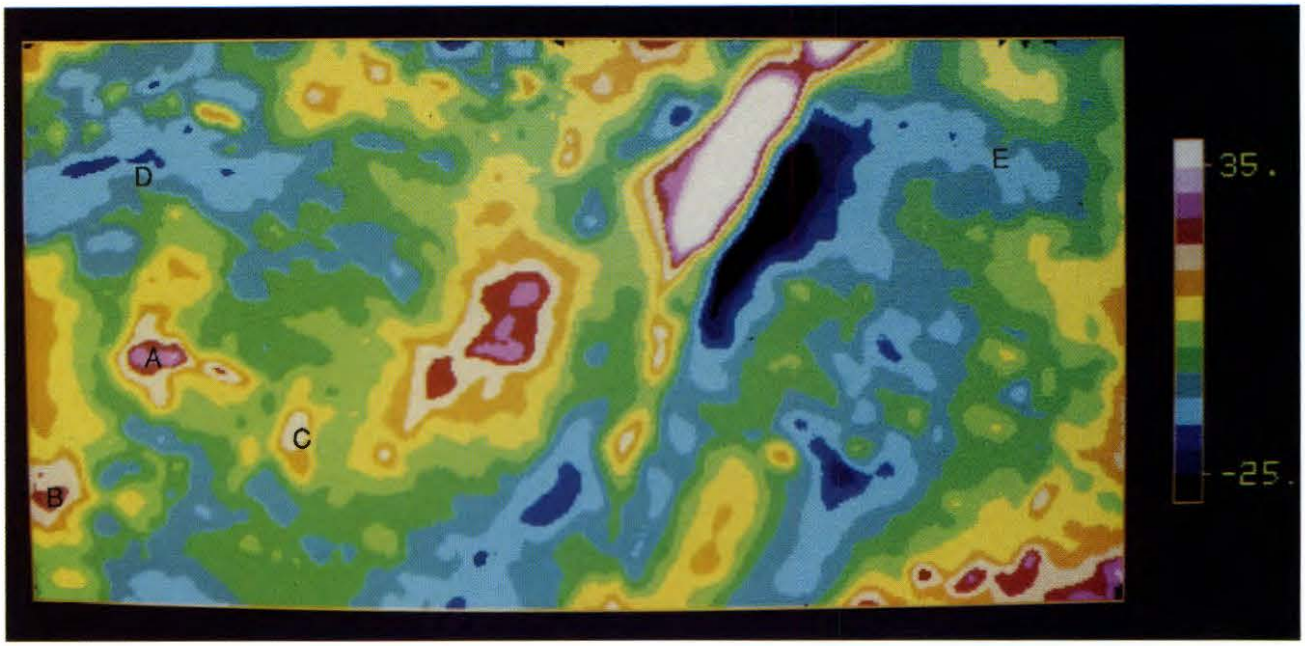


FIGURE 5—GRAVITY MAP OF KANSAS, SECOND-ORDER TREND REMOVED.

the presence of a high-density rock intruded into the upper crust. The cross sectional shape is also roughly that of a symmetrical basin with depth of 25–35 km (16–22 mi). Chase and Gilmer (1973) suggest a vertical prism of mafic material extending to great depth into the upper mantle. More recently, Serpa et al. (1984), based on a deep seismic COCORP profile in northeastern Kansas, suggest that the basalt occurs in an asymmetrical basin. The top of this basalt is some 4 km (2.4 mi) below the present Precambrian surface and is overlain by several kilometers of arkosic sandstone. Somanas et al. (this volume) reprocessed the COCORP seismic line and derived a model using constraints from gravity, magnetic, and drill data. They suggest a rift basin filled with interbedded basalt and clastic rocks at 2–6 km (1.2–3.7 mi) beneath sea level and flanked by two bodies of Precambrian clastic rocks. A thin dike of intrusive rock (about 1 km [.6 mi] wide), cutting through the clastic rock body in the east, accounts for the secondary magnetic high there. Three moderately magnetic to nonmagnetic deep bodies at 16–30 km (10–19 mi) contribute the remaining portion of the gravity and magnetic signals.

Although the aforementioned models are thought-provoking and have some attractive features, they are not without weaknesses and do not exclude alternative interpretations. For instance, although the COCORP line passes near a well (W in fig.5) located near the crest of the gravity high that encountered Precambrian arkosic rocks, most of the rocks found in wells drilled to the Precambrian along the gravity high in Kansas are volcanic. Arkosic rocks are found predominantly over the flanking gravity lows. The Somanas et al. (this volume) model suggests that the central trough of volcanic rocks is physically separated from the flanking wedges of arkose. Why these bodies are not in contact, but separated, presumably by granitic rocks, is unclear. Further work is needed to distinguish between the various proposed cross sectional models of the MGA.

