General Disclaimer

One or more of the Following Statements may affect this Document

- This document has been reproduced from the best copy furnished by the organizational source. It is being released in the interest of making available as much information as possible.

- This document may contain data, which exceeds the sheet parameters. It was furnished in this condition by the organizational source and is the best copy available.

- This document may contain tone-on-tone or color graphs, charts and/or pictures, which have been reproduced in black and white.

- This document is paginated as submitted by the original source.

- Portions of this document are not fully legible due to the historical nature of some of the material. However, it is the best reproduction available from the original submission.

Final Report

THE SOUTH-CENTRAL UNITED STATES MAGNETIC ANOMALY

Prepared by

Patrick J. Starich
Geophysics Section
Department of Geosciences
Purdue University
West Lafayette, IN 47907

for the

Principal Investigators

William J. Hinze and Lawrence W. Braile
Department of Geosciences
Purdue University
West Lafayette, IN 47907

June, 1984

THE SOUTH-CENTRAL UNITED STATES

MAGNETIC ANOMALY

A Thesis

Submitted to the Faculty

of

Purdue University

by

Patrick James Starich

In Partial Fulfillment of the

Requirements for the Degree

of

Master of Science

August 1984

ACKNOWLEDGEMENTS

TABLE OF CONTENTS

LIST OF FIGURES

Appendix
Figure

ABSTRACT

Starich, Patrick James. M.S., Purdue University, August 1984. The South-Central United States Magnetic Anomaly. Major Professor: William J. Hinze.

The South-Central United States Magnetic Anomaly is the most prominent positive feature in the MAGSAT scalar magnetic field over North America. The anomaly correlates with increased crustal thickness, above average crustal velocity, negative free-air gravity anomalies and an extensive zone of Middle Proterozoic anorogenic felsic basement rocks.

The anomaly and the magnetic crust are bounded on the west by the north-striking Rio Grande Rift, a zone of lithospheric thinning and high heat flow in central New Mexico. The anomaly extends eastward over the Grenville age basement rocks of central Texas and is terminated to the south and east at the buried extension of the Ouachita Orogenic System which is the southern edge of the North American craton. The anomaly also extends eastward across Oklahoma and Arkansas to the Mississippi Embayment. A subdued northeasterly extension of the anomaly continues into the Great Lakes region. The feature terminates along the east-west boundary of the felsic terrain in southern Kansas.

Spherical dipole source inversion of the MAGSAT scalar data and subsequent calculation of reduced-to-pole and derivative maps provide additional constraints for a crustal magnetic model which corresponds geographically to the extensive Middle Proterozoic felsic rocks trending northeasterly across the United States. These felsic rocks contain insufficient magnetization or volume to produce the anomaly, but are rather indicative of a crustal zone which was disturbed during a Middle Proterozoic thermal event which enriched magnetic material deep in the crust.

I. INTRODUCTION

The study of long-wavelength magnetic anomalies has become increasingly important in the investigation of the regional structure and composition of the earth's crust. The availability of regional magnetic maps from extensive aeromagnetic surveys and composite magnetic anomaly maps together with the data recorded by global satellite magnetic mapping have revolutionized the study of these long-wavelength anomalies. Magnetic anomaly maps produced from POGO satellite data (Regan et al., 1975; Mayhew, 1982a) and more recently from MAGSAT data (Langel et.al., 1982) are useful for interpreting and correlating magnetic anomalies at satellite elevations with their geotectonic sources in the earth's crust (e.g., Langel, 1982; Frey, 1982; Hinze et al., 1982; Taylor, 1982; von Frese et al., 1982a).

The MAGSAT Scalar Magnetic Field

The MAGSAT $2°$ averaged scalar magnetic field over the central United States is shown in Figure 1. These data, part of a global data set, were collected by the MAGSAT satellite from November 1979 to June 1980 at a mean
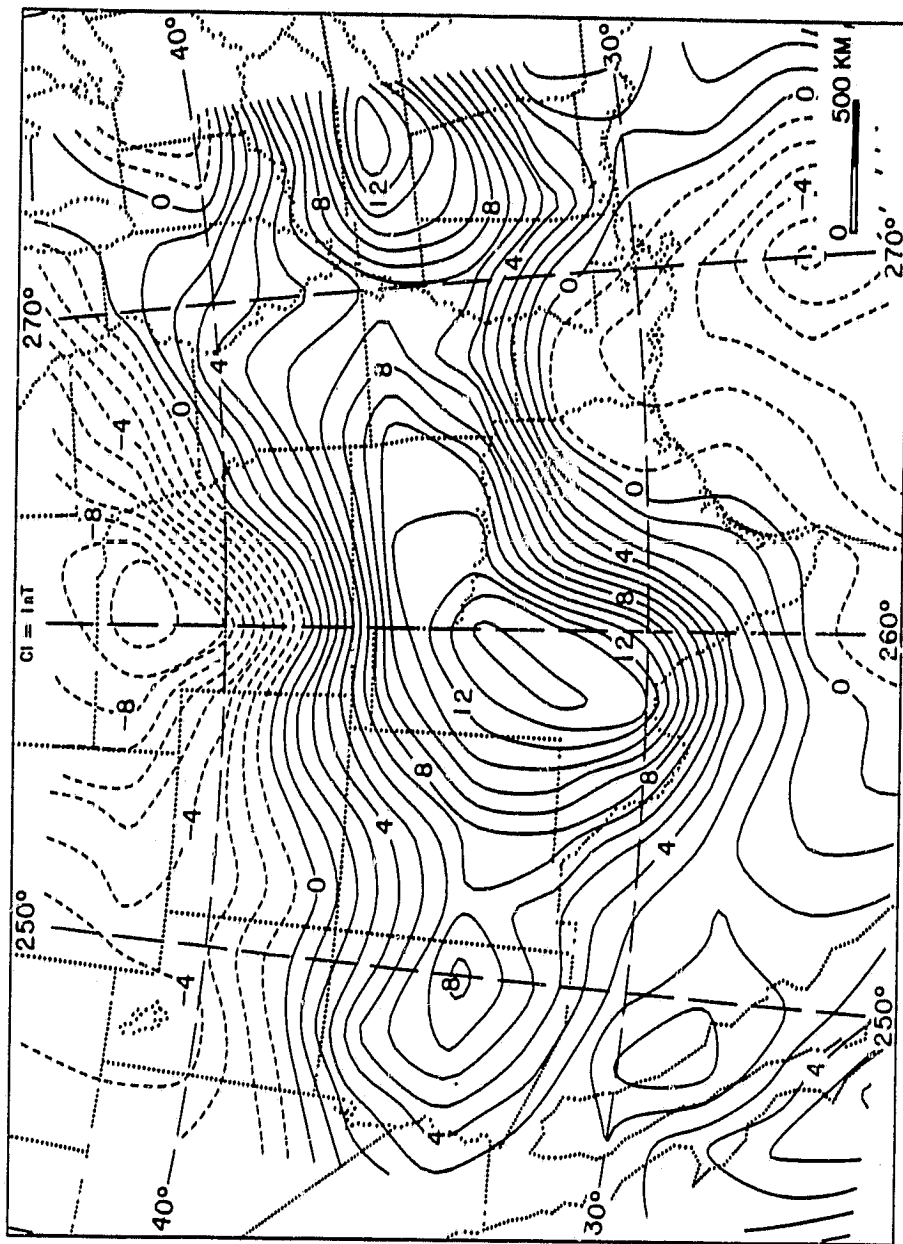
Figure 1. MAGSAT 2° averaged scalar field over the central
United States. Contour interval = 1 nT

elevation of 400 km using instruments which measured both magnetic vector components and total magnetic intensity. The data were processed by scientists at the NASA/Goddard Space Flight Center to isolate quiet-time data and to remove estimates of the earth's main field (core derived) and external fields due to magnetospheric currents (Langel et al., 1982). The scalar data were then averaged over 2° by 2° areas while eliminating spurious data (Langel et al., 1982). The resulting residual field is due to magnetic sources in the earth's crust and has been verified (Schnetzler et al., 1984) over the continental United States by comparison with the recently compiled U.S.G.S./ SEG Composite Magnetic Anomaly Map for the United States (1982).

The MAGSAT Field Over the Central United States

Many of the prominent long-wavelength magnetic features which appear in the MAGSAT field over the central U.S. (Figure 1) were first recognized in POGO data (Regan et al., 1975; von Frese, 1980; Mayhew, 1982) and NOO Project Magnet data (von Frese et al., 1982b; Sexton et al., 1982). The largest magnetic anomaly in the MAGSAT map in Figure 1 is the South-Central United States Magnetic Anomaly (SCUSMA). This extensive positive anomaly attains its highest amplitude over the Texas Panhandle and extends northeast as far as the Great Lakes Region. The SCUSMA could arise from a number of complex geological, structural

and geophysical conditions in the earth's crust, but has not been related to any known crustal elements.

The principal objective of this investigation is to determine the origin of the SCUSMA and to develop a geologically reasonable magnetic crustal model for the anomaly in the MAGSAT scalar field. Assuming that the anomaly is produced by a complex superpositioning of crustal magnetic effects, the problem requires integration of available regional geological and geophysical information and application of a variety of processing and enhancement techniques to constrain and refine a magnetic model of the earth's crust.

II. GEOLOGIC SETTING

The South-Central United States Magnetic Anomaly lies over the southern portion of the North American craton. Rifting has affected several areas of the craton during Precambrian and Phanerozoic time, but otherwise the cratonic interior has remained relatively stable since Precambrian time with most tectonism restricted to slow, broad vertical movements. The eastern, southern and western margins of the craton have undergone periods of extensive orogenesis since the end of Precambrian time. Direct knowledge of basement geology is limited to a relatively small number of drill holes which have penetrated the Phanerozoic sedimentary cover and a few areas where crystalline basement rocks are exposed at the surface. This information has been augmented by critical interpretation of geophysical information which has revealed much about the basement geology of North America. The complex basement rocks which compose the southern portion of the craton provide important evidence of the magnetic sources which produce the SCUSMA and should also provide useful contraints for developing a crustal magnetic model.

Major Tectonic Elements

Figure 2 illustrates the major tectonic elements that lie within the study area. The stable craton is bounded to the south and east by the Ouachita and Appalachian Orogenic Systems, and to the west by the Rocky Mountain Uplift and the Rio Grande Rift. Several episodes of rifting are apparent from the distribution of rifts in Figure 2, but the craton has remained relatively stable since Precambrian time. This complex configuration of tectonic elements should provide insight into the magnetic sources contained within the crust of the central United States.

The Appalachian Orogenic System borders the eastern Midcontinent of the United States, and flanks the Grenville terrain which lies to the west. This extensive belt developed as a geosynclinal sedimentary trough along the eastern limit of the Grenville rocks during the opening of the proto-Atlantic ocean in early Paleozoic time (King, 1977). The sedimentary trough later evolved into a complexly folded and intruded mountain belt along the convergent North American plate boundary which eventually collided with the African plate by Middle to Late Paleozoic time. The Appalachian Orogenic System is present only in the extreme southeast portion of the study area.

The Ouachita Orogenic System, probably an extension of the Appalachian System (Thomas, 1976), also developed along the early Paleozoic edge of the continent as a geosynclinal
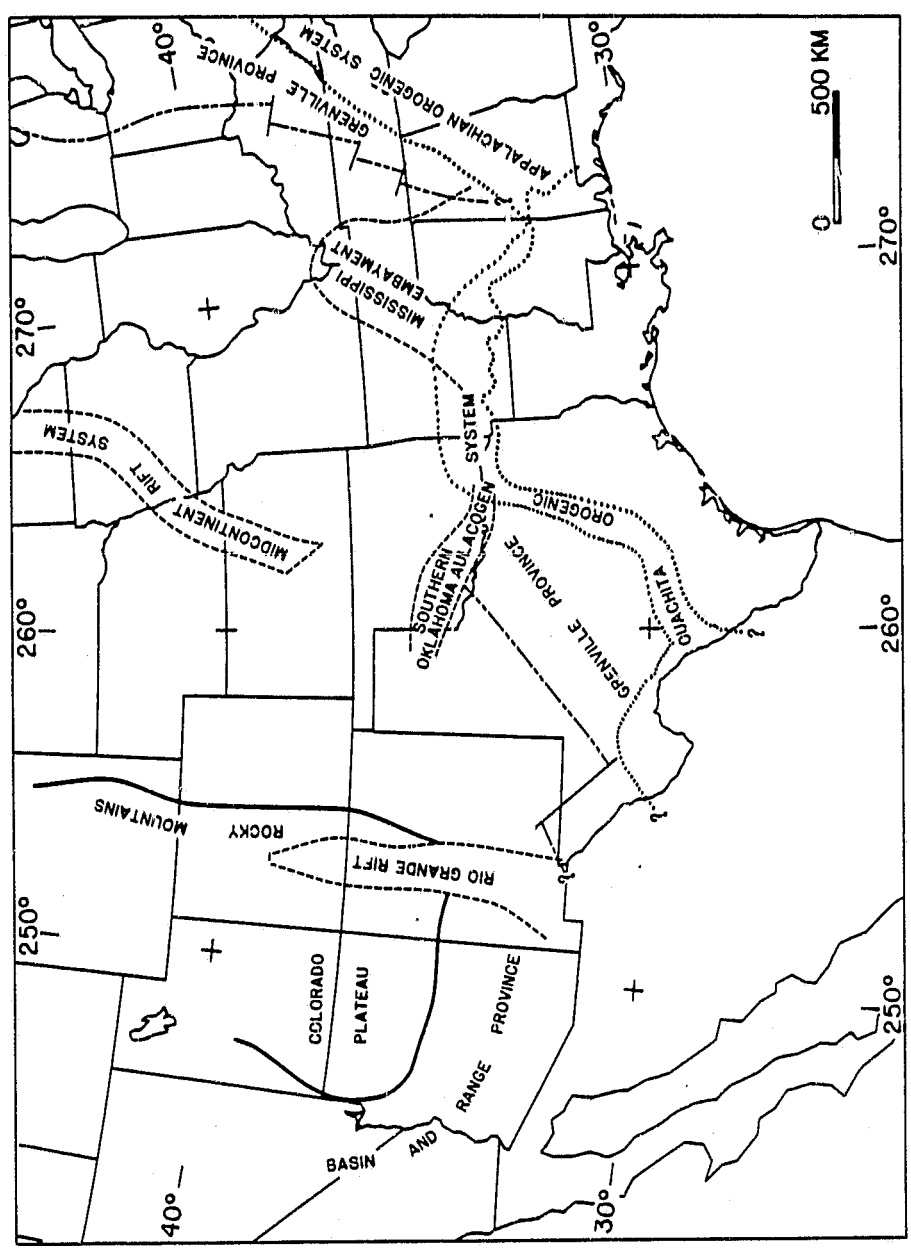
Figure 2. Major tectonic elements of the central United States (after King. 1977).

trough and was later deformed by plate convergence in Middle Paleozoic time (King, 1977; Dickinson, 1984). The Ouachita System is only exposed in parts of southeast Oklahoma, western Arkansas, and west Texas. Its position in the subsurface of the Gulf Coast of Texas remains elusive, although attempts have been made to trace it in the subsurface (Keller and Cebull, 1973). Even with the information provided by surface outcrops and geophysical data, most of the Ouachita System shown in Figure 4 can only be inferred as deep well control is extremely sparse. If the complex igneous and metamorphic rocks that appear at surface outcrops persist along this orogenic belt, interpretation of the MAGSAT scalar field may be useful in tracing the buried Ouachita System (Mayhew and Galliher, 1982).

The Southern Oklahoma Aulacogen developed in Late Precambrian or Early Cambrian time and is probably associated with the initial rifting of the proto-Atlantic (Dickinson, 1984). This northwest trending feature contains a complex of igneous rocks and rift-related sedimentary rocks and was reactivated during Middle to Late Paleozoic time as a consequence of the Ouachita Orogeny (King, 1977; Dickinson, 1984). The aulacogen extends from southern Oklahoma into the Texas panhandle and southern Colorado (Keller et al., 1983)

The Rio Grande Rift is an area of thinned lithosphere, high heat flow, and continental rifting in central New

Mexico (Dickinson and Snyder, 1979; Dickinson, 1984; Wasilewski and Mayhew, 1982). The rift trough is filled with interlayered basalt and sediments and began to form in Late Oligocene time with rifting culminating by Late Miocene time (Dickinson and Snyder, 1979). Dickinson and Snyder (1979) have related the rifting event with the upwelling of low density mantle through a slab free window which formed during the subduction of the Pacific Farallon plate and the developement of the San Andreas Transform fault.

The Colorado Plateau is a large area of uplifted crust in northern Arizona, northwestern New Mexico, eastern Utah and southwest Colorado. Dickinson (1984) has noted that the elevation of the plateau is not entirely due to its thickness, and suggests that this massive uplift is underlain by more bouyant mantle material. The Colorado Plateau area coincides with a significant positive anomaly in the MAGSAT scalar field (see Figures 1 and 4) over Arizona.

The Basin and Range Province bounds the Colorado Plateau to the south and west. An extensional tectonic area, the Basin and Range is characterized by its thinned crust, horst and graben faulting, tilted blocks and basaltic volcanism extending throughout southern Arizona, southern California, and Nevada (Dickinson, 1984). The uplift of the Colorado Plateau and the developement of the Basin and Range Province have occurred since Middle Miocene time (< 15 m.y.) (Dickinson, 1984; Dickinson and Snyder, 1979).

The Rocky Mountains, an area of massive crustal thrusting and uplift, developed during the Laramide Orogeny which began in Late Cretaceous time and continued until Late Eocene time. This major topographic feature extends from New Mexico north through Colorado, Utah, Wyoming, Idaho, Montana and into Canada. Dickinson (1984) suggests that the contractional basement tectonics related to the subducting Pacific-Farallon plate maybe responsible for the major uplifts and thrusts of the Rocky Mountain region.

The Mississippi Embayment is an area of thick sedimentary accumulation which extends north from the Gulf Coast area of Louisiana and Mississippi along the Mississippi River valley and into southern Missouri and southern Illinois. It is generally believed that the Mississippi Embayment formed during the Mesozoic reactivation of the Reelfoot Rift zone which developed during the Precambrian in association with an extensive rifting event which led to the developement of the proto-Atlantic (Ervin and McGinnis, 1975; Keller et al., 1983). Evidence for this interpretation has developed in the form of potential field models (von Frese et al., 1981; Ervin and McGinnis, 1975; Austin and Keller, 1979).

