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KANSAS BASEMENT STUDY USING SPECTRALLY FILTERED
AEROMAGNETIC DATA

by

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ABSTRACT

A recently compiled 72,000 line-kilometer aeromagnetic survey of the State of Kansas, flown under uniform specifications, provides an excellent data base for spectral enhancement techniques. A suite of spectrally filtered maps of Kansas are proving useful in the regional study of Precambrian basement. The pole correction map (i.e., the reduced-to-pole map minus the original map) enhances an east-west trending boundary between terranes of different Precambrian age. The second vertical derivative map reveals extensive basement faults trending southwest through central Kansas. The combination of high frequency-pass and trend-pass filters reveals the bounding faults of the Central North American Rift System (CNARS). The upward and downward continuation filters are also useful in delineating basement terranes. These maps reveal extreme parallelism between the Humboldt fault, which bounds the eastern side of the Nemaha uplift, and the CNARS. This suggests that the Humboldt fault probably developed as one of the eastern-most faults of the CNARS in late Precambrian time and was reactivated in late Paleozoic time. Recent seismicity indicates that some of the CNARS faults are active today.

INTRODUCTION

The Kansas Geological Survey (KGS) recently completed an 80,000 km aeromagnetic survey of the State of Kansas. This study compiles and extends earlier preliminary reports (Yarger, 1980, 1981; Yarger and others, 1978a, 1976) on regional interpretation of Kansas aeromagnetic data.

The KGS airborne proton precession magnetometer system, which consists primarily of Geometrics equipment with digital recording, was flown at ± 1 nT sensitivity and two-second sampling rate. The magnetic sensor ("bird") was trailed 30 m from the Twin Beech D-18 aircraft used in the survey. An Automax G-2 35mm camera, electronically triggered by the magnetometer, was used for flight path recovery.

The survey was conducted separately in eastern and western Kansas with ~340 km east-west flight lines and ~345 km north-south tie lines. The flight lines were spaced 3.2 km apart and the tie lines were spaced approximately 32 km apart. Navigation was accomplished by visual sighting along section line roads. In eastern Kansas the airplane was flown at a fixed barometric elevation of 762 m above sea level. In western Kansas the flight elevations were 915 m above sea level in the eastern portion and 1370 m above sea level in the westernmost quarter of the state. The ground clearance, which averaged ~365 m, was measured by radar altimeter and digitally recorded along with the magnetic measurements.

Details of the flight path recovery procedure appear elsewhere (Yarger, 1981 and 1982). After assignment of longitude and latitude to all magnetic measurements, a time-extrapolated IGRF75 value was computed at each measurement location and subtracted from the total-intensity-magnetic field. The temporal variations in the magnetic field were

removed by analysis of the mismatches of magnetic-field values at the tie line-flight line intersections. This procedure, which does not require a recording base station, assumes that diurnal drift during flight is a smoothly varying, low-order polynomial in time. The polynomial coefficients were determined by minimizing magnetic-field residuals at flight line-tie line intersections (for further detail, see Yarger and others, 1978b and Yarger, 1982).

A master grid of total-intensity-magnetic-field values for the State was prepared with 0.16 km (0.1 mi.) east-west spacing and 3.2 km (2 mi.) north-south spacing, which is nearly equivalent to the original measurement spacing. The grid was determined by shifting magnetic-field values from nearly straight flight lines to nearby grid lines. The overall grid location was determined by minimizing (in the least-squares sense) the difference between grid-line and flight-line coordinates. The gridding procedure, which takes advantage of a regularly spaced grid-like flight-line pattern, avoids smoothing that normally occurs when gridded by the available computer algorithms written primarily for arbitrarily spaced data. The master grid, which represents the residual total-intensity-magnetic field, is useful for machine contouring over a wide range of scales and contouring intervals. It is also useful for most quantitative analyses, because the gridding procedure has preserved the original integrity of the data. A color map, machine contoured from this grid, has been published at a scale of 1:500,000 and contour interval of 50 nT (Yarger and others, 1981). Figure 1 presents a photo-reduction of a black and white version of this map.

FILTER APPLICATION

Several spectrally filtered versions of the original contour map (Fig. 1) are used in this regional interpretation. The purpose of filtering a map is to remove certain unwanted characteristics and to enhance desirable characteristics that are diagnostic of geology. Because of the simple mathematical form of most potential field filters in the spectral domain, it is advisable to transform the original unfiltered map to the spectral domain, apply the filters, then transform the filtered map back to the spatial domain for use in interpretation (Gunn, 1975). A suite of spectrally filtered magnetic maps has proven useful in this study of Kansas basement composition, paleotectonics, and age terranes. Certain filtered maps reveal magnetic patterns, not readily apparent in the original unfiltered map, that are related to basement geology.

Kansas was divided into two equal 216 by 216 grids for input to the FFT program (Singleton, 1969). The grid cell size is approximately 1.6 km on a side. The eastern and western grids overlapped by 15 cells. The filtered maps were compiled using a variable black-and-white density scale instead of the more traditional contour lines. This format was chosen for several reasons. Density maps are considerably cheaper and faster to produce. Some of the filtered maps have a large dynamic range or may have sharp gradients that are difficult to contour. Finally, the reader can more easily discern relative magnitudes on density maps when restricted to a black and white format.

Figures 2 through 9 are a suite of eight filtered maps, which are useful in enhancing basement features. These figures are a subset of a much

larger suite of filtered maps originally examined. The filtered maps were derived from a combination of two or more filters.

Figure 2 is a map reduced to the pole and downward continued to 760 m above sea level. Reduction to the pole removes the distortion caused by the earth's inclined magnetic field (approximately 65° from the horizontal in Kansas). This results in a slight migration to the north of anomaly maxima and an increase, in some cases, of anomaly amplitudes. All maps appearing in Figures 2 through 9 have been reduced to the pole. The data of the western half of the map were downward continued to 760 m above sea level so as to be comparable to the data of the eastern half, which were recorded at 760 m above sea level.

In the remainder of the text, all maps that have been downward continued to the eastern flight elevation of 760 m above sea level are referred to as "leveled" maps.

Figure 3 presents a pole correction map, which is the reduced-to-pole map minus the unreduced-to-pole map. This map was originally compiled to check the reduction-to-pole-filter, but has proven useful itself as diagnostic of basement terrane. The pole correction map represents distortion in the original map caused by the inclined magnetic field.

Figure 4 presents an aeromagnetic map upward continued to 9 km above sea level and emphasizes deep-seated, long-wavelength magnetic sources within the crust. Figure 5 presents an aeromagnetic map downward continued to 850 m below sea level, which corresponds roughly to the average elevation of the Precambrian surface, and emphasizes magnetic sources at or near the Precambrian surface.

Figure 6 presents an aeromagnetic map leveled and high-frequency pass filtered. This filter passed all radial frequencies above 0.4 cycles/km and

attenuated lower frequencies. We used a gaussian attenuation function with a half-width of 0.13 cycles/km. This map emphasizes anomalies caused by magnetic sources at or near the Precambrian surface to a greater extent than does the downward-continued map (Fig. 5). Figure 7 presents an aeromagnetic map leveled, high-pass filtered, and trend-pass filtered. This map is the same as Figure 6 except for the addition of a filter that passes anomalies trending northeast $\pm 45^\circ$. This map emphasizes anomalies caused by magnetic sources at or near the Precambrian surface and also trending northeast $\pm 45^\circ$.

Figure 8 complements Figure 7 and emphasizes anomalies caused by sources at or near the Precambrian surface and trending northwest $\pm 45^\circ$. Note that the simple addition of Figure 8 to Figure 7 would yield the original high-pass-filtered map in Figure 6.

Figure 9 presents the aeromagnetic map leveled, with the second vertical derivative calculated. This map emphasizes near-vertical contacts between contrasting magnetization at or near the Precambrian surface.

BASEMENT GEOLOGY OF KANSAS

The Precambrian basement complex in Kansas is part of the Midcontinent craton, which is the concealed southern extension of the Canadian Shield. A relatively thin mantle of Phanerozoic sedimentary rocks 150 to 3000 m (500-10,000 ft.) thick covers the basement.

Bickford and others (1981) recently compiled a basement-rock-type map of Kansas and adjacent Midcontinent states, based on available basement-well samples (Fig. 10). The Kansas portion of this map is based on a

study of more than 800 thin sections from basement-well samples. The basement terrane in northern Kansas is characterized by granitic to quartz monzonitic intrusive rock, estimated to have been emplaced at depths of 6.5 to 13 km. These mesozonal rocks often have cataclastic to extensively sheared textures, particularly along the Nemaha Ridge. Zircon dates (U/Pb) in northeastern Kansas and northwestern Missouri indicate an age of 1625 m.y. for this terrane. In contrast, basement wells in southern Kansas reveal silicic volcanic rocks and associated shallowly emplaced granite. These volcanic and epizonal rocks are not cataclastically deformed and have a nominal age of 1400 m.y.

The belt of northeast-trending gabbroic rock in north-central Kansas is the southern extension of the Central North American Rift System (CNARS) (Ocola and Meyer, 1973). This aborted rift system can be traced to the Lake Superior region, where the outcropping rocks are of Keweenawan Age (about 1100 m.y.). A basin of arkosic sandstone to siltstone, designated Rice Formation (Scott, 1966) in Kansas, flanks and extends to the south of the trough of mafic rift intrusives.

The present structural framework, as depicted in Figures 11 and 12, was formed largely during the late Paleozoic Era and has not materially changed since then. The Nemaha Ridge is a major linear feature, which crosses eastern Kansas from Nemaha County to Sumner County and extends into Nebraska and Oklahoma. The Nemaha Ridge is faulted along the eastern side, where the crystalline basement rocks on the west side of the Humboldt fault are upthrown more than 800 m in some areas. The configuration of the Precambrian surface (Fig. 11) exhibits a northeasterly trending grain in a swath through Kansas approximately 145 km wide and bounded on the

east by the Humboldt fault. Outside this zone, the prevailing grain trends northwest.

