Major magnetic features in Kansas and their possible geologic significance

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Introduction

Specification of statewide aeromagnetic survey

During the late 1970's, the Kansas Geological Survey (KGS) conducted a 45,000 line-mi (72,000 line-km) regional aeromagnetic survey of the state of Kansas. The flight lines were flown east-west and spaced 2.0 mi (3.2 km) apart. North-south tie lines were spaced approximately 20.0 mi (32.2 km) apart. A 1:500,000-scale color contour map was compiled (Yarger et al., 1981). Sheet 2 (in back pocket) is a color contour aeromagnetic map of the state. A black-and-white photo-reduced rendition of the 1981 map is shown in fig. 1. Magnetic data are also available in digital form (see appendices I and II for magnetic-tape formats).

The KGS airborne aeromagnetic system, used for the regional survey, consisted of a Geometrics G–806 proton precession magnetometer, a Geometrics G–704 data acquisition system, a Cipher 70 digital magnetic tape recorder, a Sperry RA–227 radar altimeter, an Automax G–2 35-mm camera with a 100-ft (30-m) film magazine, and a solid-state intervalometer built by KGS personnel. The magnetic sensor, housed in an aerodynamically stabilized "bird," was trailed 100 ft (30 m) from the aircraft. The system was flown in a Twin Beech D-18 aircraft and the magnetometer was operated at 1 nT (nanotesla) sensitivity and 2-sec sampling interval. The data-reduction procedures are discussed by Yarger et al. (1978) and Yarger (1983a).

Specifications of detailed aeromagnetic survey in southeastern Kansas

In 1985 the KGS completed a high-sensitivity detailed aeromagnetic survey of the Joplin two-degree quadrangle, which is located between west longitudes 94° and 96° and north latitudes 37° and 38°. This covers a nine-county area in southeasternmost Kansas and a smaller area in extreme southwestern Missouri. The east-west flight lines were spaced 1/2 mi (.8 km) apart and the north-south tie lines were spaced approximately 10 mi (16 km) apart. For this survey, the KGS magnetometer system was modified and installed in a DeHavilland Beaver airplane. The Geometrics G–806 magnetometer was upgraded to permit operation in the following sensitivity/sampling interval modes: 0.25 nT/2 sec., 0.5 nT/1 sec, and 1.0 nT/1 sec. The Joplin quadrangle survey was flown at 0.25 nT with a 2-sec sampling interval. The 2-sec sampling rate, along with a typical DeHavilland Beaver ground speed of 100 mph (160 km/hr), corresponds to a data spacing of approximately 300 ft (90 m) along the flight line. The sensor was installed in the end of a fiberglass "stinger" extending approximately 10 ft (3 m) from the rear of the aircraft. Three orthogonal coils were installed in the forward part of the stinger between the sensor and the aircraft to permit cancellation of the aircraft's magnetic field at the sensor location. The aeromagnetic data are available to the public from the KGS.

Summary of regional interpretation

Magnetic-field measurements in Kansas on a regional scale are primarily useful for the study of the buried Precambrian rocks. As depicted in fig. 2, the magnetic field "sees" through the relatively nonmagnetic sedimentary rocks and reflects crystalline basement composition and relief. The geologic signal remains after subtracting the regional field resulting from the earth's core. Basement rock compositions are responsible for most of the geologic signal in the magnetic field in Kansas. Typical anomaly magnitudes, due to difference in basement composition, range from 10 to 1,000 nT. Anomalies due to normal basement relief range from 0 to 10 nT. The total intensity changes as much as 100–200 nT over the Humboldt fault, which has over 2,000 ft (600 m) of throw in places.

Previous work on the interpretation of the regional magnetic field in Kansas appears in Yarger (1983b) and Yarger (1985). The plan view of the basement composition, presented in fig. 3, best summarizes these results. This map is based on interpretation of the anomaly magnitudes and gradients of the total-intensity magnetic-field map (fig. 1), a suite of spectrally filtered maps, and on the work by Bickford et al. (1981) on Precambrian samples.

A distinct boundary appears to exist between the northern 1,625-m.y.-old mesozonal granitic terrane and the southern 1,400-m.y.-old epizonal granitic and rhyolitic terrane, whose magnetic signature is a series of nearly contiguous lows trending west across the state. The southern

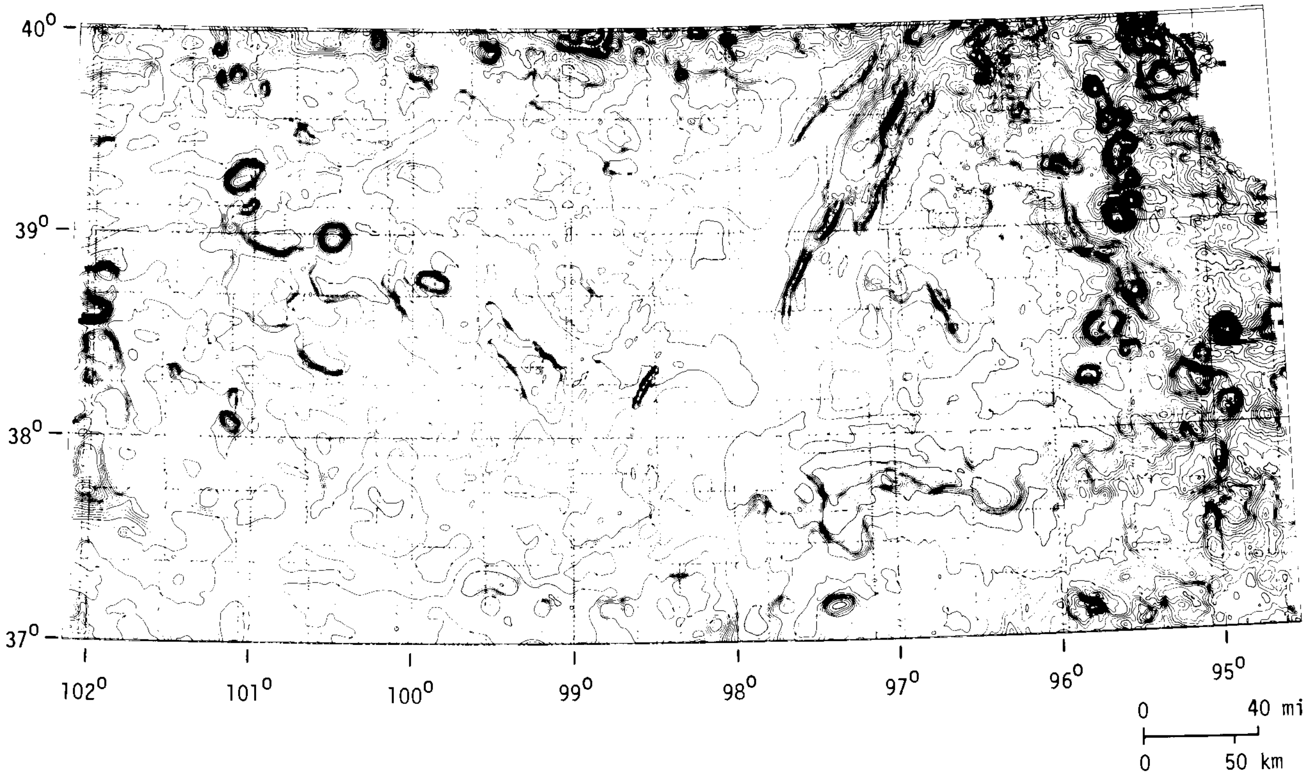


FIGURE 1—AEROMAGNETIC MAP OF KANSAS. Photo-reduction of black and white version of 1:500,000 color aeromagnetic map by Yarger et al. (1981). Contour interval 50 nT. Hachures indicate closed lows.

