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**MAPPING MAGNETIZED GEOLOGIC  
STRUCTURES FROM SPACE:  
THE EFFECT OF ORBITAL  
AND BODY PARAMETERS**

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Abstract

When comparing previous satellite-magnetometer missions (such as Magsat) with proposed new programs (for example, Geopotential Research Mission, GRM) it is important to quantify the difference in scientific information obtained. We use the ability to resolve separate magnetic blocks (simulating geological units) as a parameter for evaluating the expected geologic information from each mission. This study evaluates and quantifies the effect of satellite orbital altitude on the ability to resolve two magnetic blocks with varying separations. Other parameters which were changed were: inclination and intensity of the dipolar field, and orientation of the magnetized blocks.

Our results indicate a systematic, but non-linear, relationship between resolution and distance between magnetic blocks as a function of orbital altitude. The proposed GRM would provide an order-of-magnitude greater anomaly resolution than the earlier Magsat mission for widely separated bodies (>500 km); difference in resolution increases even more dramatically as body separation approaches the altitude of GRM. The resolution achieved at any particular altitude varies by about a factor of ten depending on the location of the bodies and up to about a factor of two depending on orientation.

## Introduction

This study examines the variation in spatial resolution of the magnetic anomaly field with altitude of observation. It was motivated by speculation regarding the improvement in measurement capability afforded by future satellite missions designed to measure the magnetic field at very low altitudes--down to the 100 to 150 km range. However, this study also sheds some light on interpretation of the magnetic anomaly field already measured by the POGO and Magsat missions at 325 to over 600 km altitudes.

Spatial resolution is qualitatively defined in this paper as the ability to distinguish, as separate entities, two bodies of equal magnetization and shape separated and surrounded by material of a different magnetization. The model is shown in Figure 1a. Two identical prismatic bodies, 200 km by 200 km in area, 40 km thick, have equal magnetic susceptibilities which contrast with the surrounding volume by +0.0005 (cgs units). Distance between the bodies (d) is varied, as well as the height (altitude) of the observation (Fig. 1b). The effect of two other variables which influence resolution are also considered--the location of the bodies on the Earth (accounting for the variation of field strength and inclination over the Earth), and the orientation of the two bodies with respect to magnetic north.

Quantitatively, resolution is defined in this report as the difference between the average amplitude of the two maximum over the two bodies and the minimum amplitude between the two bodies, measured on the profile connecting the centers of the blocks. In the profiles of Figure 1c, resolution (R) is defined as:

$$R = (A_1 + A_2)/2 - B$$

It can be seen from the three fields modeled at different altitudes that resolution is a strong function of altitude (Fig. 1b, 1c). Modeling is performed using a spherical Earth, Gauss-Legendre quadrature integration technique (von Frese et al., 1981).

#### Resolution as a Function of Altitude

Modeling was first performed with the two bodies in a fixed orientation (east-west) and at a fixed geomagnetic location (field inclination =  $75^\circ$ , main field amplitude = 57,000 nT), but with the observation plane at different heights and the bodies separated by differing distances. Figure 2 shows the resolution as a function of altitude for two bodies separated by 450 km. The approximate altitudes for previous or proposed new missions are shown: POGO (Polar Orbiting Geophysical Observatory) between 400 and 650 km, Magsat between 350 and 450 km, GRM (Geopotential Research Mission) at 150 km (Taylor et al., 1983), and tether (von Tiesenhausen, 1984) from the shuttle as low as 100 km. It can be seen that, for this body separation, the gain in resolution afforded by the lower altitude of GRM compared to Magsat is about an order of magnitude; about another factor of two improvement over the GRM is achieved by the tether.

Figure 3 also shows modeled resolution as a function of altitude, but now for a range of body separations from 50 km to 550 km, instead of just the one body separation shown in Figure 2. Figure 4 is the same data as used in Figure 3, but plotted as resolution versus separation for various altitudes. Note, particularly in Figure 4, that at any altitude, resolution remains relatively constant over a range of separation, when the separation is greater than the altitude; when body separation becomes less than the altitude, resolution falls off rapidly. As a consequence, the almost exactly

order of magnitude improvement in resolution of GRM at 150 km altitude over Magsat at its lower extreme of 350 km altitude for wide body separations (500 to 600 km), increases to almost a factor of 30 at 250 km body separation, and to a factor of 300 at 150 km body separations.

Figure 3 emphasizes the effect this has on the ability to compare geologic rift features (e.g. Rio Grande rift, U.S. with East Africa rift) of different widths from GRM compared to Magsat altitudes. At GRM altitude, rifts of widths  $>150$  km, for example, will differ in resolution by only about a factor of two; at the low end of the Magsat altitude (350 km) separations of 150 km to 550 km differ by a factor of about 50. Thus, at Magsat altitudes it is more difficult to isolate the effects of body separations from varying effective-susceptibility contrast or volume of magnetic material.

The noise level in Magsat data has been found to be about  $\pm 1$  to  $\pm 2$  nT (Langel et al., 1982; Strangway and Arkani-Hamed, 1984); this is a sum of instrumental and environmental noise. Figures 3 and 4 show that for bodies of susceptibility contrast of 0.0005, separations of 450 km and greater are needed so that the resolution at Magsat altitude is approximately equal to the noise level. At the GRM altitude of 150 km, a separation of 100 km is clearly above the noise level, and a separation of 50 km will have a signal to noise (S/N) level of  $\sim 1$ . As there is a one-to-one trade-off between susceptibility and volume, the large increases in S/N discussed above means that bodies of much smaller magnetic susceptibility contrast or volume can be distinguished above instrument and environment noise at the lower altitudes.