Basement Geology

Figure 3 is a generalized map of the basement lithologies present in the study area, which was compiled
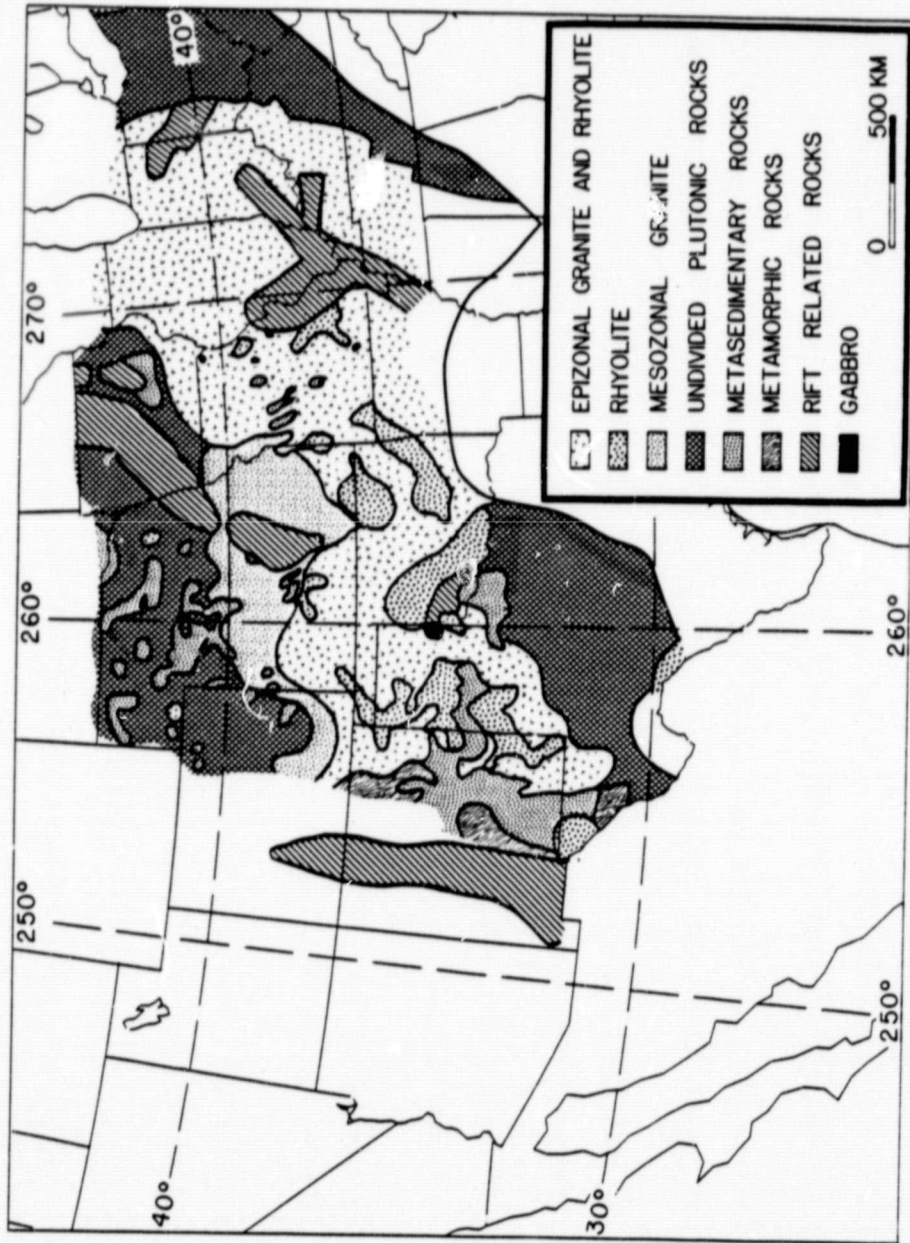
Figure 3. Basement lithology of the central United States (after Van Schmus and Bickford, 1981, Denison et al., 1984, Hinze et al., 1984).

from a variety of sources (Van Schmus and Bickford, 1981; Denison et al., 1984; Hinze et al., 1984). These data were originally gathered from scattered drill holes, outcrops and interpretation of geophysical data. Figure 4 is an age province map which was compiled largely from work presented by Van Schmus and Bickford (1981) and Denison et al. (1984). The age province map shows that virtually all the rocks which compose the basement are Precambrian in age.

An Early Proterozoic (1.6 to 1.8 b.y.) igneous and metamorphic terrain underlies most of Nebraska, northern Kansas, western Iowa, northwest Missouri and eastern Colorado (Figures 3 and 4) (Denison et al., 1984; Van Schmus et al, 1981). According to Van Schmus et al. (1981) these rocks include a wide variety of metasedimentary and metavolcanic rocks in addition to plutonic rocks which are dominated by felsic varieties which range from tonalite to granite. Both Silver et al. (1977) and Van Schmus et al. (1981) suggest that this terrain may be composed of two belts of similar composition, a 1.7 to 1.8 b.y. belt to the north and a younger belt about 1.61 to 1.68 b.y. in age lying immediately to the south. The two belts have been lumped into one terrain for this study, as they both have similar composition and age. An area of granitic gneiss (> 1.6 b.y.), metasedimentary, and metavolcanic rocks underlies much of eastern New Mexico. These rocks lie within the
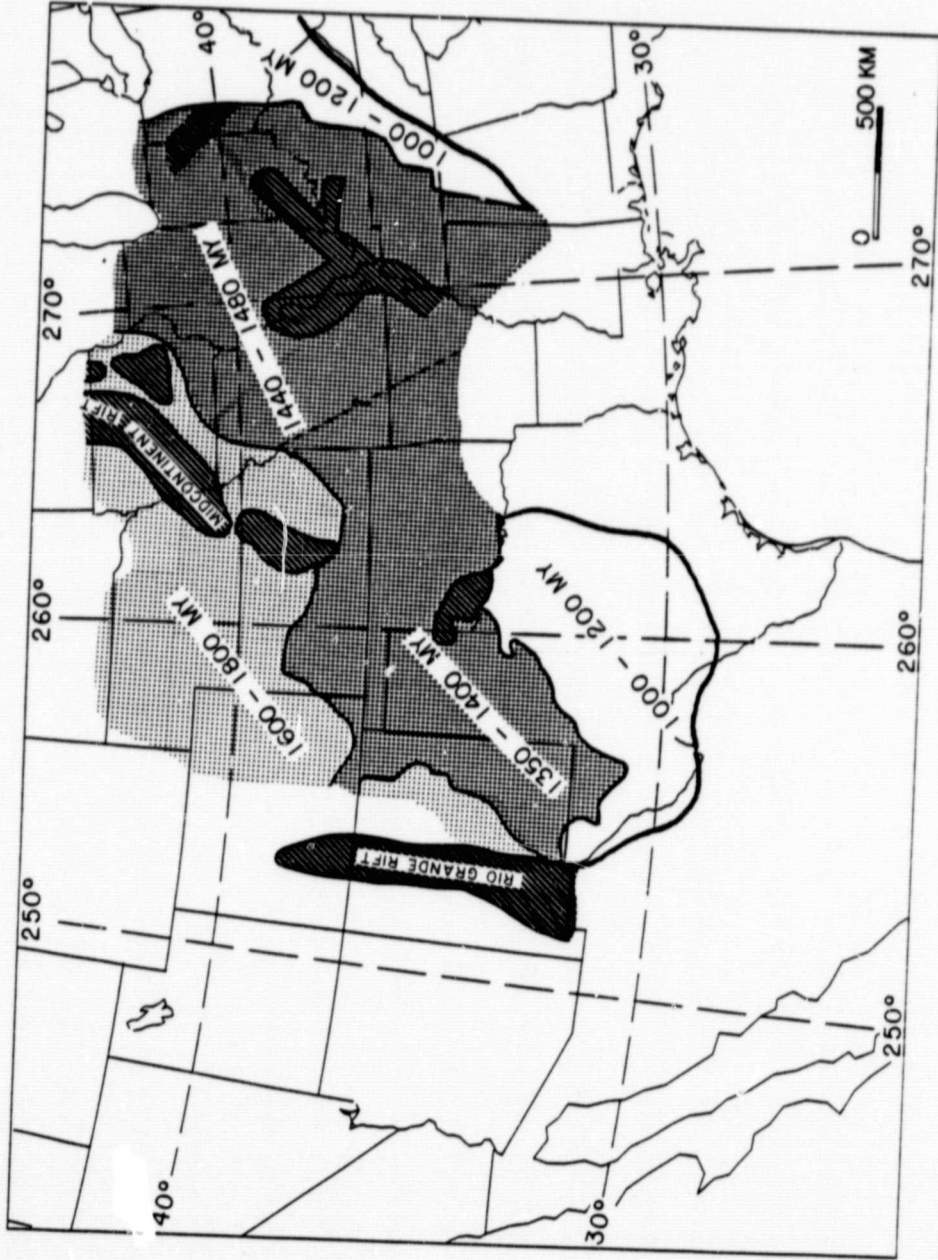
Figure 4. Basement age provinces of the central United States (after Van Schmus and Bickford, 1981).

SCUSMA and may be area of the SCUSMA and may be related to the early Proterozoic terrain to the north (Van Schmus et al., 1981).

A younger belt of Middle Proterozic (1.2 to 1.5 b.y.) igneous rocks extends from central Wisconsin southwest across the Midcontinent as far as central Arizona and southern California (Figures 3 and 4) (Denison et al., 1984). This terrain is chiefly composed of undeformed epizonal and mesozonal granite plutons, and rhyolites with an almost complete absence of mafic or intermediate type rocks (Denison et al., 1984; Van Schmus et al., 1981). Some of the granite plutons intrude the older Proterozoic terrain to the north and west (Van Schmus et al., 1981). Van Schmus et al. (1981) note that the plutons decrease in age from nearly 1.5 b.y. in central Wisconsin to approximately 1.2 b.y. in the southwestern United States. These rocks appear to underlie most of Texas, northeastern New Mexico, Oklahoma, southern Kansas, northern Arkansas, and Missouri (Dension et al., 1984; Yarger, 1983). The same geologic terrain extends into central Iowa, Illinois, Indiana and western Ohio where it terminates at the Grenville Front (Denison et al., 1984).

Subsurface extensions of the Canadian Grenville Province (1.1 b.y.) underlie much of the eastern Midcontinent (Figure 3). Grenville age terrain also outcrops in the Llano Region of central Texas and extend as far as the Marathon Uplift area of west Texas along the

southeast border of the Middle Proterozoic terrain (Figures 3 and 4) (Denison et al., 1984; Hinze et al., 1984; King, 1977).

The rocks of the Cambrian (510 to 530 m.y.) Wichita Mountains igneous complex of south-central Oklahoma include epizonal granite, layered gabbro, rift related rhyolites and basalts as well as metasedimentary rocks (Denison et al., 1984; King, 1977; Hinze et al., 1984).

Rift related igneous and sedimentary rocks occur in the basement of several large zones of the study area (Figure 3). Igneous rocks may include felsic varieties, but mafic flows are the most common. Sedimentary rocks are commonly graywackes derived from igneous rocks. The Keweenawan (1.1 b.y.) Midcontinent Rift System is the most extensive of the rifted areas and trends southwest out of the northern Great Lakes region through Minnesota and into central Kansas. The Cambrian Carlton Rhyolite of the Southern Oklahoma Aulacogen trends northwest through southern Oklahoma and into the Texas panhandle, flanking the Wichita Mountains igneous complex (Denison et al., 1984; Dickinson, 1984). The youngest of the rift related igneous rocks occur in the Cenozoic Rio Grande Rift Area of central New Mexico. The zone is a graben faulted trough containing mafic volcanic rocks interlayered with associated sediments. The region has been determined to be a zone of lithospheric thinning and elevated heat flow (Keller et al., 1979) related to the extensional tectonics

which characterize much of the southwestern United States (Dickinson, 1984). The Reelfoot Rift zone which occurs along the axis of the Mississippi Embayment was first recognized by Ervin and McGinnis (1975) as an aulacogen or failed rift arm. The rift formed during Precambrian time with the opening of the proto-Atlantic and was reactivated during Mesozoic time (Keller et al., 1983). Additional rift zones, inferred from potential field and seismic data and well control occur in eastern Illinois, eastern Indiana, Ohio, Kentucky, and Tennessee (Denison et al., 1984).

III. GEOPHYSICAL DATA

Several previously compiled geophysical data sets are useful in constraining and interpreting the magnetic sources which produce long-wavelength anomalies. These include a variety of potential field data and crustal seismic studies for most of United States. In some cases, these data have been reprocessed and recompiled to facilitate their correlation with the magnetic and geologic data. This section is an examination of these geophysical data in order to clarify their usefulness for constraining a magnetic model of the crust.

Composite U.S. Magnetic Anomaly Map Data

Figure 5 is an illustration of the Composite U.S. Magnetic Anomaly Map (Hinze and Zietz, 1984) recently compiled by the U.S. Geological Survey and the Society of Exploration Geophysicists (1982). The magnetic anomalies cover a broad range of both intensity and wavelength. The magnetic signature in the central United States is dominated by a long wavelength anomaly superimposed with numerous shorter wavelength features with higher intensities. The long wavelength component correlates well

Figure 5. Composite Magnetic Anomaly Map (C.M.A.M.) of the Conterminous United States (U.S.G.S./SEG, 1982). Contour interval = 2 nT.

SCALE : km

0   500   1000

with the distribution of the Middle Proterozoic felsic terrain across the central United States, the Grenville age rocks in central Texas and the metamorphic rocks of eastern New Mexico and west-central Texas. The shorter wavelength anomalies may be produced by individual near surface epizonal plutons which exist within the basement terrain (Denison et al., 1984; Yarger, 1982).

The U.S. Composite Magnetic Anomaly Map (C.M.A.M.) has been digitized and recalculated at elevations of 160 km., 320km. and 400km. (Figures 6, 7, and 8 respectively) by Schnetzler et al. (1984). These versions of the map are smoother and reduced in amplitude due to their increased distances from the crustal sources.

Schnetzler et al. (1984) have examined the differences between these versions of the Composite Magnetic Anomaly Map and the MAGSAT field derived by Mayhew and Galliher (1982), to test the validity of the MAGSAT data. After removing a long-wavelength component and upward continuation of the C.M.A.M. data to satellite elevations, a gennerally good correspondence with the MAGSAT data was shown to exist. Schnetzler et al. (1984) concluded that major descrepancies over Wyoming and Minnesota are due to base level problems with certain surveys incorporated into the C.M.A.M.. The north striking Rio Grande Rift anomaly, clearly visible in central New Mexico on the C.M.A.M. maps, is also a source of discrepancy between the two data sets. The Rio Grande Rift
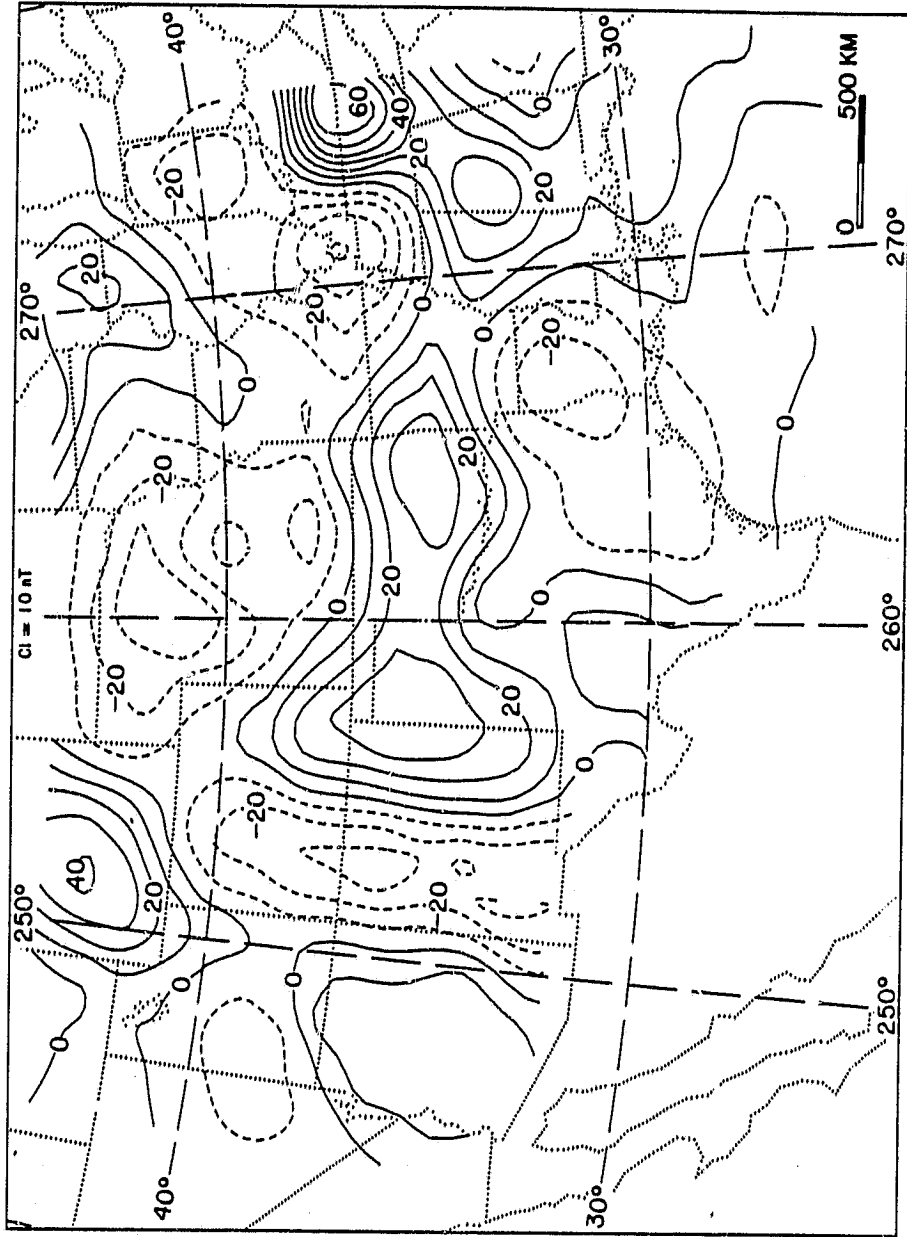
Figure 6. Upward continued (160 km) C.M.A.M. over the central United States (Schnetzler et al., 1984). Contour interval = 10 nT.
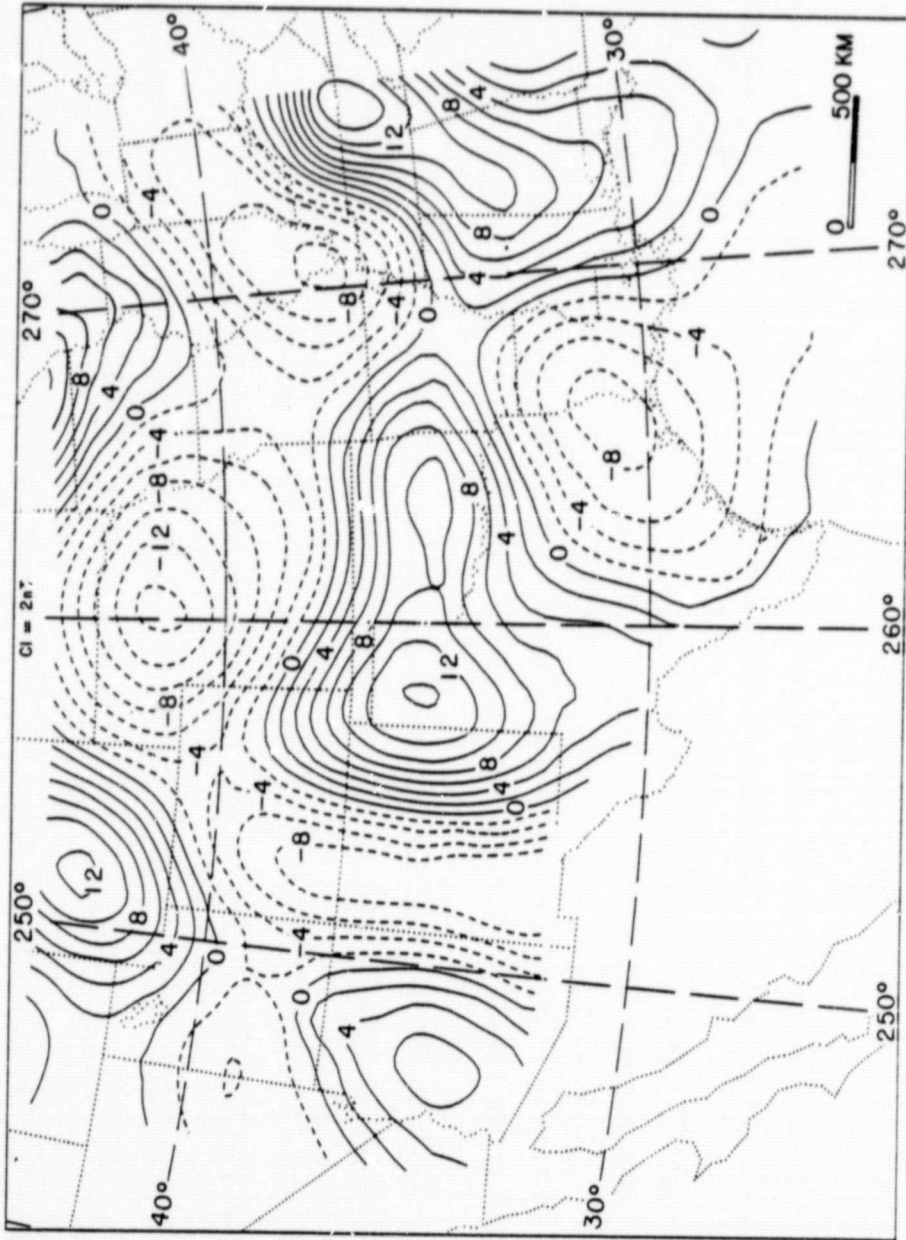
Figure 7. Upward Continued (320 km) C.M.A.M. over the central
United States (Schnetzler et al., 1984). Contour interval = 2
nT.
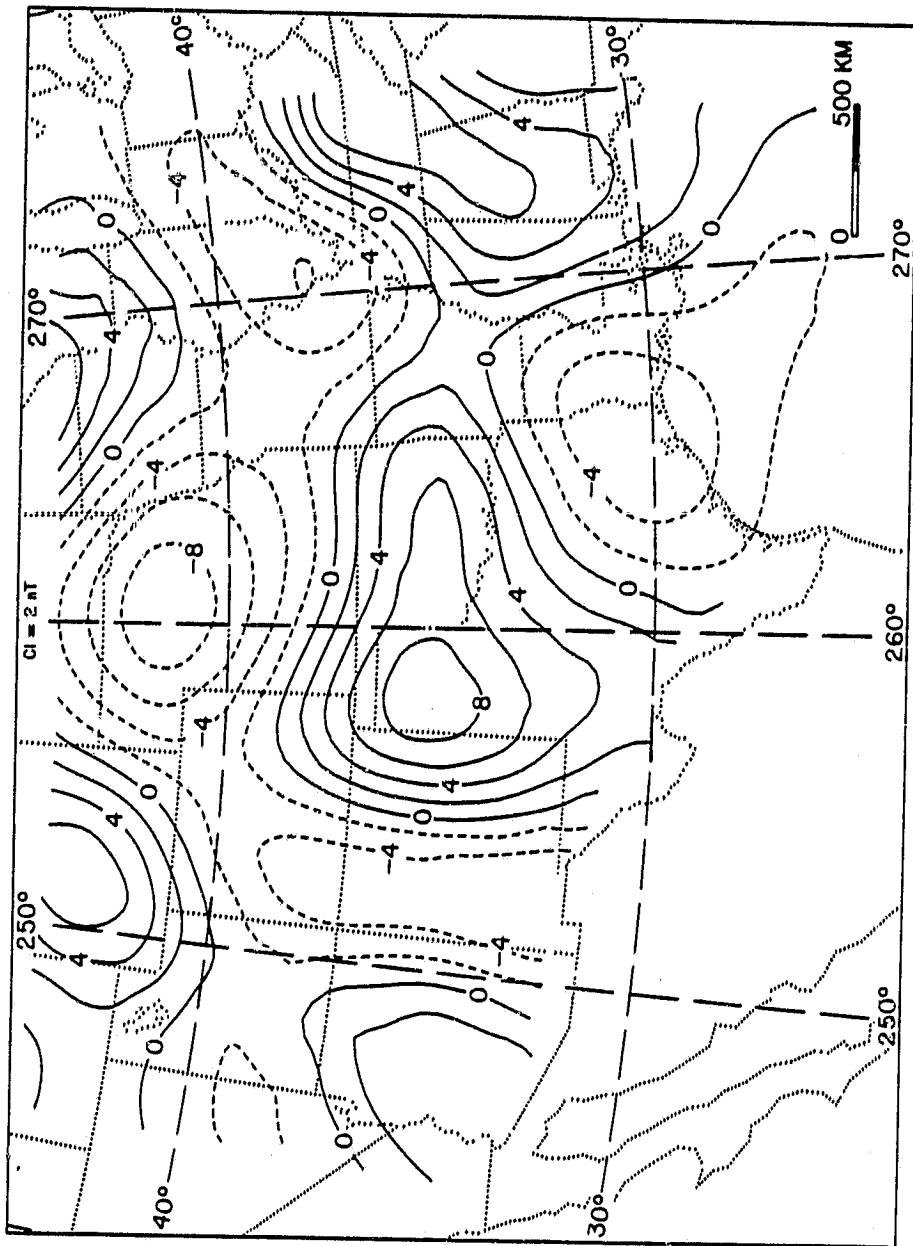
Figure 8. Upward Continued (400 km) C.M.A.M. over the central United States (Schnetzler et al., 1984). Contour interval = 2 nT.

