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Petrologic Model of the Northern Mississippi Embayment Based on Satellite Magnetic and Ground Based Geophysical Data

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ABSTRACT

Magnetization, derived from gravity-seismic data from the northern Mississippi Embayment, is evaluated relative to magnetization values obtained from satellite magnetic data. A magnetization contrast of approximately −0.54 A/m determined from the geophysical model compares favorably to a value of approximately −0.47 A/m from a Magsat United States Apparent Magnetization contrast map. The negative magnetization contrast, required by the Magsat data, is unusual as rift zones with the exception of those which are currently active are associated with positive magnetization. The model presented here favors an intrusion of low Curie temperature mafic rock at the base of the crust. Alternate possibilities, a shallow Curie isotherm or remanence in a direction other than that of the current main field, seem less likely as reported regional heat flow values are too low and remanence is attenuated at depth.

INTRODUCTION

Both POGO [1] and Magsat [2] anomaly maps show the magnetic anomaly low seen by aeromagnetic surveys [3] over the Mississippi Embayment aulacogen. The aulacogen, thought to be the failed arm of a late Precambrian [4] or late Paleozoic [5] triple junction associated with the opening of the Gulf of Mexico, is an area of continuing or renewed seismic activity. Interest in the Mississippi Embayment stems not only from its seismicity (the highest in the eastern United States), but also from its tectonics. Despite general similarities to the nearby "Kentucky Body" [6] e.g., both are indicated by Bouguer gravity highs and are thought to be Precambrian rifts, the magnetic low of the Mississippi Embayment is in sharp contrast to the strong magnetic high in the area of the "Kentucky Body"

In a recent paper, von Frese et al. [7] completed preliminary modeling of the Mississippi Embayment POGO magnetic anomaly utilizing the Austin and Keller [8] modification of a regional geophysical analysis by Ervin and McGinnis [4]. By assigning a negative magnetization contrast to a proposed mantle-derived intrusion, von Frese et al., were able to match the amplitude of the satellite magnetic anomaly but not the spatial aspects of its source region. Their gravity model compares very favorably, however, to observed free-air gravity upward continued to 450 km in both source location as well as magnitude.

This paper describes results obtained by using a somewhat different modeling approach. In order to derive a petrologic model from the geophysical data, the crustal profile of Austin and Keller [8] is converted to a magnetization profile by assigning susceptibilities, based on regional geology and rift petrology, to the crustal layers. This magnetization profile is then compared to the corresponding section of a magnetization contrast map [9] which is derived from satellite anomaly data. This map, despite being one additional step removed from the actual measurements, offers higher resolution and closer geographic coincidence between the anomalies and their source regions than do satellite anomaly maps [9]. Resolution is important to the present study as the length of the profile studied, 640 km is of the order of twice the resolution of satellite magnetic anomaly maps [2].

1. Crustal Profile

The Ervin and McGinnis [4] gravity profile (Fig. 1) extends from Yellville, Arkansas southeastward to Scottsboro, Alabama. It crosses the Mississippi Embayment and the Mississippi Valley Graben which lies within the northern part of the embayment. The Ervin and McGinnis model was modified by Austin and Keller [8] as the result of an analysis of group and phase velocity dispersion from Rayleigh waves recorded near St. Louis, Missouri and Oxford, Mississippi. The Austin and Keller cross-section (Fig. 2) is used in this study due to the additional seismic constraint and one less crustal layer; however, for the purpose of this study, the two models are virtually indistinguishable.

2. Magnetization Profile

The first step in constructing a magnetization model from the geophysical model is to convert the density-seismic velocity model layers to magnetic susceptibility (rock) layers. Neither densities nor seismic velocities uniquely define rock compositions; they can, however, along with other data, provide constraints on rock types. The geophysical model of Ervin and McGinnis along with rift petrology generalizations [10,11] form the basis for the transformation in this discussion.