A simple cross sectional model (such as the one shown in fig. 6) derived from an east-west gravity profile (B-B′ in fig. 1) is useful for estimating the minimum amount of basalt and arkose within the rift zone in northern Kansas. The cross sectional area of the basalt and sandstone obtained from the model were multiplied by the estimated length of the prism (350 km [218 mi]) to arrive at the volume of each, using density contrasts of +0.3 gm/cc and -0.3 gm/cc for basalt and sandstone, respectively. The minimum volume of basalt and sandstone were found to be 36,000 $km^3$ and 16,000 $km^3$.

The MGA is characterized in northern Kansas by a 60-mgal gravity high. Although this positive gravity feature is

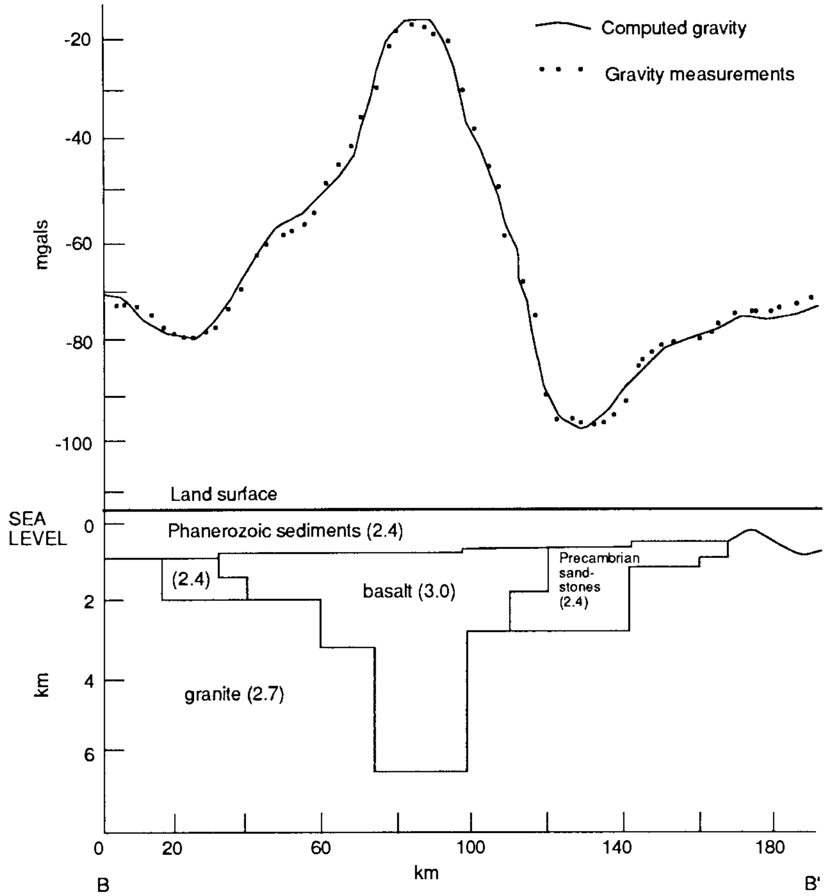


FIGURE 6—GRAVITY MODEL OF MGA IN NORTHEASTERN KANSAS.

easily traced southwesterly to the Kansas–Oklahoma border fig. 5), its amplitude abruptly decreases to approximately 20 mgals in Saline County. An east-west profile (C–C′ in fig. 1) across the MGA in southern Kansas was also studied (fig. 7). A regional trend, indicated by the dotted line in fig. 7, was first subtracted from the Bouguer gravity profile before modeling. The resulting cross sectional model is shown in fig. 8. The predicted minimum amounts of basalt and sandstone in southern Kansas were approximately 1,500 km$^3$ for each.

A broad +30-mgal anomaly (fig. 5) containing several positive closures is present in extreme southeastern Kansas in the counties of Montgomery, Labette, and Cherokee. These small circular features may be somehow correlated with the magma-feeder pipes which supplied the rhyolite that makes up the basement in this area (Bickford et al., 1979). It is unlikely that the actual sources for these positive anomalies are rhyolitic rocks, because rhyolite is generally less dense than granite (Clark, 1966). These anomalies may represent a more mafic phase of the magma at depth or a later intrusive event.

The Nemaha Ridge, shown bounded by the Humboldt fault in northeastern Kansas (fig. 9), has little gravity expression (fig. 1). This is probably due to the lack of density contrast between the uplifted basement rock and the surrounding sedimentary rocks (Woollard, 1959). Also, the proximity of the MGA may mask any small signal the ridge might produce. In south-central Kansas, a +15-mgal northeast-trending anomaly in Sumner, Sedgwick, and Butler counties overlies the Nemaha Ridge. This anomaly is also situated on the western part of the Wichita magnetic low, a large pronounced magnetic low in the region (Yarger, 1983, 1985).