anomaly is minimized in the MAGSAT data which was filtered to reduced north trending anomalies due to satellite tracking errors. Comparison of the upward continued C.M.A.M. data with the MAGSAT scalar data verifies the existence of the principal magnetic features at satellite elevations.

At an elevation of 160 km the SCUSMA appears on the U.S. Magnetic Anomaly Map as a single anomaly with three separate maxima (Figure 7). A north striking element over eastern New Mexico and the Texas and Oklahoma Panhandle area is truncated to the west by a negative anomaly associated with the Rio Grande Rift in central New Mexico. Extensions of this feature overlie west-central Texas, trend into eastern Oklahoma and central Arkansas where it is terminated by the negative Mississippi Embayment Anomaly. The feature is truncated to the south along the Ouachita Orogenic System in southern Arkansas, and northeast Texas and terminates to the north along the northern limit of the Middle Proterozoic felsic rocks in southern Kansas. A subdued element of this positive anomaly extends out of the Great Lakes Region and into northern Missouri.

At an elevation of 320 km the upward continued magnetic anomaly map is smoother with the two elements in Texas and Oklahoma further reduced in amplitude and more consolidated (Figure 7). The positive element trending out of the Great Lakes Region is even more subdued and extends only as far south as southern Iowa and northern Illinois.

At an elevation of 400 km, the mean elevation of the MAGSAT field in Figure 1, the U.S. Composite Magnetic Anomaly Map shows the SCUSMA as a single positive feature centered over the Texas Panhandle area with north and east striking components (Figure 8). The positive anomaly in eastern Iowa, Wisconsin and northern Illinois is further separated from the Texas-Oklahoma anomaly by a saddlepoint in central Missouri. The zero contour along the Texas gulf coast correlates with the Ouachita Orogenic System.

Free-Air Gravity Anomaly Data

Figure 9 shows a 1° averaged Free-Air gravity field which has been isolated from a larger data set for North America and filtered to pass wavelengths longer than 4°. A somewhat smoother version of this map ($\lambda \geq 8°$) has been described by von Frese et al. (1982a). The Free-air gravity anomaly is effectively a map of the crustal isostatic anomaly (Bott, 1982). Positive Free-air anomalies correspond to areas of the crust which are under compensated and negative Free-air anomalies correspond to areas of the crust which are over compensated.

The central portion of the map in Figure 9 is dominated by an area of negative Free-air gravity anomalies which trend southwest from the Great Lakes Region, in the northeast corner of the map, into central Texas. Except for a positive anomaly in south-central Oklahoma, the negative anomalies correlate well with the Middle
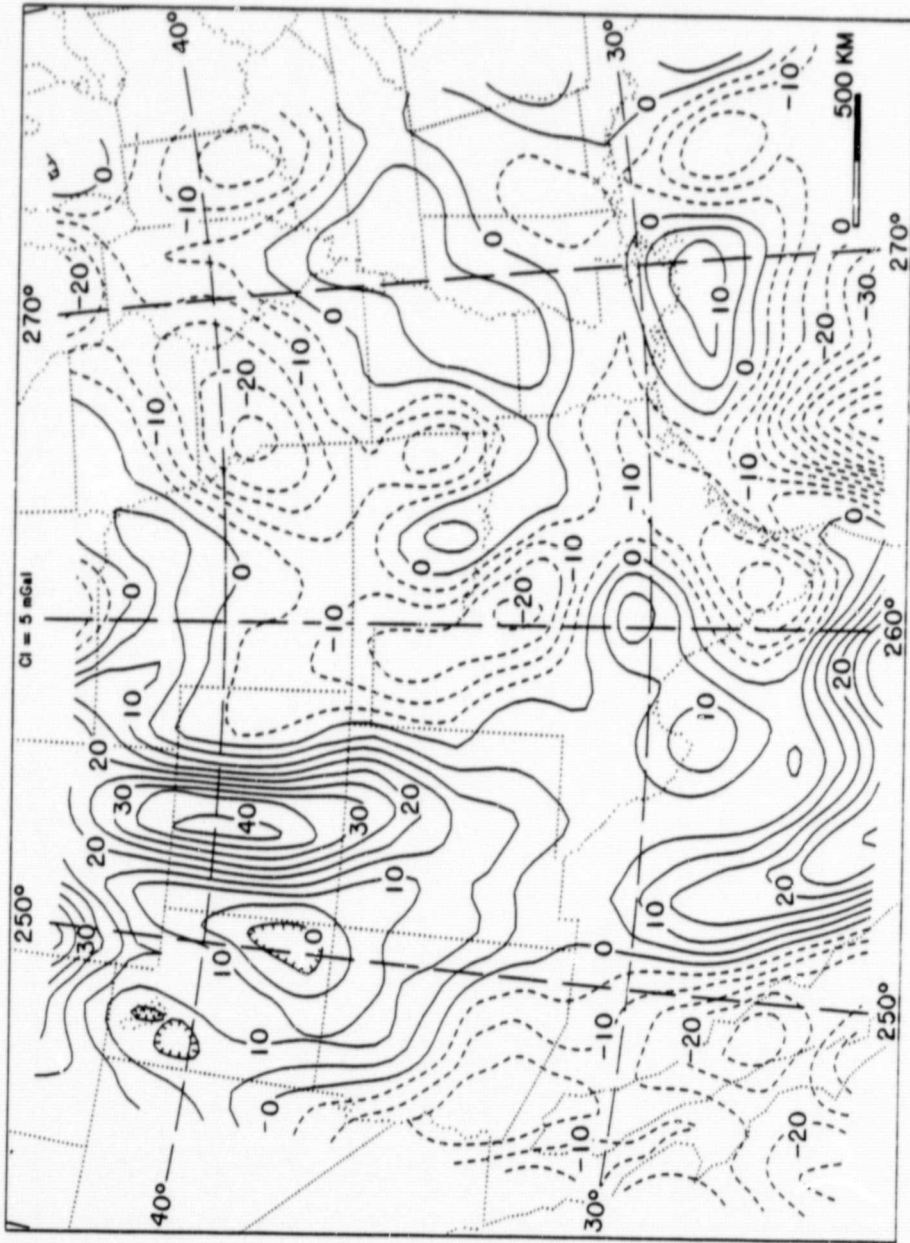
Figure 9. 1° averaged low-pass filtered (λ ≧ 4°) Free-air
gravity anomaly over the central United States. Contour
interval = 5 mGal.

Proterozoic granite-rhyolite terrain. The positive anomaly in Oklahoma appears to be associated with the Southern Oklahoma Aulacogen (see Figure 5), and transects the negative anomaly trend. Positive anomalies in central Texas and the Big Bend area of Texas correlate with the Grenville age terrain and are bounded in the vicinity of the Ouachita System. A near zero Free-air gravity signature in northern Kansas and Nebraska correlates with the older Proterozoic terrain indicating that this region is near isostatic equilibrium. Except for a positive anomaly over the Mississippi delta, the map also indicates that much of the Gulf Coast area is in equilibrium. The Free-air gravity map should provide a useful tool for constraining a magnetic model by using it to delineate the basement terrains in the study area.

Bouguer Gravity Anomaly Data

Figure 10 is a map of Bouguer gravity data gridded at 0.5° intervals and filtered to pass wavelengths greater than 200 km and gridded a 0.5° intervals. These data have been separated from a larger set of data which was compiled by the U.S. Geological Survey and the Society of Exploration Geophysicists (1982). The map shows negative anomalies west of E261° longitude and generally positive anomalies to the east. Interpretation of this map is complicated by isostatic effects which are inversely related to major topographic features. However, some broad generalizations and correlations should be noted.
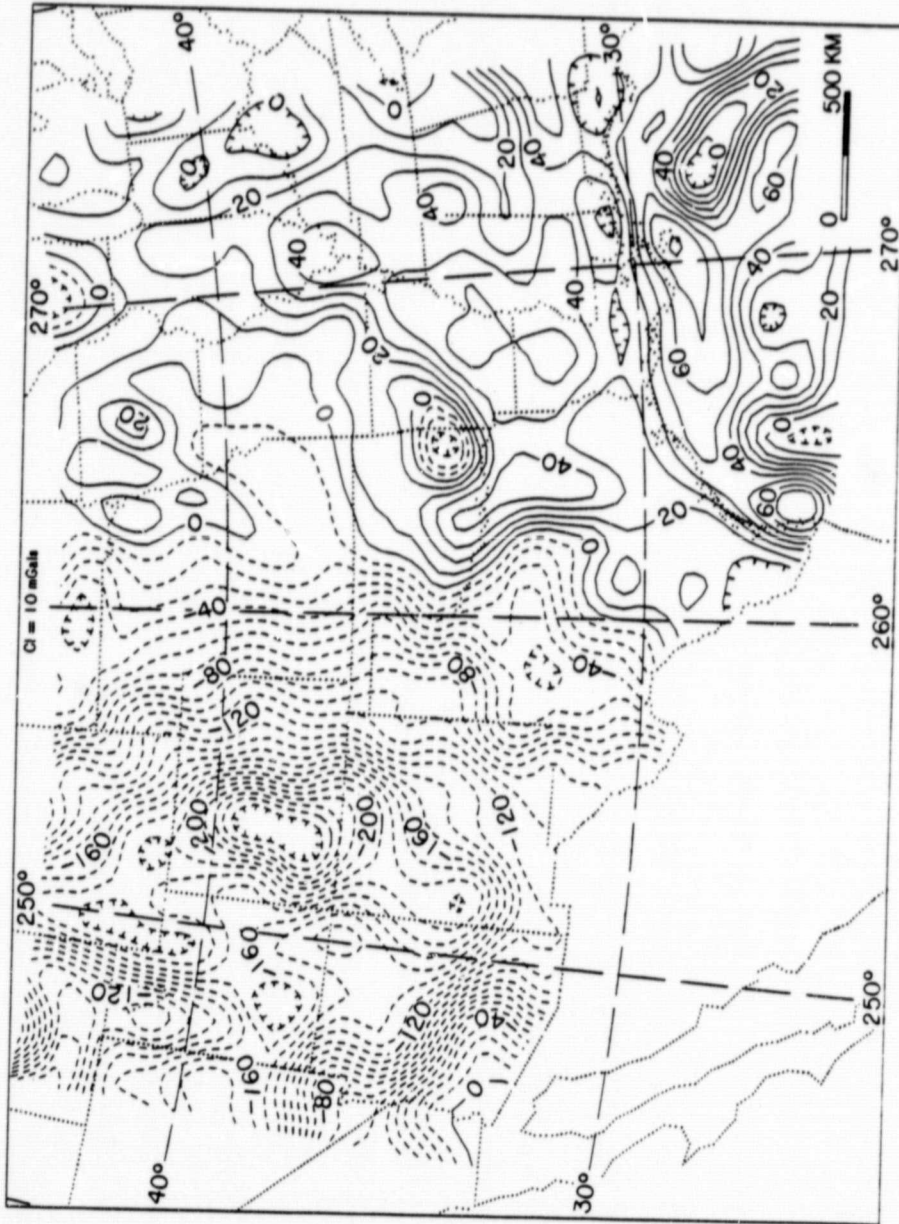
Figure 10. 16 km averaged low-pass filtered (λ ≧ 200 km) Bouguer gravity anomaly over the central United States (U.S.G.S./SEG, 1982) Contour interval = 10 mGal.

The SCUSMA, west of the elevated great plains region (~ E260°), correlates with an area of near zero (±10 milligals) Bouguer gravity anomalies. The contours within this zone trend northeast through most of eastern Oklahoma, northwest Arkansas, Missouri, eastern Kansas, eastern Iowa and western Illinois (Figure 10). These northeast trending gravity contours are interrupted by a north trending positive anomaly which is associated with the Mississippi Embayment in southern Illinois. The zone is also a region of relatively low topography, and therefore, appears to be in isostatic balance. Comparison of the Bouguer gravity map with the lithologic and age provinces in Figures 3 and 4 yields a correlation of this subdued zone of Bouguer gravity anomalies with the Middle Proterozoic granite-rhyolite terrain which transects the central United States.

A strong locally negative Bouguer gravity anomaly is present in southeast Oklahoma and approximately correlates with the Ouachita Mountains. A positive anomaly trends northwest from east Texas through southern Oklahoma and into the Texas Panhandle which correlates with the Southern Oklahoma Aulacogen.

A most noticable aspect of the Bouguer gravity map is the close correspondence between the zero contour and the trend of the buried Ouachita System in Texas (see Figure 5). The western half of Texas and the eastern half of New Mexico are dominated by negative Bouguer gravity values ranging from -20 to -150 mGals. This negative area grades

northwestward into the thickened crust of the Rocky Mountain region. The northerly trend of the contours in this area is disturbed by a positive anomaly which correlates with the Middle Proterozoic granite-rhyolite terrain in central Texas. To the west, the same trend is disturbed by a positive anomaly corresponding with the thick crust of the Colorado Plateau in northeast Arizona.

In central New Mexico a subtle north trending flexure in the gravity contours correlates with the Rio Grande Rift zone. The short-wavelength gravity signature of the Rio Grande Rift zone was subdued when these data were filtered. The Midcontinent Rift System produces a distinct northeast striking anomaly which trends through central Kansas, western Iowa and into the Superior Province outside the map area.