The Forest City Basin is located mostly in Iowa, Missouri, and Nebraska. The southwestern corner, which is the deepest part of the basin, lies in northeastern Kansas and is bounded on the west by the Nemaha Ridge. The Cherokee Basin in southeastern Kansas and northeastern Oklahoma could be considered a shallow southern extension of the Forest City Basin. However, a mildly positive feature, the Bourbon Arch, separates the two basins.

The southern end of the Salina Basin, its deepest part, lies in north-central Kansas. In Kansas it is bounded on the east by the Nemaha Ridge and on the west by the central Kansas uplift. It terminates to the south at an unnamed saddle. Before post-Mississippian deformation, it formed part of the larger ancestral North Kansas Basin. The maximum thickness of sedimentary rocks found in the basin is 1400 m (Merriam, 1963). To the south lies the Sedgwick Basin, which is a northern shelf extension of the large Anadarko Basin in Oklahoma. The Hugoton Embayment, which covers much of western Kansas, is also an extension of the much-deeper Anadarko Basin in Oklahoma.

REGIONAL INTERPRETATION OF AEROMAGNETIC DATA

The relative total-intensity magnetic map (Fig. 2) depicts a rather complex crustal magnetization pattern in eastern Kansas. The dynamic range of the total magnetic field is almost 2000 nT. The contour levels range from 450 to 2350 nT, with an average value of approximately 1200 nT. The base level of the map was established arbitrarily by adding

1500 nT after subtraction of the IGRF from the absolute total intensity. Relative to the IGRF, the magnetic field in Kansas is anomalously low by some 300 nT. If the IGRF accurately describes the large-scale magnetic field intensity in the Midcontinent, then the net magnetization of the crust in Kansas is slightly below average.

Basement Terranes

Comparison of the magnetic patterns (Figs. 1, 2) with the Precambrian relief map (Fig. 11) reveals little obvious correlation. The Humboldt fault, which has over 800 m of vertical displacement in some places, is only weakly discernible. The correlation can be seen in the alignment of magnetic contours along the fault, as in southern Nemaha, northern Pottawatomie, and Wabaunsee counties (see figures 11 and 12 for location of counties). The influence of vertical displacement can also be seen in southern Morris County where the fault trace splits the north-northwest-trending anomaly. The horizontal gradient of the anomaly on the high side (west side) of the fault is steeper than the gradient on the low side. Thus, the source rock for the anomaly was probably emplaced before vertical displacement along the fault. The presence of this anomaly across the fault also suggests no major (less than 500 meters) strike-slip movement along the fault. The difference of 50 nT on either side of the Humboldt fault, which represents maximum basement relief in Kansas, suggests that most other basement relief features in Kansas will have less than a 50 nT influence on the total magnetic field. Careful evaluation, however, of the low amplitude--maximum gradients along individual magnetic profiles may yield quantitative depth to basement information (Steenland, 1965).

The total-intensity aeromagnetic maps (Figs. 1, 2) exhibit a northwest-trending grain consistent with the Precambrian surface terrane (Fig. 11). This grain is interrupted in northeastern Kansas by the Midcontinent Geophysical Anomaly (MGA), a northeast-trending linear positive anomaly flanked by adjacent linear negative anomalies. (The positive anomaly, caused by CNARS rocks of gabbroic composition, is discussed in the section on the Central North American Rift System.) The MGA appears to terminate in central Kansas against a roughly linear trend of negative anomalies. This negative trend consists of a nearly continuous band across the State defined by total-intensity amplitude <1200 nT. The most prominent low is centered over Wichita (Sedgwick County); negative anomalies of lesser magnitude continue westward to the Kansas-Colorado border. This trend can also be traced into Missouri (Missouri Geological Survey, 1943). The southern boundary of this band is clearly visible in the pole correction map (Fig. 3). This boundary corresponds to a sharp magnetization contrast, suggesting contrasting rock types. This apparent contrast may correspond to a distinct boundary between the older mesozonal granitic terrane to the north and the younger epizonal granitic terrane to the south. This "spectral" boundary is caused by an abrupt attenuation of high-frequency signal, from south to north, and presumably corresponds to the onset of the southern edge of the mesozonal granitic terrane or to some kind of transition zone between the two basement terranes. This boundary is also evident in the high-frequency pass filtered map (Fig. 6). The northern boundary of the transition zone(?) is not so sharply defined. Outside the CNARS the width of the transition zone varies from 25 to 50 km. The zone may

correspond to foundered granitic rock overlain by a Precambrian sedimentary or metasedimentary wedge. Alternatively, the band could be caused by nonmagnetic granitic basement. The apparent east-west trending basement terrane boundary is also evident on the high-frequency-pass-filtered map (Fig. 6) and the second vertical-derivative map (Fig. 9). The boundary is also discernible on the upward-continued map (Fig. 4), which emphasizes the deep-seated magnetic character of the crust.

Intrusives

The extreme northeastern portion of the aeromagnetic map (Figs. 1, 2) shows a series of strong, positive, roughly circular anomalies with diameters of approximately 15 km. Basement cores from two of these anomalies, located in Douglas and Miami counties, yielded U/Pb zircon ages of about 1350 m.y. (Steeles and Bickford, 1981). Although these rocks are more coarse-grained than rocks in the southern terrane, they are clearly epizonal granite and related to them (Bickford and others, 1981). The Miami County core contains about two percent magnetite by weight (Steeles and Bickford, 1981), which may account for the positive magnetic anomalies. The close similarity of the circular magnetic anomalies suggests that most, if not all, of them probably are caused by intrusive bodies similar to those drilled in Douglas and Miami counties. Thus, the 1625-m.y. terrane in northeastern Kansas and northwestern Missouri may be peppered with isolated, shallow granite plutons, possibly related to the 1400-m.y. granitic terrane to the south, but younger by some 50 m.y. This series of circular magnetic highs, along with similar highs in Missouri (Missouri Geological Survey, 1943), roughly track the boundary of the southern half

of the Forest City Basin. These mid-Proterozoic granitic plutons may have been intruded along a zone of weakness that later influenced the formation of the late-Paleozoic Forest City Basin.

At least six major near-circular anomalies occur in western Kansas, five of which are closely associated with the granitic terrane boundary discussed previously. Over the entire State there are at least five circular intrusive bodies just to the north of the terrane boundary (Fig. 1). These could possibly be the remnants of volcanic centers associated with Precambrian plate convergence along this boundary.

The Central North American Rift System

The pervasive influence of the Central North American Rift System on the Kansas crust is best seen in Figures 6, 7, and 9. Figure 7, which emphasizes high-frequency northeasterly trending anomalies, indicates that the rift system extends south across the entire State.

A magnetic quiet zone (± 10 nT, Figure 6) surrounds the magnetic high along the mafic belt and corresponds to a basin filled with clastic rocks of (presumably) Keweenawan age. The magnetic quiet zone is caused by the extreme depth to magnetic basement, presumably granite, which foundered during the extensional phase of the CNARS. Both the eastern and western boundaries of this Keweenawan basin are fairly sharply defined, suggesting that they may be fault bounded.

The magnetic lineations to the southwest of the magnetic quiet zone, which are most prominent in Figures 7 and 9, probably correspond to block faulting and possibly to mafic dike intrusion that occurred during the initial stage of rifting.

Apparently the rift in southern Kansas did not progress beyond the stage of block faulting and dike intrusion, whereas the rift in northern Kansas developed to a more mature stage of volcanic flows followed by foundered crust and clastic deposits. The fracture system in southern Kansas probably is representative of the crust throughout the CNARS during the early stages of rifting, before upwelling of Keweenawan volcanics occurred. This southwest-trending system indicates that the CNARS extends to the Kansas-Oklahoma border.

The Humboldt fault (Figs. 10, 11), which borders the eastern side of the Nemaha Ridge, closely parallels the CNARS across the State, suggesting that this apparent post-Mississippian fault may be a reactivated CNARS fault. This Proterozoic forerunner of the Humboldt fault may have developed within the easternmost part of the CNARS crust, which was not involved in subsequent foundering. Alternatively, the Humboldt fault may be a zone of pre-Keweenawan crustal weakness that has been reactivated, or it may not have formed until Paleozoic time.

Possible Basement Faults

The trend-pass-filtered maps (Figs. 7, 8) reveal significant magnetic lineations in both the northeast and northwest directions. The most prominent northeast linear trends correspond to the rift system through central Kansas, but a number of northwest trends lie outside the rift, particularly in northwestern Kansas. Figure 8 exhibits northwest-trending magnetic lineations extending over large parts of the State, most of which are interrupted within the rift zone. This, of course, implies that the northwest grain is older than the rift.

For comparison with known basement structure, the magnetic lineations apparent in Figures 4 through 9 are compiled in Figure 13. The magnetic lineations mapped are at least 50 km long or belong to a trend of shorter segments at least 50 km long. In addition to suites of northeast- and northwest-trending lineations across the State (Fig. 13), a third suite of east-northeast lineations is evident in southern Kansas.

The number of magnetic lineations far outnumbers the previously mapped faults in the Precambrian. However, a number of one-to-one correlations are evident. The northern half of the Humboldt fault, which borders the eastern sides of the Nemaha Ridge, shows up clearly as a continuous magnetic lineation. The northwest-trending magnetic lineation in Rush County matches the southwest-bounding fault of the Rush Rib (Fig. 11). This fault (Merriam, 1963) lies along the postulated Precambrian age boundary (Fig. 3) discussed earlier. Good correlation with the northeast-trending fault segments in western Reno and Pratt counties also exists. The fault through Ellsworth County, which trends northwest along the southwest side of the Ellsworth Ridge (Fig. 11) apparently serves as the northern boundary for several of the southwest-trending magnetic linears within the rift zone.

