SATELLITE MAGNETIC MODELING OF NORTH AFRICAN HOT SPOTS

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One of the primary objectives of the MAGSAT mission was to measure the intensity and direction of magnetization of the Earth's crust [Lange, 1982]. A significant effort has already been directed to the large crustal anomalies first delineated by the POGO mission, but the MAGSAT data are capable of spatial resolution of the crustal field to 250 km wavelength with reliability limits to less than 1 nT in the mean [Sailor et al., 1982]. One of the difficulties of dealing with less than the most robust of the MAGSAT anomalies is that often we have no more than the magnetic fields themselves to constrain geophysical models of the interior, and thus do not have an independent means of assessing the quality of the crustal anomaly data in interpreting the subsurface.

Mayhew [1982b] has used satellite magnetic data to constrain Curie isotherm depths. Using an equivalent layer magnetization model derived from magnetic anomalies measured by the POGO satellites [Mayhew, 1982a], he was able to demonstrate in the Rio Grande Rift a remarkable correlation between heat flow predicted by magnetically-derived Curie isotherm depths and the regionally smoothed measured heat flow values. In the absence of heat flow data, or in the presence of badly scattered observations, alternative manifestations of the thermal structure of the lithosphere might be used to test the utility of satellite magnetic data to determine Curie isotherm depths. In turn, confidence in the Curie depth estimates will establish regional lithospheric thermal structure. We have considered a model of thermal isostasy as an indirect means of determining lithospheric thermal structure (and by implication, heat flow) to test against satellite magnetic data.

We have used the North African volcanic provinces of Ahaggar, Tibesti, and Darfur to provide a means of evaluating the MAGSAT data. On the basis of the hot spot tectonic hypothesis [Burke and Wilson, 1972] that these regions mark concentrated excess heat flow from the mantle, it was possible to construct a simple, testable susceptibility model of the lithosphere to test against the MAGSAT data.

The notion that the elevated basement [Gass et al., 1978] of these hot spot regions is due to thermal isostasy leads to a simple relationship between the lithosphere-asthenosphere boundary depth, D, and mean lithosphere density, mean asthenosphere density, thermally perturbed topographic elevation, h, and the thickness, L, of a reference (non-perturbed) lithosphere [Morgan and Phillips, 1983]. If heat sources in the lithosphere are ignored, then the depth to the Curie isotherm is the product of the ratio of Curie temperature to asthenosphere temperature and the lithosphere depth D. The depth to the Curie isotherm is therefore a direct function of topographic elevation but is dependent on assumed physical properties of the lithosphere. Some help is available from seismic, heat flow and gravity variations [Gass et al., 1978]. The most direct constraint is provided by Crough [1981a,b], who has estimated mean isostatic root depths of 50 and 60 km for Darfur and Ahaggar, respectively. This directly constrains the density dependence of the Curie depth for a given value of L, which may lie between values of 100 and 200 km. Indirect estimates [Fairhead and Reeves, 1977; Gass et al., 1978] of lithospheric thickness suggest a reference value of about 200 km. This value may be only typical of cratonic areas, and a lesser value may be more appropriate as a reference in non-cratonic regions.

For the study undertaken here, the dominant lateral variation in lithospheric susceptibility was taken to be variations in depth to the Curie isotherm, as discussed above. If ferromagnetic mineralization is confined to the crust [Wasilewski et al., 1979], the operative depth is the Moho or the Curie depth, whichever is shallower. For an assumed value of L, the topography of the Curie isotherm surface is obtained from quarter-degree averages of the surface topography in North Central Africa. The magnetic field predicted at the MAGSAT spacecraft altitude is obtained frm these two surfaces by Fourier transform techniques, following Parker [1972] but allowing for spatial variation in the direction of magnetization.