To the east of the Nemaha Ridge gravity high in south-central Kansas, but still within the Wichita magnetic low, is

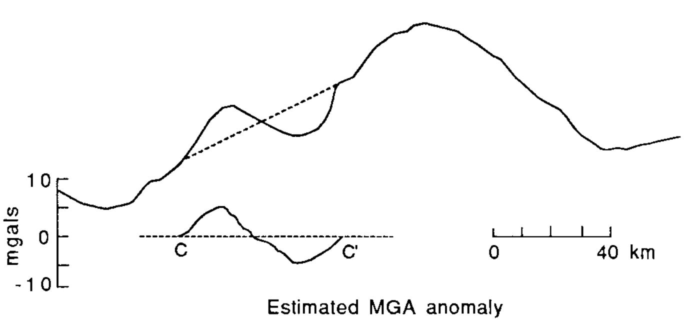


FIGURE 7—GRAVITY PROFILE ACROSS MGA IN SOUTH-CENTRAL KANSAS.

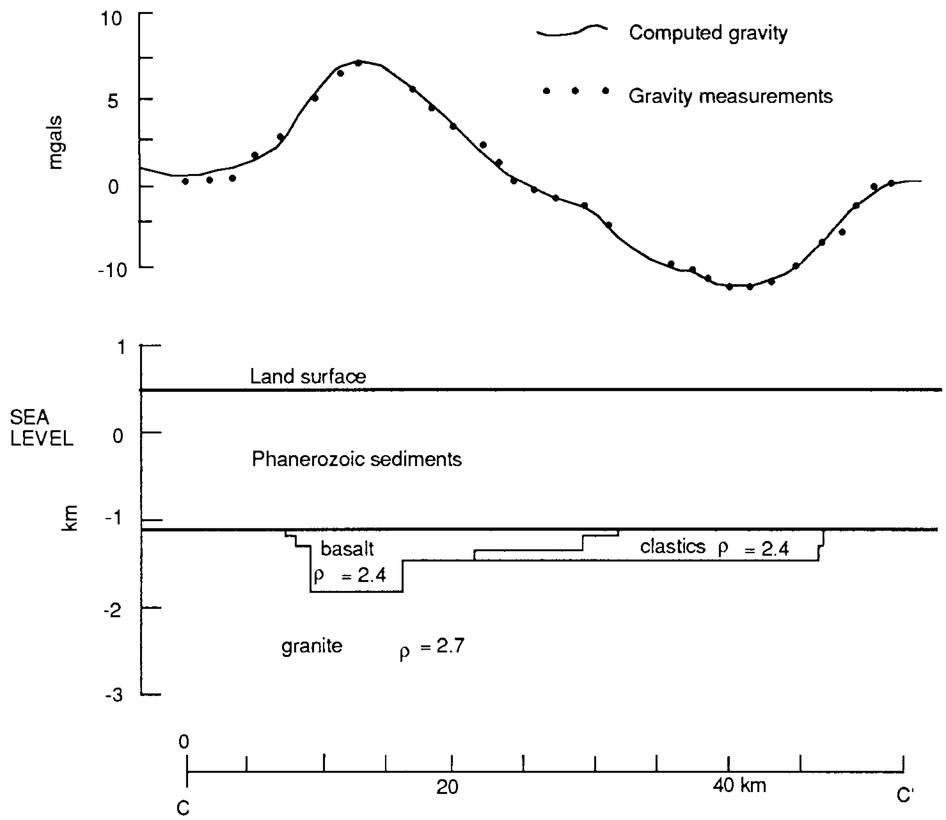


FIGURE 8—GRAVITY MODEL OF MGA IN SOUTH-CENTRAL KANSAS.

a triangular-shaped (-20 mgals) low in Greenwood County. The source for these gravity anomalies is poorly understood. The change in sign polarity of the gravity anomalies within the uniform magnetic low suggests a complex Precambrian geologic history in this region.

A small positive closure in extreme northeastern Kansas (Doniphan County) has a corresponding magnetic high, indicating a mafic source body in the basement.

Mafic rock underlying the Salina basin west of the MGA in north-central Kansas (Republic, Jewell, Smith, and Mitchell counties) is the probable source for the +15-mgal anomaly in this region. This could be related to an intrusive event that led to the formation of the Salina basin, as has been suggested for other basins in the midcontinent (e.g., McGinnis, 1970).

A broad +25-mgal high in Barton County and a +15-mgal high in Norton County correlate with the southwestern and northwestern ends of the Central Kansas uplift. A +15 mgal-high coincident with the Norton and Phillips County line suggests an intra-basement mafic body in this region. This body also gives rise to a positive magnetic anomaly. A positive anomaly with a very steep gradient along the Rawlins–Decatur County line suggests a fairly shallow basement intrusive body.

Other significant anomalies include a 130 x 100-km (81 x 62-mi) "L"-shaped +25-mgal high centered in Wichita and Grant counties (anomaly A in fig. 5), +20-mgal high in Stanton County (anomaly B), -15-mgal high in southwestern Hodgeman County (anomaly C), a -15-mgal east-west-trending low in Sherman and Thomas counties (anomaly D), and a -15-mgal northwest-trending low in Jackson, Jefferson, and Johnson counties (anomaly E). Anomaly E is at the northwestern end of the Missouri gravity low (Guinness et al., 1982), which has been suggested to be a failed Precambrian rift.