The northwest-trending fault in Pawnee County coincides with a magnetic trend that continues to the northwest into Rush County. Part of the southwest-trending fault bounding the northwest side of the Voshell Ridge (Fig. 11) coincides with a short magnetic lineation at the intersection of McPherson, Reno, and Harvey counties.

Although the northwest-trending magnetic grain in eastern Kansas parallels the Precambrian surface grain, little one-to-one correlation with mapped faults exists. One exception is the fault through Bourbon

and Linn counties, which coincides with a magnetic trend that continues northwest into Anderson and Osage counties.

Whether all magnetic lineations correspond to basement faults is an open question. The trend-pass filter operation (Figs. 7, 8) tends to emphasize lineations by elongating them beyond their actual geographical limit. That some of them correspond to known faults strongly implies that at least some of the remaining lineations must also correspond to faults (so far undetected by boreholes). The northeast-trending magnetic lineations within the rift zone must surely correspond to faulting in Keweenawan time.

Microearthquake results for the last five years indicate that the Humboldt fault is still active. The northeastern magnetic trend through Washington, Republic, and Cloud counties, which corresponds to the postulated boundary between the rift sedimentary rocks (Rice Formation) and the older granitic terrane, is seismically active (Fig. 9). Several events indicate that the eastern boundary between the rift sedimentary rocks and granitic terrane is also seismically active. The only other significant recent seismic activity recorded within the State is located in Barber County and may be related to the southwest magnetic trend through Harper and Barber counties.

CONCLUSIONS

The recently compiled aeromagnetic map of Kansas (Yarger and others, 1981) is very useful in studying the composition and paleotectonics of the Precambrian crust. Examination of the magnitudes and gradients of the total-intensity-magnetic-field map and of a suite of spectrally filtered

maps, in light of existing geologic information, has yielded the following regional interpretation of the Precambrian crust in Kansas.

The postulated Precambrian terranes are summarized in Figure 14. A rather distinct boundary appears to exist between the northern 1625-m.y.-old mesozonal granitic terrane and the southern 1400-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 boundary of this band of lows is sharply defined by steep horizontal gradients and short wavelengths. The magnetic source of this band is not clear. Gravity measurements in this region are being taken by the Kansas Geological Survey; along with potential field modeling, these measurements should help to clarify the origin of these magnetic minima.

Drilling results from two of the 14 circular magnetic highs in northeastern Kansas suggest that the older 1625-m.y.-old crust in northeastern Kansas is pockmarked with younger, 1350-m.y.-old granitic plutons similar in composition to the southern, 1400-m.y.-old terrane of epizonal granite and rhyolite. One to two percent (by weight) magnetite found in the two basement cores may account for the positive magnetic anomalies, whose magnitudes range from 500 to more than 1000 nT.

The CNARS 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 1100-m.y. rift that extends into the 1400-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 of basement origin are present. 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 correspond to previously mapped basement faults, suggesting that at least a small fraction of the remaining lineations correspond to previously unknown faults. These remaining lineations must be examined by other geophysical methods to establish which ones are faults.

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 been 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.

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FIGURE CAPTIONS

Figure 1. Aeromagnetic contour map of Kansas. Contour interval is 50 nT. (Photo-reduction of map compiled at a scale of 1:500,000).

Figure 2. Aeromagnetic map reduced to pole and downward continued to 760 m above sea level.

Figure 3. Pole correction map. This map represents the difference between Figure 2 and the unreduced-to-pole version of Figure 2 (not shown). The continuous line delineates a north-south horizontal magnetic gradient trending east-west.

Figure 4. Aeromagnetic map reduced to pole and upward continued to nine kilometers above sea level. The continuous east-west trending line delineates a possible deep-seated paleoplate boundary within the crust. The dashed lines outline the possible deep-seated boundaries of the CNARS.

Figure 5. Aeromagnetic map reduced to pole and downward continued to 850 m below sea level.

Figure 6. Aeromagnetic map reduced to pole, leveled, and high-pass filtered. Radial frequencies below 0.4 cycles/km were attenuated by a gaussian function with half-width of 0.13 cycles/km. The continuous line outlines the extent of rift sediments (Rice Formation).

Figure 7. Aeromagnetic map reduced to pole, leveled, high-pass filtered, and trend-pass filtered northeast $\pm 45^\circ$. The dashed lines outline the suggested boundaries of the main part of the CNARS.

Figure 8. Aeromagnetic map reduced to pole, leveled, high-pass filtered, and trend-pass filtered northwest $\pm 45^\circ$.

Figure 9. Aeromagnetic map reduced to pole, leveled, with second vertical derivative calculated. The black dots represent microearthquakes from 1977 to 1982, after Steeples (1980) and Steeples (1982, personal communication).

Figure 10. Map of basement rock types. After Bickford and others (1981).

Figure 11. Configuration of the top of Precambrian rocks in Kansas. After Cole (1976).

Figure 12. Generalized structural map of the Precambrian. After Merriam (1963).

Figure 13. Magnetic lineations. The lineations were derived from Figures 4 through 9.

Figure 14. Precambrian terranes in Kansas. Inferred from magnetic maps and Precambrian age data of Bickford and others (1981).