### Effect of Location on Resolution

The above discussion is based on modeling at 75° main field inclination and 57,000 main field amplitude; thus, the results are strictly applicable to only a limited region of the Earth. This section examines the effect of different field inclinations and intensity on resolution. This, in effect, is examining the effect of location of the bodies on the earth on resolution, since changes in the main field inclination and intensity can be related to location.

Assuming an axial geocentric dipole model for the Earth's main field (i.e., where the field is represented by a dipole aligned along the rotational axis), the strength of the field (F) at geographic latitude (L) is given by

$$F = F_0 (1 + 3 \sin^2 L)^{1/2}$$

and the inclination (I) of the field as a function of geographic latitude is given by

$$I = \tan^{-1}(2 \tan L) \quad (\text{Irving, 1964}).$$

Combining the two equations gives

$$F = F_0 [1 + 3 \sin^2 (\tan^{-1} [\frac{\tan I}{2}])]^{1/2}$$

$F_0$  is the average field at the equator and is taken here to be 31,000 nT. The variation of field strength with inclination (solid line) and geographic latitude with inclination (dashed line) is shown in Figure 5.

Figure 6 indicates the modeled variation of resolution with body separation at five different locations on the earth. The observational altitude is 150 kms, and the body parameters are the same as the previous section (east-west orientation, size, magnetic susceptibility, etc.). There is a very large variation (almost an order of magnitude) in the resolution, in nT,

between the same bodies at the magnetic equator and at the pole. Given a noise level in satellite data of  $\pm 1$  to 2 nT it can be seen that the two bodies separated by 150 to 350 km, at the geomagnetic equator will have S/N ratios approximately  $\leq 1$ , while at high latitudes ( $I=75$  to  $90^\circ$ ), S/N will be  $\sim 5$  to 10 over the same separation range. Although Figure 6 is based on an observational altitude of 150 km, the same relative variation with location holds for other altitudes.

#### Effect of Orientation of the Bodies on Resolution

Previously we have modeled two bodies which were oriented in an east-west direction (*i.e.*, a line joining the centers of the blocks was parallel to geomagnetic latitude). Now we examine the effect of a different orientation of the bodies. Figure 7 compares east-west orientated bodies with north-south oriented ones (*i.e.*, where the line connecting the center of the bodies is parallel with geomagnetic longitude lines) for two body separations. It can be seen from this figure that the observations made in the last section, that resolution is a strong function of latitude, is not as significant for N-S oriented bodies, although there is still a considerable effect of inclination (= latitude) on resolution in the N-S orientation.

The major conclusion to be drawn from Figure 7, however, is that the orientation of the bodies has a marked effect on the resolution for field inclinations  $< 60^\circ$ ; at inclination  $\geq 60^\circ$  the difference in resolution is small ( $< 1$  nT) between N-S and E-W oriented bodies. North-south oriented bodies can be resolved more readily than E-W oriented bodies.

This phenomena may partially explain the east-west stripping seen in satellite anomaly field maps at low geomagnetic latitudes (Langel et al., 1982).

Given an orthogonal grid of equal area blocks of constant magnetic susceptibility contrast of 0.0005, separated by 250 km in both the N-S and E-W directions, it can be seen from Figure 8 that at low geomagnetic latitudes ( $I = 15^\circ$  in this case) a resolution of about 4 nT is achieved between rows, but only about 1 nT resolution is achieved between the columns. If the noise in the data is about  $\pm 1$  nT, then the columns are not resolved (in an east-west direction) but the rows (north-south direction) are resolved. Thus, the grid of blocks would appear as long east-west trending anomalies, similar to what is observed in the satellite maps.

### Conclusions

1. Resolution is a very strong function of altitude, but is also strongly dependent upon the distance between the bodies when separation is less than the altitude.
2. The increase in resolution due to decrease in altitude from Magsat (~350 km) to GRM (150 km), for bodies separated by distances approximately equal to or greater than Magsat altitude (350 to 550 km) is about an order of magnitude. As the separation decreases below the altitude of Magsat, the increase in resolution dramatically increases (to a factor of ~30 for body separation of 250 km and to a factor of ~300 at 150 km body separation).
3. A decrease in altitude from GRM (150 km) to the minimum altitude for a tether from the shuttle (100 km) would allow an increase in resolution of ~2 for separations greater than GRM altitude. Increase in resolution goes to ~3 for separations approximately equal to GRM altitude (150 km), and to ~5 for 50 km separation.

4. At approximately GRM and lower altitudes, widely separated bodies (>250 km) are distinct--that is, bodies of different separation have approximately the same resolution at any given altitude. This situation simplifies interpretation, as differences in resolution can be attributed to differences in susceptibility or volume.

5. Resolution is also a function of main field inclination. At body separations of ~250 to 350 km and observational altitude of 150 km resolution varies by approximately a factor of 8 depending on field inclination; the lowest resolution is at the magnetic equator and highest at the poles. This effect must be taken into account when comparing anomalies over continental size regions.

6. Resolution is also a function of body orientation. North-south oriented bodies have higher resolution than east-west oriented bodies; above inclinations of  $\sim 60^\circ$ , however, the differences are small. This change in resolution with main field inclination is less for N-S bodies than E-W. This variation in resolution with orientation may partly explain the east-west stripping seen in the Magsat and POGO anomaly maps.