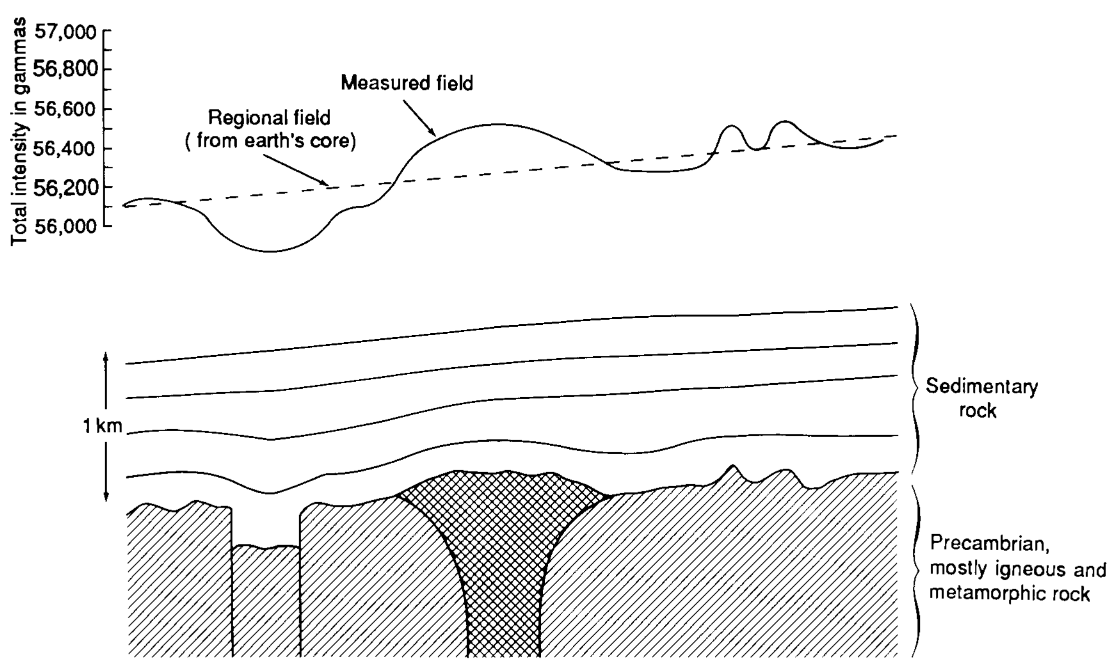


FIGURE 2—GEOLOGIC CROSS SECTION. Hypothetical characterization of the relation between midcontinent basement rocks and the earth's magnetic field.

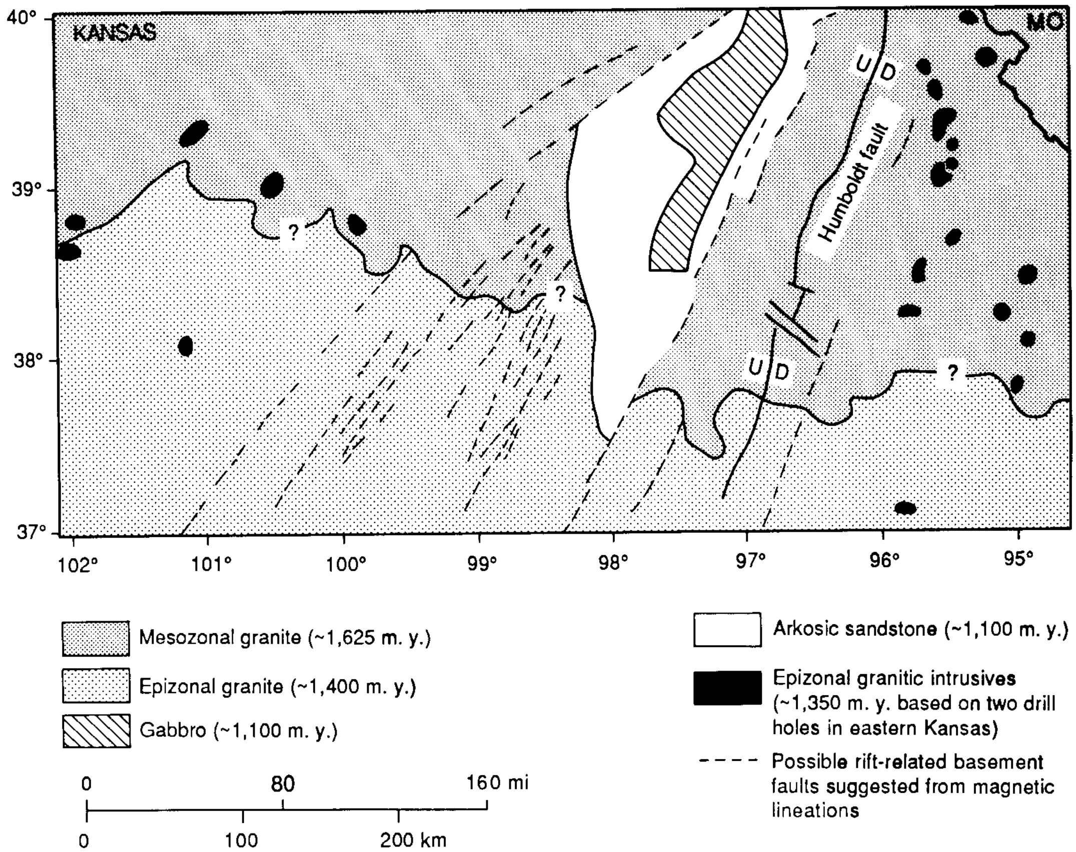


FIGURE 3—PRECAMBRIAN TERRANES IN KANSAS. Interpreted from spectrally filtered magnetic maps (Yarger, 1983b) and rock samples (Bickford et al., 1981).

boundary of this band of lows is sharply defined by steep horizontal gradients and short-wavelength anomalies. The magnetic source of this band is unclear.

Drilling results from two of the 14 circular magnetic highs in northeastern Kansas suggest that the older 1,625-m.y.-old crust in northeastern Kansas is pockmarked with younger 1,350-m.y.-old granitic plutons similar in composition to the southern 1,400-m.y.-old terrane of epizonal granite and rhyolite. One to 2% (by weight) magnetite found in the two basement cores accounts for the positive magnetic anomalies, whose magnitudes range from 500 to more than 1,000 nT.

The CNARS (Central North American rift system) extends through Kansas and probably into Oklahoma. Although large volumes of mafic volcanics clearly did not reach the Proterozoic surface in southern Kansas, magnetic evidence strongly indicates that block faulting and possibly dike intrusion accompanied the initial stages of continental rifting. The southern portion of the 1,100-m.y.-old rift that extends into the 1,400-m.y.-old crust in Kansas did not evolve into the more mature stages of deep rift-valley formation accompanied by voluminous volcanics and clastics as did the main part of the rift to the north.

Three main suites of magnetic lineations, most probably of basement origin, are present in the spectrally filtered maps (e.g., fig.4). Predominately northwest-trending lineations are found in southeastern and northwestern Kansas, whereas central Kansas is dominated by north-northeast-trending lineations. Both of these trends are present in south-central Kansas, resulting in a system of roughly orthogonal, intersecting lineations. A third suite of east-northeast-trending lineations is present in southern Kansas. Several of the magnetic lineations coincide with mapped basement faults, suggesting that at least a small fraction of the remaining lineations correspond to previously unknown faults. The lineations are probably caused by small vertical offsets of the crystalline rocks, mineralization along the fault zone, or both.