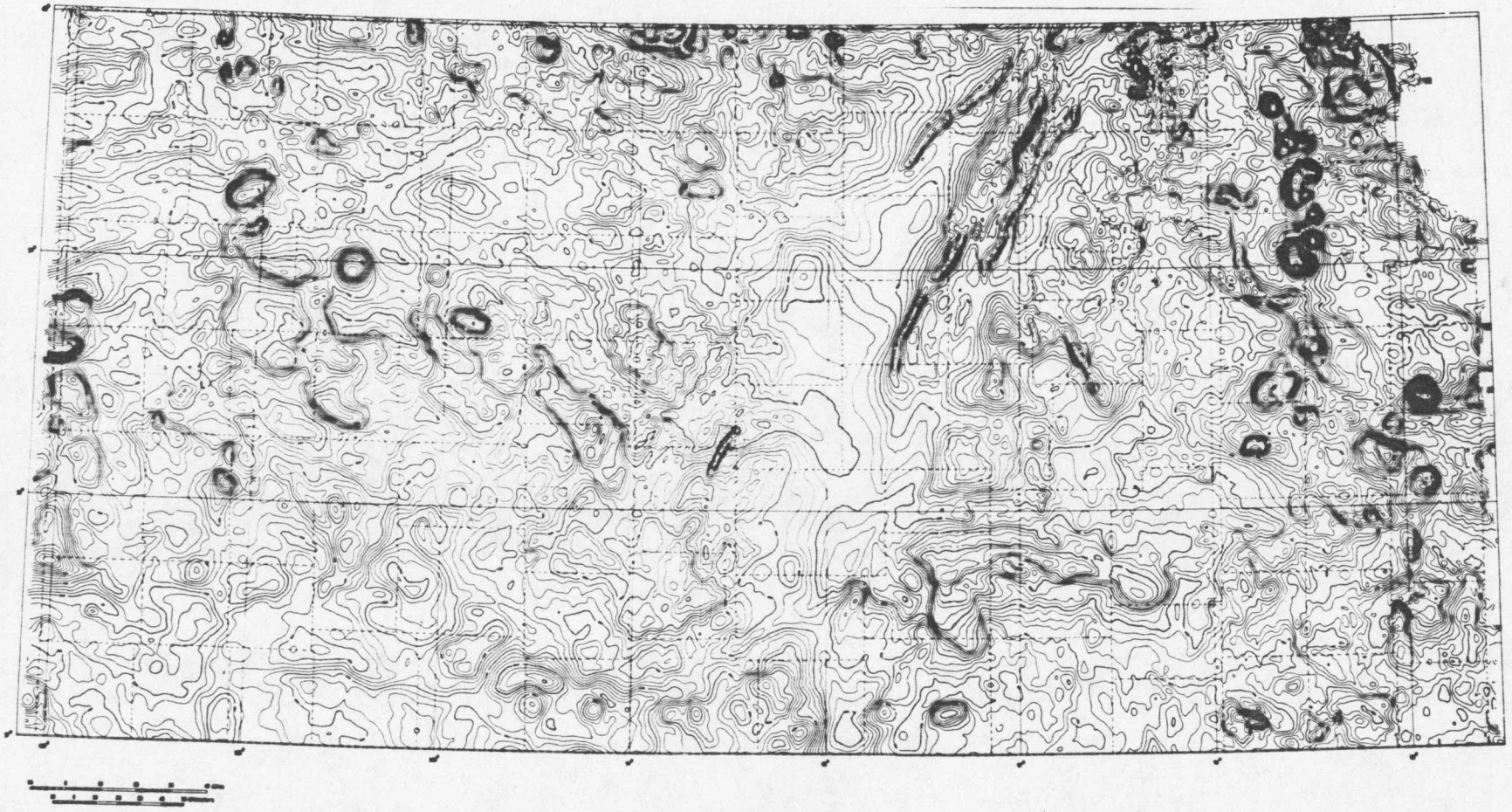


Figure 1

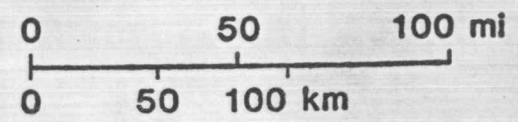
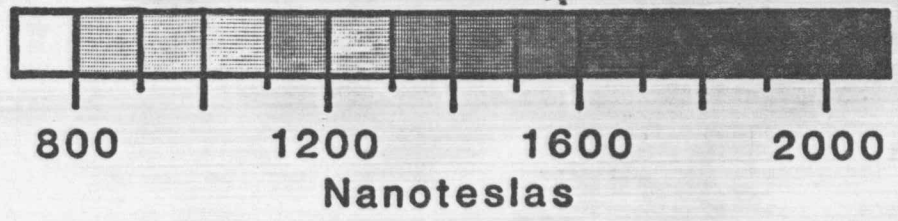
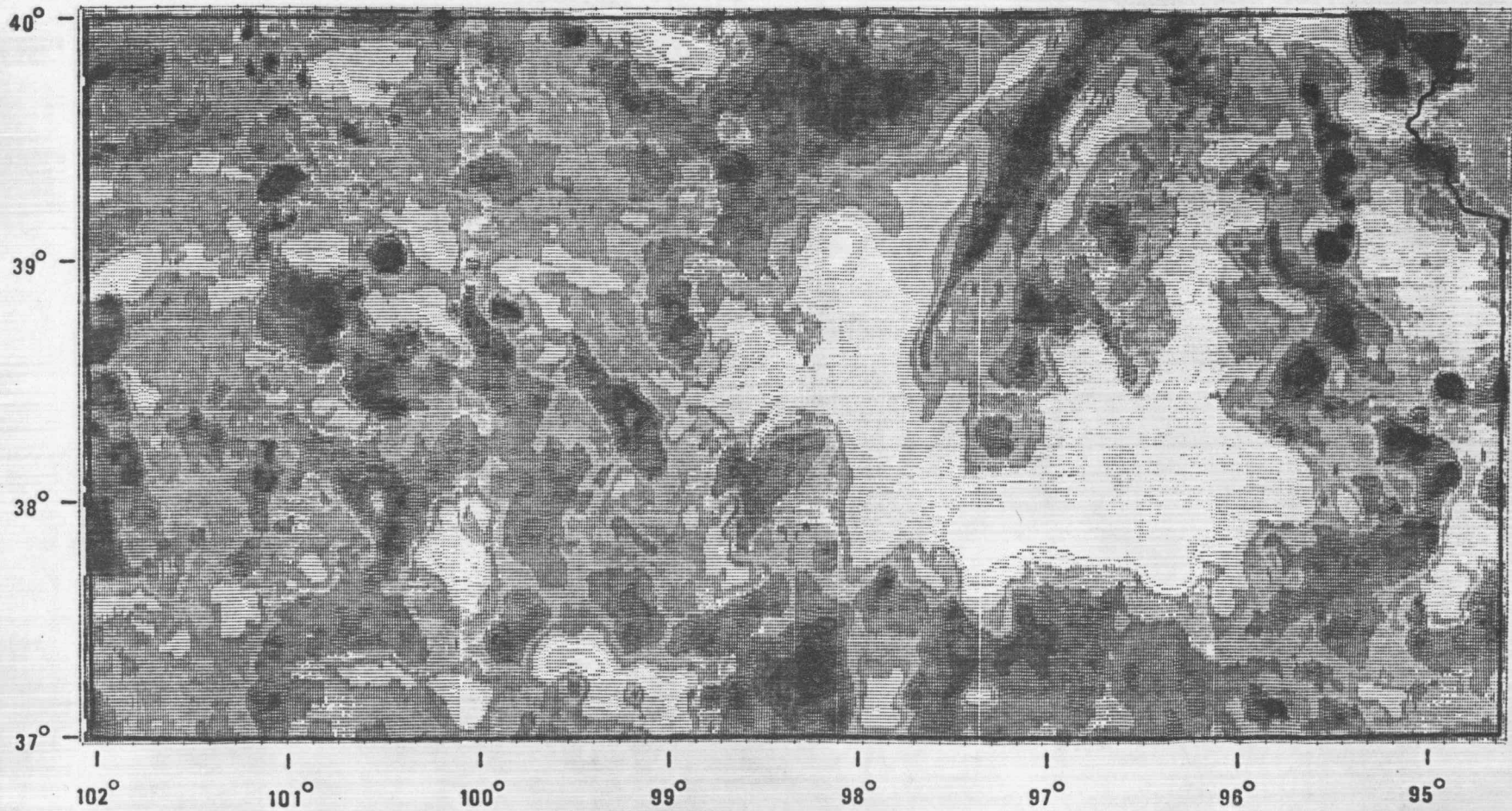