Layer I, the lowermost layer (Fig. 2), is the upper mantle which is made up largely of peridotites [12,13]. Layer II is a gabbroic partial melt of the upper mantle. Layer III is the lower crust which was upward-domed during the early stages of rifting. There is no unanimity of opinion on the composition of the lower crust, and indeed it appears to be laterally and vertically inhomogeneous [14,15]. Xenolithic studies [16,17] plus upturned crustal sections, such as the Ivrea Zone [18,19], indicate the lower crust is largely comprised of igneous intrusive rocks as well as amphibolite to granulite grade metamorphic rocks of variable composition. Layer IV is the upper crust which is generally assumed to be of granitic to granodioritic composition; however in this area mafic plutons, possibly intruded during the late Mesozoic reactivation of the rift, border the Mississippi Valley Graben. One of these intrusions, the Covington Pluton, appears as a local 30 mgal Bouguer gravity high in the observed data along the pro-

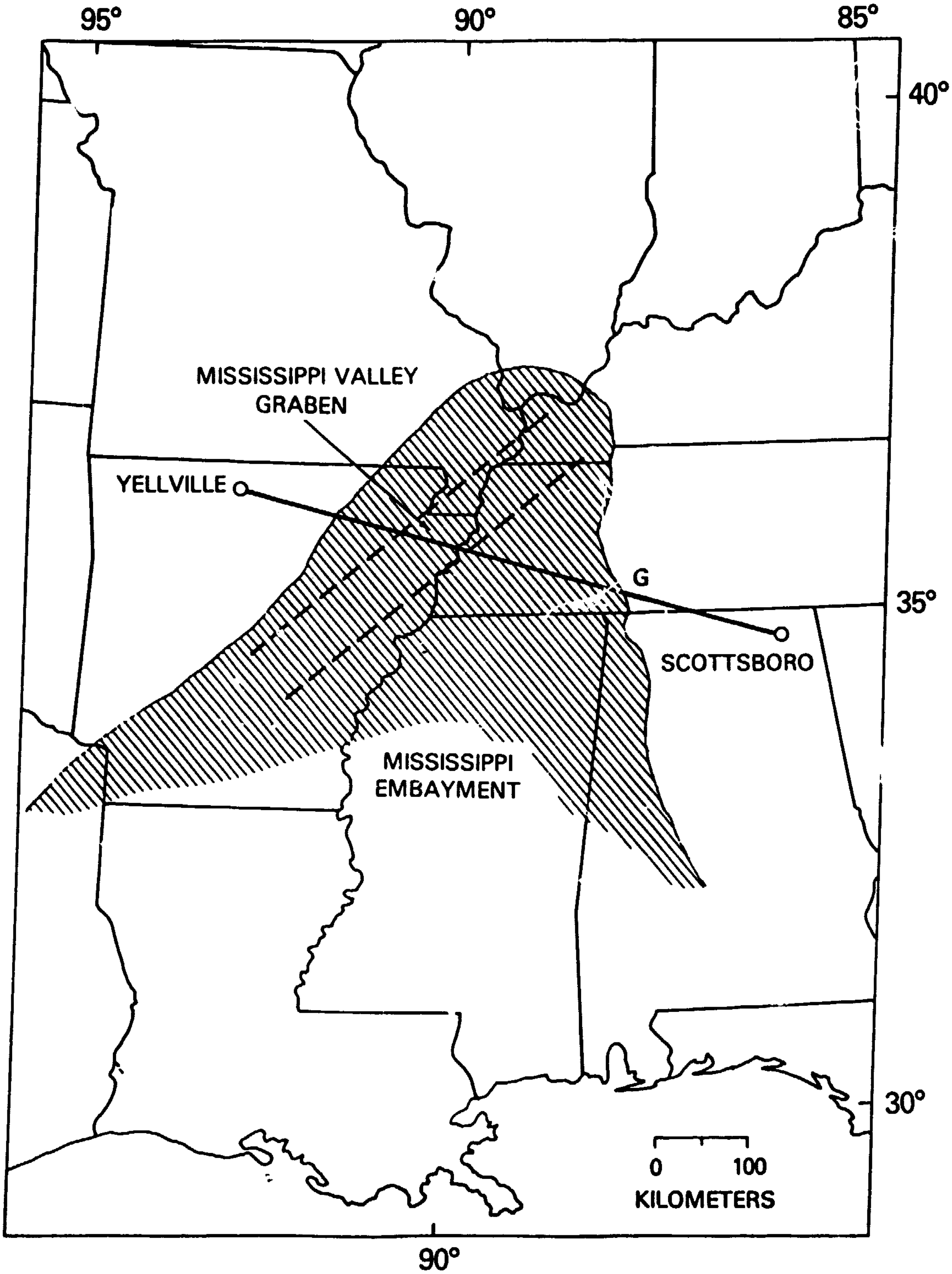

Figure 1. "G" gravity profile of Ervin and McGinnis [4] with the approximate limits of the Mississippi Valley Graben.