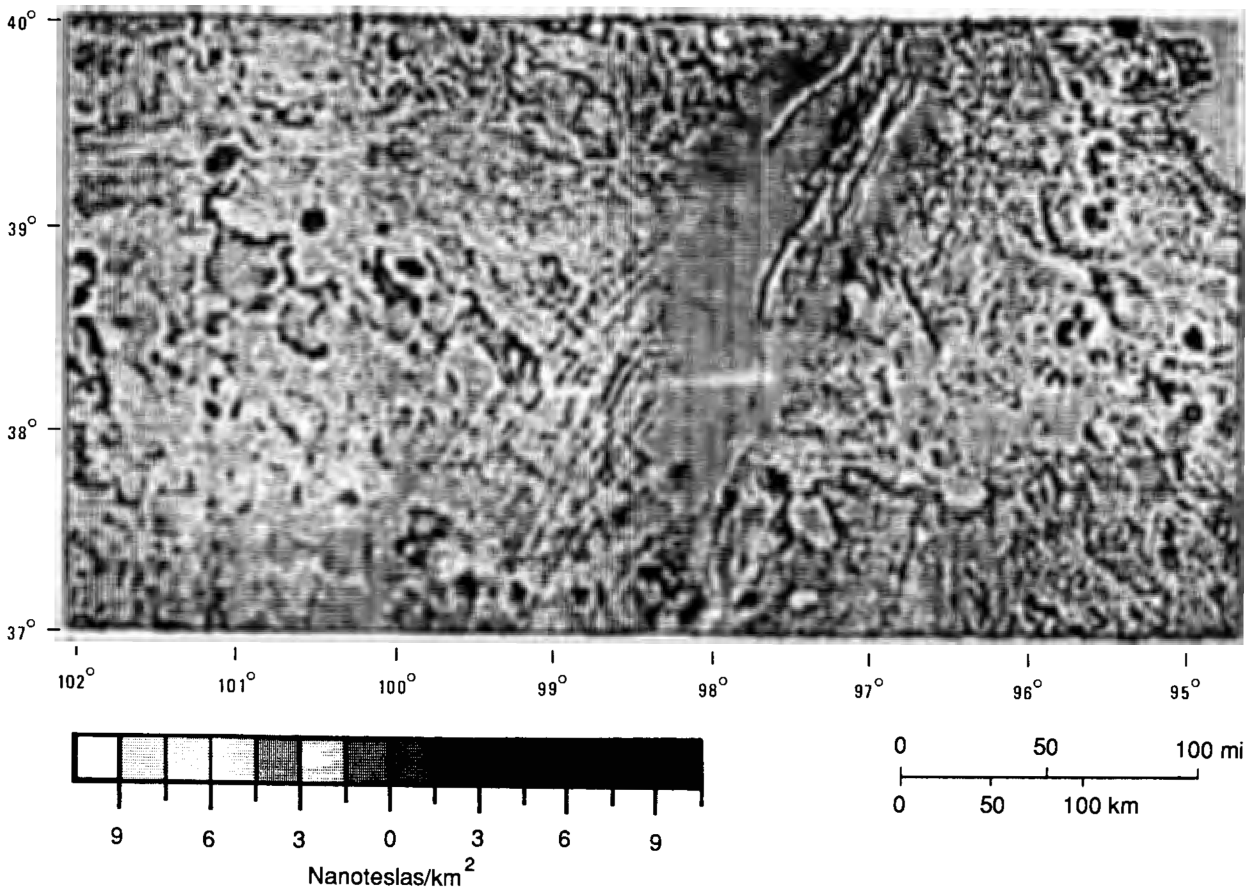


FIGURE 4—AEROMAGNETIC MAP OF KANSAS REDUCED TO THE POLE, LEVELED, WITH SECOND VERTICAL DERIVATIVE CALCULATED (from Yarger, 1983b).

The Humboldt fault, bounding the eastern side of the Nemaha Ridge, parallels the CNARS system, suggesting that it may have developed in Keweenawan time and was reactivated in late Paleozoic time. Recent microearthquake results in Kansas indicate that the Humboldt fault is still active. Some activity along two other magnetic lineations within the CNARS has occurred.

New results

Cross section model of CNARS

Until recently, most workers have assumed that the basalts and gabbros associated with the CNARS form a more or less continuous unit from the present Precambrian surface to relatively deep crustal levels. A recent deep seismic (COCORP) profile across the CNARS in northern Kansas indicates different structures. Serpa et al. (1984) interpret from the seismic data a deep-seated basalt block underlying several kilometers of Precambrian clastic sediments (Rice Formation). Although one drill hole near the COCORP line does bottom in the Rice Formation, other drill-hole evidence in northern Kansas suggests the COCORP model may not be generally applicable to the CNARS in Kansas. Of the eight holes encountering Precambrian rocks in northern Kansas that are located towards the center of the CNARS anomaly, one bottoms in Rice (COCORP line), two in granite, and the remaining five in gabbros. Of the 15 holes to the Precambrian along the eastern edge of the gravity anomaly, approximately half bottom in Rice and half in gabbro. Farther to the east, approximately eight drill holes located in the gravity low bottom in the Rice Formation (drill-hole information from Bickford, private communication, 1983).

The older model, which requires basalt at the present Precambrian surface, is still viable. The gravity and magnetic anomalies are consistent, although not unique, with this model (fig. 5). Details of the gravity modeling are discussed in Lam and Yarger (this volume). The modeled magnetic profile (fig. 5) was computed by using the same body derived from the independent gravity modeling. The

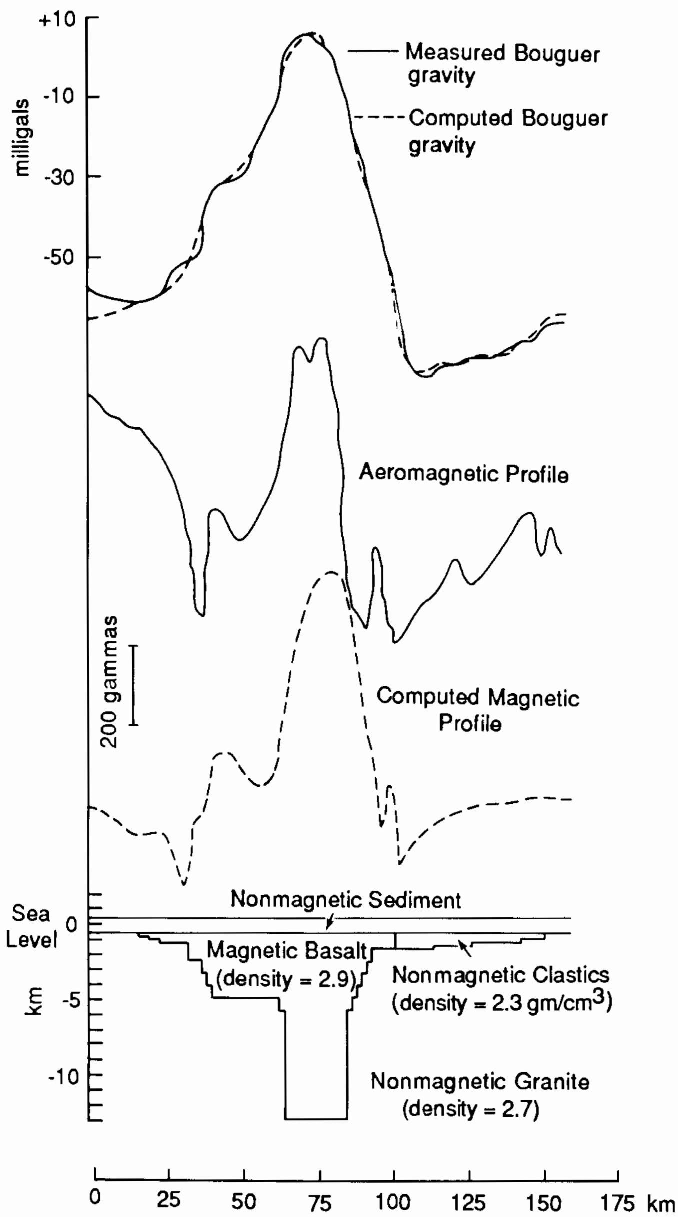
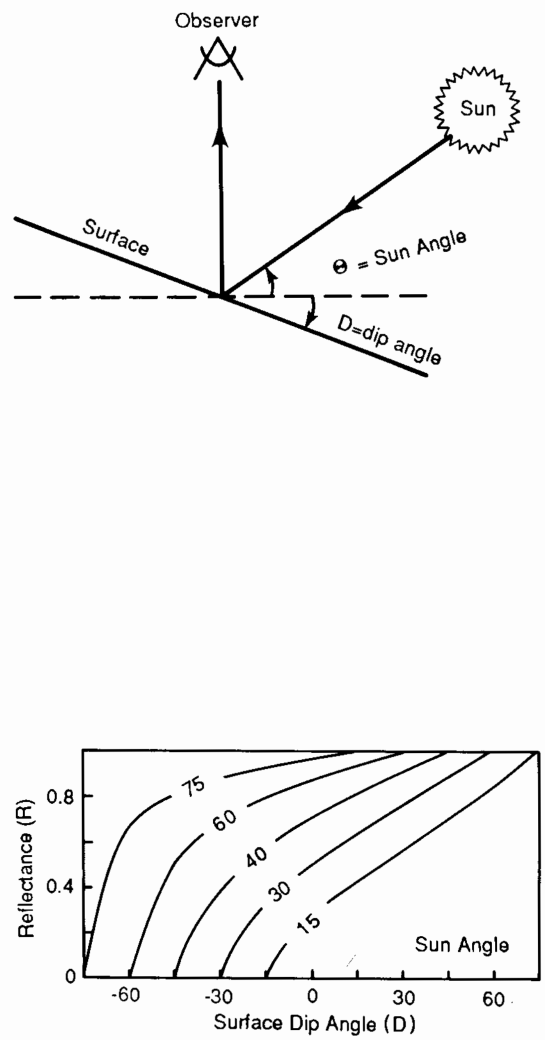


FIGURE 5—CROSS SECTIONAL MODEL OF THE CNARS USING GRAVITY AND MAGNETIC PROFILES. Profile is located at 39.5° north latitude across the midcontinent rift.



Lommel–Seeliger Law:

$$R = \frac{1+\sin(\theta)}{\cos(D)/(1+\cos(\theta+D))}$$

FIGURE 6—SHADED-RELIEF GEOMETRY AND REFLECTANCE LAW.

modeling required a paleomagnetic direction that was consistent with the estimated inclination (70°) and declination (270°) 1.1 b.y. ago (more discussion of this follows in a later section). The shape of the computed magnetic profile is remarkably similar to the measured profile. According to this model, the narrow highs and lows on either side of the central anomaly are due to edge effects of the basalt body. The width of the computed magnetic anomaly is too wide. Independently modeling the magnetics would achieve better agreement.