We have generated vertical component maps at MAGSAT orbital altitudes of these lithospheric thermal models. The region of the North African hot spots is magnetically bounded by the Bangui anomaly on the south, the positive anomaly associated with the West African Craton on the west, and the magnetic high associated with the Mediterranean and southern-most Europe on the north. Since we have not modeled these features, our interpretation is confined to those thermal anomaly patterns interior to this magnetic boundary. In this region our model can account for the sign (polarity) and position of the two major anomalies seen on the published vertical component map [Langel et al., 1982]. As predicted by the model, the negative anomaly at approximately 22 deg N, 10 deg E is associated with the Ahaggar hot spot and the positive anomaly centered at approximately 15 deg N, 22 deg E is associated with the Darfur hot spot.

We recognize difficulties with both the model and the data. In the former case it is the simplifying assumptions, the most significant of which may be that all input parameters to the model are laterally uniform except for the surface topography. In future modeling efforts we hope to obtain a better regional characterization of the lithosphere by employing satellite-to-satellite tracking (SST) gravity data.

A more serious problem may be the quality of the data itself. The smaller anomalies are close to or less than the spectral coherence limit of 700 km wavelength as determined by Sailor et al. [1982]. A Kp cutoff of 2 on the data produces a more spatially coherent map pattern in North Central Africa than a Kp cutoff of 3. The former data set (as derived from "Investigator-B Tapes") is, however, relatively sparse over much of this region, and coherence tests of data taken at different times over the same region are very limited. Further, the sparseness of the data leads to a significant sensitivity of the disposition of the small anomalies and the details of the large anomalies to the type of averaging procedures used on the data set. These considerations affect our ability to use the data to estimate model parameters.

We are continuing to address the data questions and relate the results to the sensitivity of the thermal model parameters. Such results will be useful for future magnetic mapping missions.

References

1. Burke, K., and J.T. Wilson, Is the African Plate Stationary?, Nature, 239, 387-390, 1972.

2. Crough, S.T., Free-air gravity over the Hoggar Massif, northwest Africa: Evidence for alteration of the lithosphere, Tectonophysics, 77, 189-202, 1981a.

3. Crough, S.T., The Darfur Swell, Africa: Gravity constraints on its isostatic compensation, Geophys. Res. Lett., 8, 877-879, 1981b.

4. Fairhead, J.D., and C.V. Reeves, Teleseismic delay times, Bouguer anomalies and inferred thickness of the African lithosphere, Earth Planet. Sci. Lett., 36, 63-76, 1977.

5. Gass, I.G., D.S. Chapman, H.N. Pollack and R.S. Thorpe, Geological and geophysical parameters of mid-plate volcanism, Phil. Trans. R.Soc. Lond. A., 288, 581-597, 1978.

6. Langel, R.A., The magnetic Earth as seen from MAGSAT, initial results, Geophys. Res. Lett., 9, 239-242, 1982.

7. Langel, R.A., C.C. Schnetzler, J.D. Phillips and R.J. Horner, Initial vector magnetic anomaly map from MAGSAT, Geophys. Res. Lett., 9, 273-276, 1982.

8. Mayhew, M.A., An equivalent layer magnetization model for the United States derived from satellite altitude magnetic anomalies, J. Geophys. Res., 87, 4837-4845, 1982a.

9. Mayhew, M.A., Application of satellite magnetic anomaly data to Curie isotherm mapping, J. Geophys. Res., 87, 4846-4854, 1982b.

10. Morgan, P., and R.J. Phillips, Hot spot heat transfer: Its application to Venus and implications to Venus and Earth, J. Geophys. Res., 88, 8305-8317, 1983.

11. Parker, R.L., The rapid calculation of potential anomalies, Geophys. J. R. Astr. Soc., 31, 447-455, 1972.

12. Sailor, R.V., A.R. Lazarewicz and R.F. Brammer, Spatial resolution and repeatability of MAGSAT crustal anomaly data over the Indian Ocean, Geophys. Res. Lett., 9, 289-292, 1982.

13. Wasilewski, P.J., H.H. Thomas and M.A. Mayhew, The Moho as a magnetic boundary, Geophys. Res. Lett., 6, 541-544, 1979.