Seismic Crustal Properties

Braile et al. (1983) have recently compiled seismic data from a variety of crustal surveys recorded throughout the United States and Canada. Figure 11 shows the distribution of refraction survey lines used in their work, which resulted in contour maps of uppermost mantle p-wave velocity, crustal thickness, and p-wave velocity of the crystalline crust for much of North America. The results of their study may prove useful in constraining the sources which produce the South-Central United States Magnetic Anomaly.
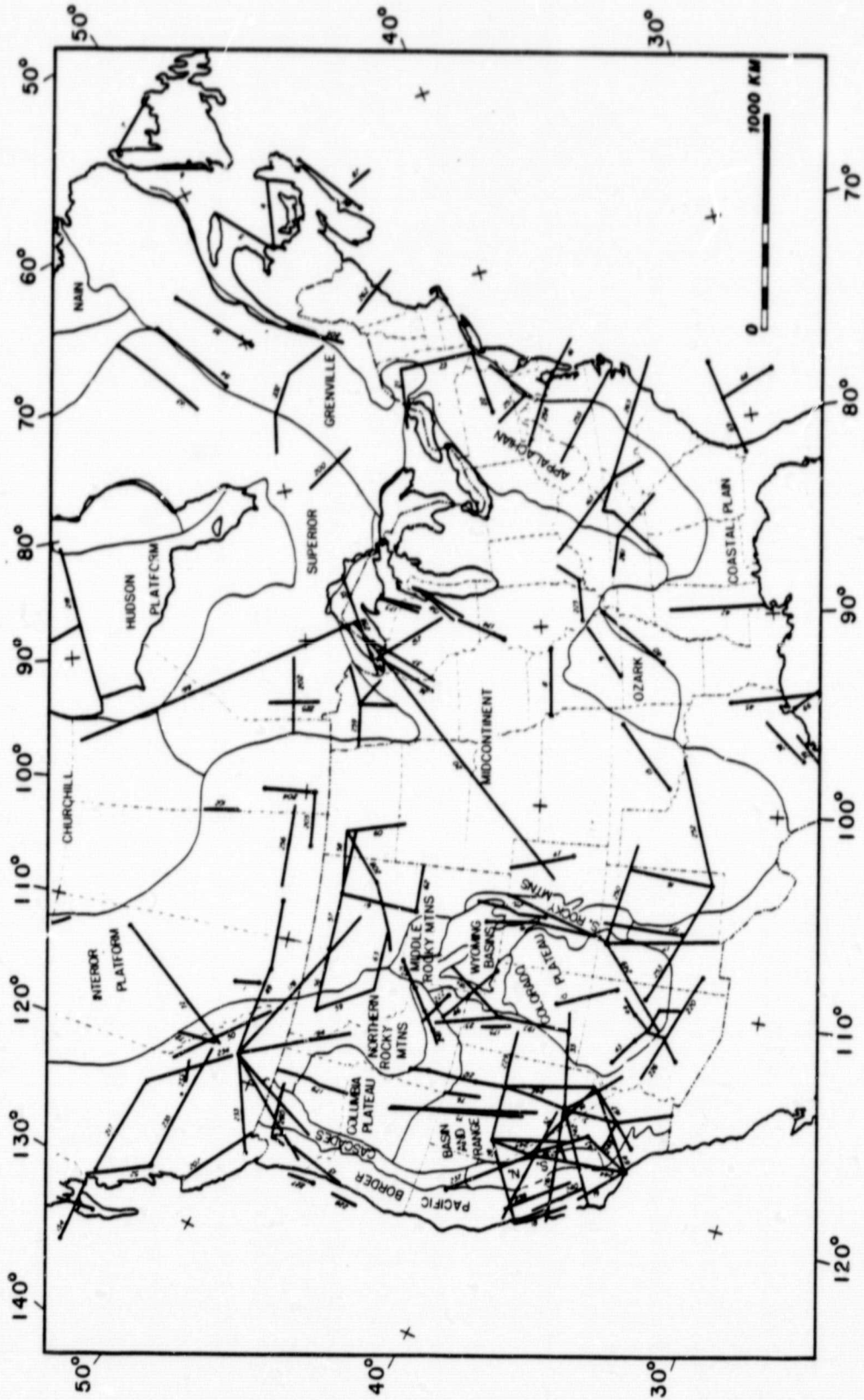
Figure 11. Distribution of refraction surveys used to compile seismic crustal properties (Braile et al., 1983).

Figure 12 is a map of the uppermost mantle compressional wave velocity distribution. The map was isolated from a larger map produced by Braile et al. (1983). The map shows generally higher velocites associated with the Gulf Coast Region and the craton, and lower velocities west of the Rio Grande Rift and the Rocky Mountain Front. While there is no direct correlation of this velocity map with the distributions of the other geological and geological data in the study area, upper mantle seismic velocity may be useful for identifying zones of high heat flow and lower density mantle. Areas of low upper mantle p-wave velocity tend to correspond to higher heat flow and thinned crust (Braile et al., 1983).

Figure 13 is a map of the average crustal compressional wave velocity distribution in the study area. Like the previous map (Figure 11), this map was taken from a larger data set produced by Braile et al. (1983). Smithson et al. (1981) have suggested that average crustal p-wave velocity is related to crustal growth and might be used to identify crustal structures and compositions related to crustal genesis. The northeast trend of the velocity contours on the map in Figure 13 parallels the northeast trend of both the Early and Middle Proterozoic terrains across the central United States. The velocities decrease from central Texas to southern Kansas with a relative low over northern Kansas and southern Nebraska and a relative high extending throughout most of central and
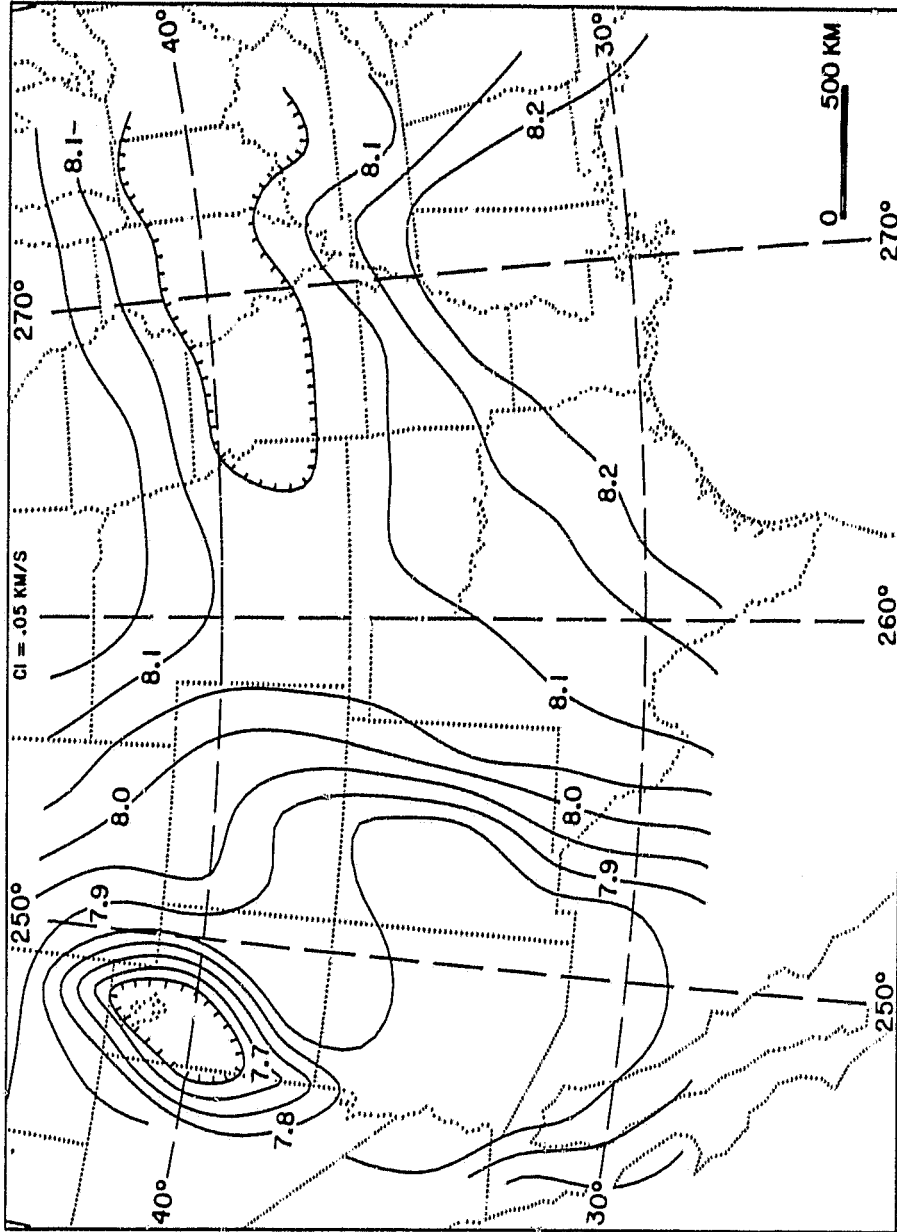
Figure 12. Uppermost mantle compressional wave velocity distribution of the central United States (Braile et al., 1983). Contour interval = 0.05 km/s.
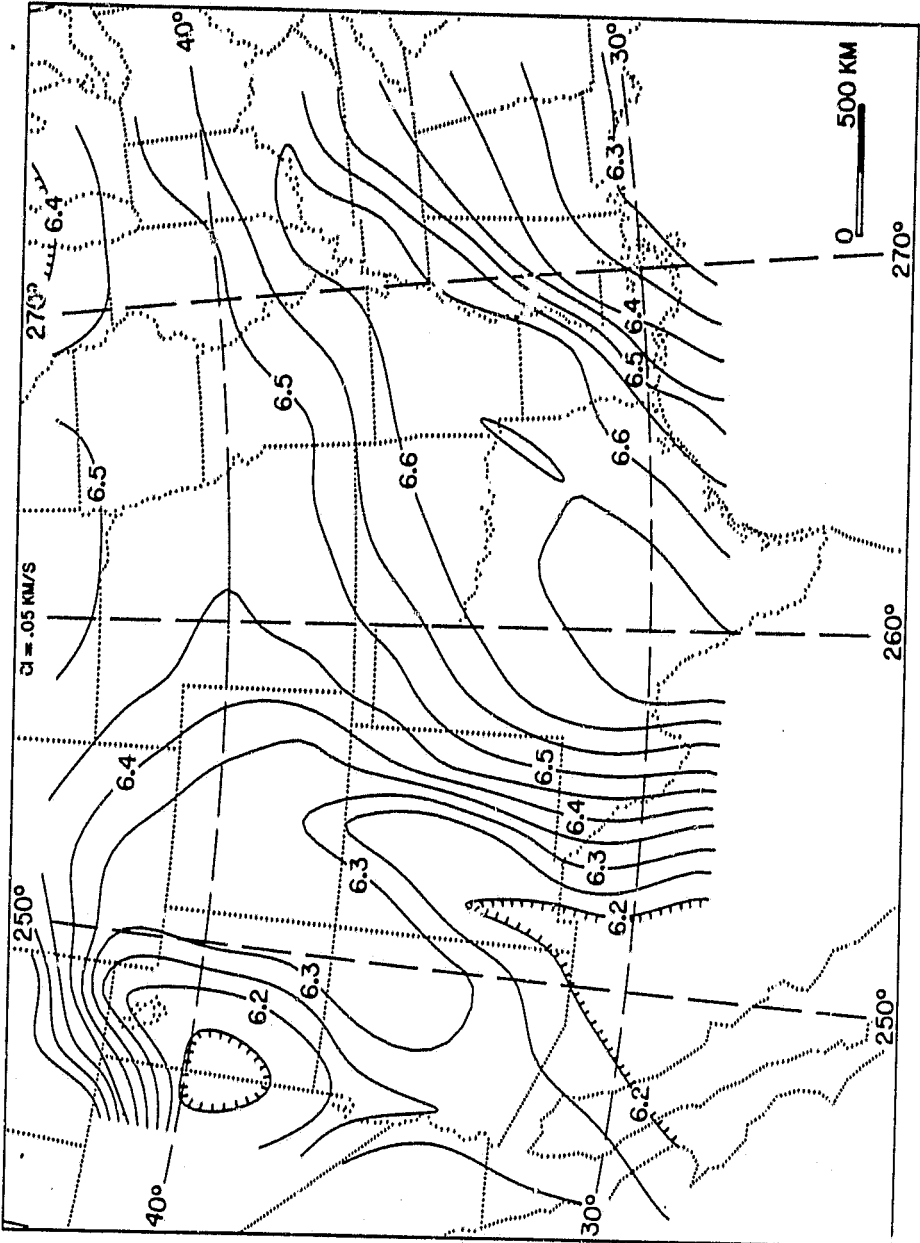
Figure 13. Average crustal compressional wave velocity distribution of the central United States (Braile et al., 1983). Contour interval = 0.05 km/s.

northeastern Texas. The relative high in Texas may be associated with the Grenville age terrain which is the basement rock of that area. This higher velocity zone extends into the vicinity of the Mississippi Embayment and the high density rocks underlying the Reelfoot Rift. The relative minimum in Kansas and Nebraska seems to correlate with the older Proterozoic belts to the north, and the gradient between the relative high and low areas correlates with the belt of Middle Proterozoic felsic terrain and the general outline of the craton. In addition, this zone of above average crustal p-wave velocities in Texas, Oklahoma and Missouri which extends into the Great Lakes Region appears to correspond to a zone of negative Free-air gravity anomalies. Higher crustal p-wave velocities are expected to correspond to a higher density crust which should produce a positive rather than a negative gravity anomaly. This paradox could result from a thickening of the crust as outlined in the following paragraph. Thickened crust will produce a negative gravity anomaly which could negate the positive effect of the higher densities. However, these apparent relationships must be used cautiously in view of the scarcity of control points in the Central United States (see Figure 11).

Figure 14 is a map of the mean crustal thickness distribution in the study area (Braile et al., 1983). Braile et al. (1973) explain that the crustal thickness in eastern North America, 42 km, is above the average, 36 km,
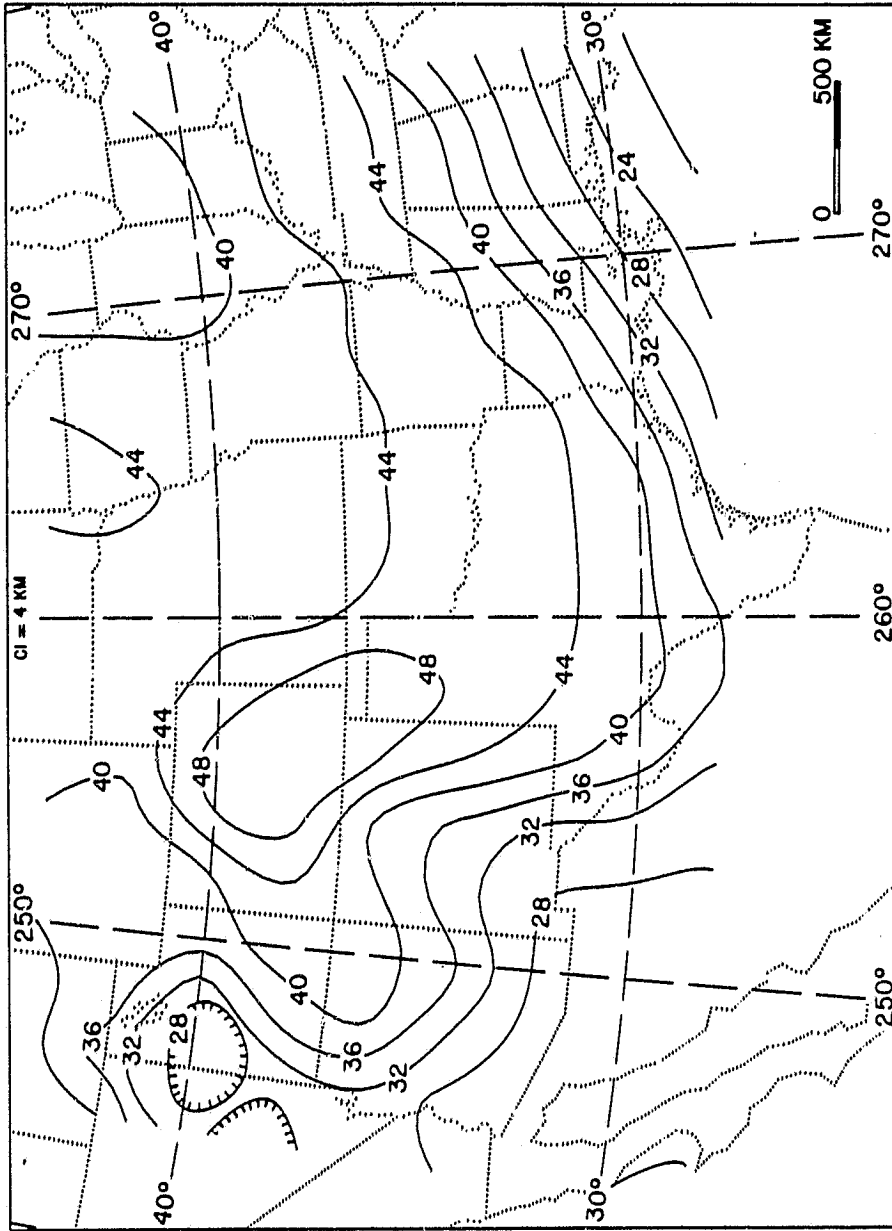
Figure 14. Mean crustal thickness of the central United
States (Braile et al., 1983). Contour interval = 4 km.

for the continent. The most prominent feature on the crustal thickness map is a large area of thickened crust extending from central Colorado through northern Texas, Oklahoma, Arkansas, and parts of Tennessee and Kentucky. While correlation of this feature with the SCUSMA and the other data is somewhat subjective, the thicker crustal zone does correspond with the positive anomalies in the upward continued U.S. Composite Magnetic Anomaly Maps (Figures 6,7 and 8).

IV. MAGNETIC AND GRAVITY PROCESSING

The MAGSAT data in Figure 1 have previously been processed to remove the core derived and external field components and smoothed by 2° averaging resulting in a residual scalar data set which permits identification of long-wavelength anomalies in a global perspective (Langel et al., 1982). Correlation of these long-wavelength anomalies with their crustal sources can be hindered by distortion due to the variable intensity and orientation of the earth's magnetic field which provides the primary source of induction for magnetic elements in the crust. In addition, a certain amount of ambiguity prevents the direct interpretation of crustal sources from potential field measurements. This ambiguity is enhanced by the superpositioning of induced magnetic and remanent magnetic components and the variability of source parameters, such as depth, thickness, susceptibility and lateral extent. For these reasons, enhancement usually precedes the interpretation of magnetic anomalies.

Inversion of the MAGSAT Scalar Data

Spherical equivalent point source inversion of the MAGSAT scalar field (Figure 1) by a least squares method (von Frese, 1981) was performed to provide dipole susceptibility models which are useful for interpretation and calculation of enhanced approximations of the MAGSAT field. The inversion technique relates a set of spherical potential field measurements, in this case the MAGSAT 2° averaged scalar data, to a predetermined distribution of dipole sources. By iterative matrix inversion, the process fits least squares approximations to the field until a desired level of precision is obtained (von Frese, 1980). The resulting dipole model can be used to calculate enhanced representations of the original field with variable inducing parameters and at a variety of elevations.