Theory of shaded-relief images

The technique of shaded relief, or oblique synthetic illumination of maps, has been available for some time (e.g., Batson et al., 1975), but was primarily used for topographic relief. This technique can be applied equally well to any two-dimensional mapped variable.

The basic idea of this approach is to treat the magnetic map as a topographic map. The magnetic field values must be scaled to topographic relief units. A useful scale for the Kansas magnetic data is 31 nT/km, i.e. a magnetic high of 31 nT correponds to a topographic high of 1 km (.6 mi). The image is then synthetically illuminated by the sun at an oblique angle above the horizon (angle θ in fig. 6). The observer is directly overhead. Because of the oblique sun angle, there will be a shading effect on the sides of hills opposite the sun. The reflectance from the sun seen by the observer depends on the dip angle of the surface, the illumination angle, and the reflectance law used. There are a wide variety of possible reflectance laws to choose (Horn, 1981). The Lommel–Seeliger Law is a popular choice because it has a fairly simple expression and is based on actual sun-earth scattering experiments. The reflectance strongly depends on the angle between the reflecting surface and the sun. Maximum reflectance occurs when the sun strikes the surface at a perpendicular angle ($\theta + D = 90^0$), and zero reflectance occurs when the sun cannot "see" behind the hill ($\theta + D < 0^0$). There also is an azimuthal dependence (not shown).

Application of shaded relief to magnetic data

Many combinations of sun-elevation angles and scaling factors were investigated. The values most useful for bringing out magnetic patterns and lineations in Kansas were found to be a sun angle of approximately 15° and a scaling factor of approximately 31 nT/km. Fig. 7 is the result of illuminating the aeromagnetic map using a sun azimuth of 300° and the above parameters. This map emphasizes horizontal magnetic gradients that trend to the north-northeast. The rift zone is very well defined and coincides with earlier results from spectral filtering (fig. 3). The new features this map reveals are a distinct zone of northeast-trending lineations in the northwest corner of the state and a less distinct west-trending pattern near the Kansas–Oklahoma border in western Kansas. The approximate boundaries of these trends are indicated by solid lines (labeled with question marks) in fig. 10. Fig. 7 delineates the magnetic lineations in the southern part of the rift zone, perhaps better than previously found by spectral filtering (fig. 3).

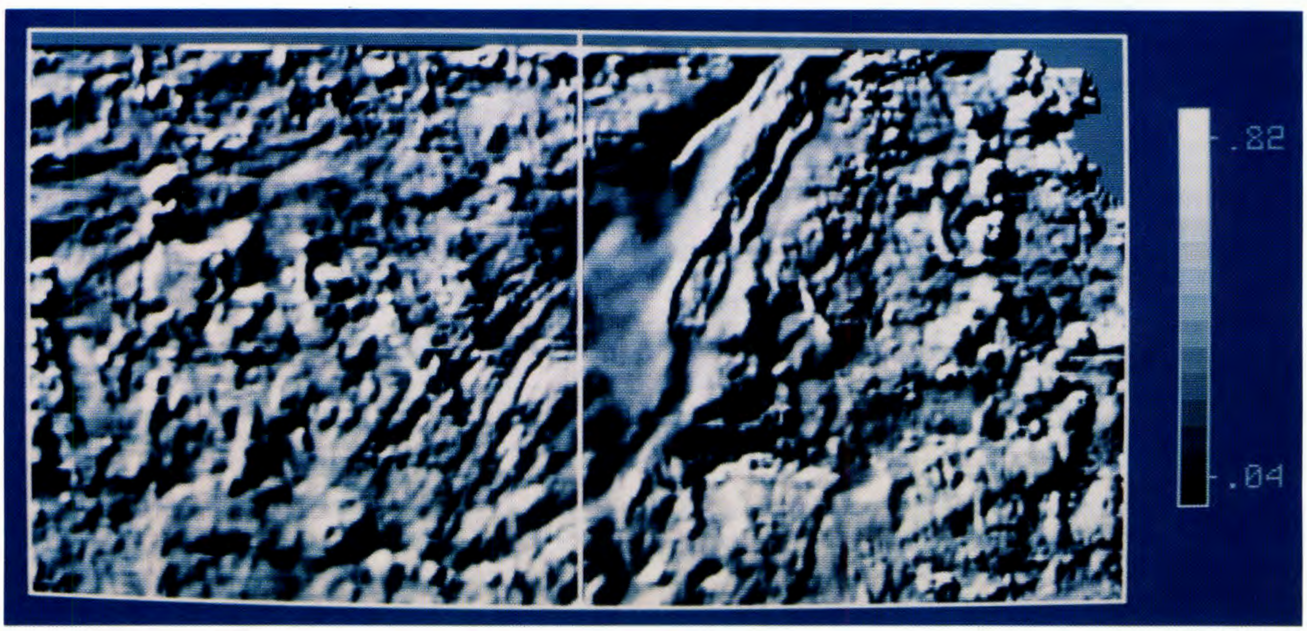


FIGURE 7—AEROMAGNETIC SHADED-RELIEF MAP. Sun azimuth = 300°; sun angle above horizon = 15°; vertical-scaling factor = 31nT/km.

Fig. 8 enhances gradients trending N. 60° E. (150° sun azimuth). The proposed east-trending boundary in southeastern Kansas separating the two Precambrian terranes, discussed earlier, is clearly indicated. This figure, as does fig. 7, suggests that the southwest-trending lineaments in the southern part of the rift zone terminate, perhaps at the west trending feature in southwestern Kansas. Previously, it was assumed that these lineaments (probably ancient faults or dikes southwest of the main basalt/gabbro trend) continued into Oklahoma.

Fig. 9 reveals a pervasive northwest-trending grain throughout the state. These lineaments largely disappear within the rift zone. The most prominent, nearly continuous, lineament in fig. 9, which is shown as a dashed line in fig. 10, extends from the southeast corner to nearly the northwest corner of the state. This lineament also is seen in the gravity data (Lam and Yarger, this volume).

Fig. 10 shows Precambrian terrane features that have been interpreted from a combination of spectral analyses (fig. 3) and oblique illumination (figs. 7, 8, and 9) of the state magnetic map (fig. 1) and gravity data. The basalt/gabbro trend has been extended to the Kansas–Oklahoma border on the basis of new gravity data (Lam and Yarger, this volume).

Using the sun-angle and scaling-factor values mentioned earlier, a shaded-relief map was generated for 12 different sun azimuths (0°, 30°, . . ., 330°). Figs. 7, 8, and 9 represent three of the 12. This suite of maps contains substan-

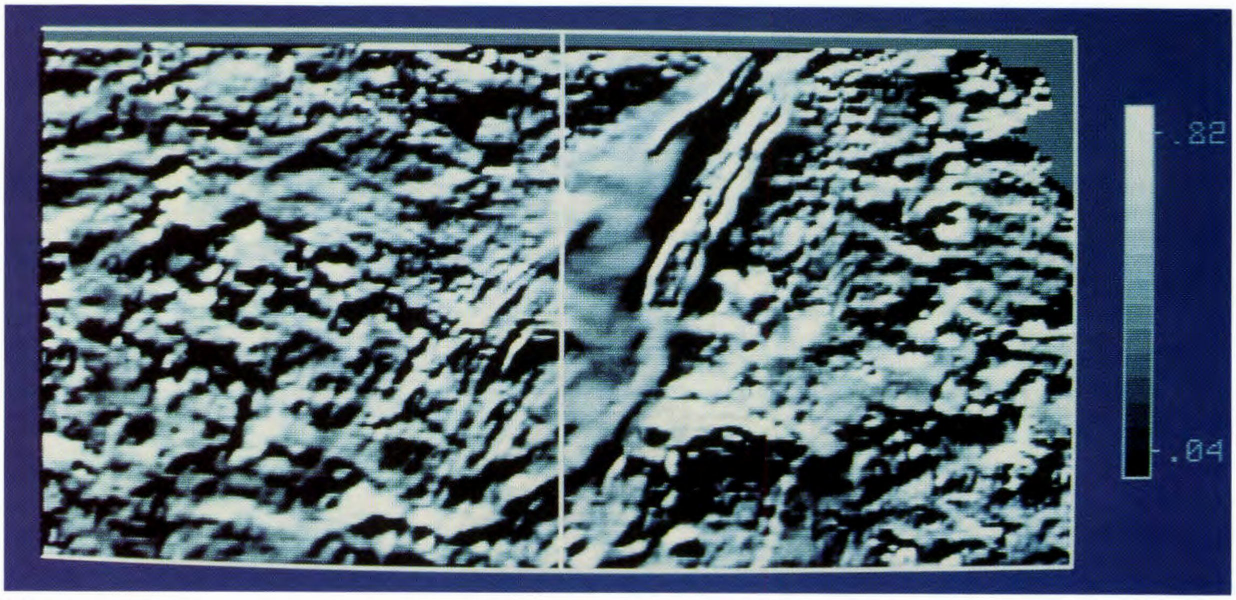


FIGURE 8—AEROMAGNETIC SHADED-RELIEF MAP. Sun azimuth = 150°; sun angle above horizon = 15°; vertical scaling factor = 31 nT/km.