# Lineaments and trends

To better study the shallow basement sources responsible for the gravity anomalies and trends, a seventh-order trend surface was removed from the original map (fig. 1), resulting in the residual shown in fig. 10. The symmetrical nature of the MGA (a central high with its flanking lows) and the continuation of the anomaly to the Oklahoma border

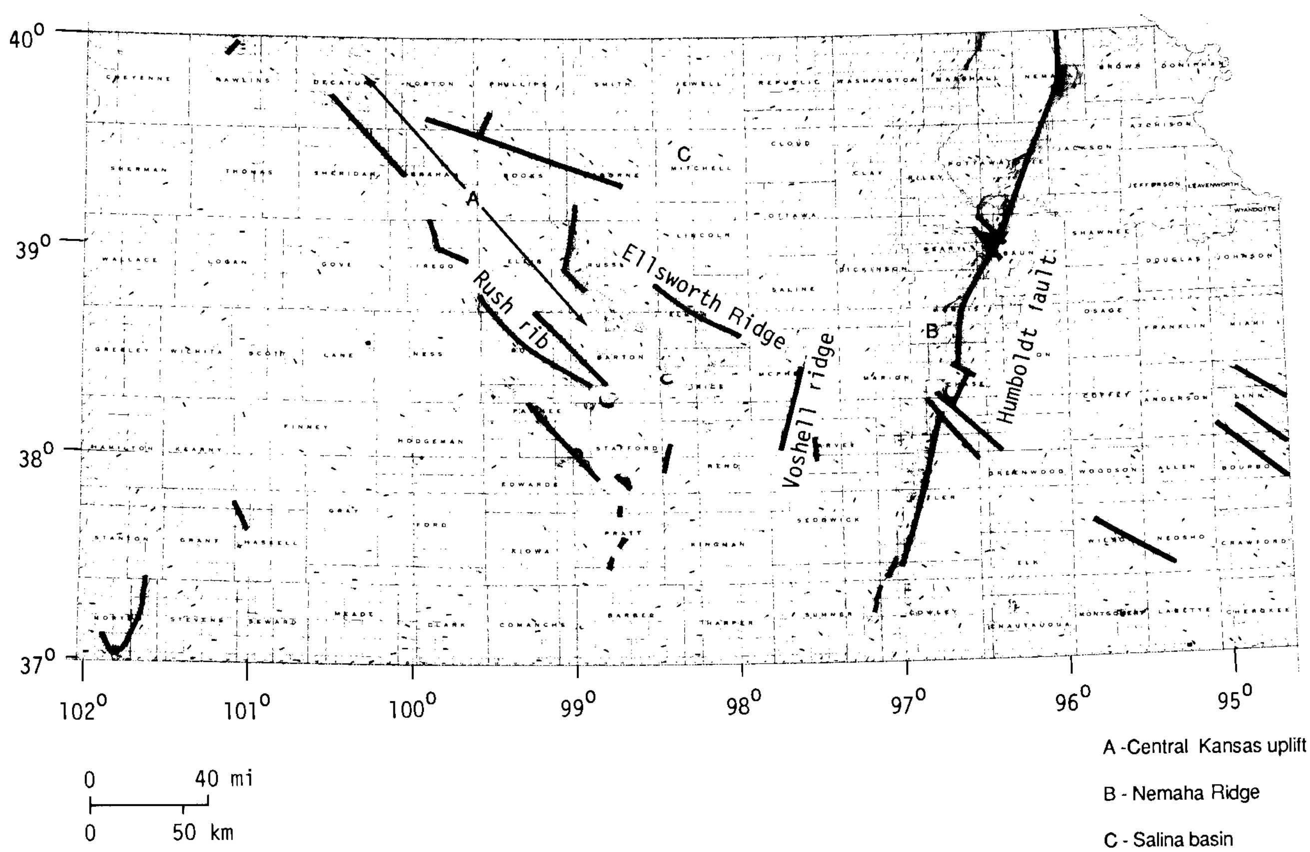


FIGURE 9—STRUCTURAL CONTOUR MAP OF THE TOP OF PRECAMBRIAN IN KANSAS, SHOWING MAJOR FAULTS.

show up more distinctly. The signature of the Nemaha Ridge becomes visible in eastern Kansas. The Central Kansas uplift (southeast end) and the Nemaha Ridge(southern end) anomalies are situated symmetrically about the MGA. Could they possibly have been one entity before 1.1 b.y. ago and then separated during rifting? The northwest-trending offset of the Central Kansas uplift anomaly at the concurrence of Rush, Barton, and Pawnee counties coincides with the trend of basement faulting in the area (Cole, 1974). An extensive northwest-trending lineament that passes through the state (P–P′ in fig. 10) suggests the existence of an ancient (pre-1.1-b.y.B.P.) cross-state fracture zone.

The synthetic oblique illumination method was applied to the gravity data in eastern Kansas to generate a suite of reflectance maps. The simulated sun was at a horizon of 30° and the azimuth varied from 0° to 360°. The ratio between the gravity amplitude and the spatial dimension was 0.75 mgal/km. A result of this process, applied to fig. 1, is shown in fig. 11.