In order to test the usefulness of different source spacings, equivalent point source inversions of the MAGSAT data were calculated for dipole spacings of 2.0°, 2.4°, 3.0° and 4.0° at a crustal depth of -20 km which is approximately one-half the mean crustal thickness. The resulting equivalent point sources were then used to calculate approximations of the MAGSAT field at an elevation of 400 km using coefficients for the core derived field from Langel et al. (1982). An examination of the results of these inversions appears in the Appendix. The

2.0° dipole grid produced a field which fit the MAGSAT data best of all four of the dipole grids. However, the inversions which produced the 2.0° dipole grid and the 2.4° dipole grid both showed a significant degree of instability. Although useful for processing and enhancement, the 2.0° dipole grid is meaningless for purposes of interpretation. The 3.0° dipole grid (Figure 15) appears stable and reproduces the MAGSAT field well enough to be useful for interpretation, but it was not used for further processing. The susceptibility distribution map in Figure 15 shows an extensive positive feature which resembles the SCUSMA of the MAGSAT field (Figure 1). This 3.0° distribution of dipole susceptibilities is also in good agreement with the distribution of apparent magnetization contrasts developed by Mayhew and Galliher (1982) for the United States. Negative susceptibilities dominate the Gulf Coast area and the zero contour corresponds with the position of the Ouachita System. Negative susceptibilities also predominate in the northern portion of the map and appear coincident with the Early Proterozoic basement rocks of that region. A negative trend in the contours correlates with the thin magnetic crust of the Rio Grande Rift in central New Mexico and positve susceptibilities correlate with the southern Colorado Plateau.

Figure 16 is the equivalent point source representation generated from the 2.0° grid of dipoles.
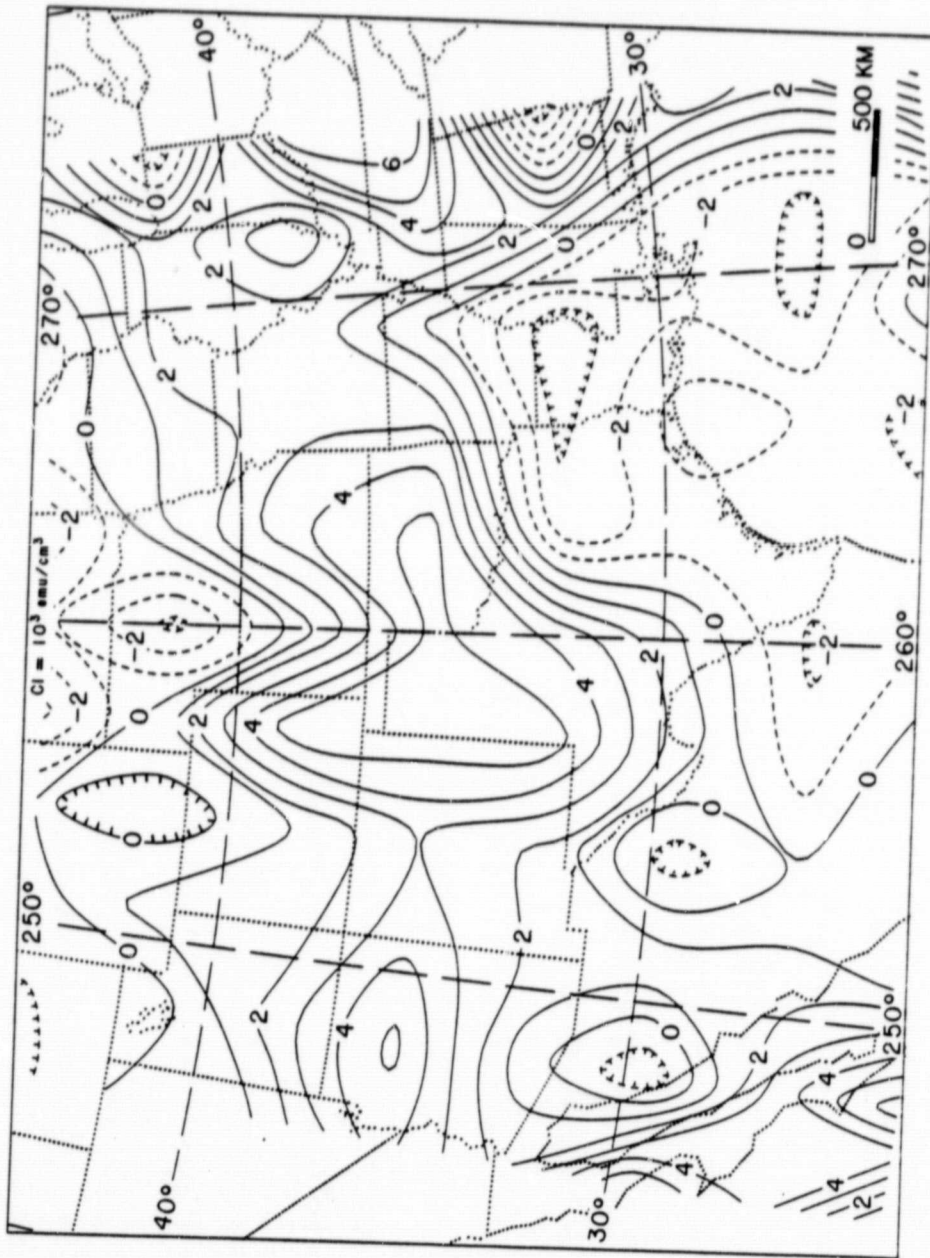
Figure 15. Dipole magnetic susceptibility derived by equivalent dipole source inversion (3° grid) of the MAGSAT scalar field. Dipole depth = -20 km. Contour interval = 10^3 emu/cm^3.
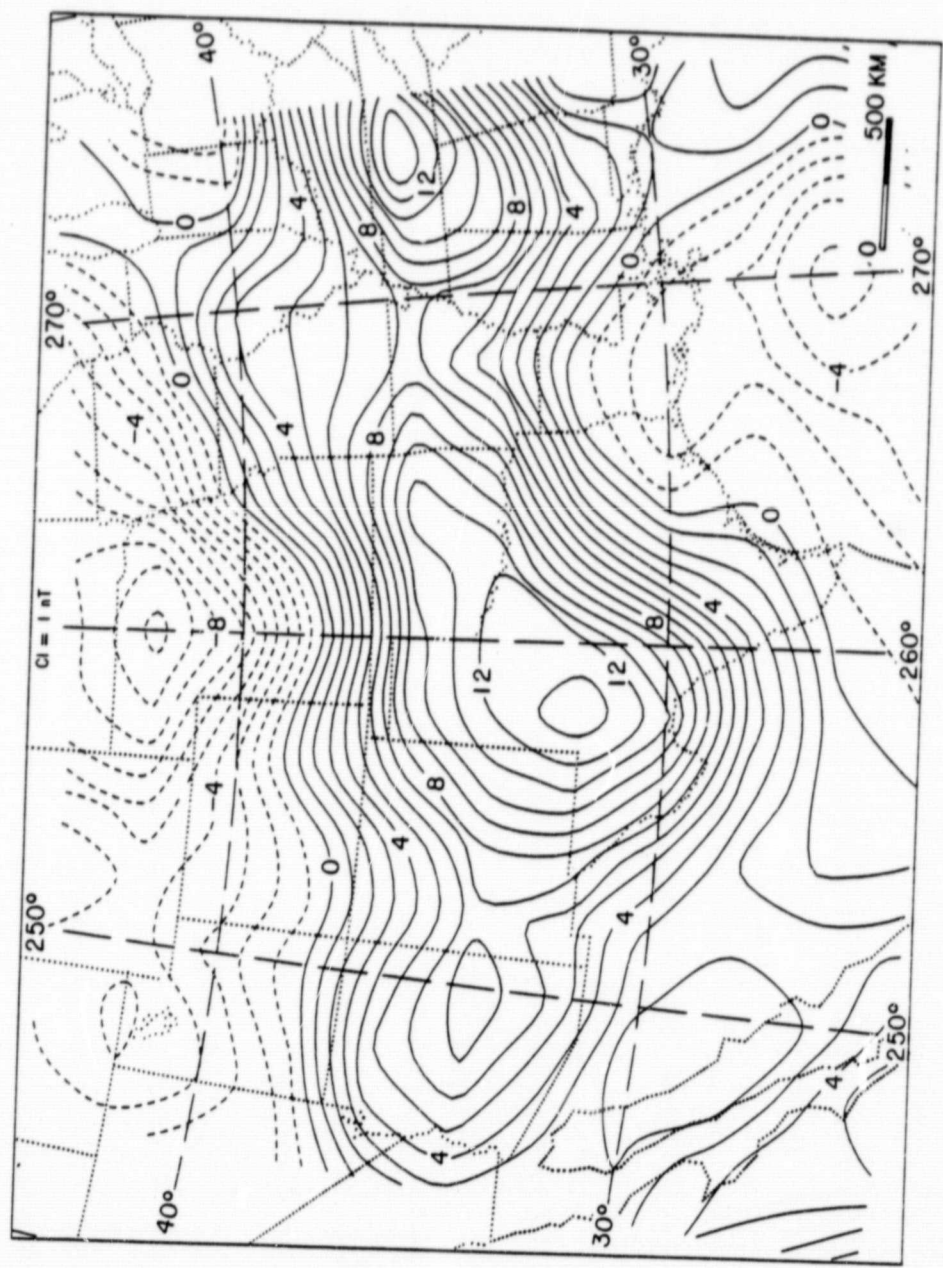
Figure 16. Equivalent dipole source representation of the MAGSAT scalar field. Elevation = 400 km. Contour interval = 1 nT.

This map closely matches the MAGSAT 2.0° averaged data in both amplitude and overall character.

Reduction to Pole

A reduced-to-pole field was calculated from the 2° dipole sources for an inducing field of 60,000 nanoteslas (nT) with radial polarization, using a technique implemented by von Frese (1980). The resulting reduced-to-pole map appears in Figure 17. Assuming negligible remanent magnetization in the ancient crustal sources of the central United States (Hinze and Zietz, 1984), the reduced-to-pole map should correlate more closely to the magnetic sources in the crust. Reduction-to-pole removes the distortion effects produced by the geographically variable orientation and magnitude of the earth's field (Nettleton, 1976). The reduced-to-pole map shifts magnetic anomalies to a position directly over their sources thereby providing information which is useful for determining the location of the sources which produce the SCUSMA

Derivative Calculations of Magnetic and Gravity Data

A first radial derivative map (Figure 18) of the reduced-to-pole map was calculated by generating the reduced-to-pole field at elevations of 395 and 405 km. The difference between the two fields at the same geographic position was divided by 10 km, yielding a gradient approximation. The zero contour of this radial derivative
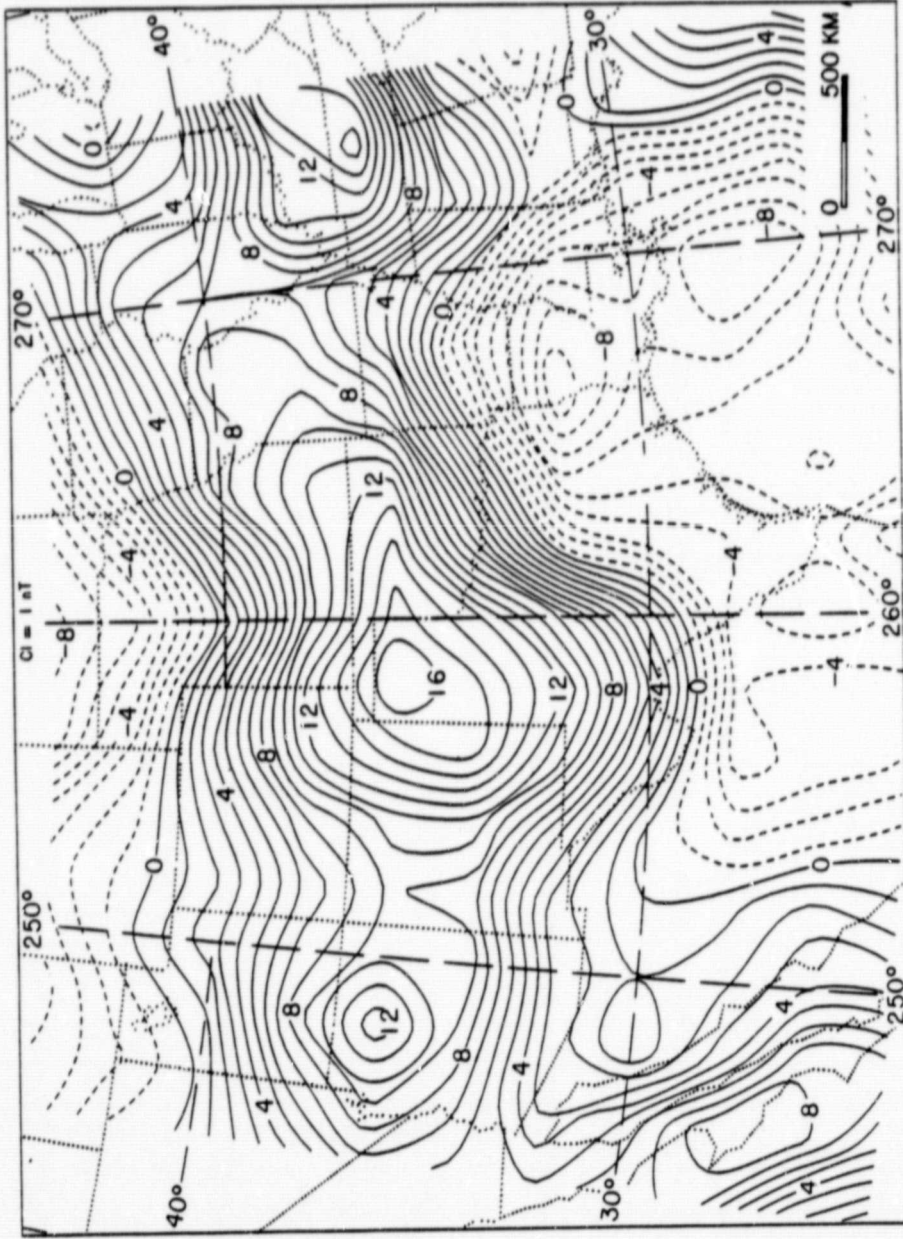
Figure 17. Reduced-to-pole equivalent dipole source representation of the MAGSAT scalar field. Elevation = 400 km. Contour interval = 1 nT.
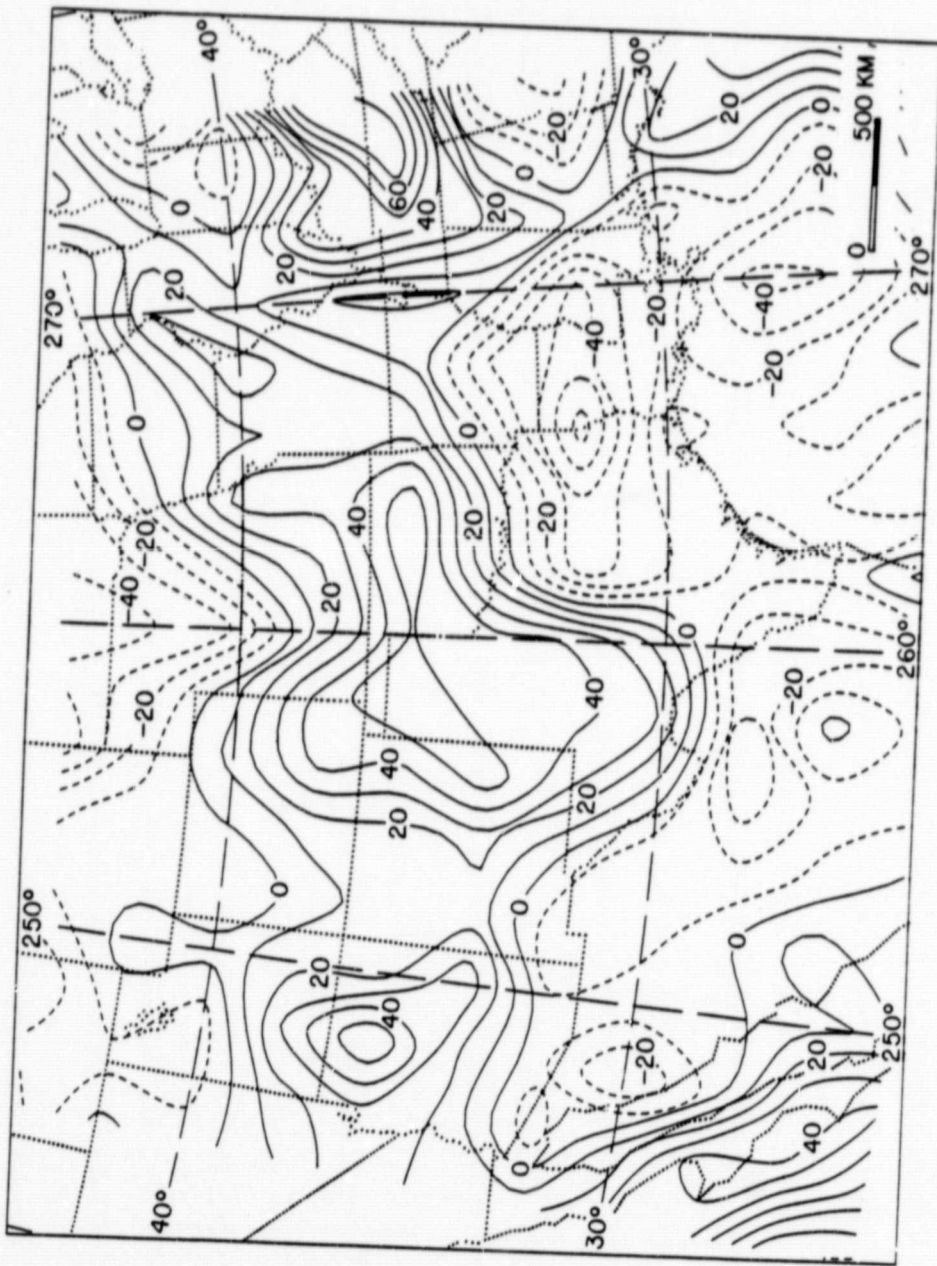
Figure 18. First radial derivative approximation of reduced-to-pole MAGSAT scalar field. Elevation = 400 km. Contour interval = 10×10⁻³ nT/km.

map corresponds to the points of inflection in the reduced-to-pole map, and more closely approximates the lateral extent of the magnetic sources which produce the MAGSAT field. A first vertical derivative map (not shown) was also calculated in the wavenumber domain using a method implemented by Reed (1980). This approach assumes that the gridded data are uniformly orthogonal, a seemingly invalid assumption for spherically gridded data. However, the distortion due to processing the spherical grid with this orthogonal method proved to be negligible. Therefore, the wavenumber derivative filter was used to calculate the first vertical derivative of the Free-air gravity map (Figure 19) without regridding and repeating the spherical inversion used in the magnetic field processing.