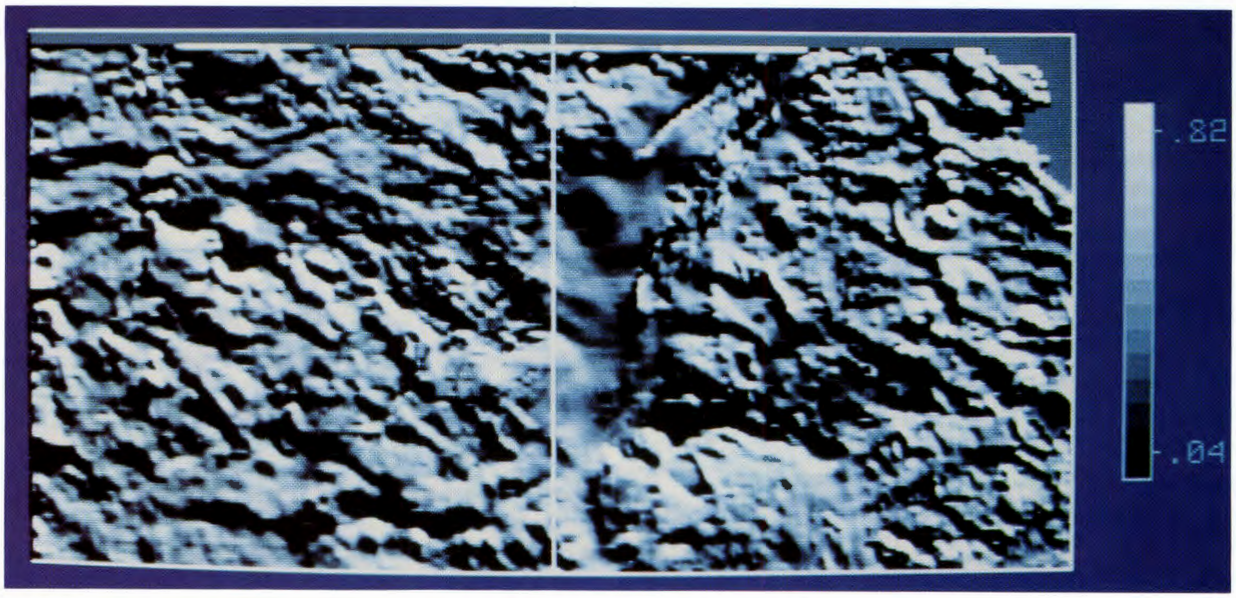


FIGURE 9—AEROMAGNETIC SHADED-RELIEF MAP. Sun azimuth = 30°; sun angle above horizon = 15°; vertical scaling factor = 31 nT/km.

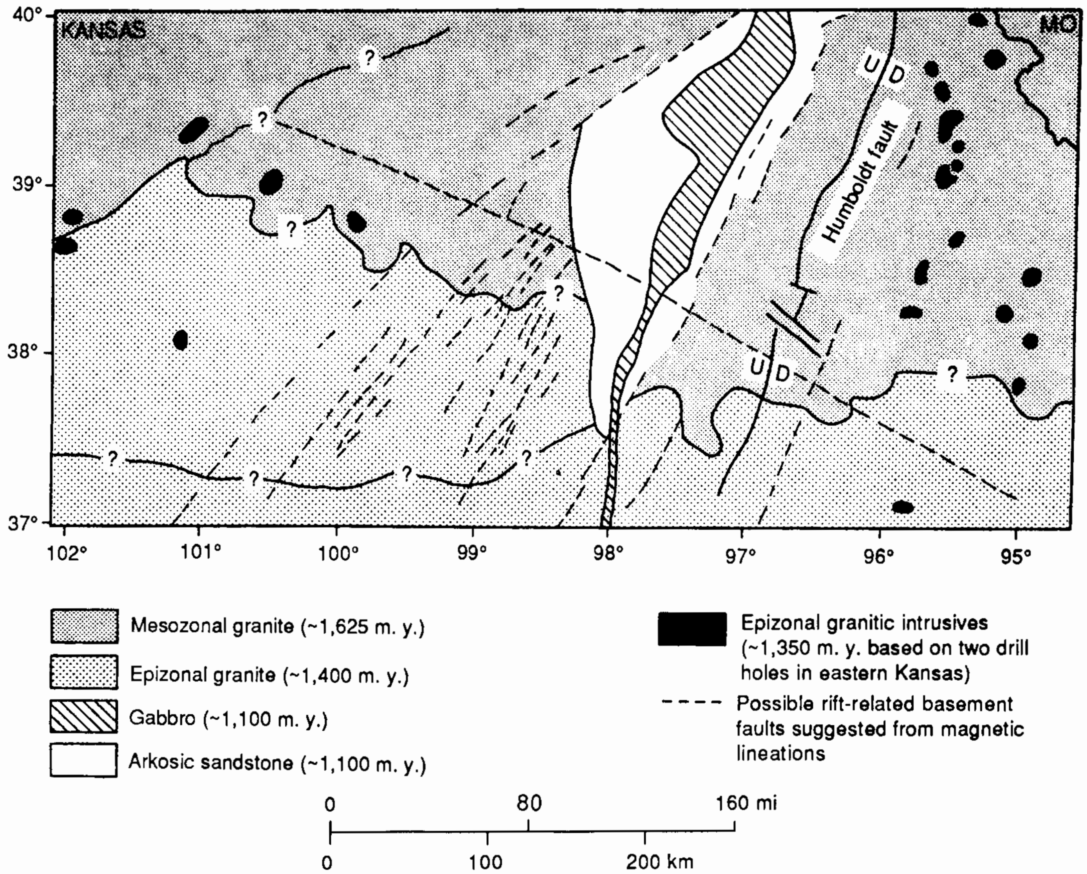


FIGURE 10—PRECAMBRIAN TERRANES IN KANSAS. This is fig. 3 updated with information from shaded-relief maps and new gravity data.

tially more lineaments than do the spectrally filtered maps discussed earlier. The oblique illumination method appears to do a superior job of enhancing lineaments in the magnetic data. These lineaments do not appear to be artificially created by this method. Individual lineaments are not strictly directionally dependent, but persist for numerous different illumination azimuths. A summary of magnetic lineaments found on the 13 maps appears in fig. 12. Lineaments less than 9.4 mi (15 km) are not shown. The lineaments are composed of approximately equal populations of northeasterlies and northwesterlies (fig. 13). The northwesterlies are distributed more or less uniformly throughout the state. Northwesterly grain also is evident in the gravity fields of Missouri, Iowa, Nebraska, and South Dakota. Arvidson et al. (1982) suggested the trends are related to collisional processes which occurred during assembly of the midcontinent crust 1.6–1.7 b.y. ago. The northeasterlies are concentrated primarily in central Kansas as part of the rift system, but do occur elsewhere, particularly in western Kansas. It is not clear if the northeasterlies outside the rift zone are related to the 1.1-b.y. rifting event. Workers in the Great Lakes region suggest that the rift there developed along an older fracture system (Klasner et al., 1982). This conclusion is based mainly on age dating of dikes colinear with the rift. If this same relation holds in Kansas, faults parallel and subparallel to the rift may predate 1.1 b.y.