Figure 2

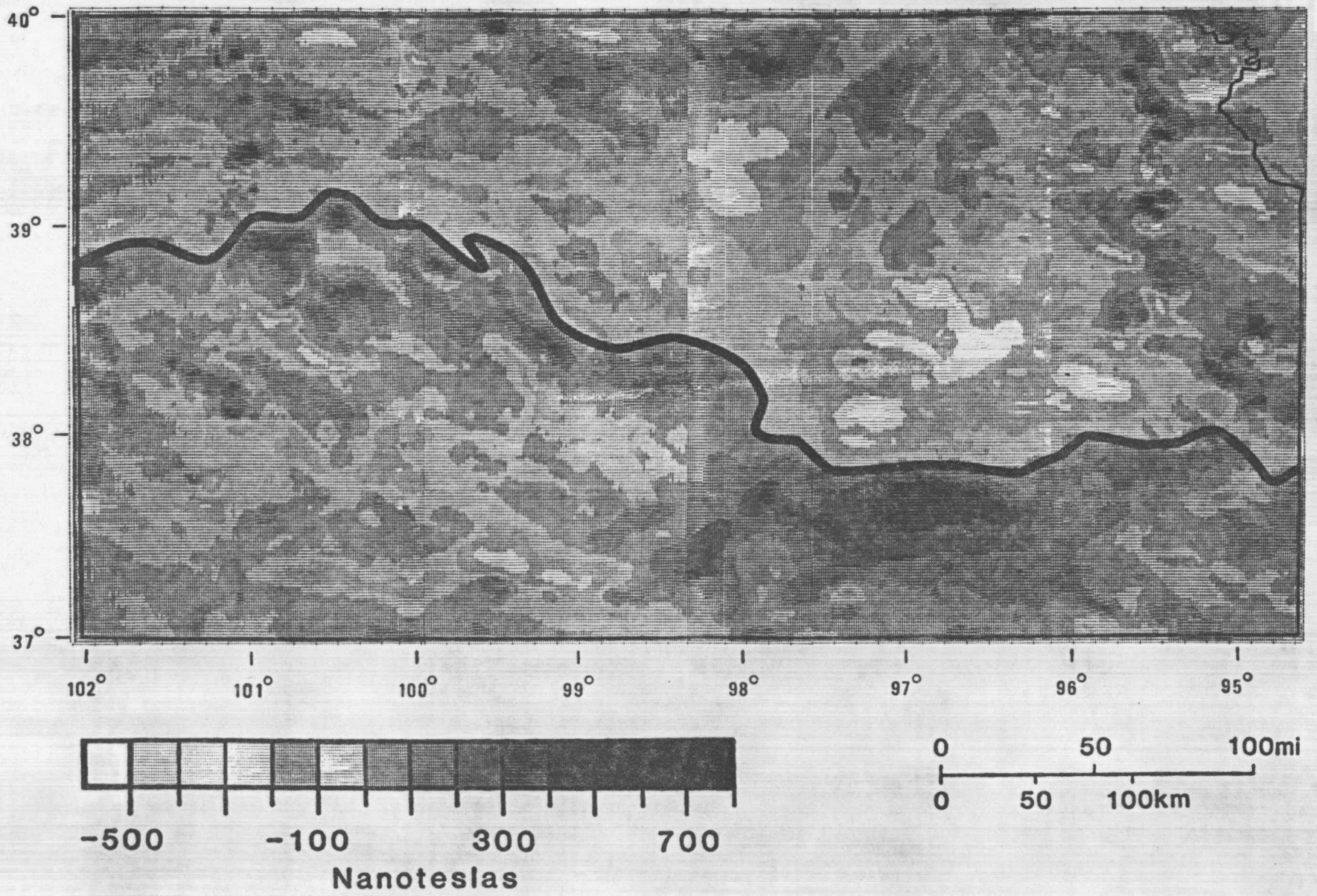


Figure 3

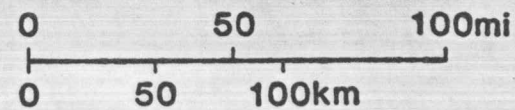
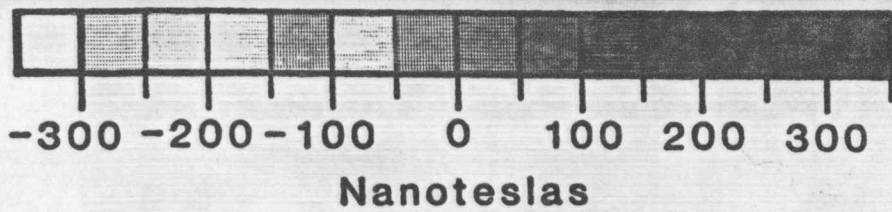
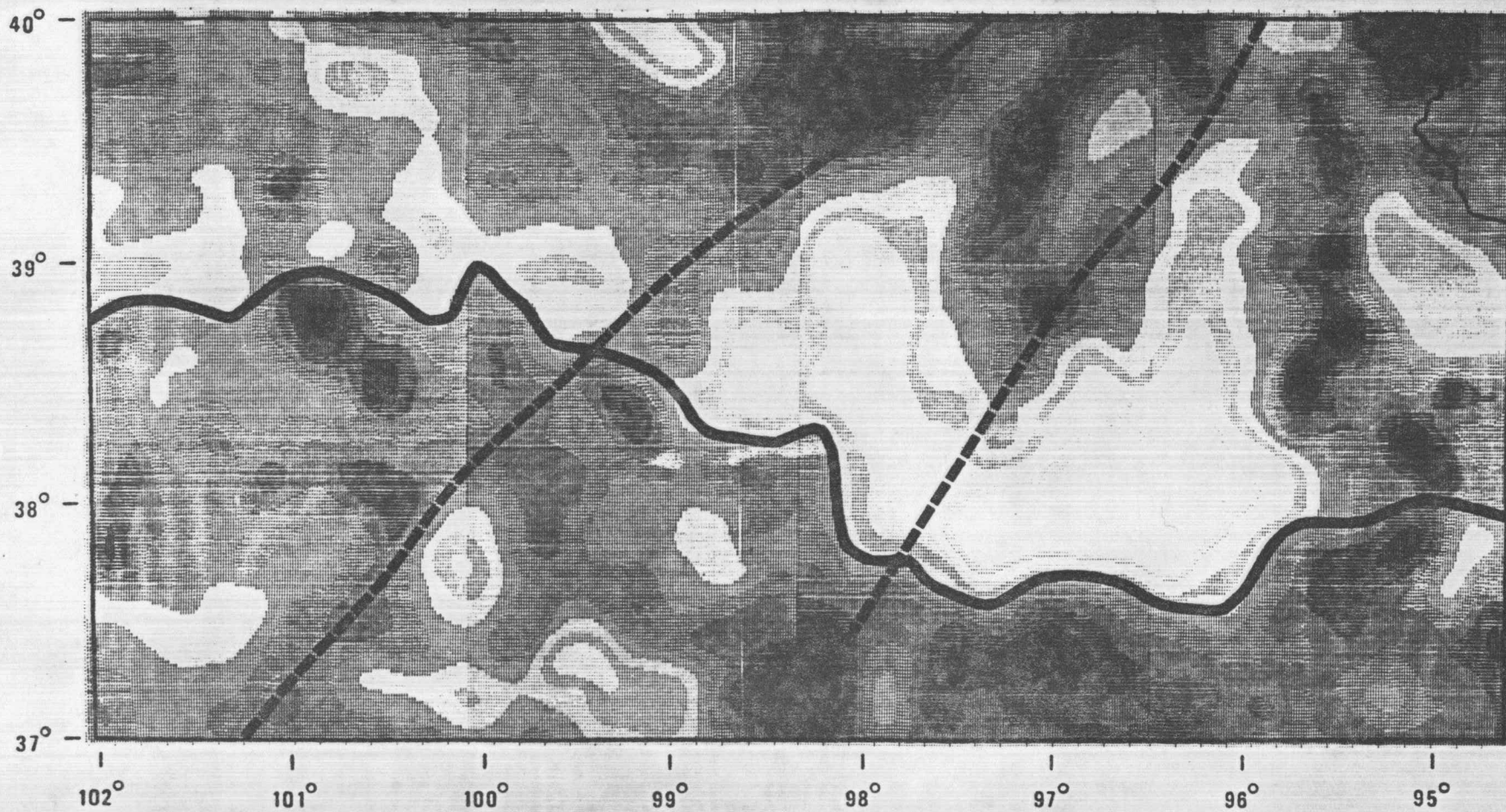


Figure 4

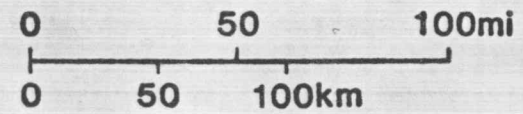