The first vertical derivative calculation of the Free-air gravity data results in a map with enhanced high frequency components. Like the radial derivative map of the reduced-to-pole magnetic data, the zero contour of the Free-air gravity vertical derivative map corresponds to the points of inflection in the original Free-air data set and closely corresponds with the lateral extent the sources of the anomalies.
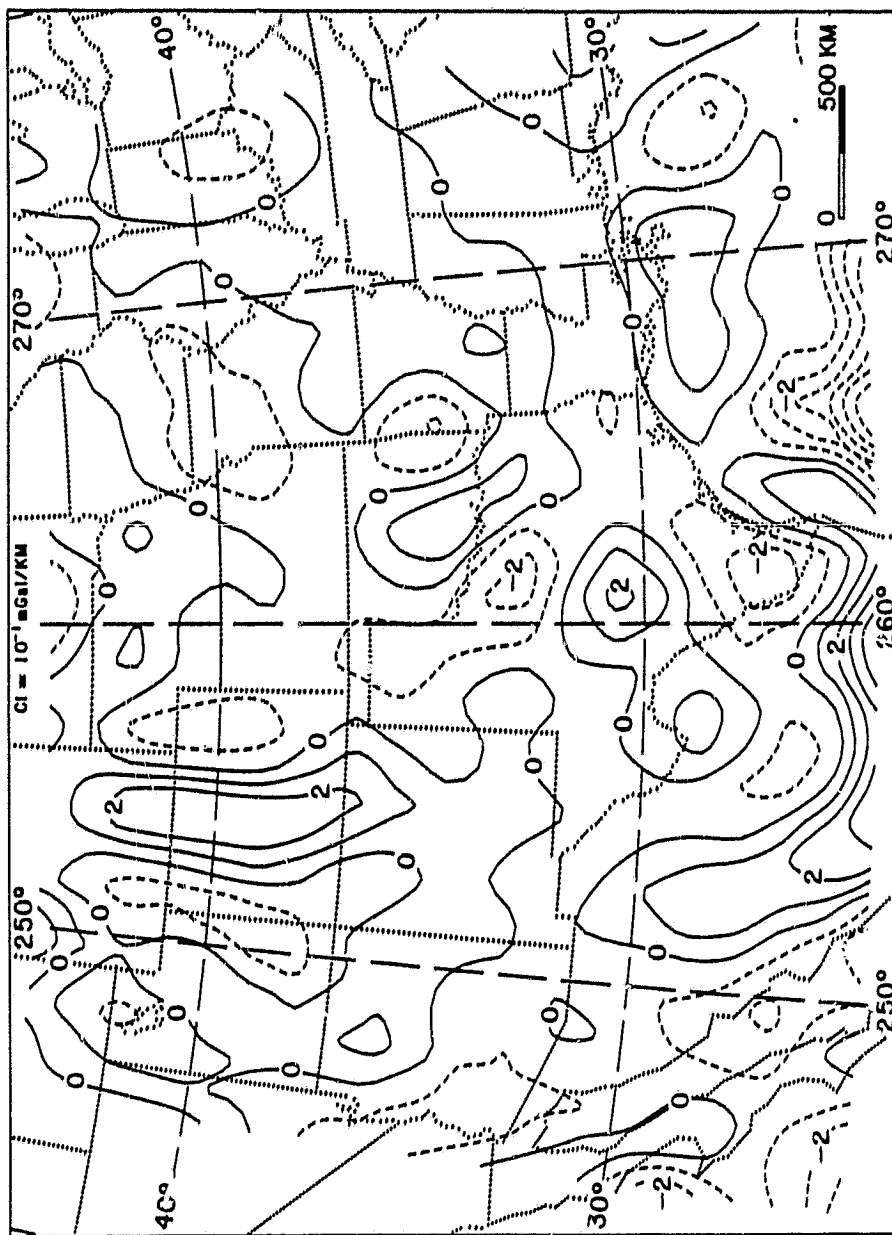
Figure 19. First vertical derivative of Free-air gravity
anomaly field. Contour interval = 10^{-1} mGal/km.

V. INTERPRETATION AND MODELING

Long-wavelength magnetic anomalies observed at satellite elevations may be due to several sources: magnetization contrasts between juxtaposed crustal blocks, combined effects of numerous small high amplitude anomalies, variations in the thickness of the effective magnetic crustal layer, regional changes in the magnetic mineralogy and large scale mafic intrusions (Wasilewski and Mayhew, 1982). Mayhew (1982) has illustrated that undulations in the Curie isotherm can produce long-wavelength magnetic anomalies at satellite elevations. In addition, Wasilewski and Mayhew (1982) demonstrate that mafic granulite facies rocks which can exist in the lower crust may cause sufficient magnetization contrasts to give rise to long wavelength anomalies.

The basement rocks of the central United States are composed of three extensive age provinces and a variety of igneous and metamorphic rock types which could provide the magnetization contrasts necessary to produce the SCUSMA. The superposition of the high intensity magnetic effects due to less extensive features may also contribute to the overall amplitude of this anomaly in the MAGSAT field.

Variations in the thickness of the magnetic crust generally correspond to crustal thickness, except in areas of high heat flow like the Rio Grande Rift zone. With these boundary conditions in mind, this section will be devoted to identifying crustal magnetic sources through correlation of the MAGSAT field with the various data sets already presented, and developing a geologically reasonable crustal magnetic model through forward modeling techniques.

Initial Interpretation

Many of the data sets presented previously have shown varying degrees of correlation with the SCUSMA of the MAGSAT scalar field. Examination of various geological and geophysical data indicate that the South-Central United States Magnetic Anomaly shows significant correlation with:

-the undeformed Middle Proterozoic granite-rhyolite terrain which extends across the central United States, the Grenville age rocks in central Texas and the older metamorphosed igneous and sedimentary rocks of eastern New Mexico and the Panhandle of Texas,

-the igneous complex of the Southern Oklahoma Aulacogen,

-a zone of negative Free-air gravity anomalies which correlate with the

Middle Proterozoic felsic terrain. It trends northeast from central Texas to the Great Lakes region and is indicative of over compensated lithosphere

-a zone of positive Free-air anomalies in the southwest Texas which correlate with Grenville age rocks,

-a zone of near zero Bouguer gravity anomalies trending northeast from southern Oklahoma into the Great Lakes region which correlates with the Middle Proterozoic felsic terrain,

-a zone of above average crustal p-wave velocity which correlates with both the Middle Proterozoic granite-rhyolite terrain and the Grenville age rocks of Texas,

-a zone of increased crustal thickness which trends easterly across the central United States.

Furthermore, the South-Central United States Magnetic Anomaly appears to be confined within the limits of certain tectonic and age provinces. Figure 20 is an illustration of the structural provinces and the reduced-to-pole MAGSAT scalar map. These correlations include:
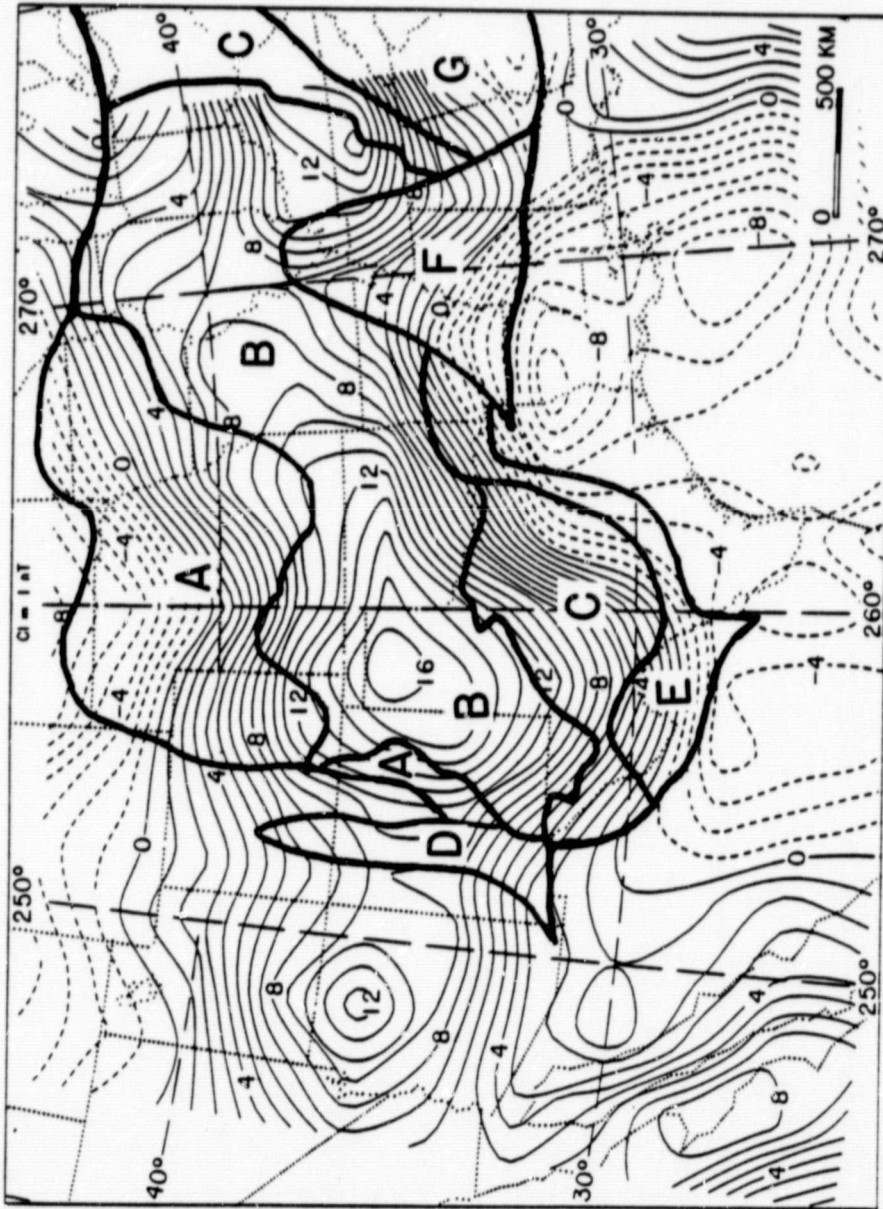
Figure 20. Reduced-to-pole MAGSAT map with basement structural provinces: A. Early Proterozoic plutonic rocks, B. Middle Proterozoic granite and rhyolite, C. Grenville age plutonic rocks, D. Rio Grande Rift zone, E. Ouachita System, F. Mississippi Embayment, G. Appalachian System.

-the Ouachita Orogenic System which correlates with the southeastern boundary of the reduced-to-pole anomaly as well as the approximate zero contour of the Bouguer gravity data in east-central Texas and marks the effective boundary of the craton,

-the Rio Grande Rift which serves as the boundary of the anomaly as well as the western limit of the cratonic magnetic crust in central New Mexico,

-the Mississippi Embayment anomaly which interrupts the northeast trend of the anomaly in central Missouri and northeast Arkansas,

-the southern limit of the older Proterozoic rocks which strike east through central Kansas and correlates with negative magnetic anomalies in both the MAGSAT scalar field and the upward continued U.S. Magnetic Anomaly Maps, near zero Free-air gravity anomalies and positive Bouguer gravity anomalies.

In view of the above correlations it appears as though the SCUSMA is produced primarily by magnetization

associated with the belt of Middle Proterozoic granite-rhyolite terrain, but not directly related to these felsic rocks.

Allingham (1976) found magnetic susceptibility values of 0.0017 emu/cm^3 for granites and 0.0028 emu/cm^3 for rhyolites exposed in the St. Francois Mountains of Missouri. Other values ranging from 0.0002 to 0.0022 emu/cm^3 have been reported for Middle Proterozoic granites in southeastern Missouri (Allingham, 1966), and Klasner et al. (1984) report susceptibility values of nil to 0.002 emu/cm^3 for the Middle Proterozoic quartz monzonite and syenitic plutons of the Wolf River Batholith in Wisconsin. These susceptibility values could produce sufficient magnetization to give rise to the SCUSMA if the felsic rocks extended to great depth in the crust. However, the high average crustal velocities in this province suggest that denser mafic rocks exist deeper in the crust. A highly magnetic mafic component in the crust could contain the sources which produce magnetic anomalies at satellite elevations (Wasilewski and Mayhew, 1982). The presence of the anorogenic felsic rocks at the basement surface may be useful for delineating this highly magnetic segment of the crust from zones of less magnetic basement rocks. The Grenville age rocks of Texas, the metaigneous and metasedimentary rocks of west-central Texas and eastern New Mexico, and the igneous complex of the Southern Oklahoma Aulacogen appear to contribute to a north trending

component of the SCUSMA which is centered over Texas. However, the Grenville age rocks in the eastern United States and Canada produce no positive features in the Magsat scalar data. O'Hara and Hinze (1980) note the broad low amplitude character of the magnetic anomalies of the Grenville Province near Lake Huron, and Hinze et al. (1983) describe the Grenville Province in the eastern United States as associated with alternating negative-positive "birdseye" magnetic anomalies. Therefore, the Grenville age rocks in Texas may actually contribute very little to the SCUSMA.

Forward Modeling

An initial magnetic model for the South-Central United States Magnetic Anomaly was developed by constraining the limits of a magnetic source to lie within certain boundaries. Wasilewski and Mayhew (1979) suggest that the Moho serves as the boundary of the magnetic crust. Therefore, the crustal thickness map (Figure 14), developed by Braile et al. (1983), was used as the lower limit of the initial model. The SCUSMA correlates well with a belt of Middle Proterozoic granite-rhyolite terrain, Grenville age rocks in Texas and metamorphic rocks in west-central Texas and eastern New Mexico. The limits of these terrains were used to constrain the lateral limits of the initial model. Lastly, a 1 km thick layer of sedimentary rocks was removed from the top of the initial model to account for

the approximate thickness of the nonmagnetic sedimentary rocks which cover the central United States.

Prior to three-dimensional modeling, two-dimensional modeling was used to determine the general character of the three-dimensional model. Using a susceptibility contrast of 0.005 emu/cm³. and a vertically polarized inducing field with an intensity of 60,000 nT, two-dimensional magnetic profiles were generated using a method developed by Talwani et al. (1959). These profiles (not shown) were then compared with values from the reduced-to-pole field to arrive at necessary modifications in the initial model prior to modeling in three-dimensions. The two-dimensional modeling helped to achieve an amplitude which was comparable to the amplitude of the SCUSMA in the reduced-to-pole MAGSAT map, and constrain the susceptibility contrast of the source to a value of 0.0014 emu/cm³.

Three-dimensional forward modeling techniques were utilized to further develop a flat earth crustal magnetic model. Recent findings (Parrot et al., 1984) indicate that flat earth modeling for spherical sources results in less than ten percent error for prisms with dimensions comparable to this model. While the susceptibility contrast (0.0014 emu/cm³) was held constant, the lateral boundaries and the depth to the top of the model were adjusted to produce the anomaly in Figure 21. Cross sections A-A' and B-B' (Figures 22 and 23 respectively) illustrate the vertical configuration of the model.
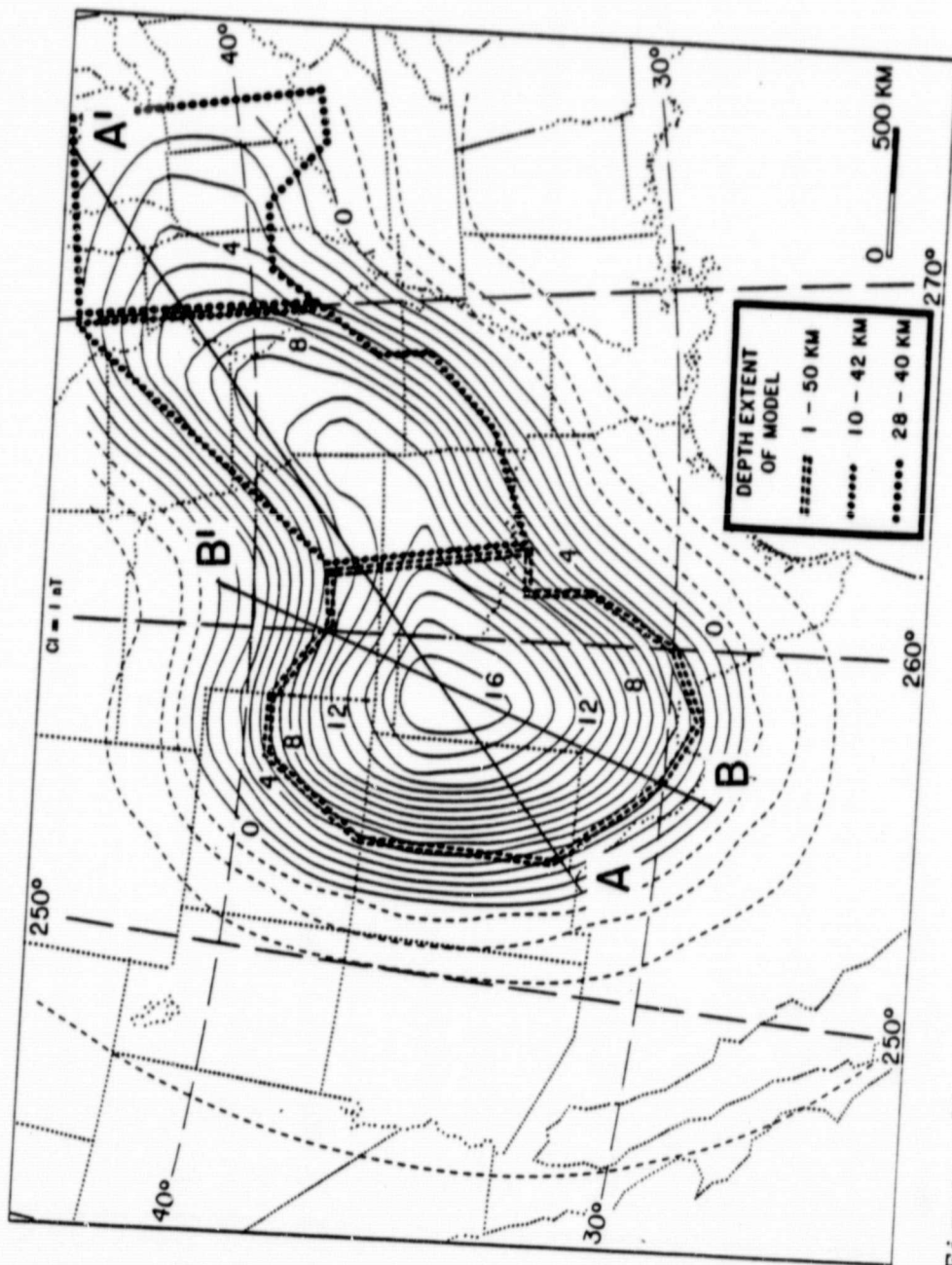
Figure 21. Three dimensional distribution of crustal magnetic model and superimposed theroretical magnetic field. Model cross-sections at A-A' and B-B'. Contour interval = 1 nT.
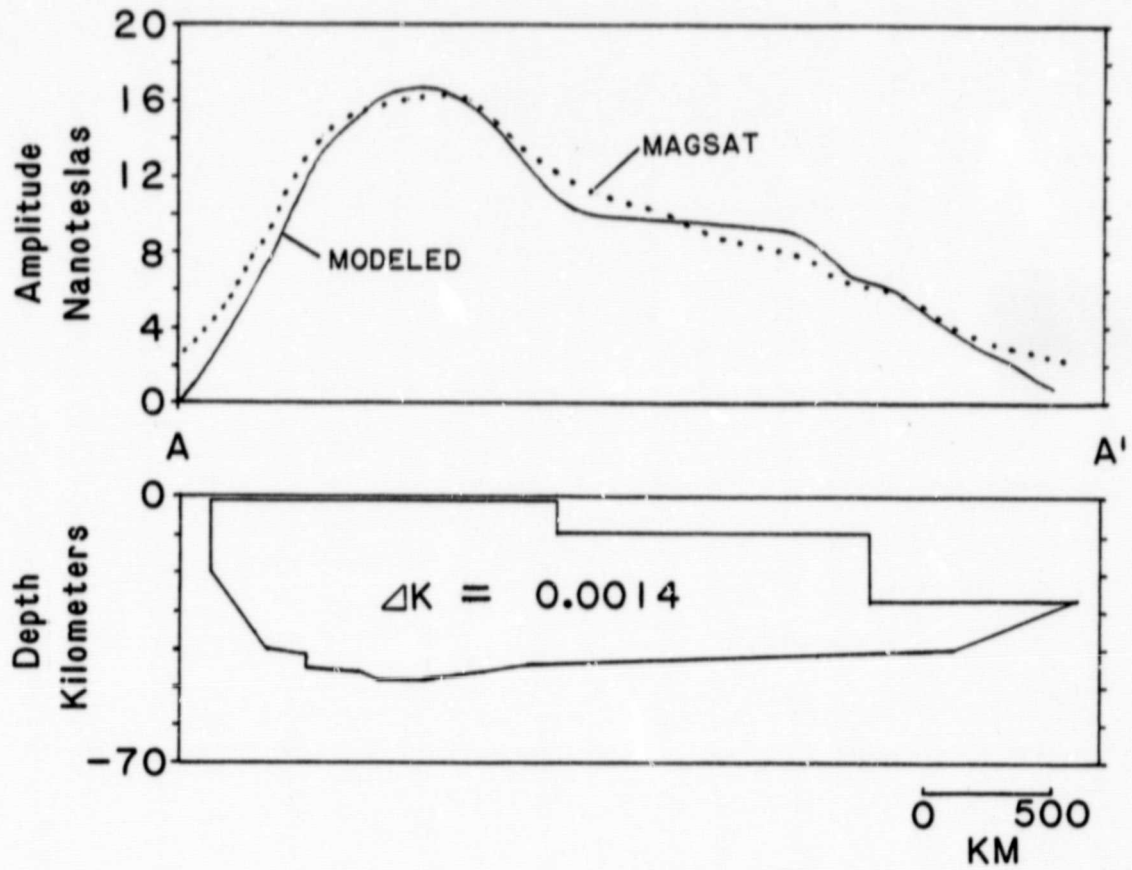
Figure 22.   Model cross-section A-A'.
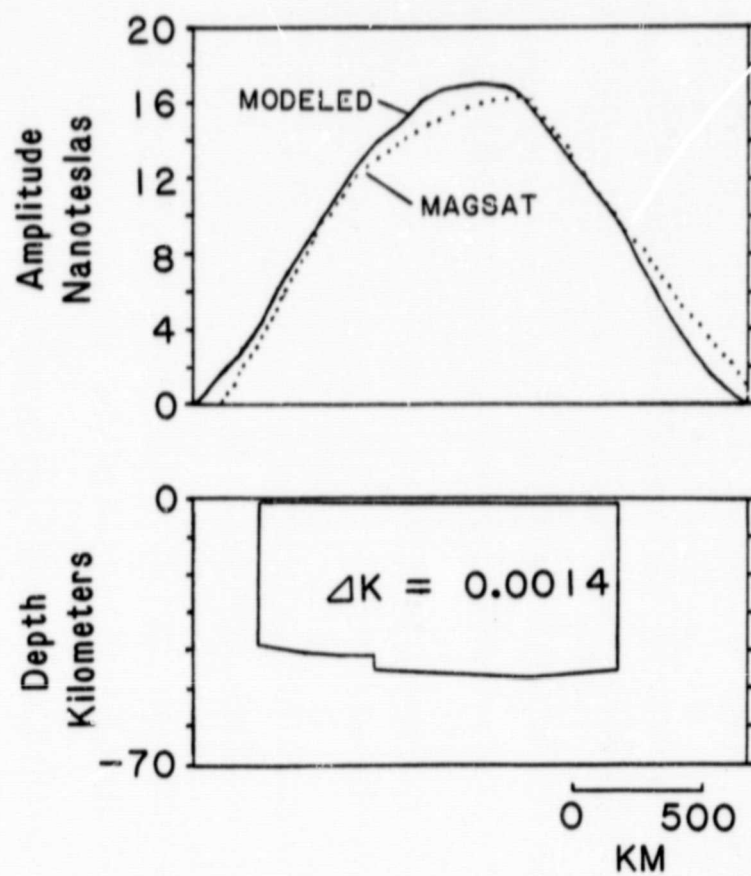
Figure 23.   Model cross-section B-B'.