Paleomagnetic directions in Kansas

Paleomagnetic directions during Keweenawan time are an important consideration when doing magnetic modeling in the rift area. The predicted paleolatitudes (paleomagnetic inclinations) and paleomagnetic declinations for central Kansas during the past 2.8 b.y. are shown in figs. 14 and 15. These calculations are based on paleopole-path data for North America compiled by Irving (1978). The Precambrian sampling sites are located mostly in the Great Lakes region (U.S. and Canada) and in the western United States. These

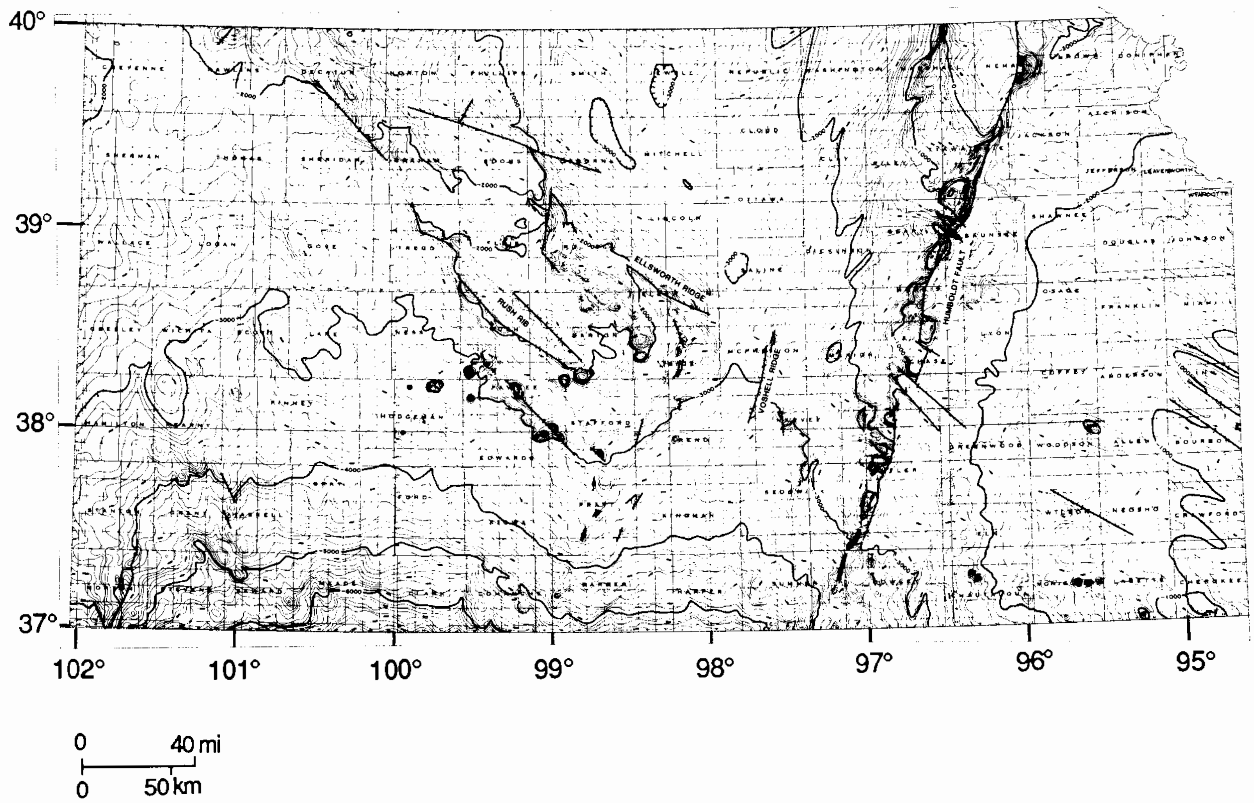


FIGURE 11—PRECAMBRIAN RELIEF. Photo reduction of 1:500,000 map by Cole (1976).

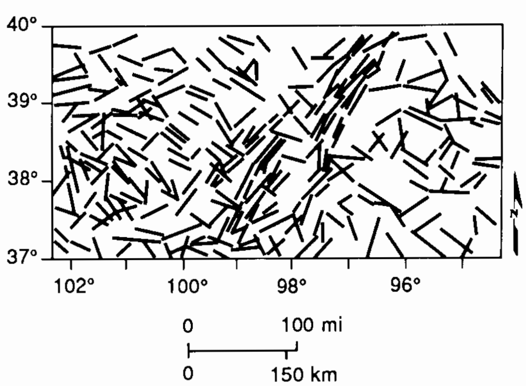


FIGURE 12—MAGNETIC LINEAMENTS IN KANSAS. Lineaments were derived from a suite of 12 shaded-relief maps with different azimuths.

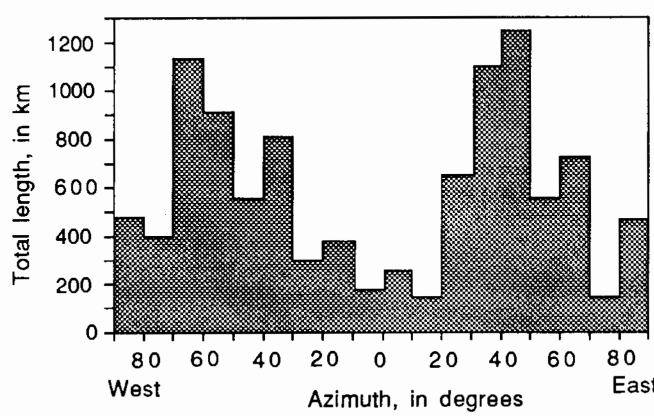


FIGURE 13—HISTOGRAM OF TOTAL LINEAMENT LENGTH VERSUS DIRECTION DERIVED FROM FIG. 11.

figures should be useful to anyone attempting magnetic modeling in Kansas. The paleomagnetic inclination, I, (used in modeling) is related to paleolatitude, θ, by the simple relation $\cot\theta = 1/2 \tan I$. Maintaining consistency with paleomagnetic data is particularly important within the rift zone because of the substantial remanent magnetization of the basalts and gabbros; Q values of 1 to 10 are common (DuBois, 1962). There is some confusion in the literature regarding normal and reversed poles during Keweenawan time. This arises because Kansas was in the southern hemisphere 1.1 b.y. ago. Rocks cooled during normal polarity at that time will appear to have reversed polarity today in the northern hemisphere. The modeling shown in fig. 5 is consistent with Irving's paleopath, if there was a pole reversal (i.e. a positive magnetic inclination of 70° and a magnetic declination of approximately 270°) and a large Q value (i.e. the induced magnetization is negligible). The reversed-pole paleolatitude plot (not shown) can be determined by simply reflecting the normal polarity plot (fig. 14) about 0°. The reversed-pole declination plot is found by subtracting values

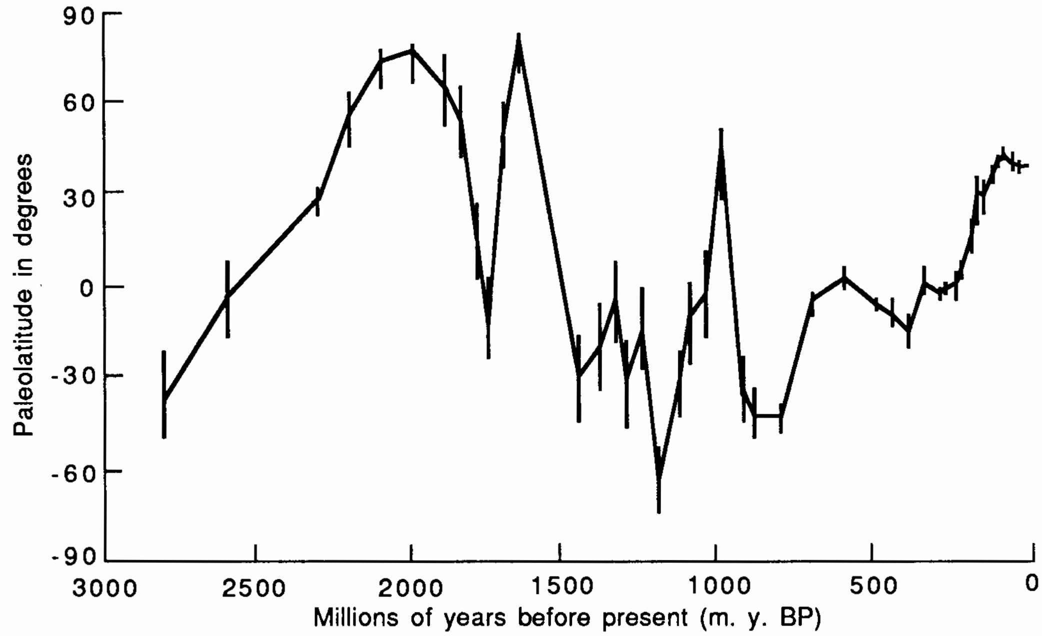


FIGURE 14—PALEOLATITUDE FOR CENTRAL KANSAS. Calculated from paleopole path of North America by Irving (1978).