This type of map tends to enhance horizontal gravity-gradient trends that are perpendicular to the sun-angle azimuth. In fig. 11, lineaments trending north-northeast are enhanced. A striking feature of this map is that it seemingly indicates the extent of the rift zone (shown by arrows in fig. 11). This north-northeast-trending zone appears to be fault-bounded on both sides and is approximately 125–150 km (78–93 mi) wide.

Bickford et al. (1979) determined the Rb-Sr ages of basement rock samples and identified an older (1.7-b.y.B.P.) northern terrane and a 1.4-b.y.B.P. southern terrane. Yarger (1983, 1985) analyzed the Kansas aeromagnetic data and also noted an east-west boundary that appears to separate the

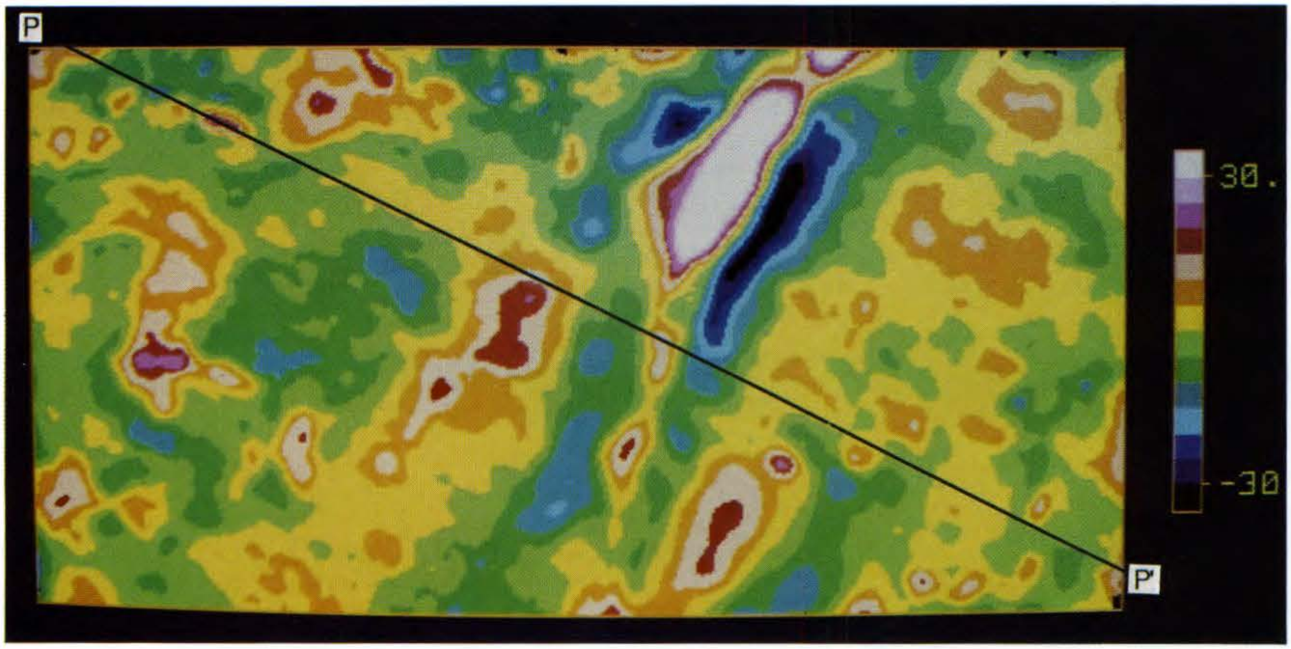


FIGURE 10—GRAVITY MAP OF KANSAS, SEVENTH-ORDER TREND REMOVED.