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## Figures

- Figure 1: (a) Model of geologic blocks used to generate anomaly fields. The two blocks have a magnetic susceptibility contrast with surroundings of 0.0005 (cgs units), and a variable edge-to-edge separation of  $d$ .
- (b) Anomaly field generated by modeled blocks separated by 150 km, at main field inclination of  $75^\circ$  and intensity ( $F$ ) of 57,000 nT, measured at three observational altitudes: 450 km, 300 km and 150 km.
- (c) Magnetic anomaly profiles  $X-X'$  through the center of each block for the three observational altitudes. Amplitudes  $A$  and  $B$  are used in our definition of resolution:  $(A_1 + A_2)/2-B$ . Since the two blocks have the same magnetic susceptibility,  $A_1$  and  $A_2$ , the field over each block, are equal.
- Figure 2: Resolution as a function of altitude. Bodies separated in an east-west direction by 450 km;  $\Delta X = 0.0005$  (cgs units); main field inclination =  $75^\circ$ ,  $F = 57,000$  nT. The approximate average altitude for past or planned missions are shown: POGO at  $>400$  km, Magsat at about 350 km to 450 km, GRM at 150 km and a tether from the shuttle down to 100 km.
- Figure 3: Resolution as a function of altitude for bodies of varying separation. Bodies are separated in an east-west direction,  $\Delta X = 0.0005$  (cgs units), field inclination =  $75^\circ$ ,  $F = 57,000$  nT.
- Figure 4: Resolution as a function of block separation for varying observational altitudes.  $I = 75^\circ$ ,  $F = 57,000$  nT, east-west body separation,  $\Delta X = 0.0005$  (cgs units).

Figure 5: Main field strength ( $F$ ) as a function of field inclination (solid line), and geographic latitude as a function of field inclination (dashed line) for an axial geocentric dipole model for the Earth's core field.

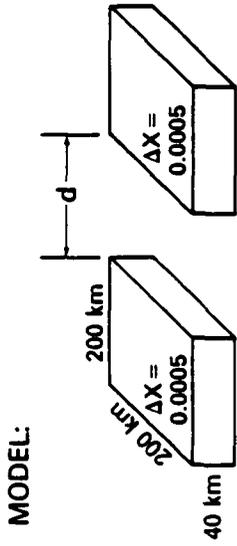
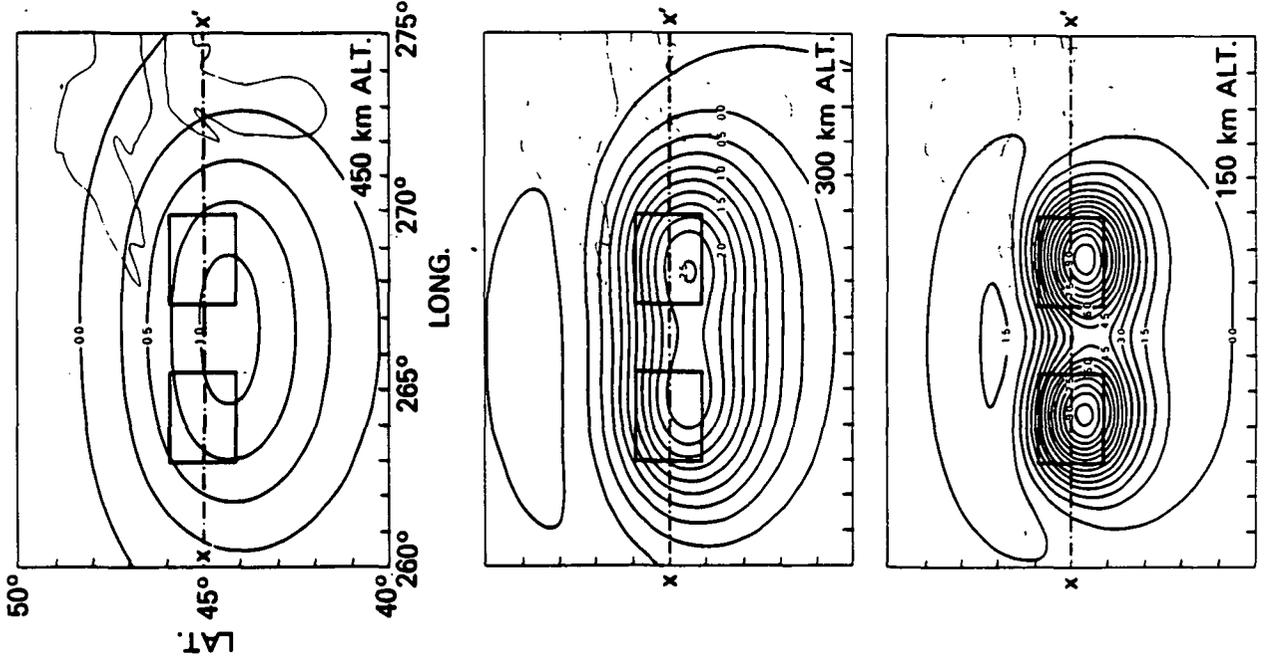
Figure 6: Resolution as a function of body separation for varying main field inclinations ( $I$ ). Altitude of observation = 150 km, body orientation is east-west,  $\Delta X = 0.0005$  (cgs units). The approximate geographic latitude ( $L$ ) corresponding to the inclination, assuming a axial geocentric dipole model, is also shown.

Figure 7: Resolution as a function of main-field inclinations for two different body orientations (parallel and perpendicular to geomagnetic latitudes: E-W and N-S) and two body separations (150 and 350 km).  $\Delta X = 0.0005$  (cgs units) and observational altitude = 150 km.

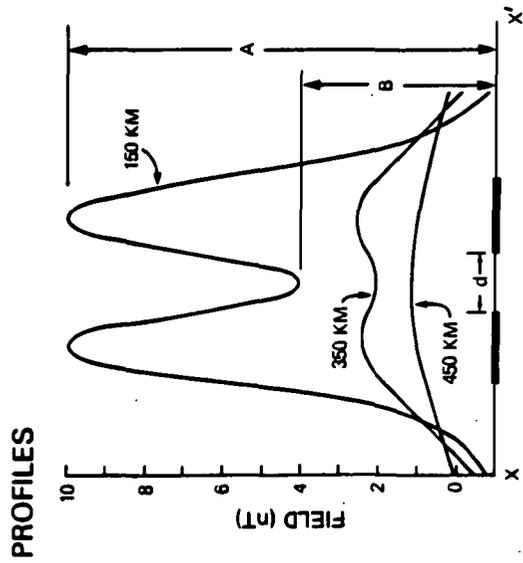
Figure 8: Magnetic anomaly field above blocks oriented in an orthogonal grid. Block parameters are as shown in Fig. 1a. Separations between blocks in both the N-S and E-W directions are 250 km (note that the scales are different in the E-W and N-S directions). Observational altitude = 150 km. Main field inclination =  $15^\circ$ , intensity = 32,000 nT. Dashed lines represent block boundaries. Contour interval = 0.5 nT.