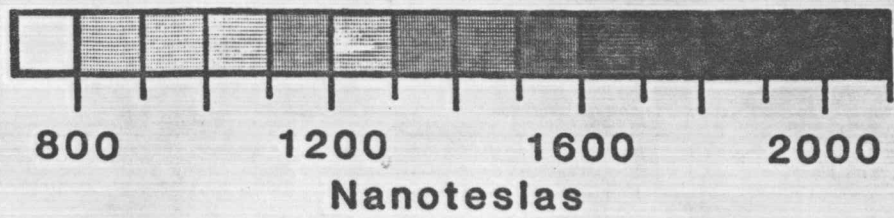
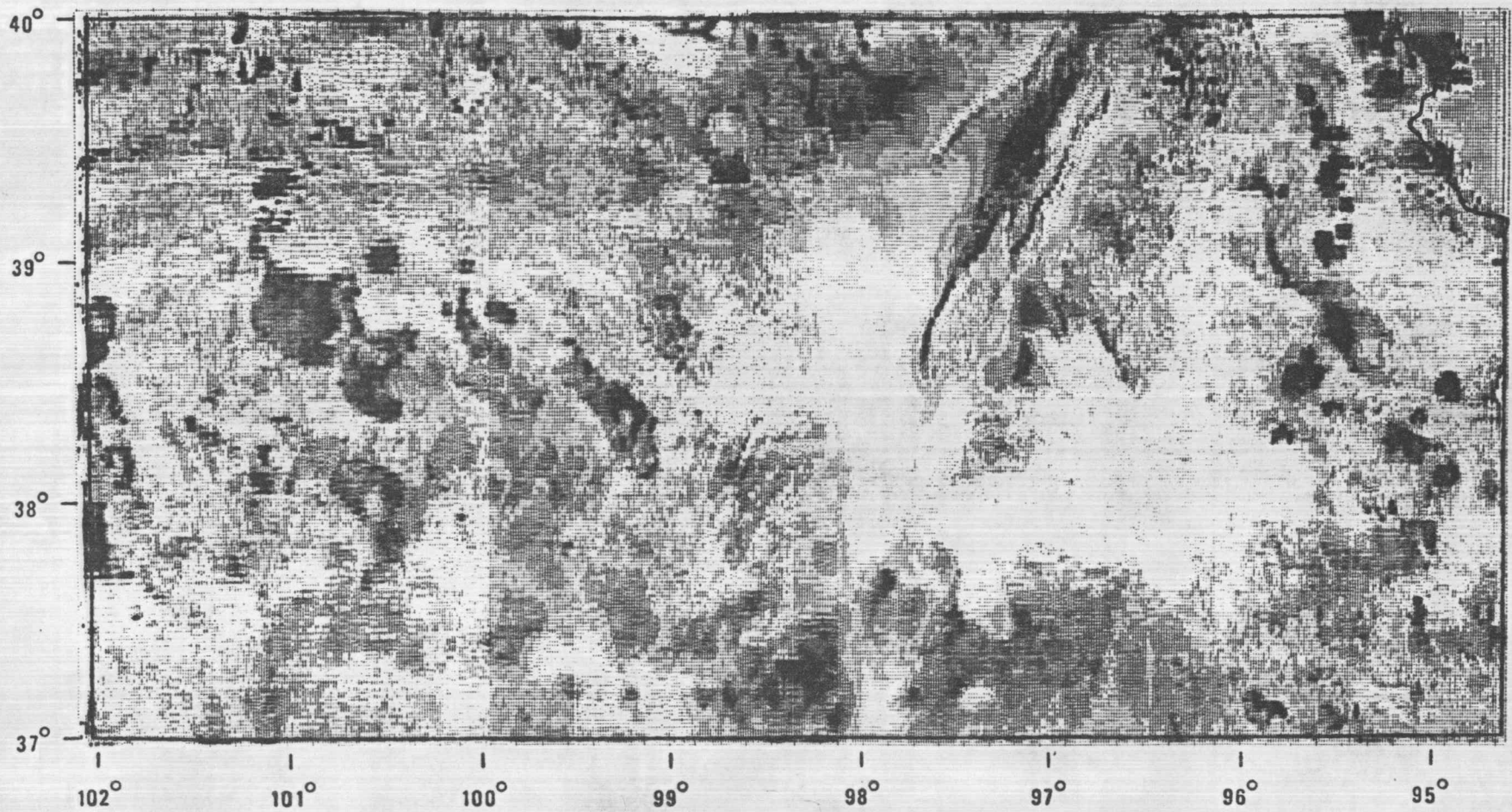


Figure 5

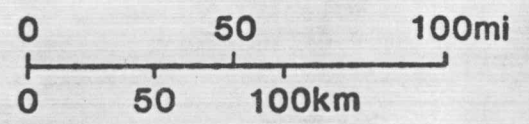
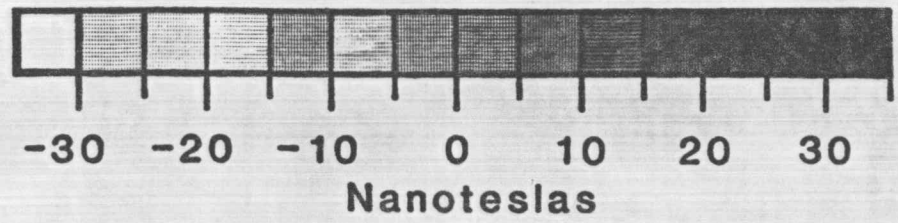
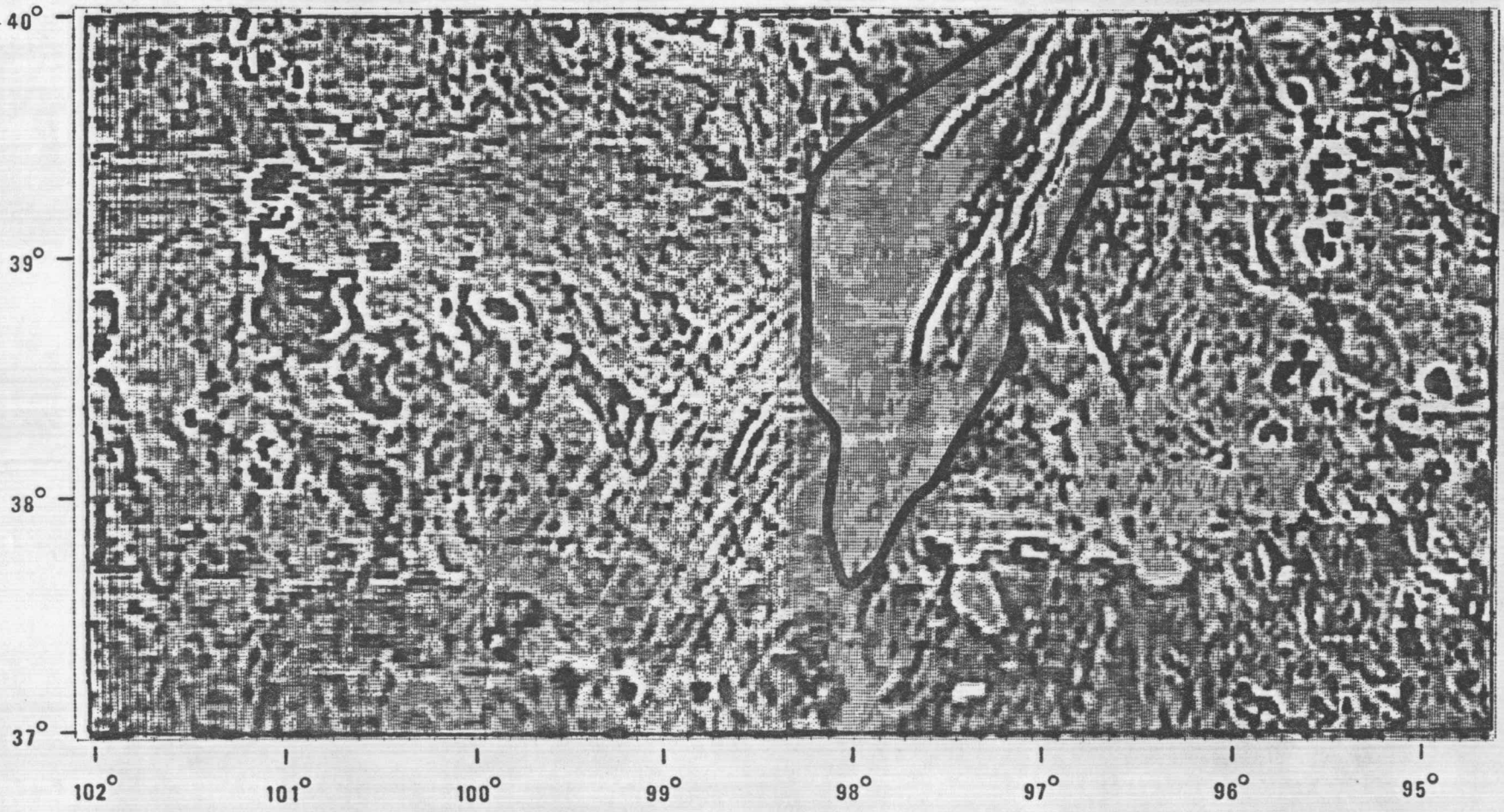