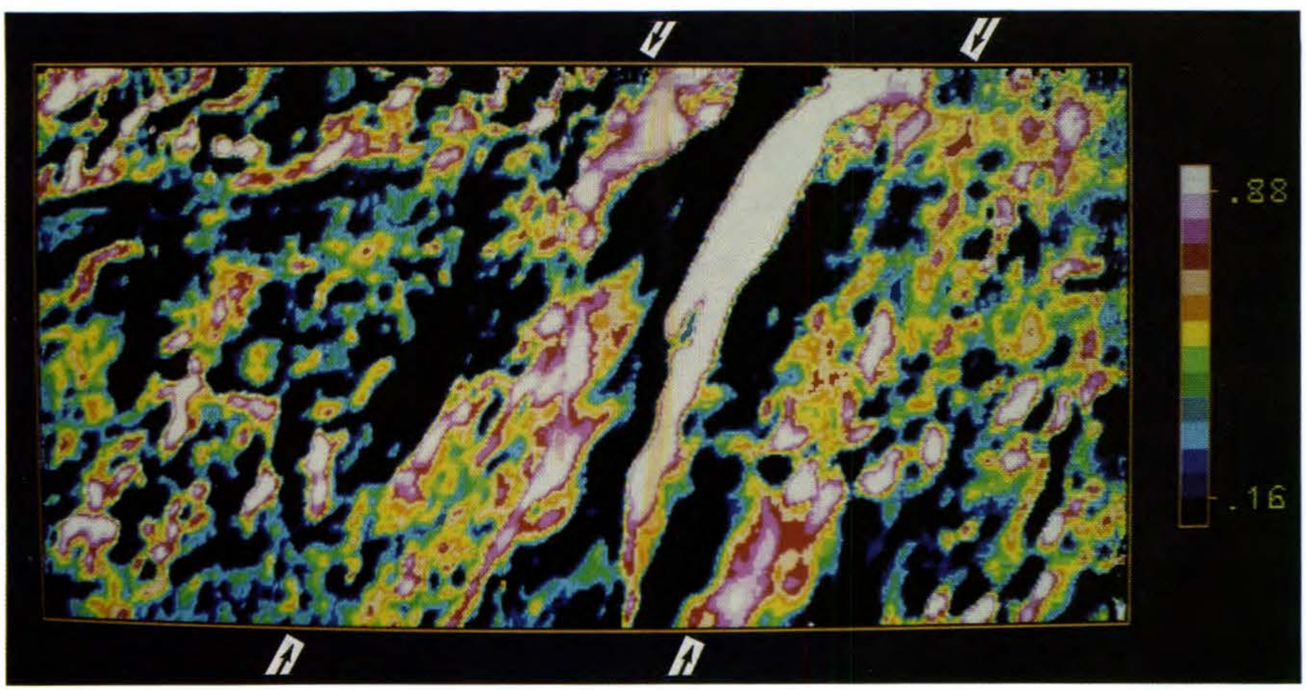


FIGURE 11—OBLIQUE ILLUMINATION OF GRAVITY WITH THE SUN AT 30° ABOVE THE HORIZON AND AN AZIMUTH OF 300°. Gravity-to-distance factor is 0.75 mgal/km.

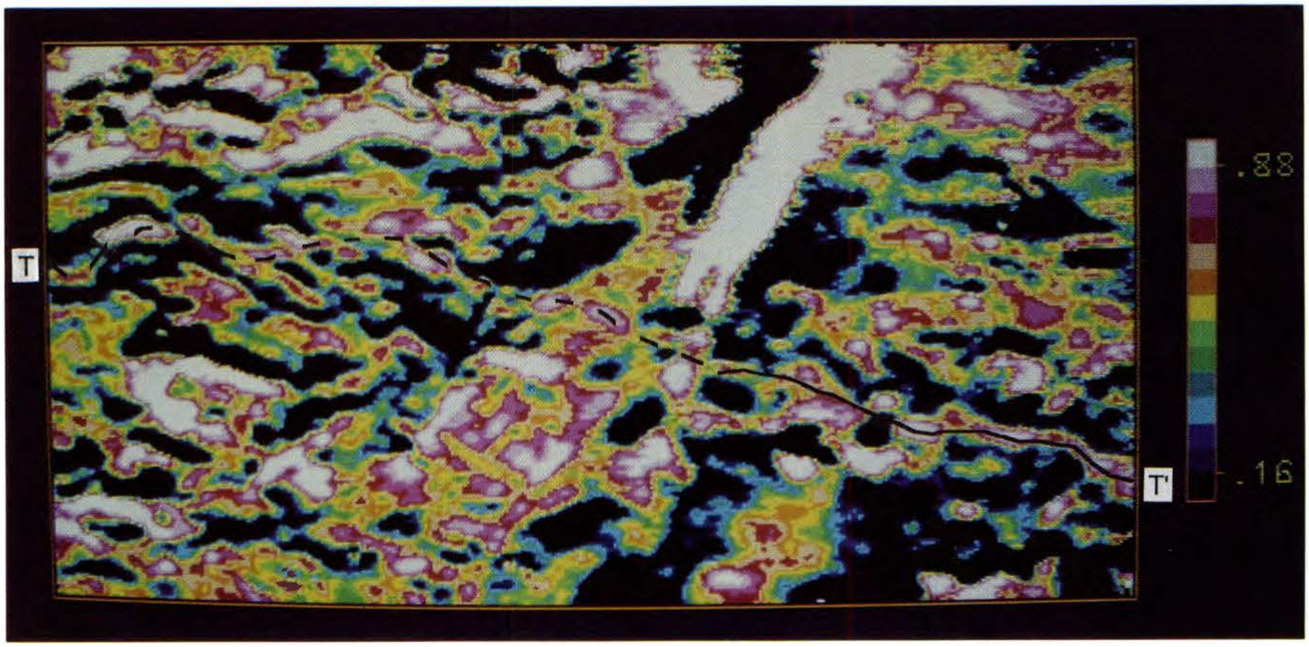


FIGURE 12—OBLIQUE ILLUMINATION OF GRAVITY WITH THE SUN AT 30° ABOVE THE HORIZON AND AN AZIMUTH OF 180°. Gravity-to-distance factor is 0.75 mgal/km.