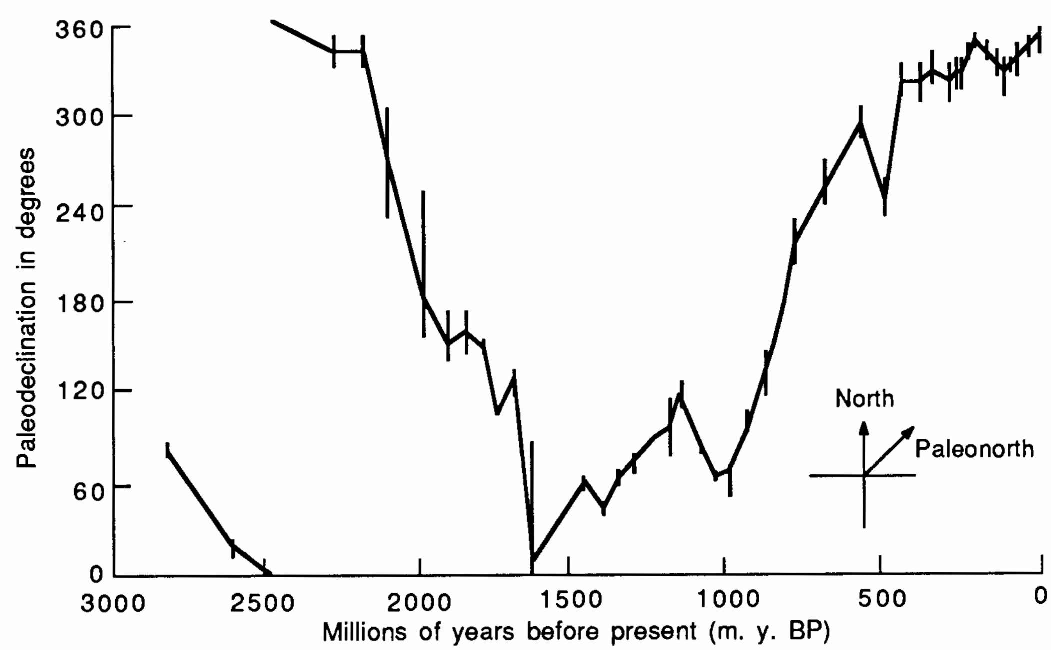


FIGURE 15—PALEODECLINATION, ASSUMING NORMAL MAGNETIC-POLE POLARITY, FROM PALEOPOLE PATH OF NORTH AMERICA BY IRVING (1978).

in fig. 14 from 360°. For example, the magnetic declination at 1.1 b.y. ago is approximately 90° (from fig. 14) which corresponds to 270° for rocks cooled during a reversed-polarity epoch. Likewise, the reversed-polarity inclination at 1.1 b.y. is approximately 70° because it is -70° on the normal-polarity plot (fig. 14).

Conclusions

A 45,000 line-mi (72,000 line-km) regional aeromagnetic survey of Kansas is useful in studying the composition and paleotectonics of the Precambrian basement. These data are available on a magnetic tape and as a 1:500,000 scale map. For more information, contact the Publication Sales office of the Kansas Geological Survey.

A 15,000 line-mi (24,000 line-km) high sensitivity detailed survey of the Joplin 2° quadrangle has been completed. The data from this survey will be made available as a map and as a digital data tape. The KGS has its own airborne aeromagnetic system and contemplates conducting further detailed surveys. The specific areas to be surveyed and time frame followed could be determined by interest within the scientific and exploration community and availability of funding. The data from these new surveys will also be made available to the public.

This high-quality aeromagnetic data, acquired in uniformly specified surveys, lends itself extremely well to a variety of interpretation techniques, including spectral filtering, synthetic oblique illumination, and cross sectional modeling.

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Appendix I

Eastern Kansas aeromagnetic-data tape format

Compiled by the Kansas Geological Survey, University of Kansas, West Campus, Lawrence, Kansas, 66046.

Flight lines spaced 2 mi (3.2 km) apart were flown east or west along section lines. Each flight line is approximately 210 mi (335 km) long. Tie lines were flown north or south spaced approximately 20 mi (32 km) apart. There are 107 flight lines and 10 tie lines. The tie lines were flown in two phases (northeast section and south east section), so there are two files per tie line. There is one file per flight line, yielding a total of 127 files on the tape. The northernmost flight line (1 mi [1.6 km] north of the Kansas–Nebraska border) is labeled number 501, and the next line down is numbered 1. The flight line numbers increase, incrementing by two, to the south to 207 for the southernmost line. In addition, two lines were flown between normal 2-mi (3.2-km) spaced lines and were numbered 74 and 76. The tie-line numbers are the number of miles from the tie line to the Kansas–Missouri border. The surveyed area on this tape comprises the eastern half of Kansas. All flight lines and tie lines were flown at a fixed elevation of 2,500 ft (750 m) above sea level.

The tie lines were used for making flight-line drift corrections (see Yarger et al., 1978, for further details). A small fraction of the tie line-flight line intersections in high-gradient areas were not used for drift determination. Tie lines should not be used for contouring but can be used for profile modeling.

EBCDIC character format
9 track, 1,600 bits/in
no labels, no serials, no slew characters
127 files
physical record = 9,000 characters (8 bits)
2,250 words (32 bits/word)
logical record = 90 characters
logical record format = (1X, F6.1, I2, 2F8.4, 3I6, F10.5, I6, 2F8.1, 2I3)

Logical Word	Format	Content
1	F6.1	line number
2	I2	flight-direction number (1 = E, 2 = W, 3 = N, 4 = S)
3	F8.4	west longitude in degrees
4	F8.4	north latitude in degrees
5	I6	measured absolute magnetic field in gammas
6	I6	residual magnetic field in gammas (word 6 = word 5 - word 7 + 1,500 + correction for diurnal drift)
7	I6	IGRF (75) calculated for flight date
8	F10.5	time of measurements in hours (central daylight time, 24-hour clock)
9	I6	camera fiducial (frame) number
10	I3	landmark flag (0 = landmark, 1 = otherwise)
11	I6	radar altimeter output in millivolts
12	F8.1	ground clearance in ft calculated from word 11
13	F8.1	ground elevation in ft above sea level calculated from word 12 and word 14
14	I3	flag for constant flight elevation above sea level in ft (0 = 2,500; 1 = 3,000; 2 = 4,500)
15	I3	same as word 14

Eastern Kansas aeromagnetic data tape

File	Flight Line No. and Direction	Date Flown
1	501E 1 mi north of Kansas border	6/23/75
2	1 W 1 mi south of Kansas border	6/23/75
3	3 E 3 mi south of Kansas border	6/20/75
4	5 W	6/20/75 etc.
5	7 E	6/19/75
6	9 W	6/19/75
7	11 E	6/17/75
8	13 W	6/17/75
9	15 E	6/13/75
10	17 W	6/13/75
11	19 E	6/12/75

File	Flight Line No. and Direction	Date Flown
12	21 W	6/12/75
13	23 E	6/12/75
14	25 W	6/12/75
15	27 E	6/11/75
16	29 W	6/11/75
17	31 E	6/06/75
18	33 W	6/06/75
19	35 E	6/03/75
20	37 W	6/03/75
21	39 E	6/05/75
22	41 E	3/19/75
23	43 W	3/19/75
24	45 W	5/27/75
25	47 E	5/27/75
26	49 W	6/05/75
27	51 E	6/04/75
28	53 W	6/04/75
29	55 E	4/30/75
30	57 W	4/30/75
31	59 E	4/21/75
32	61 W	4/21/75
33	63 W	3/25/75
34	65 W	3/14/75
35	67 W	3/13/75
36	69 W	1/16/75
37	71 E	3/13/75
38	73 W	1/16/75
39	74 E	4/09/75
40	75 E	6/20/74
41	76 W	4/09/75
42	77 W	8/20/74
43	79 W	6/24/75
44	81 E	6/24/75
45	83 W	7/10/75
46	85 E	7/10/75
47	87 W	7/07/75
48	89 E	7/07/75
49	91W	7/07/75
50	93 E	7/07/75
51	95 W	7/21/75
52	97 E	6/15/76
53	99 W	6/15/76
54	101 E	6/16/76
55	103 W	6/16/76
56	105 W	6/30/76
57	107 E	6/30/76
58	109 W	12/17/76
59	111 E	12/17/76
60	113 W	7/12/76
61	115 E	7/12/76
62	117 W	7/13/76
63	119 E	7/13/76
64	121 W	7/13/76
65	123 E	7/13/76
66	125 W	7/20/76
67	127 E	7/20/76
68	129 W	7/21/76
69	131 E	7/21/76