Comparison of the final model with the distribution of lithologies in Figure 3 and the age provinces in Figure 4 provides a close correlation with the Middle Proterozoic felsic terrain, the Grenville terrain in Texas and the metamorphic rocks of eastern New Mexico and west-central Texas. Although this crustal model with its uniform susceptibility contrast is a nonunique idealization, the geometry of the model indicates a decrease in the magnetization of the crust from the southwest to the northeast.

Several theories for the developement of the Middle Proterozoic anorogenic felsic rocks in North America have been proposed (Van Schmus and Bickford, 1981; Higgins, 1981; Anderson, 1983). Anderson (1983) has recognized the invasion of these granites into the Early Proterozoic terrain. He suggests that the Middle Proterozoic anorogenic magmas are derived from both mantle diapirism and subsequent fusion of the heterogenous Proterozoic rocks already in place. During the process of crustal heating, magnetic materials may have been enriched in the lower crust by differentiation. This process is one explanation for the negligible magnetization in the Middle Proterozoic granites at the basement surface (Klasner et al., 1984, Hinze and Zietz, 1984).

Although modeling of magnetic anomalies at satellite elevations provides little information about crustal genesis, some interesting implications have resulted from the modeling process. The magnetic model is bounded by the Moho and becomes thinner to the northeast. Although the exact position of the magnetic layer in the crust is ambiguous, crustal velocity data and the proposed thermal event suggest a deep crustal source. The lateral boundaries between the three segments of the model (Figure 21) are for the convenience of modeling only and bear no significance for delineating magnetic sources in the crust. However, the implications of these boundaries indicate that the magnetic sources diminish in volume or magnetization or both to the northeast. Ultimately the sources of the SCUSMA are controlled by a combination of both variable thickness of the magnetic crustal layer and a heterogenous distribution of magnetic minerals in the earth's crust. Mantle derived magmas which intruded and fused with a heterogenous crust could have different degrees of magnetization as is suggested by the volume distribution of the model.

A positive anomaly lies over the southern Colorado Plateau in the MAGSAT scalar field and appears to be an extension of the SCUSMA. An attempt was made to model this feature using the reduced-to-pole MAGSAT scalar field and the first radial derivative map of the reduced-to-pole field to approximate the lateral extent of the causative
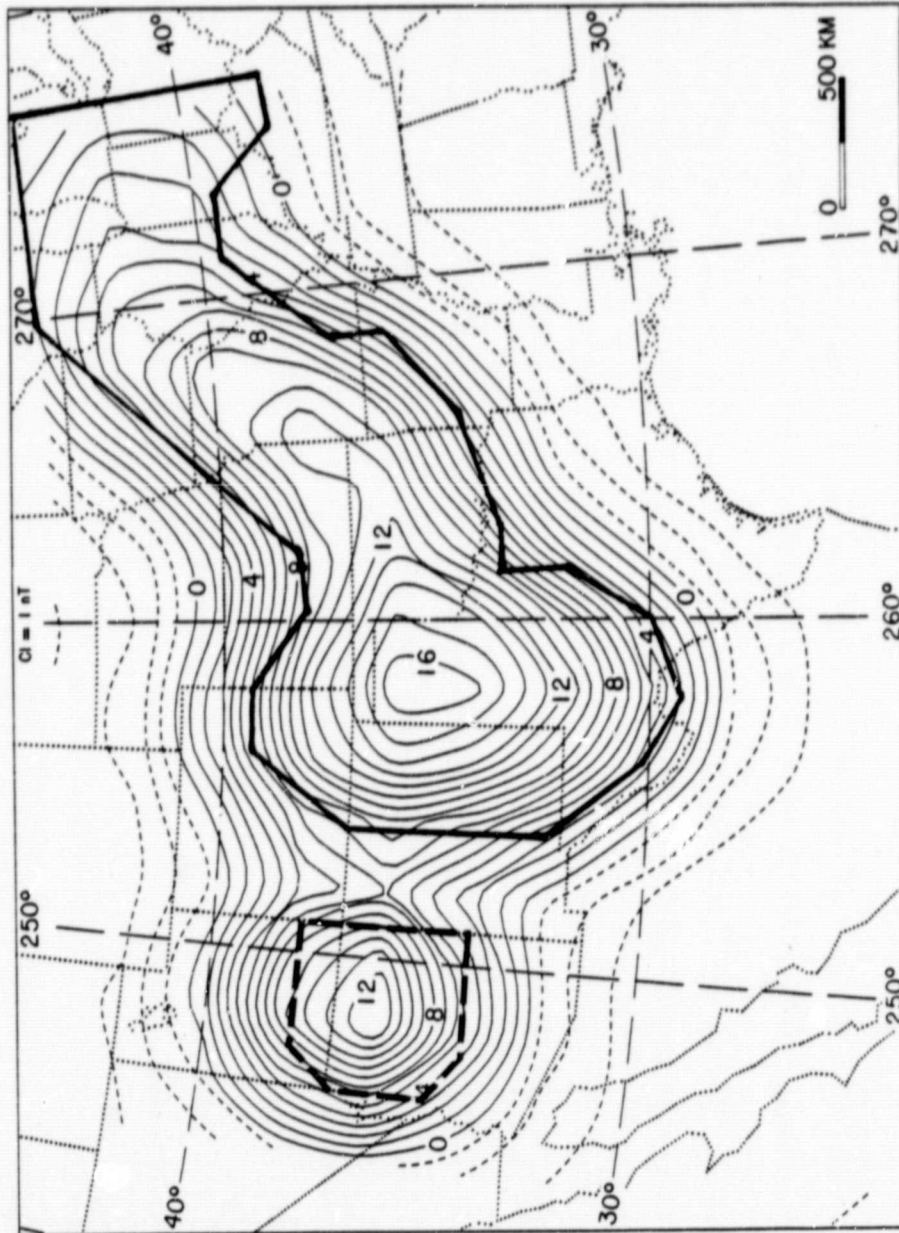
Figure 24. Three dimensional distibution of crustal magnetic
model including Colorado Plateau area with superimposed
theoretical magnetic field. Depth of model extends from 1-42
km in Colorado Plateau area. Elevation = 400 km. Contour
interval = 1 nT.

magnetic sources. As before, the Moho was chosen as the lower limit of the initial model. The resulting modeled field appears in Figure 24. A susceptibility contrast of 0.0028 emu/cm^3 was required to obtain a three dimensional anomaly with an amplitude comparable to the feature in the reduced-to-pole MAGSAT map. This implies that the sources of the positive anomaly over the southern Colorado Plateau may involve a more highly magnetic crust that the sources which produce the South-Central United Magnetic Anomaly. The resulting modeled anomaly has a much steeper gradient that the feature in the reduced-to-pole MAGSAT field.

VI. CONCLUSIONS

The primary objective of this investigation was to determine the origin of the South-Central United States Magnetic Anomaly and to develop a geologically reasonable magnetic crustal model. The study involved the examination and correlation of geological and geophysical data in a integrated interpretation of the MAGSAT scalar field. Inversion of the MAGSAT data and subsequent enhancement of both MAGSAT data and Free-air anomaly gravity data and average crustal p-wave velocity data provided additional constraints suggesting the presence of a dense mafic lower crustal layer. Two-dimensional and three-dimensional modeling helped to refine a geologically reasonable crustal magnetic model within the constraints imposed by the geological and geophysical properties of the crust in the central United States. The final model corresponds primarily to the distribution of Middle Proterozoic granite-rhyolite rocks which transect the central U.S., and to a lesser extent rocks which may underlie Grenville age terrain in central Texas, metamorphic terrain in eastern New Mexico and the igneous complex of the Southern Oklahoma Aulacogen. Additional magnetic effects are produced by the

superpositioning of smaller sources contained within these terrains.

The resulting model indicates that the sources which produce the South-Central United States Magnetic Anomaly are related to the extensive Middle Proterozoic anorogenic granite and rhyolite which may have been derived in part from the lower crust by an extensive thermal event. Such a thermal event may have produced a highly magnetic lower crust by differentiation and enrichment of magnetic material. The Grenville age rocks of central Texas may contribute very little to the amplitude of the SCUSMA. The model also indicates these magnetic sources diminish in volume or magnetization or both to the northeast where the SCUSMA extends into the Great Lakes region. Although the various geological and geophysical correlations together with the final magnetic model provide little information regarding the genesis of this Middle Proterozoic felsic terrane, the uneven distribution of the magnetic sources indicates that these rocks may be derived in part from heterogenous crustal material, already in place by Middle Proterozoic time. Magnetic sources may have been enriched in the lower crust by differentiation caused by a mantle related thermal event.

Attempts to develop a crustal model for the positve MAGSAT anomaly over the southern Colorado Plateau resulted in a magnetic model with unusually high magnetization indicating that the sources of this feature may arise from a more highly magnetic crust.

BIBLIOGRAPHY

BIBLIOGRAPHY

Allingham, John W., 1976, Interpretation of aeromagnetic anomalies in southeastern Missouri, a study of the relations of aeromagnetic anomalies to the Precambrian igneous geology and related mineral deposits; U.S. Geological Survey open-file report 76-868, 319p.

Allingham, John W., 1966, Aeromagnetic anomalies in the Bonne Terre area of the southeast Missouri mining district; Society of Exploration Geophysicists Mining Geophysics, v 1, 36-53.

Anderson, J.L., 1983, Proterozoic anorogenic plutonism of North America; Geological Society of America Memoir 161, 133-154.

Bott, M.H.P., 1982, The Interior Of The Earth- its structure, constitution and evolution; Elsevier Scientific Publishing Co., Inc.., , 403p.

Braile, L.W., Hinze, W.J., von Frese, R.R.B. and Keller, G.Randy, 1983, Seismic properties of the crust and upper-mantle of North America: from technical report to Goddard Space Flight Center, NASA grant NCC5-21.

Denison, R.E.,Lidiak, E.G., Bickford, M.E., Kisvarsanyi, E.B., 1984, Geology and geochronology of precambrian rocks in the central interior region of the United States; U.S. Geological Survey Professional Paper, in press.

Dickinson, William R., 1984, Plate tectonic evolution of the southern cordillera; in press

Dickinson, William R. and Snyder, Walter S., 1979, Geometry of subducted slabs related to San Andreas transform; Journal of Geology, v 87, 609-627.

Higgins, M.D., 1981, Origin of acidic anorogenic rocks, crust or mantle?;EOS, v 62, 437.

Hinze, W.J., von Frese, R.R.B., Longacre, M.B., Braile, L.W., 1982, Regional magnetic and gravity anomalies of South America; Geophysical Research Letters, v 9, no. 4, 314-317.

Hinze, W.J., Braile, L.W., Keller, G.R., and Lidiak, E.G., 1983, Geophysical-geological studies of possible extensions of the New Madrid fault zone; U.S. Nuclear Regulatory Commission annual report NUREG/CR-3174, v 1, 87p.

Hinze, W.J., Braile, L.W., von Frese, R.R.B., Lidiak, E.G., Denison, R.E., Keller, G.R., Roy, R.F., Swanberg, C.A., Aiken, C.L.V., Morgan, P., and Gosnold, W.D., 1984, Exploration for hot dry rock geothermal resources in the midcontinent USA; Final Report to Los Alamos National Laboratory, contract no. 9-X60-2133K-1, v 1.

Hinze, W.J., and Zietz, I., 1984, Composite magnetic anomaly map of the conterminous United States: The utility of regional gravity and magnetic anomaly maps; Society of Exploration Geophysicists Special Volume, in press

Keller, G.R. and Cebull, S.E., 1973, Plate tectonics and the ouachita system in Texas, Oklahoma, and Arkansas; Geological Society of America Bulletin, v 83, 1659-1666.

Keller, G.R., Bland, A.E., and Greenberg, J.K., 1982, evidence for a major Late Precambrian tectonic event (rifting?) in the eastern midcontinent region, United States; Tectonics, v 1, 213-223.

Keller, G.R., Lidiak, E.G., Hinze, W.J., and Braile, L.W., 1983, The role of rifting in the tectonic developement of the midcontinent, U.S.A.; Tectonophysics, no. 94, 391-412.

King, Phillip B., 1977, The Evolution Of North America, Princeton University Press, 197p.

Klasner, J.S., King, E.R. and Jones, W.J., 1984, Geological interpretation of gravity and magnetic data for northern Michigan and Wisconsin: The Utility of regional gravity and magnetic maps; Society of Exploration Geophysicists Special Volume, in press.

Langel, R.A., 1982, The magnetic earth as seen from MAGSAT, intial results; Geophysical Research Letters, v 9, 239-242.

Langel, R.A., Phillips, J.D., and Horner, R.J., 1982, Intial scalar magnetic anomaly map from MAGSAT; Geophysical Research Letters, v 9, 269-272.

Longacre, M.B., Hinze, W.J., von Frese, R.R.B., 1982, A satellite magnetic model of northeastern South American aulacogens; Geophysical Research Letters, v 9, 318-321.

Mayhew, M.A. and Galliher, S.C., 1982, An equivalent layer magnetization model for the United States derived from MAGSAT data; Geophysical Research Letters, v 9, 311-313.

Mayhew, M.A., Thomas, H.H., Wasilewski, P.J., 1982, Satellite and surface geophysical expression of anomalous crustal structure in Kentucky and Tennessee; Earth and Planetary Science Letters, v 58, 395-405.

Mayhew, M.A., 1982a, An equivalent layer magnetization model for the United States derived from satellite altitude magnetic anomalies; Journal of Geophysical Research, v 87, 4837-4845.

Mayhew, M.A., 1982b, Application of satellite magnetic anomaly data to Curie isotherm mapping; Journal of Geophysical Research, v 87, 4846-4845.

Nettleton, L.L., 1976, Gravity and Magnetics in Oil Prospecting; McGraw-Hill, Inc., New York, 464p.

O'Hara, N.W., and Hinze W.J., 1980, Regional basement geology of Lake Huron; Geological Society of America Bulletin, part 1, v 9, 348-358.

Parrott, M.H., Hinze, W.J., Braile, L.W., and von Frese, R.R.B., 1984, A comparative study of spherical and flat-earth geopotential modeling at satellite elevations; EOS Transactions of the American Geophysical Union, Abstract G12-12, v 65, 181.

Reed, Jon E., 1980, Enhancement/isolation wavenumber filtering of potential field data; M.S. Thesis, Purdue University, 205p.

Regan, R.D., Cain, J.C., and Davis, W.M., 1975, A global magnetic anomaly map; Journal of Geophysical Research, v. 80, 794-802.

Schnetzler, C.C., Taylor, P.T., Langel, R.A., Hinze, W.J., 1984, Verification of MAGSAT anomaly data/comparison between the recent United States composite magnetic anomaly map and satellite results, in press.

Sexton, J.L., Hinze, W.J., von Frese, R.R.B., and Braile, L.W., 1982, Long-wavelength aeromagnetic anomaly map of the conterminous United States; Geology, v 10, 364-369.

Silver, L.T., Anderson, C.A., Crittenden, Robertson, 1977, Chronostratigraphic elements of the precambrian rocks of the southwestern and western States Geological Society of America Abstracts with Programs, v 9, p. 1176.