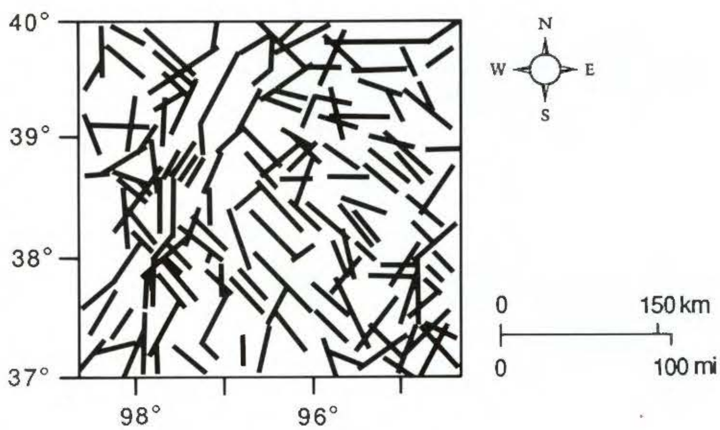


FIGURE 13—GRAVITY LINEAMENTS IN EASTERN KANSAS AS DERIVED FROM REFLECTANCE MAPS SUCH AS FIGS. 11 AND 12.

northern and southern terranes. Such a boundary (TT′) is also identified on the gravity map and is most obvious on obliquely illuminated gravity maps. Fig. 12 is the best example of this.

Gravity lineaments were drawn from the obliquely illuminated gravity maps and are shown in fig. 13. Most of the lineaments trend northeast or northwest. Fig. 14 is a histogram of the total length of lineaments at different azimuths. A broad peak centered at N 40 E is in the direction of the MGA, whereas the sharp peak at N 45 W is probably due to pre-rift fractures that for some reason were more closely aligned.

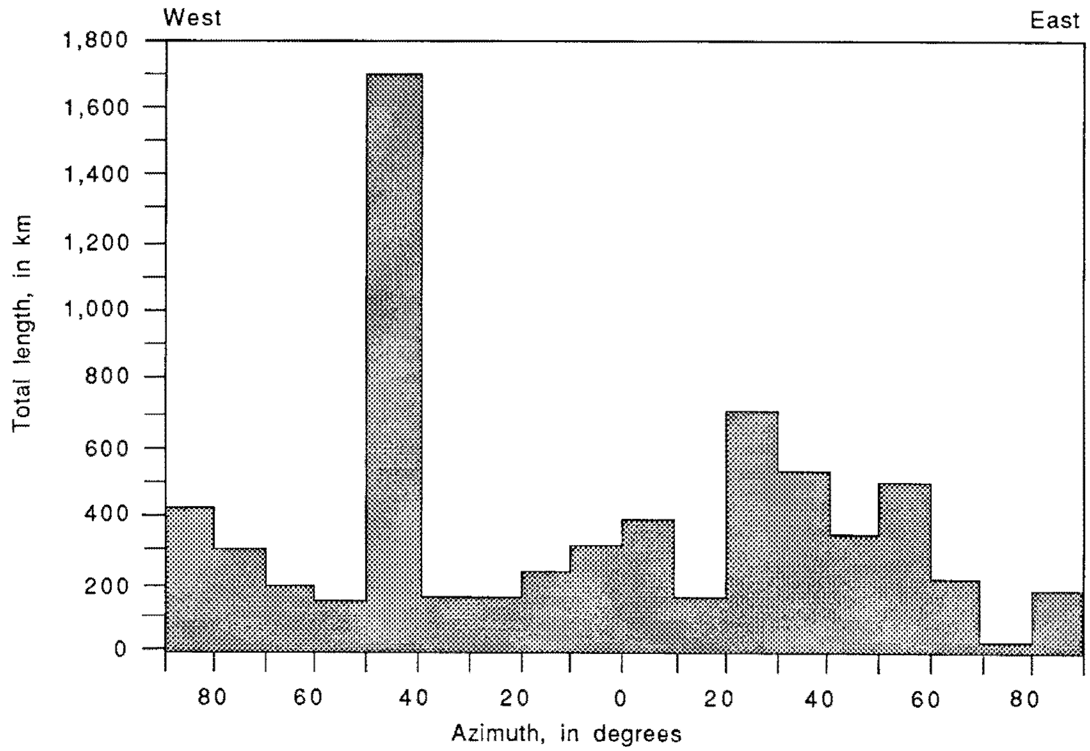


FIGURE 14—Histogram of gravity lineaments in eastern Kansas.

# Conclusion

The new Kansas gravity data represent a vast improvement in quality and coverage relative to earlier data (Woollard, 1959). Previously unresolved features found in the new data are the continuation of the MGA to the Oklahoma border, separation of a northern and southern terrane, northwest- and northeast-trending lineaments reflecting basement fractures and their relative ages, probable faults, and detailed small-scale structures within previously identified single anomalies.

This data should prove very useful for in-depth study of local areas.