File	Flight Line No. and Direction	Date Flown
70	133 E	8/13/76
71	135 W	8/13/76
72	137 W	7/30/76
73	139 E	7/30/76
74	141 W	8/16/76
75	143 E	8/16/76
76	145 W	8/19/76
77	147 E	8/19/76
78	149 E	8/20/76
79	151 W	8/20/76
80	153 W	8/27/76
81	155 E	8/27/76
82	157 W	9/10/76
83	159 E	9/10/76
84	161 W	9/22/76
85	163 E	9/22/76
86	165 W	9/24/76
87	167 E	9/24/76
88	169 W	10/08/76
89	171 E	10/08/76
90	173 W	7/22/76
91	175 E	7/22/76
92	177 W	7/23/76
93	179 E	7/23/76
94	181 W	11/04/76
95	183 E	11/04/76
96	185 W	11/10/76
97	187 E	11/10/76
98	189 W	11/22/76
99	191 E	11/22/76
100	193 W	11/24/76
101	195 E	11/24/76
102	197 W	12/03/76
103	199 E	12/03/76
104	201 W	12/14/76
	etc.	
105	203 E	12/14/76
	3 mi north of Oklahoma border	
106	205 W	12/16/76
	1 mi north of Oklahoma border	
107	207 E	12/16/76
	1 mi south of Oklahoma border	

File	Tie Line No. and Direction	Date Flown
108	1 S	4/21/75
	1 mi west of Missouri border	
109	22 S	4/03/75
	22 mi west of Missouri border	
110	43 N	4/03/75
	etc. (in northeastern Kansas)	
111	64 S	4/03/75
112	86 N	4/03/75
113	103 N	4/09/75
114	129 S	4/09/75
115	150 N	4/09/75
116	169 S	4/21/75

File	Tie Line No. and Direction	Date Flown
117	188 N	4/21/75
	1 mi west of Missouri border	
118	501 S	6/26/75
	22 mi west of Missouri border	
119	522 S	6/28/75
	etc. (in southeastern Kansas)	
120	543 N	6/26/75

File	Tie Line No. and Direction	Date Flown
121	564 S	6/26/75
122	586 N	6/28/75
123	603 N	6/26/75
124	629 S	6/28/75
125	650 N	6/28/75
126	669 S	11/01/76
127	688 N	11/01/76

Appendix II

Western Kansas aeromagnetic-data tape format

Compiled by the Kansas Geological Survey, University of Kansas, West Campus, Lawrence, Kansas, 66046.

Flight lines spaced 2 mi (3.2 km) apart were flown east or west along section lines. Each flight line is approximately 210 mi (335 km) long. Tie lines were flown north or south spaced approximately 20 mi (32 km) apart. There are 105 flight lines and 11 tie lines. There are a total of 116 files, one file per line. The northern most flight line (1 mi [1.6 km] north of the Kansas–Nebraska border) is labeled number 599. The flight line numbers increment by two sequentially to the south to 807 for the southernmost flight line. The tie line numbers are given by the number of miles from the tie line to the Kansas–Missouri border. The surveyed area on this tape comprises the western half of Kansas.

All flight lines were flown at 3,000 ft (900 m) above sea level in the eastern portion of western Kansas and 4,500 ft (1,350 m) above sea level in the western portion of western Kansas. US–283, which runs north-south (approximately 100 mi [160 km] east of Colorado border) through western Kansas, was used as a visual landmark to the pilot to change elevation. Word no. 14 on each logical record defines the elevation status of each magnetic measurement. Tie lines 188 through 293 fall east of US–283 and were flown at 3,000 ft (900 m) above sea level. Tie lines 31–397 fall west of US–283 and were flown at 4,500 ft (1,350 m) above sea level.

The tie lines were used for making flight-line drift corrections (see Yarger et al., 1978, for further details). A small fraction of the tie line/flight line intersections in high gradient areas were not used for drift determination. Tie lines should not be used for contouring, but can be used for profile modeling.

EBCDIC character format
9 track, 1,600 bits/in
no labels, no serials, no slew characters
116 files
physical record = 9,000 characters (8 bits/character) or 2,250 words (32 bits/word)

logical record = 90 characters
logical record format = (1X, F6.1, I2, 2F8.4, 3I6, F10.5, I6, 2F8.1, 2I3)

Logical Word	Format	Content
1	F6.1	line number
2	I2	flight-direction number (1 = E, 2 = W, 3 = N, 4 = S)
3	F8.4	west longitude in degrees
4	F8.4	north latitude in degrees
5	I6	measured absolute magnetic field in gammas
6	I6	residual magnetic field in gammas (word 6 = word 5 - word 7 + 1,500 + correction for diurnal drift)
7	I6	IGRF (75) calculated for flight date
8	F10.5	time of measurements in hours (central daylight time, 24-hour clock)
9	I6	camera fiducial (frame) number
10	I3	landmark flag (0 = landmark, 1 = otherwise)
11	I6	radar altimeter output in millivolts
12	F8.1	ground clearance in ft calculated from word 11
13	F8.1	ground elevation in ft above sea level calculated from word 12 and word 14
14	I3	flag for constant flight elevation above sea level in ft (0 = 2,500; 1 = 3,000; 2 = 4,500)
15	I3	same as word 14

Western Kansas aeromagnetic-data tape

File	Flight Line No. and Direction	Date Flown
1	807 W	5/30/78
	1 mi south of Oklahoma border	
2	805 E	5/23/78
	1 mi north of Oklahoma border	
3	803 W	6/05/78
	3 mi north of Oklahoma border	
4	801 E	6/07/78
	etc.	
5	799 W	6/07/78
6	797 E	6/07/78
7	795 W	6/08/78
8	793 E	6/08/78
9	791 W	6/08/78
10	789 E	6/08/78
11	787 W	6/09/78
12	785 E	6/09/78
13	783 W	6/19/78
14	781 E	6/19/78
15	779 W	6/20/78
16	777 E	6/20/78
17	775 W	6/22/78
18	773 E	6/22/78
19	771 W	9/26/78
20	769 W	6/28/78
21	767 E	6/28/78
22	765 W	6/28/78
23	763 E	6/28/78
24	761 W	6/29/78
25	759 E	6/29/78
26	757 W	7/03/78
27	755 E	7/03/78
28	753 W	7/04/78
29	751 E	7/04/78
30	749 W	7/05/78
31	747 E	7/05/78
32	745 W	7/06/78
33	743 E	7/06/78
34	741 W	7/07/78
35	739 E	7/07/78
36	737 W	7/18/78
37	735 E	7/18/78
38	733 W	7/20/78
39	731 E	7/20/78
40	729 W	7/21/78
41	727 E	7/21/78
42	725 W	7/24/78
43	723 E	7/24/78
44	721 W	7/25/78
45	719 E	7/25/78
46	717 W	7/26/78
47	715 E	7/26/78
48	713 W	7/27/78
49	711 E	7/27/78
50	709 W	7/31/78
51	707 E	7/31/78
52	705 E	8/18/78

File	Flight Line No. and Direction	Date Flown
53	703 W	8/18/78
54	701 W	8/20/78
55	699 E	8/20/78
56	697 W	5/22/79
57	695 E	5/22/79
58	693 W	5/23/79
59	691 E	5/23/79
60	689 W	5/24/79
61	687 E	5/24/79
62	685 W	5/26/79
63	683 E	5/31/79
64	681 W	5/27/79
65	679 E	5/27/79
66	677 W	5/28/79
67	675 E	5/28/79
68	673 W	6/01/79
69	671 E	6/01/79
70	669 W	6/02/79
71	667 E	6/02/79
72	665 W	6/03/79
73	663 E	6/03/79
74	661 W	6/10/79
75	659 E	6/10/79
76	657 W	6/11/79
77	655 E	6/11/79
78	653 W	6/12/79
79	651 E	6/12/79
80	649 W	6/13/79
81	647 E	6/13/79
82	645 W	6/14/79
83	643 E	6/14/79
84	641 W	6/15/79
85	639 E	6/15/79
86	637 W	6/16/79
87	635 E	6/16/79
88	633 W	6/27/79
89	631 E	6/27/79
90	629 W	7/10/79
91	627 E	7/10/79
92	625 W	7/11/79
93	623 E	7/11/79
94	621 W	7/12/79
95	619 E	7/12/79
96	617 W	7/20/79
97	615 E	7/20/79
98	613 W	7/21/79
99	611 E	7/21/79
100	609 W	7/25/79
101	607 E	7/25/79
102	605 W	7/26/79
103	603 E	7/26/79
	3 mi south of Nebraska border	
104	601 W	9/26/79
	1 mi south of Nebraska border	
105	599 W	9/26/79
	1 mi north of Nebraska border	

File	Tie Line No. and Direction	Date Flown
106	188 S	7/14/77
	188 mi west of Missouri border	
107	211 S	7/20/77
	211 mi west of Missouri border	
108	230 S	7/19/77
	etc.	
109	250 N	7/19/77
110	272 S	5/24/78

File	Tie Line No. and Direction	Date Flown
111	293 N	5/24/78
112	314 N	6/01/78
113	333 S	6/01/78
114	354 S	5/31/78
115	376 N	5/31/78
116	397 S	8/15/77
	397 mi west of Missouri border	