Figure 6

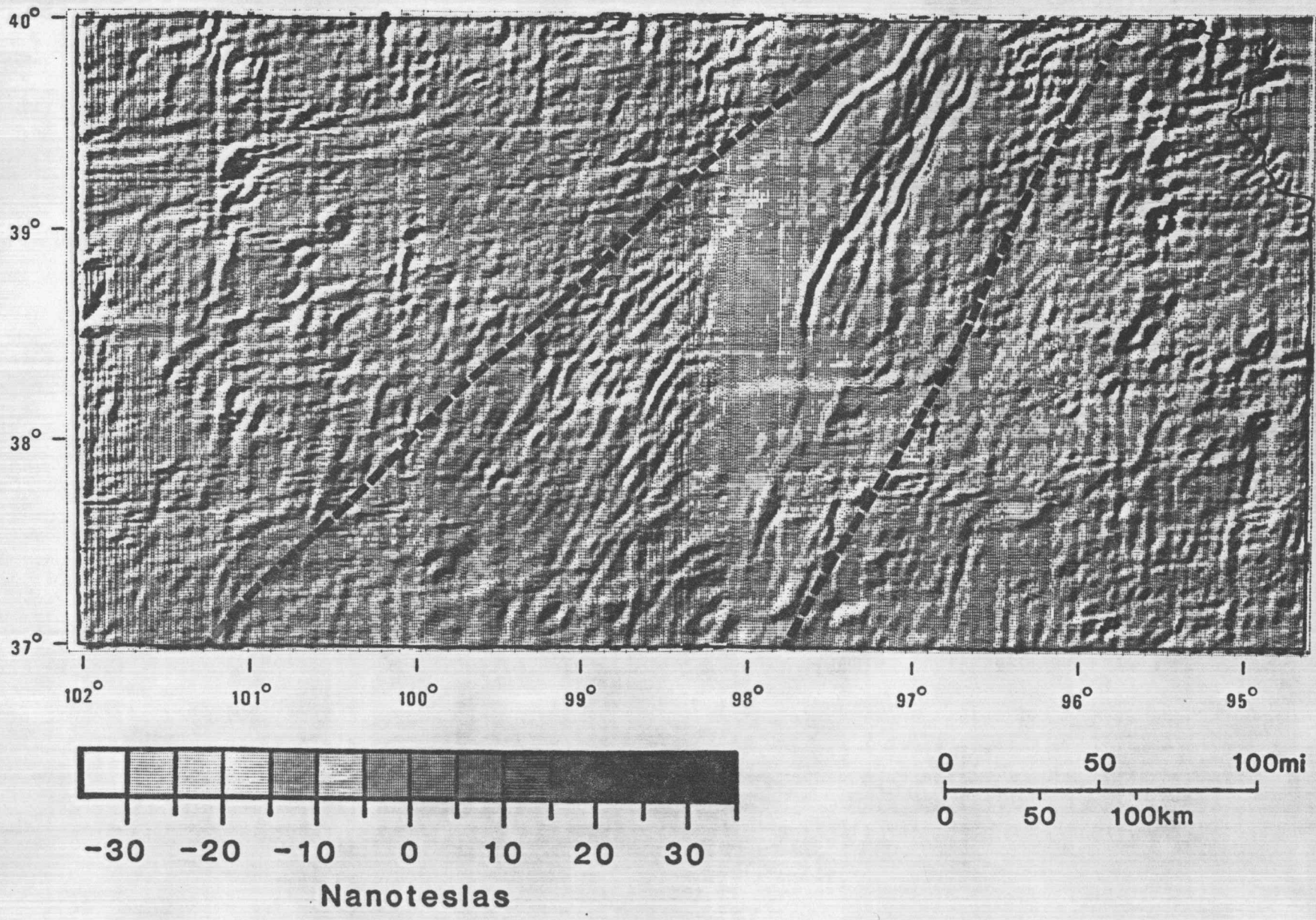


Figure 7

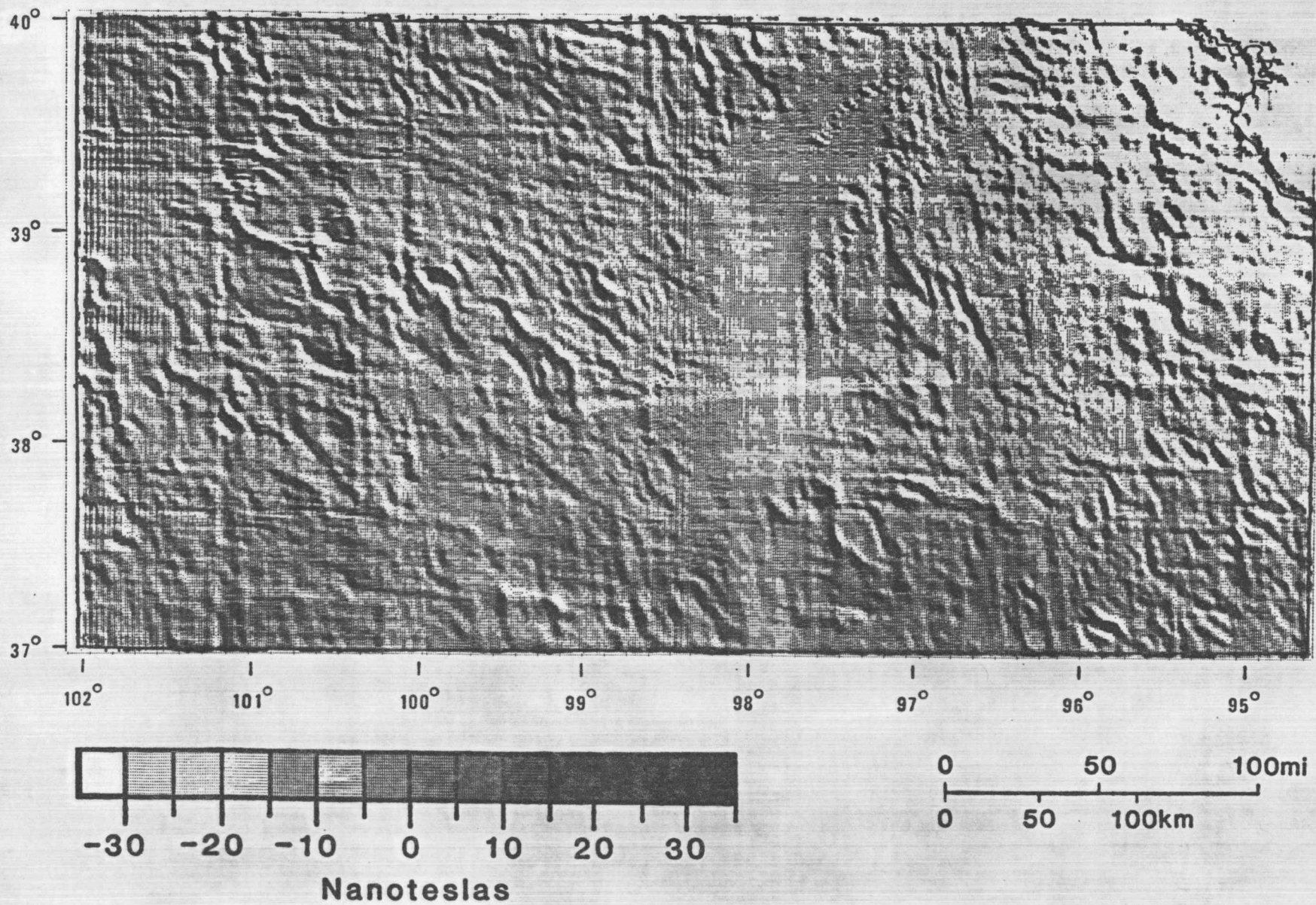


Figure 8

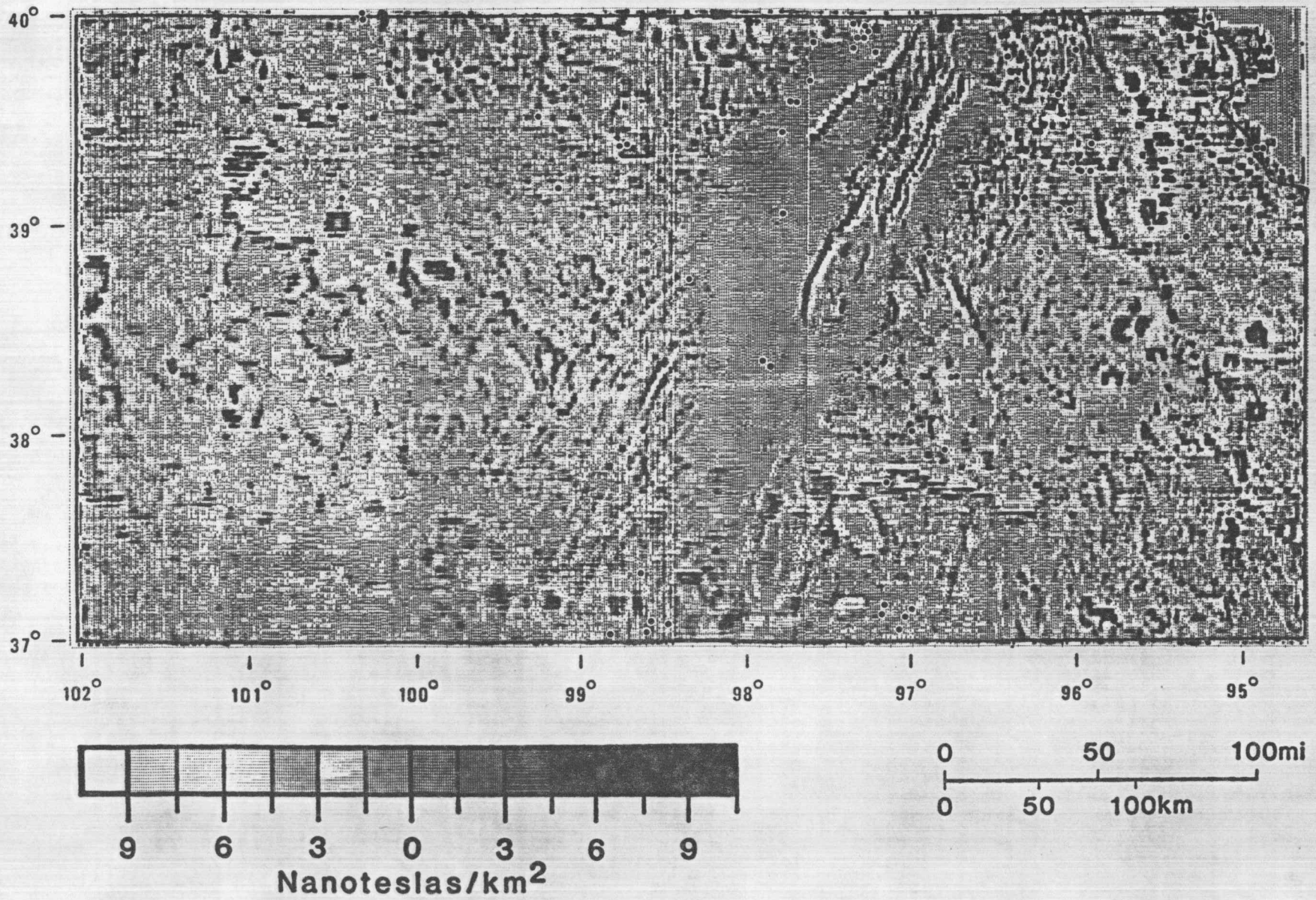


Figure 9

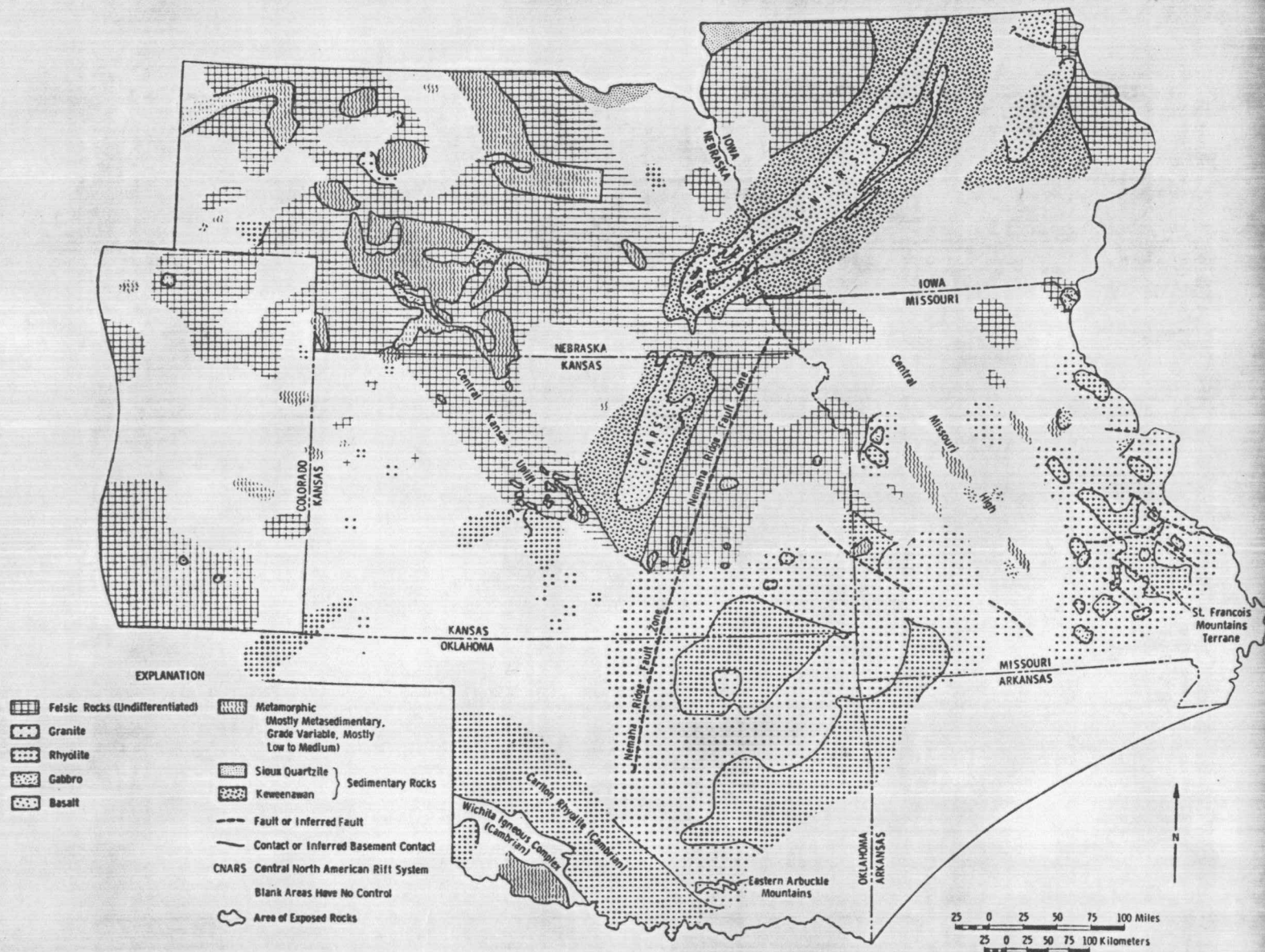


Figure 10

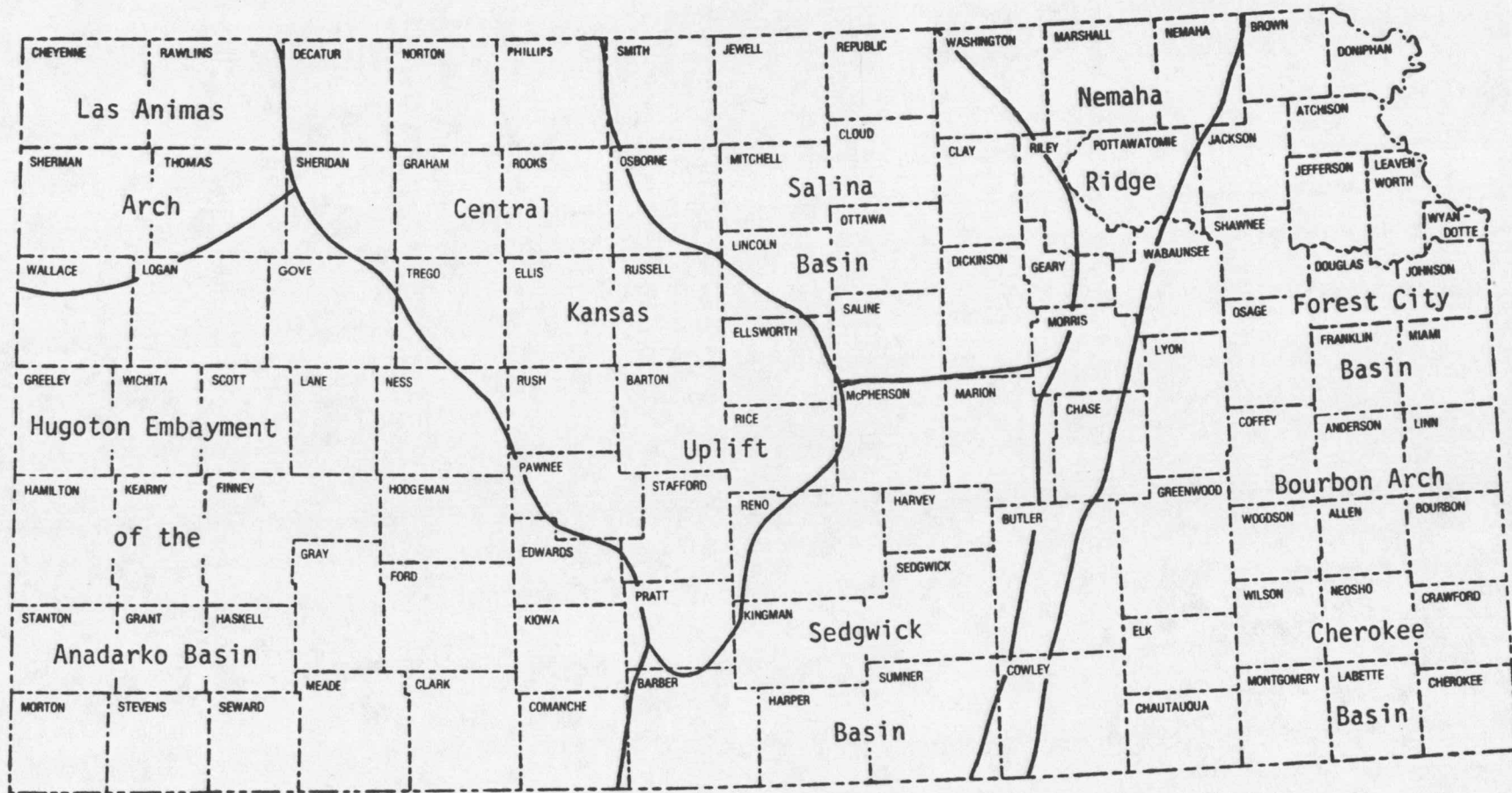


Figure 12

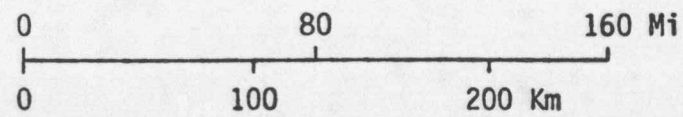
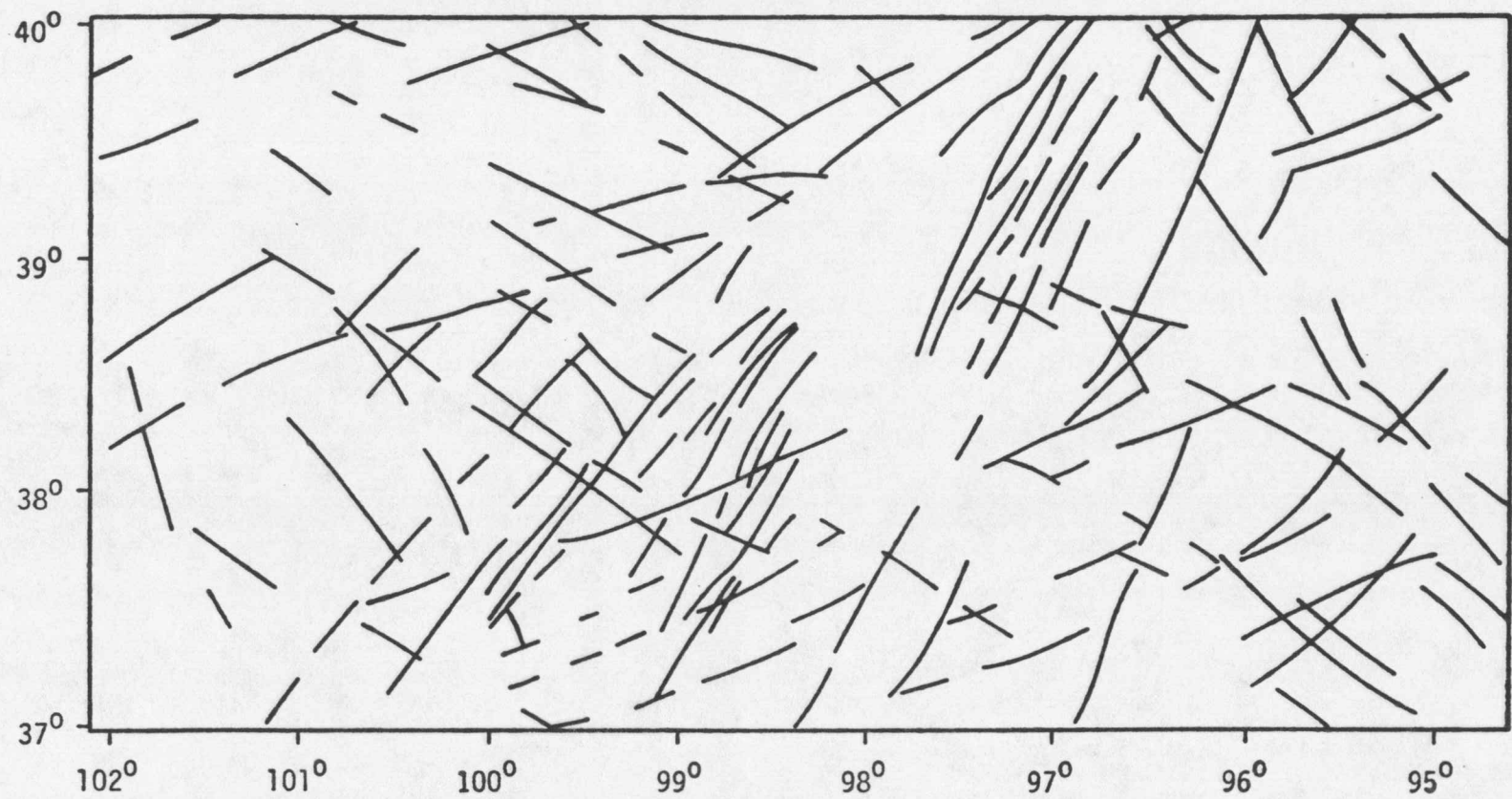