Acknowledgments—Many students carried out the gravity field work and their names are listed on the Kansas Geological Survey open-file map entitled *Bouguer gravity map of Kansas*. The gravity survey of Kansas was supported principally by the Kansas Geological Survey, and in part by the Department of Energy under grant DE–AS07–19ET27204, by the Nuclear Regulatory Comission under contract AT (49–24)–2056, and by Three-D Gravity, Inc. Yan Zhao, a visiting research associate from the South China Sea Institute of Oceanology, Academia Sinica, also participated in the gravity field work.

# References

Bickford, M. E., Harrower, K. L., Nusbaum, R. L., Thomas, J. J., and Nelson, G. E., 1979, Preliminary geologic map of the Precambrian basement rocks of Kansas: Kansas Geological Survey, Map M–9, scale 1:500,000, 1 sheet.

Bird, P., 1984, Laramide crustal thickening event in the Rocky Mountain foreland and Great Plains: Tectonics, v. 3, p. 741–758.

Chase, C. G., and Gilmer, T. H., 1973, Precambrian plate tectonics, the midcontinent gravity high: Earth and Planetary Science Letters, v. 21, p. 70–78.

Clark, S. P., Jr., 1966, Handbook of physical constants, revised edition: Geological Society of America, Memoir 97, Boulder, Colorado, 587 p.

Cole, V. B., 1976, Configuration of the top of the Precambrian rocks in Kansas: Kansas Geological Survey, Map M–7, scale 1:500,000, 1 sheet.

Fleitout, L., and Froidevaux, C., 1983, Tectonic stresses in the lithosphere: Tectonics, v. 3, p. 315–324.

Guiness, E. A., Arvidson, R. E., Strebeck, J. W., Schulz, K. J., Davies, G. F., and Leff, C. E., 1982, Identification of a

Precambrian rift through Missouri by digital image processing of geophysical and geological data: Journal of Geophysical Research, v. 87, p. 8,529–8,545.

Hinze, W. J., Wold, R. J., and O'Hara, N. W., 1982, Gravity and magnetic anomaly studies of Lake Superior; *in*, Geology in Tectonics of the Lake Superior Basin, R. J. Wold and W. J. Hinze, eds.: Geological Society of America, Memoir 156, p. 203–222.

International Association of Geodesy, 1967, Geodetic reference system: International Association of Geodesy, Special Publication 3.

King, E. R., and Zietz, I., 1971, Aeromagnetic study of the midcontinent gravity high of the central United States: Geological Society of America, Bulletin, v. 82, no. 8, p. 2,187–2,208.

Lam, C., 1987, Interpretation of statewide gravity survey of Kansas: Ph.D. dissertation, University of Kansas, 213 p.

Merriam, D. F., 1963, The geologic history of Kansas: Kansas Geological Survey, Bulletin 162, 317 p.

McGinnis, L. D., 1970, Tectonics and the gravity field in the continental interior: Journal of Geophysical Research, v. 75, p. 317–331.

Morelli, C., Ganter, C., Honkasalo, T., McConnell, R. K., Tanner, J. G., Szabo, B., Votila, V., and Whalen, C. T., 1974, The International Gravity Standardization Net 1971 (IGSN71): Publ. Spec. Bur. Cent. Assoc. Int. Geod., Paris, no. 4.

Ocola, L. C., and Meyer, R. P., 1973, Central North American rift system—1. Structure of the axial zone from seismic and gravimetric data: Journal of Geophysical Research, v. 78, p. 5,173–5,194.

Sampson, R. J., 1988, Surface III: Interactive Concepts Incorporated, Lawrence, Kansas, 277 p.

Serpa, L., Setzer, T., Farmer, H., Brown, L., Oliver, J., Kaufman, S., Sharp, J., and Steeples, D. W., 1984, Structure of the southern Keweenawan rift from COCORP surveys across the Midcontinent Geophysical Anomaly in northeastern Kansas: Tectonics, v. 3, no. 3, p. 367–384.

Steeples, D. W., 1976, Preliminary crustal model for northwest Kansas (abs.): EOS, American Geophysical Union, Transactions, v. 57, no. 12, p. 961.

Van Schmus, W. R., and Hinze, W. J., 1985, The midcontinent rift system: Annual Review of Earth and Planetary Sciences, v. 13, p. 345–383.

Vargas, J. F., 1983, Deterministic deconvolution model for high-resolution seismic data in Kansas: M.S. thesis, University of Kansas, 82 p.

Woollard, G. P., 1959, The relation of gravity to geology in Kansas; *in*, Symposium on Geophysics in Kansas, W. W. Hambleton, ed.: Kansas Geological Survey, Bulletin 137, p. 63–103.

Yarger, H. L., 1983, Regional interpretation of Kansas aeromagnetic data: Kansas Geological Survey, Geophysics Series 1, 35 p.

________, 1985, Kansas basement study using spectrally filtered aeromagnetic data; *in*, The Utility of Regional Gravity and Magnetic Anomaly Map, W. J. Hinze, ed.: Society of Exploration Geophysics; Kansas Geological Survey, Open-file Report 83–9, 36 p. (1983)

Zeller, D. E. (ed.), 1968. The stratigraphic succession in Kansas: Kansas Geological Survey, Bulletin 189, 81 p.