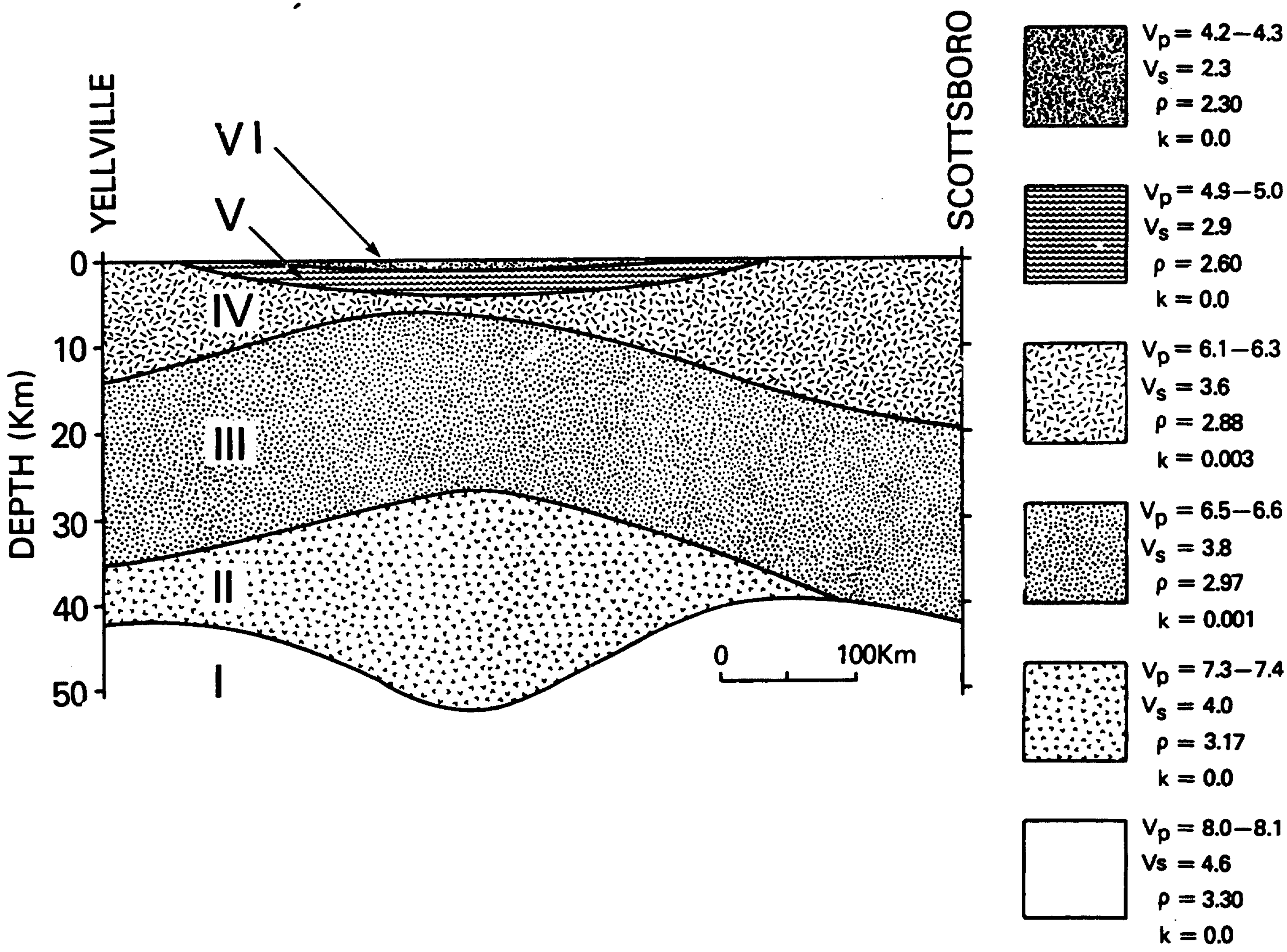

Figure 2. Gravity-seismic velocity cross-section along the "G" profile modified from Austin and Keller [8]. Seismic velocities in km/sec, densities in gm/cm^3 and magnetic susceptibilities in emu

file [4]. This short wavelength anomaly disappears however when integrated into the regional gravity model. Layers V and VI consist of unspecified sediments probably deposited during isostatic subsidence of the rifted region.

The second step consists of assigning magnetizations to the crustal layers as constrained by their assumed rock types. A survey of magnetic susceptibilities of rock types [20] shows ranges of several orders of magnitude within a given rock type. An estimate of apparent susceptibilities by Nagata [21] is consistent with the above survey to within an order of magnitude. Values used in this study are generally the weighted averages of the data of Lindsley et al. [20] except as noted. It should be clear that the prescribed values are tentative and may be modified as more data becomes available.

Layer I (Fig. 2), the upper mantle, is assigned a susceptibility of zero based on the study of Wasilewski et al. [22] in which xenoliths representative of the upper mantle were found to have negligible magnetization. Layer II, the mantle-derived gabbroic "pillow," would nominally have a value of about 0.003 emu [20,23]; alternatively, it has been shown [24,25] that gabbroic rocks formed under conditions less oxidizing than those of the Fayalite, Magnetite, Quartz (FMQ) buffer may have Curie temperatures significantly lower than that of pure magnetite (580°C). If these circumstances apply here, the layer II gabbro will have a susceptibility of zero if emplaced under any reasonable geothermal gradient (10°C/km). There is also little evidence on which to base a susceptibility for layer III, the lower crust. The modeled P-wave velocity, 6.5 km/sec, is at the more silicic end of lower crustal P-wave velocities which range from 6.4–7.4 km/sec [14]; this suggests that the lower crust in this region may be of intermediate composition. This reasoning suggests a lower crust of dioritic composition with a susceptibility of 0.001 emu [21]. A surface magnetics study [26] of the southeastern margin of the Mississippi Valley Graben gives good evidence for the susceptibility of the layer IV, upper crustal rocks. Within the graben, generally, basement rocks have modeled susceptibilities of about 0.0007 emu which are typical of granite [20], whereas a susceptibility of 0.003 emu reflects the higher oxygen fugacity, near surface mafic plutons bordering the graben [4,26]. The 0.003 emu susceptibility is used throughout layer IV as

Bouguer gravity indicates that the Covington pluton is almost continuous across the Mississippi Valley Graben along the profile. Layers V and VI consist of the upper two sedimentary layers of the Austin and Keller model. Sediments routinely have low susceptibility values [20,21] and lacking information to the contrary, we assign a value of zero to layers V and VI.