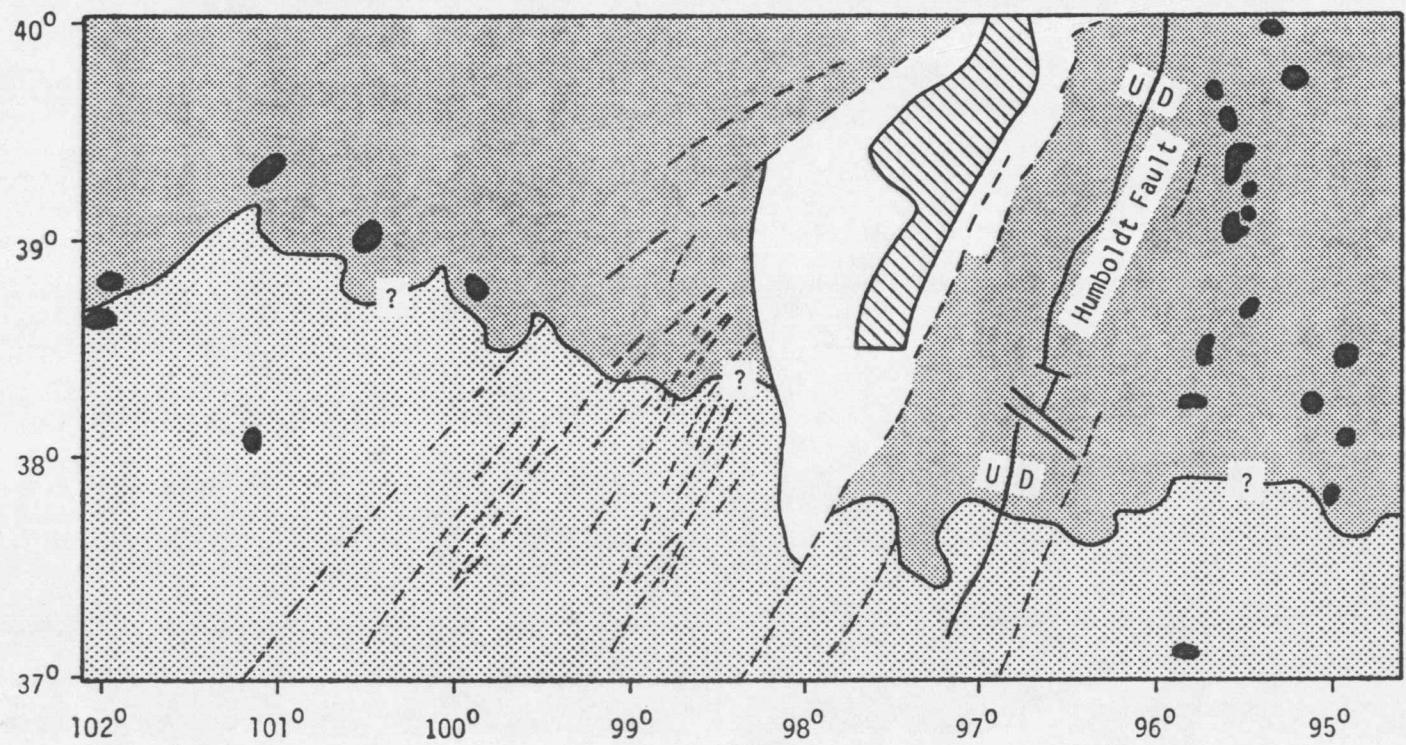








Figure 13



-  Mesozonal granite (~1625 my)
-  Epizonal granite (~1400 my)
-  Gabbro (~1100 my)
-  Arkosic sandstone (~1100 my)
-  Epizonal granitic intrusives
(~1350 my based on two drill
holes in eastern Kansas)
-  Possible rift-related basement
faults suggested from magnetic
lineations

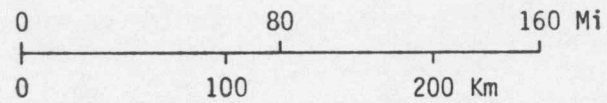


Figure 14