Figure 1

(b)



(a)



(c)

Figure 2

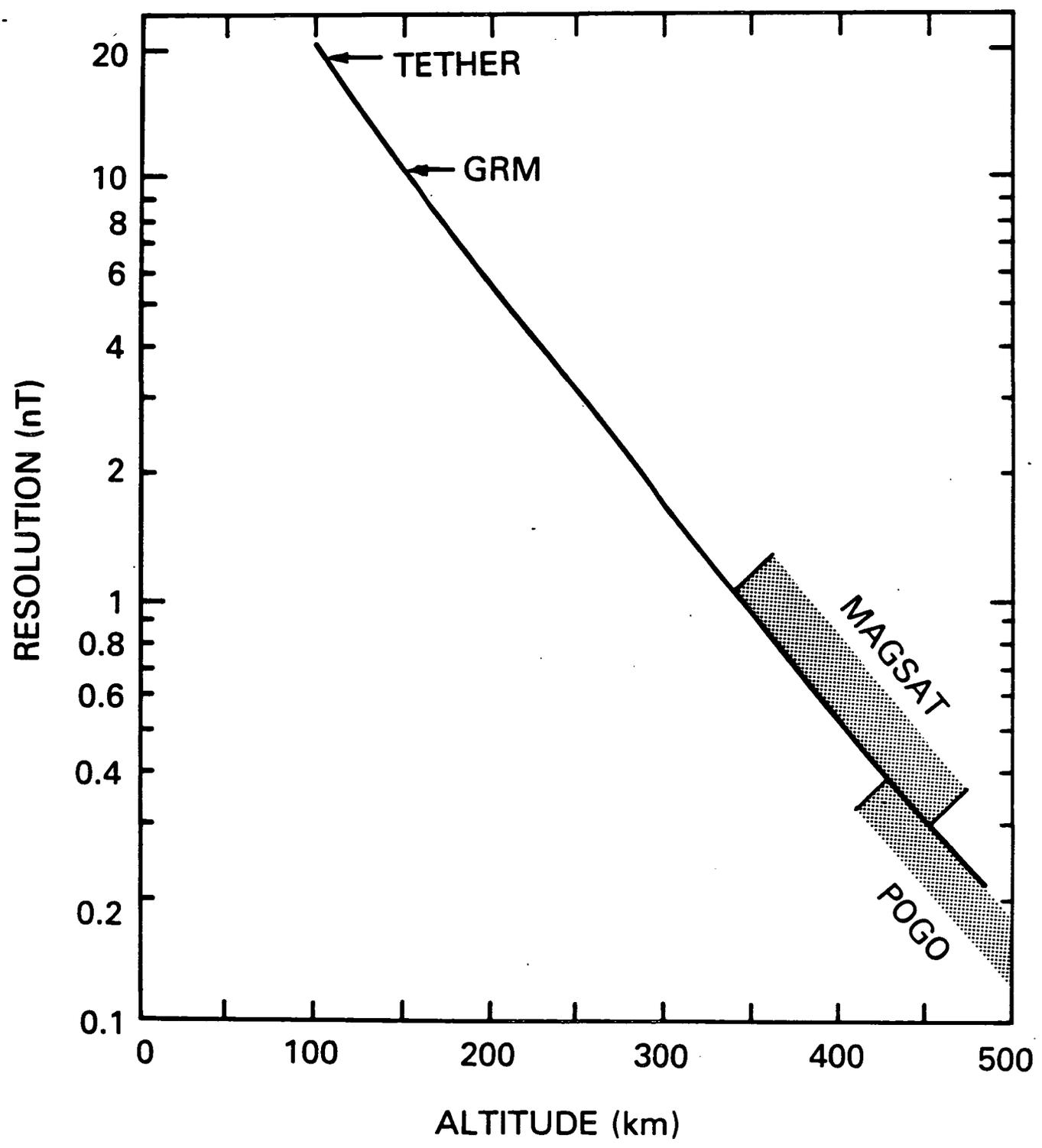


Figure 3

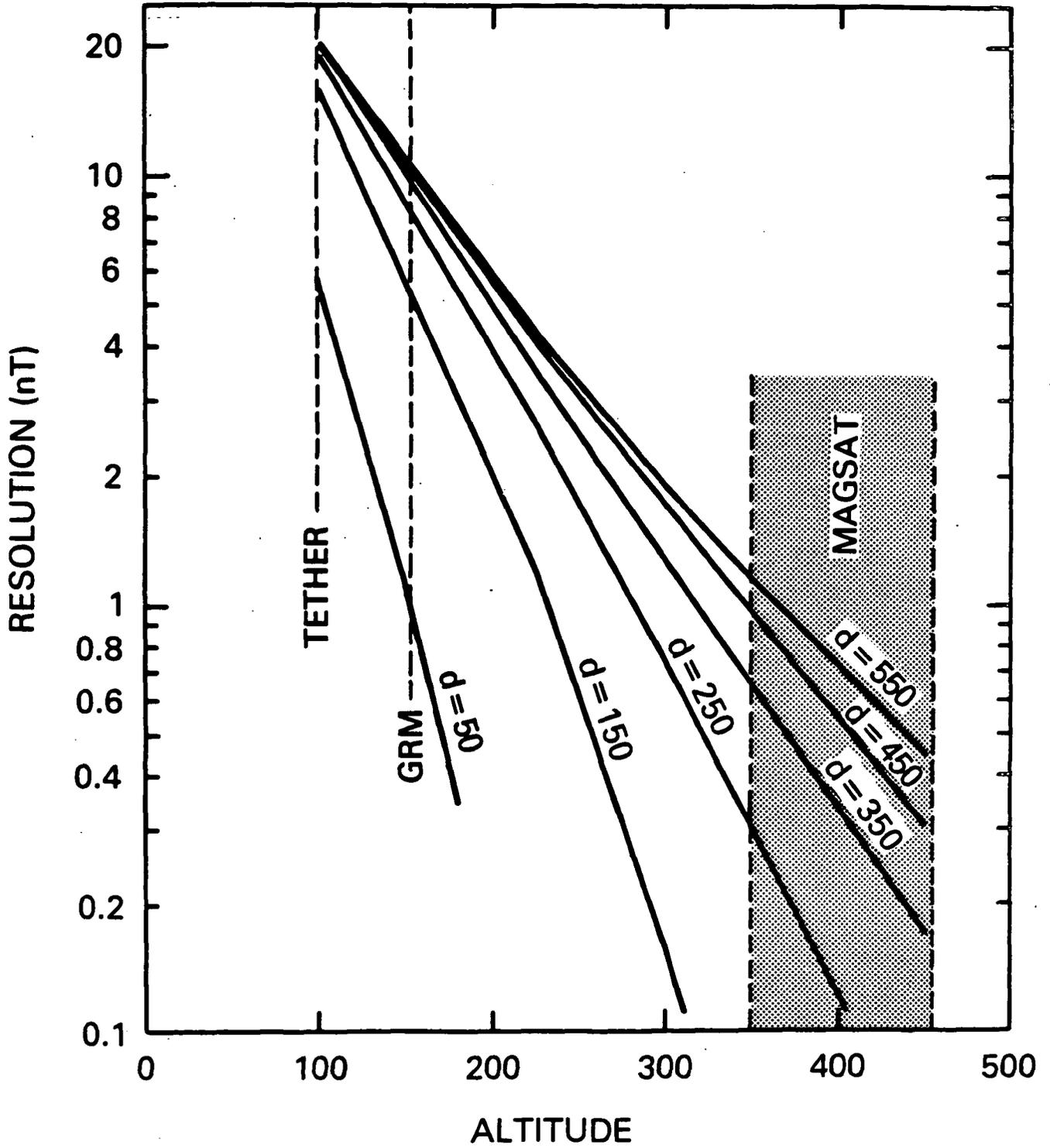


Figure 4

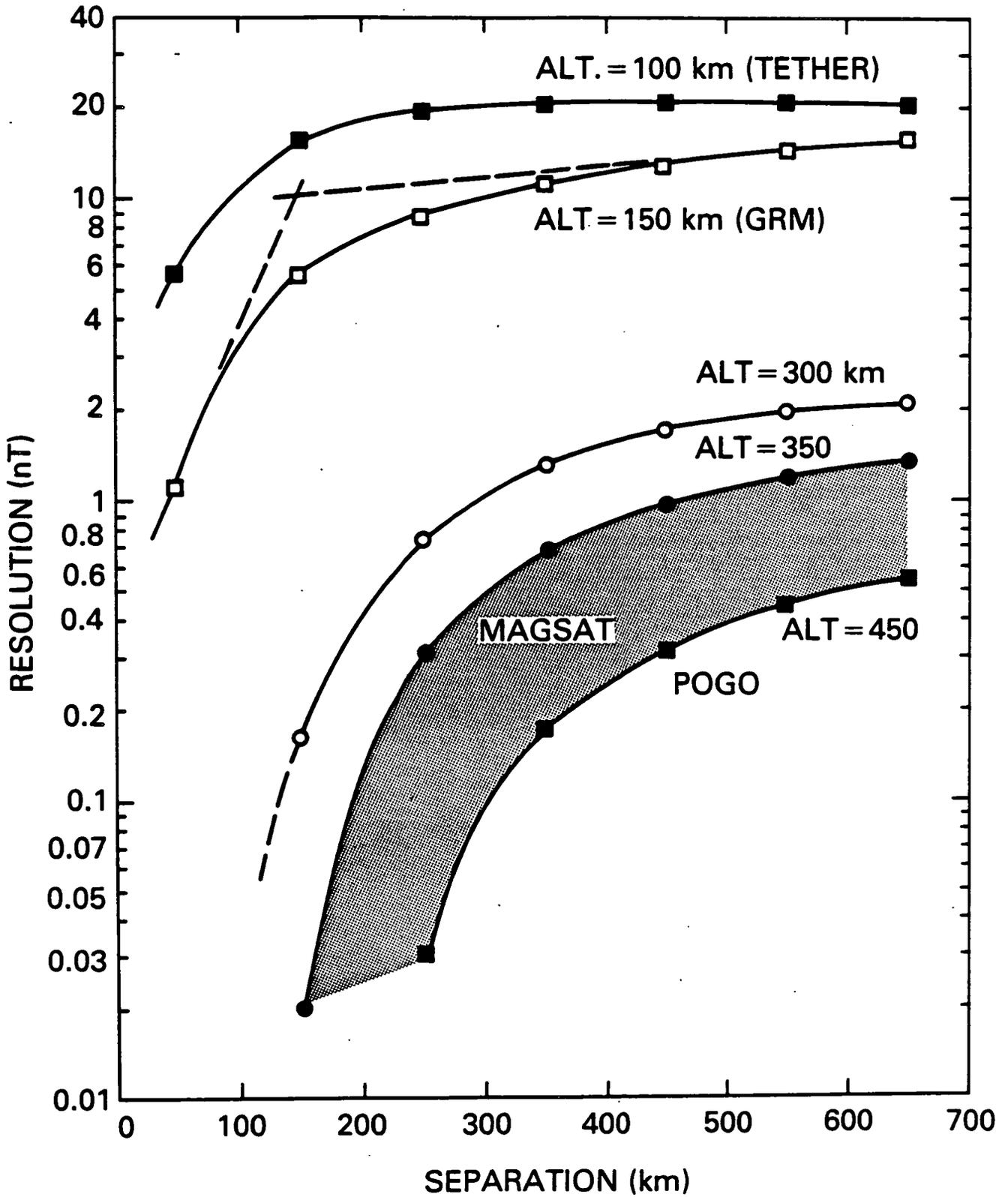


Figure 5

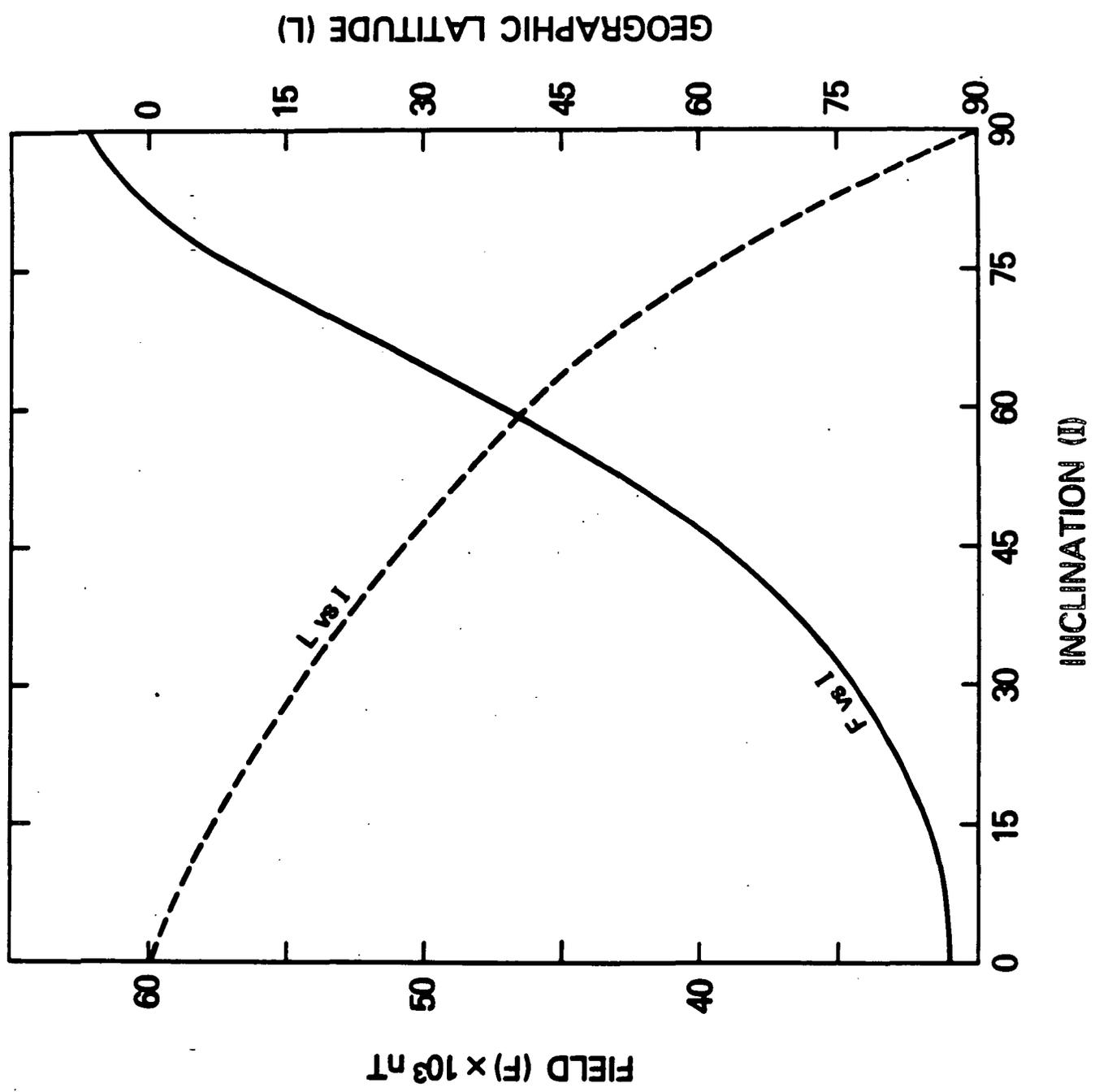


Figure 6

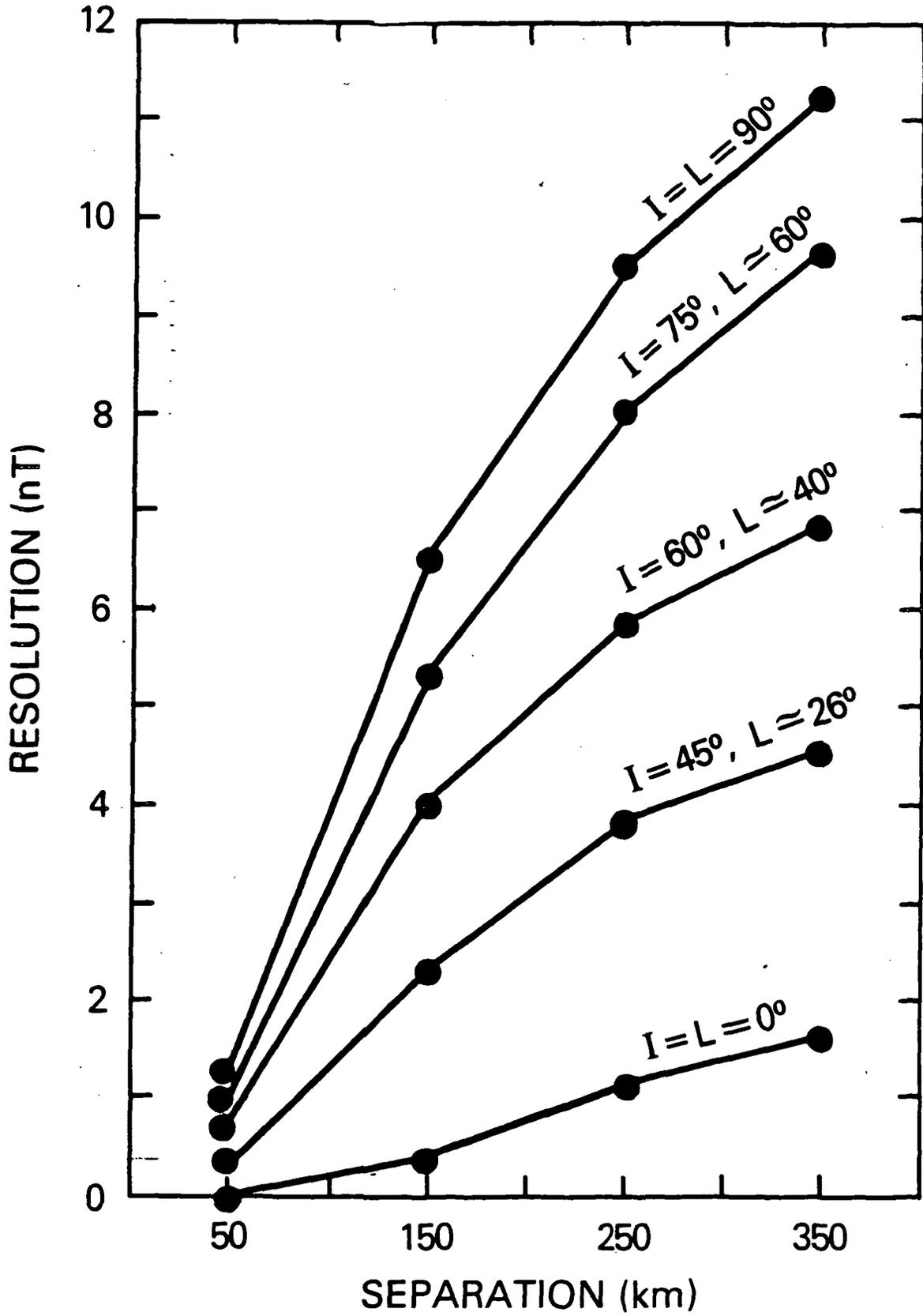


Figure 7

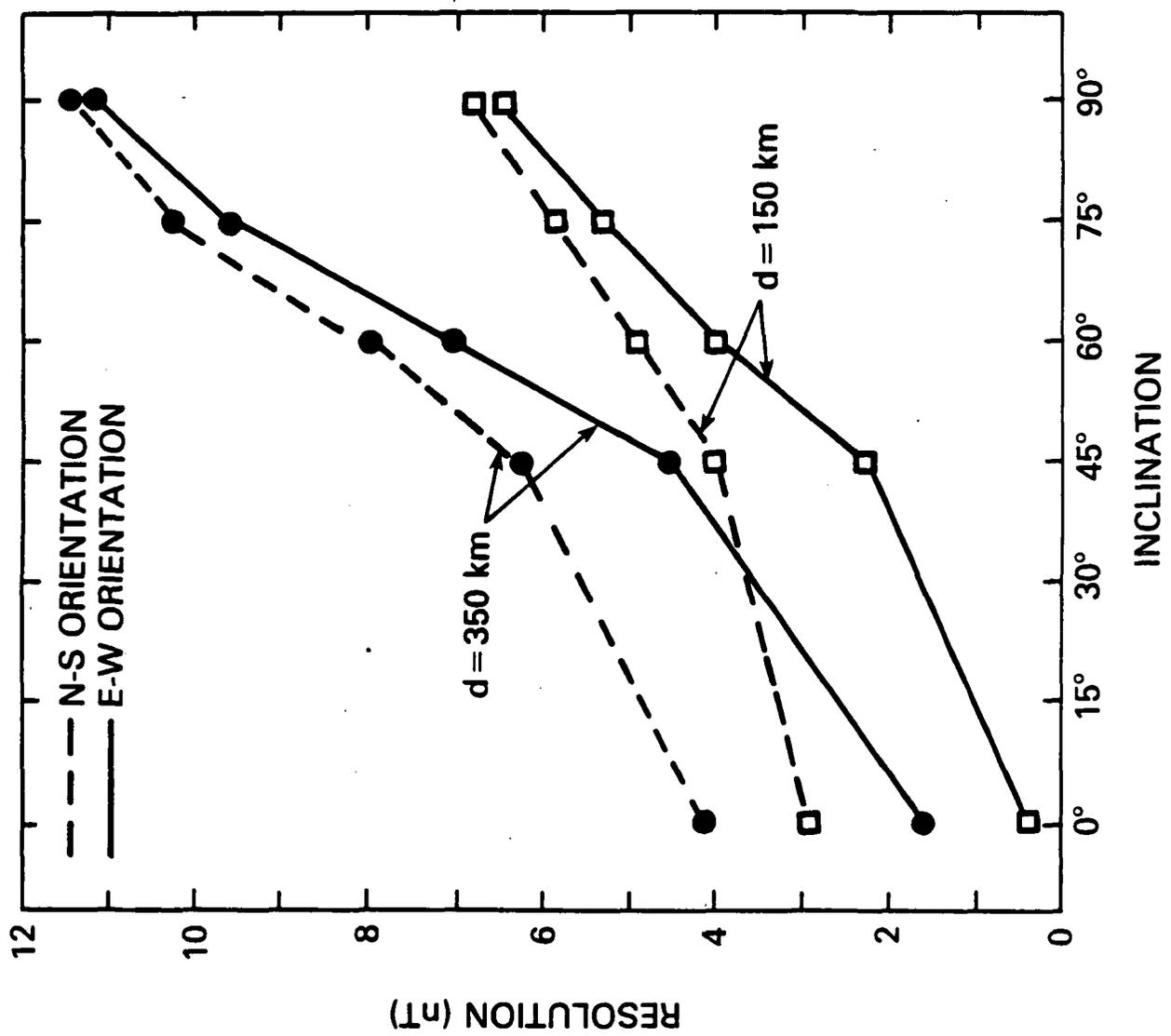