The magnetization profile is then calculated as the sum of the products of the layer thicknesses and susceptibilities (in a 50,000 nT inducing field) divided by the thickness of the total magnetic layer. For the purpose of comparison to Mayhew and Galliher's [9] Magsat Apparent Magnetization Contrast Map (Fig. 3), which assumes a 40 km magnetic layer, the computed magnetizations are normalized to a 40 km thickness.

3. Results and Discussion

The petrologically determined magnetization cross section depends heavily on the very low susceptibility assigned to a proposed gabbroic body intruded into the lower crust in the area of the Mississippi Valley Graben. The data of Haggerty [24,25] demonstrate that mafic plutonic rocks initially contain ulvospinel dominated titanomagnetite solid solutions. Unless subsequent oxidation exsolution, which is largely dependent on the oxygen fugacity and temperature of the magma or true exolution occurs, the rocks can have Curie temperatures lower than 250°C. Curie temperatures of approximately 250°C and 150°C are reported [27] for an Oki Dogo, Japan xenolithic gabbro and a xenolithic pyroxene garnet granulite from the Kilbourne Hole in the southern Rio Grande Rift, respectively; both these samples are thought to have equilibrated under relatively reducing (low oxygen fugacity) conditions. High heat flow, localized by faulting along the sides of the Mississippi Valley Graben, would be an alternative cause for the magnetization low, but there is no evidence for high heat flow in the region.

Plotted along the profile (Figure 4) are magnetizations from the Magsat Apparent Magnetization Contrast Map (Fig. 3) together with the model magnetizations. Two major discrepancies between the curves are readily apparent; a lack of correspondence of the magnetization minima in an east-west direction, and a difference in the magnetization levels.

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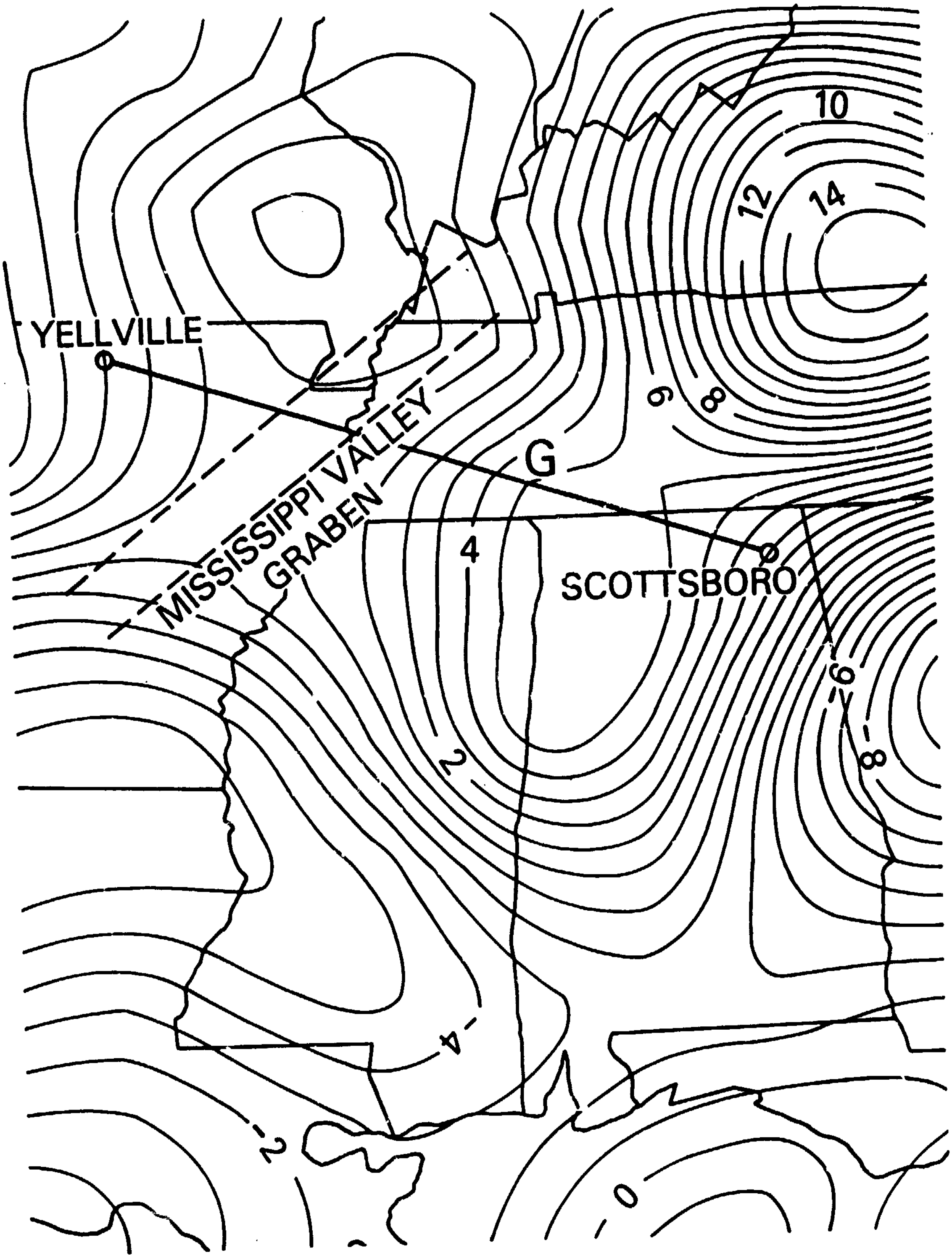