Sloss, L.L., 1964, Tectonic cycles of the North American craton; Kansas Geological Survey Bulletin, no. 169, 449-460.

Smithson, S.B., Johnson, R.A., and Wong, Y.K., 1981, Mean crustal velocity; a critical parameter for interpreting crustal structure and crustal growth; Earth and Planetary Science Letters, v 53, 323-332.

Snyder, John P., 1983, Map projections used by the U.S. Geological Survey: U.S.G.S. Bulletin no. 1532 2nd edition, 313 p.

Talwani, M.G., Worzel, J.L., and Landisman, M., 1959, Rapid computation for two-dimensional bodies with applications to the Mendocino submarine fracture zone; Journal of Geophysical Research, v 64, 49-59.

Taylor, P.T., 1982, Nature of the Canada basin – implications from satellite-derived magnetic anomaly data; Journal of the Alaska Geological Survey, v 2, 1-8.

Telford, W.M., Geldart, L.P., Sheriff, R.E., and Keys, D.A., 1976, Applied Geophysics; Cambridge University Press, Cambridge, U.K., 860p.

Thomas, W.A., 1976, Evolution of Ouachita-Appalachian continental margin; Journal of Geology, v 84, 323-342.

Van Schmus, W.R. and Bickford, M.E., 1981, Proterozoic chronology and evolution of the midcontinent region, North America; Precambrian Plate Tectonics (Kroner a., editor), Elsevier, 261-296.

von Frese, R.R.B., 1980, Lithospheric interpretation and modeling of satellite elevation gravity and magnetic data; Ph.D. Thesis, Purdue University, 165p.

von Frese, R.R.B., Hinze, W.J., Braile, L.W. and Luca, A.J., 1981, Spherical-earth gravity and magnetic anomaly modeling by Gauss-Legendre quadrature integration; Journal of Geophysics, v 49, 234-242.

von Frese, R.R.B., Hinze, W.J. and Braile L.W., 1982a, Regional North American gravity and magnetic anomaly correlations; Geophysical Journal of the Royal Astronomical Society, v 69, 745-761.

von Frese, R.R.B., Hinze, W.J., Sexton, J.L. and Braile, L.W., 1982b, Verification of the crustal component in satellite magnetic data; Geophysical Research Letters, v 9, 293-295.

Wasilewski, P.J., Thomas, H.H., Mayhew, M.A., 1979, The Moho as a magnetic boundary; Geophysical Research Letters, v 6, 541-544.

Wasilewski, P.J. and Mayhew, M.A., 1982, Crustal xenolith magnetic properties and long wavelength anomaly source requirements; Geophysical Research Letters, v 9, 329-332.

Yarger, Harold L., 1984, Kansas basement study using spectrally filtered aeromagnetic data; the utility of regional gravity and aeromagnetic maps; Society of Exploration Geophysicists Special Volume, in press.

APPENDIX

APPENDIX

Spherical equivalent dipole source inversions of the MAGSAT scalar field were performed to provide dipole susceptibility models which are useful for interpretation and calculation of enhanced MAGSAT approximations. The inversions are performed by calculating least-squares approximations relating the MAGSAT magnetic field measurements to a predetermined set of dipole sources (von Frese, 1980). The resulting spherical dipole grids can then be used to calculate representations of the MAGSAT scalar field.

Using the same technique, Mayhew and Galliher (1982) determined an optimal dipole spacing of about 220 km (~ 2.0°-2.4°) for the inversion of MAGSAT data over the United States. In this study the inversions were calculated for dipole grid spacings of 2.0°, 2.4°, 3.0° and 4.0°. The distributions of the dipole moments resulting from inversion of the MAGSAT scalar data for dipole grid spacings of 2.0° and 2.4° exhibited oscillatory instability making them unsatisfactory for interpretation. The dipole moments resulting from inversion for grid spacings of 3.0° and 4.0° were stable and useful for interpreting the

crustal distribution of the magnetic sources which produce the SCUSMA. Because of its closer spacing, the 3.0° grid (Figure 15) shows more detail than the 4.0° grid (not shown).

All four of the dipole models were then used to calculate representations of the MAGSAT scalar field at an elevation of 400 km. Magnetic profiles were recorded from each of the resulting representations at longitudes of E250°, E260° and E270° (Figure 25) and at latitudes of N28° (Figure 26), N34° (Figure 27) and N40° (Figure 28). The profiles associated with the 2.0° dipole grid most closely match the MAGSAT profiles, because the squared errors in the inversion process decrease as the number of dipole moments increases. Generally the inversion is performed for an over determined set of equations. However, the 2.0° grid represents a solution for an exactly determined set performed for an over-determined set of equations. However, the of equations, because the grid spacing of the MAGSAT scalar data is also 2.0° degrees. The profiles progressively deviate from the MAGSAT profile as the grid spacing is increased. The poorest fits appear on the E260° longitude and N34° latitude profiles which are closest to both the center of the study area and the peak of the SCUSMA.

The 3.0° grid of dipole moments produced a magnetic field representation which reasonably matches the MAGSAT scalar field as seen in the profiles. However, the 2.0°

grid of dipole moments produced the best fitting field representation, and was consequently used for further processing and enhancement.
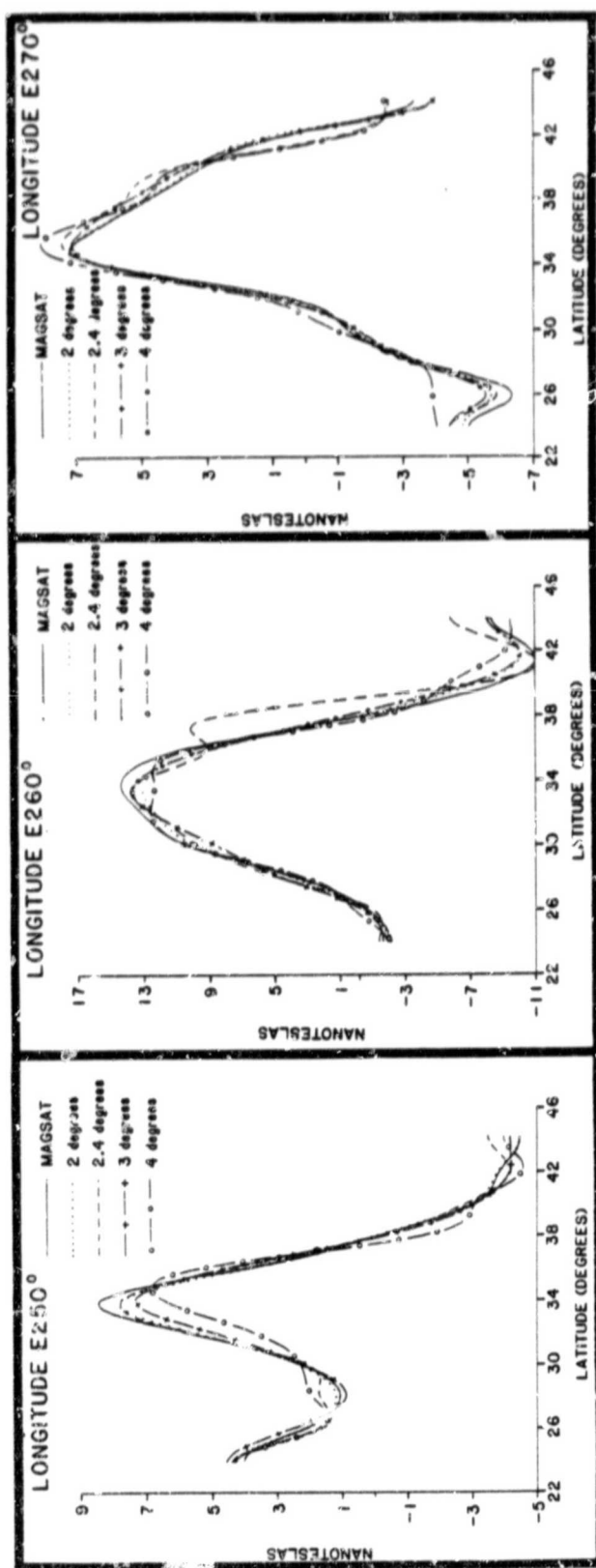
Figure 25. Comparison of longitudinal magnetic profiles across the MAGSAT scalar field and magnetic fields calculated from inversion models with dipole grid spacings of 2°, 2.4°, 3° and 4° at longitudes E250°, E260° and E270°.
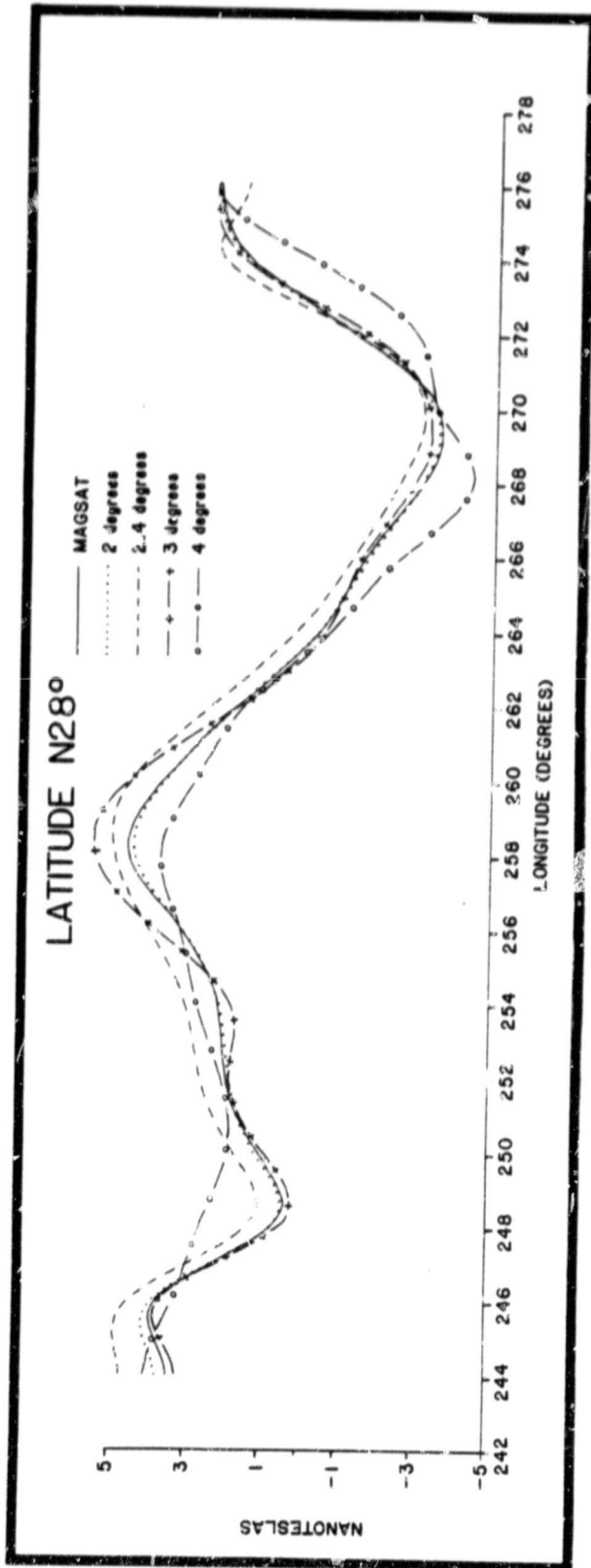
Figure 26. Comparison of latitudinal magnetic profiles across the MAGSAT scalar field and magnetic fields calculated from inversion models with dipole grid spacings of 2°, 2.4°, 3° and 4° at latitude N28°.
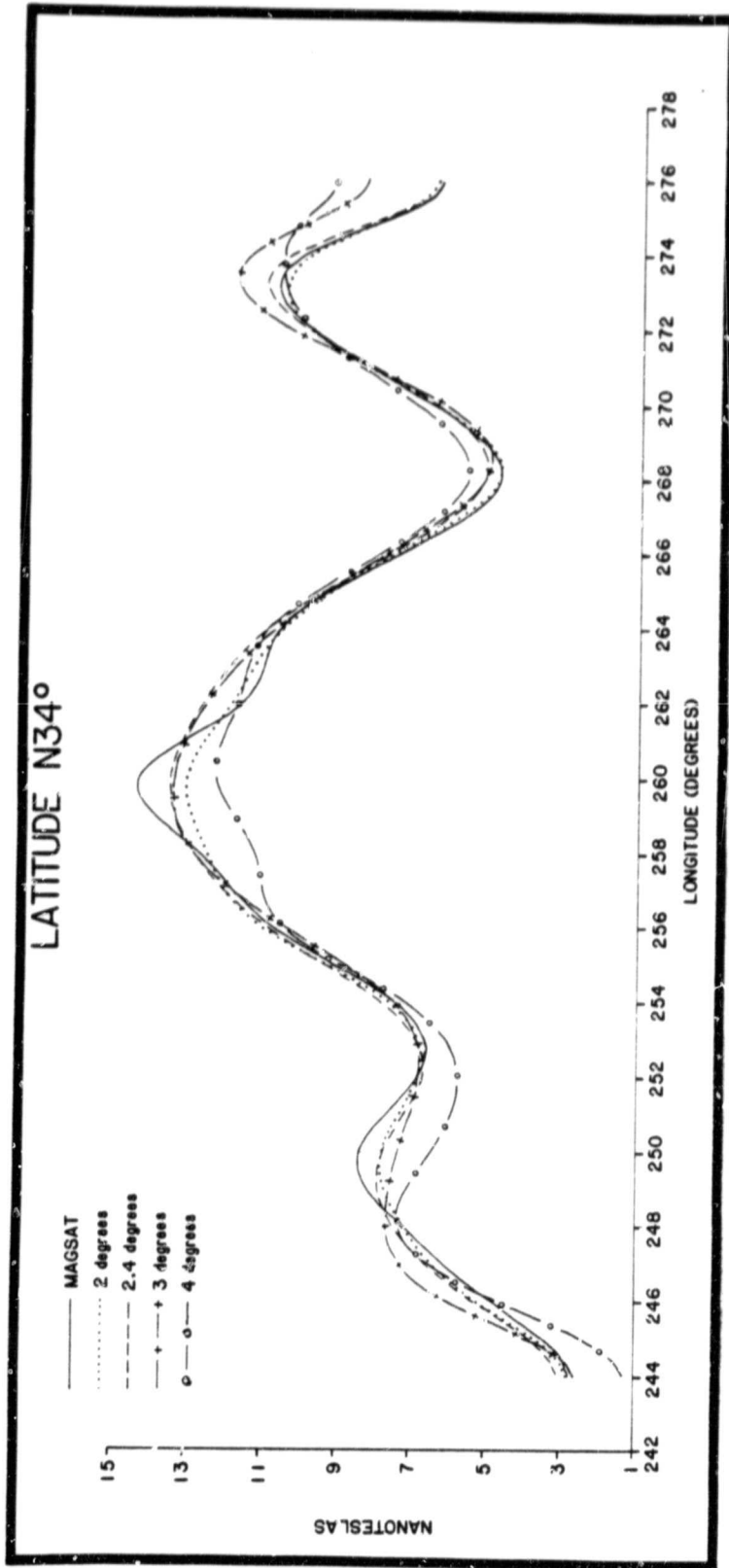
Figure 27. Comparison of latitudinal magnetic profiles across the MAGSAT scalar field and magnetic fields calculated from inversion models with dipole grid spacings of 2°, 2.4°, 3° and 4° at latitude N34°.
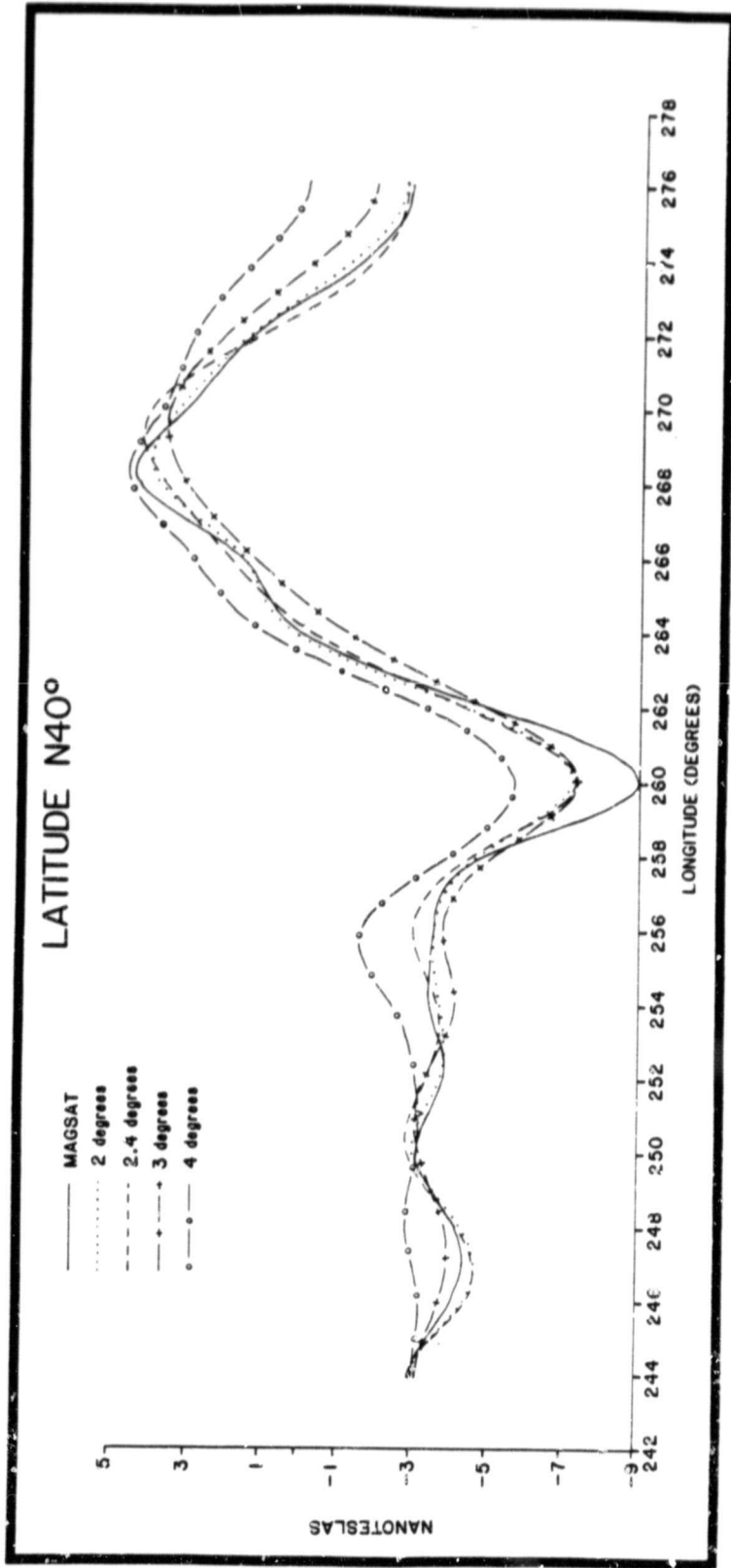
LATITUDE N40°

Figure 28. Comparison of latitudinal magnetic profiles across the MAGSAT scalar field and magnetic fields calculated from inversion models with dipole grid spacings of 2°, 2.4°, 3° and 4° at latitude N40°.