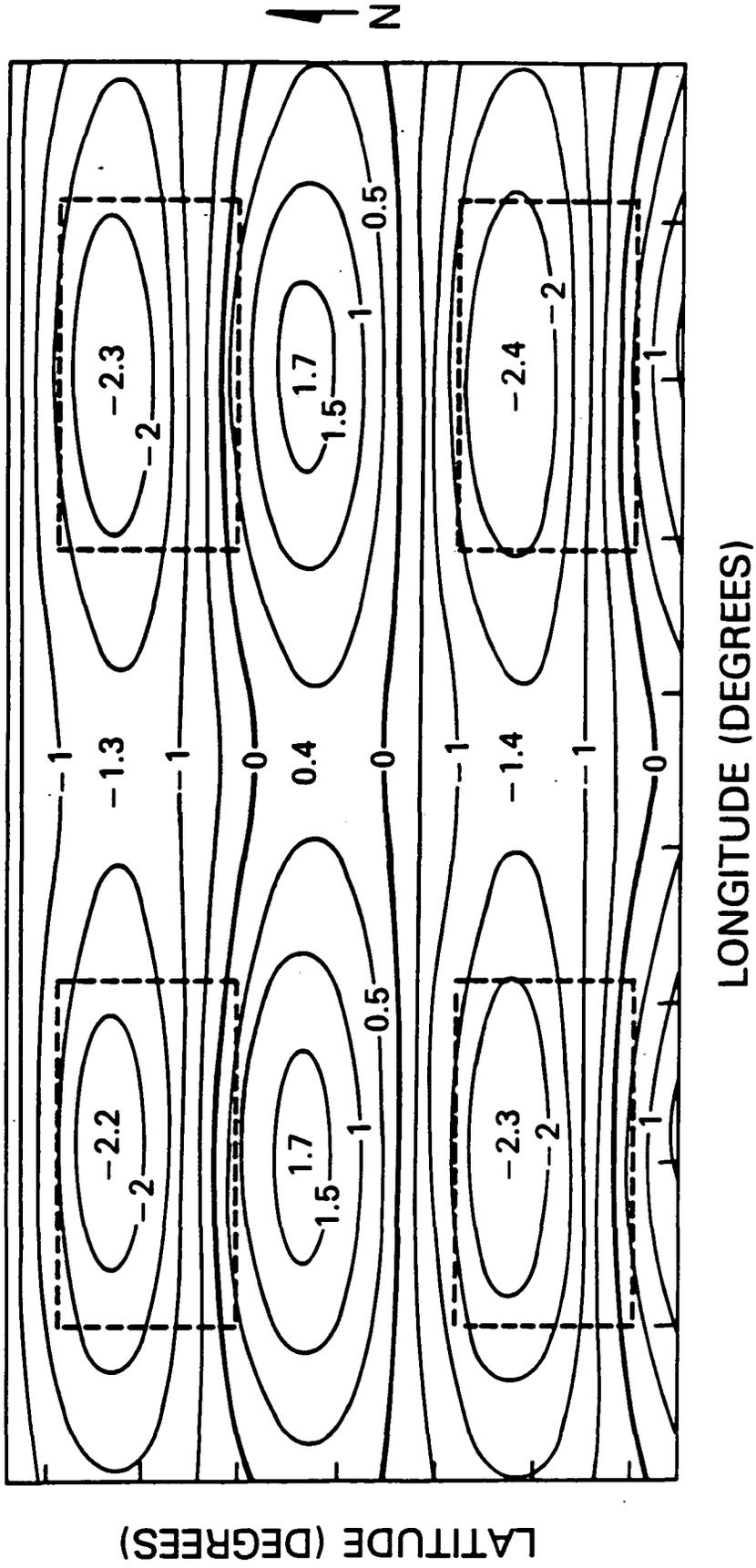


Figure 8



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16. Abstract When comparing previous satellite-magnetometer missions (such as Magsat) with proposed new programs (for example, Geopotential Research Mission, GRM) it is important to quantify the difference in scientific information obtained. We use the ability to resolve separate magnetic blocks (simulating geological units) as a parameter for evaluating the expected geologic information from each mission. This study evaluates and quantifies the effect of satellite orbital altitude on the ability to resolve two magnetic blocks with varying separations. Other parameters which were changed were: inclination and intensity of the dipolar field, and orientation of the magnetized blocks. Our results indicate a systematic, but non-linear, relationship between resolution and distance between magnetic blocks as a function of orbital altitude. The proposed GRM would provide an order-of-magnitude greater anomaly resolution than the earlier Magsat mission for widely separated bodies (>500 km); difference in resolution increases even more dramatically as body separation approaches the altitude of GRM. The resolution achieved at any particular altitude varies by about a factor of ten depending on the location of the bodies and up to about a factor of two depending on orientation.					
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