Figure 3. A section of an Apparent Magnetization Contrast Map [9] based on Magsat satellite magnetic anomaly data. Contour interval is 0.1 A/m.

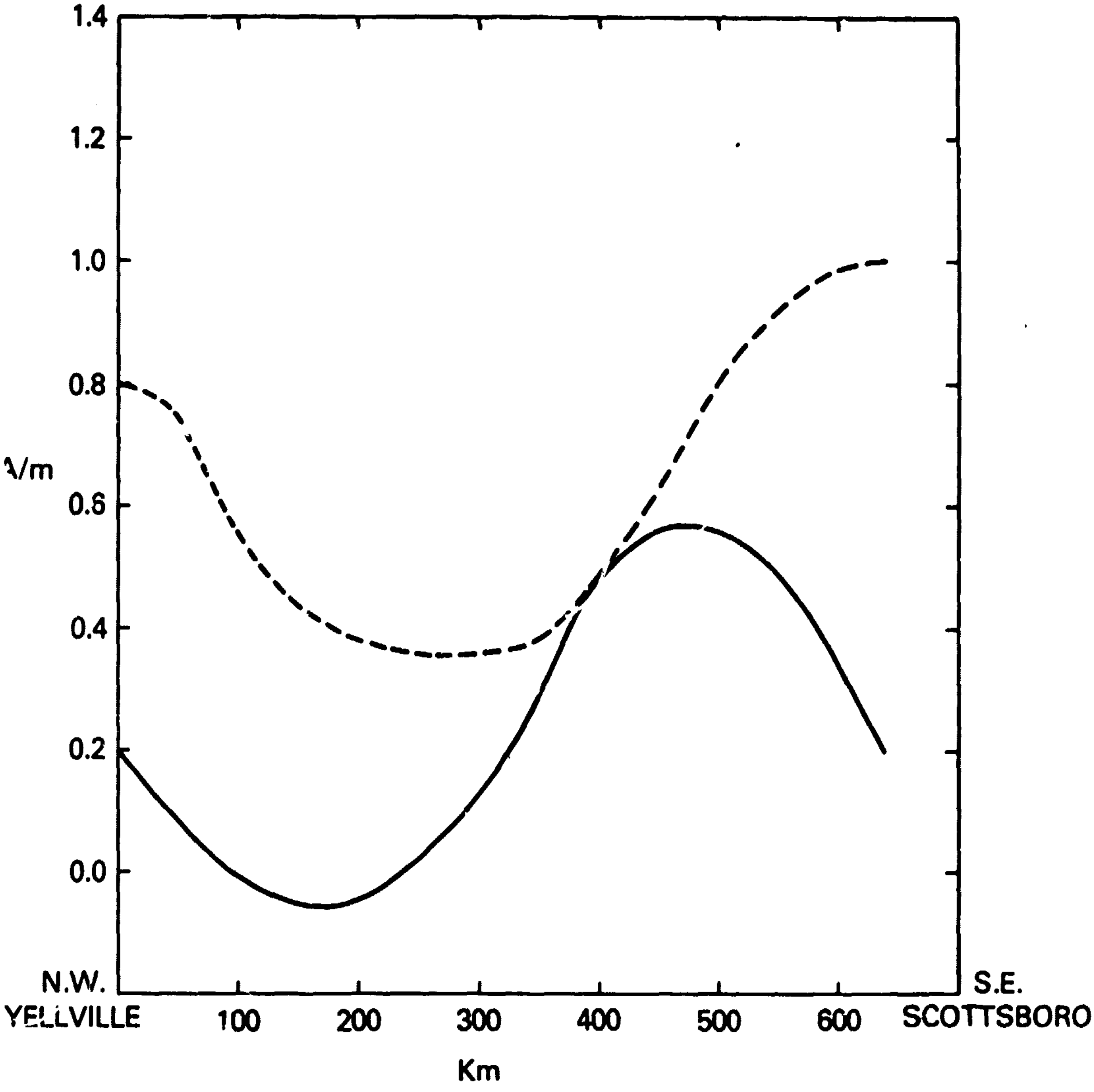

Figure 4. Magsat Apparent Magnetization Contrast (solid line, values taken from contours ı ıg. 3) and model values (dashed line) along the profile.

The magnetization level problem is not immediately solvable; there exists a zero level uncertainty in all measured magnetic anomaly data [2] but the magnetization amplitudes of approximately −0.54 and approximately −0.47 A/m for the modeled and observed magnetization anomalies respectively are in reasonable agreement. The model can be made to fit the observed more closely, but at this time it is felt that uncertainties, particularly in the magnetic susceptibilities assigned to the inferred rock layers, do not justify such action. Both magnetization contrasts are smaller than the 1.2 A/m value determined by von Frese et al. [7]; this is most likely the result of less overlap from the very large west Texas and Kentucky-Tennessee anomalies due to the better resolution of the Apparent Magnetization Contrast Map. It appears that reasonable rock magnetizations in a rifting environment can account for the observed satellite anomaly low over the Mississippi Embayment.

The spatial disagreement between the magnetization minima is probably best explained by noting that the observed magnetization low is centered on and appears to be constrained by the Mississippi Valley Graben (Fig. 3). The graben, though visible in local Bouguer gravity maps, has little expression in regional gravity maps and therefore little expression in a magnetization map modeled from the regional maps.

4. Conclusions

Satellite magnetic and aeromagnetic data indicate an anomaly low over the Mississippi Embayment. A magnetization model of a profile of the region, constructed from geophysical, petrologic and rock magnetics data is compared here to a magnetization model derived from satellite anomaly data. A reasonable similarity between the two models is found especially if short-comings; such as, a zero level uncertainty in the satellite anomaly data, a "smoothed" regional gravity model and a lack of detailed rock magnetic susceptibility data are taken into consideration.

The Mississippi Graben magnetic low contrasts with the magnetic highs of the Bangui [28] and Kentucky [6] paleorifts; however, it shows general agreement with lows modeled by Longacre et al. [29] for the South American Amazon and Takatu failed rifts. The model suggests that magnetic lows can occur over cold inactive rifts as well as hot active rifts, and that structures need not be rejected as rifts because they have low magnetization.

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