LITHOSPHERIC MAGNETIC FIELDS: ACCOMPLISHMENTS OF THE DECADE OF GEOPOTENTIAL RESEARCH

Michael Purucker[(1)]

[(1)]Raytheon at Planetary Geodynamics Lab, Goddard Space Flight Center, Greenbelt, MD 20771 (USA), Email:purucker@geomag.gsfc.nasa.gov

ABSTRACT/RESUME

The goal of the Decade of Geopotential Research is to further our understanding of the earth's magnetic and gravity fields from space. To date, those accomplishments related to the magnetic field of lithospheric origin include the following: 1) more sources, including the ocean tidal signal and large scale oceanic currents, 2) new approaches to modeling, 3) higher degree resolution, from spherical harmonic degree 42 to 90, and integration w aeromag, 4) integrating seismic, thermal, and magnetic models of the crust, 5) imaging of subduction zones and diffuse plate boundary zones, and 6) continued differentiation of the properties of oceanic and continental crust. In related fields, the accomplishments include improved understanding of the magnetic fields of Mars and Moon.

1. NEW ACCOMPLISHMENTS

$$\mathbf{B} = \mathbf{B}_{int} + \mathbf{B}_{ext} + \mathbf{B}_{tor}$$

$$= -\mathrm{grad}\left[a\,\mathrm{Re}\left\{ \sum_{n,m} \left(\frac{a}{r}\right)^{n+1} \iota_n^m P_n^m e^{im\phi} \right\} \right]$$

$$-\mathrm{grad}\left[a\,\mathrm{Re}\left\{ \sum_{n,m} \left(\frac{r}{a}\right)^{n} \varepsilon_n^m P_n^m e^{im\phi} \right\} \right]$$

$$-\mathrm{curl}\left[\mathbf{r}\,\mathrm{Re}\left\{ \sum_{n,m} \left(\frac{a}{r}\right) \Psi_n^m P_n^m e^{im\phi} \right\} \right]$$

Figure 1. Coestimation of internal, external, and toroidal fields [1] has proven to be a very effective means of separating fields with overlapping temporal and spatial characteristics.

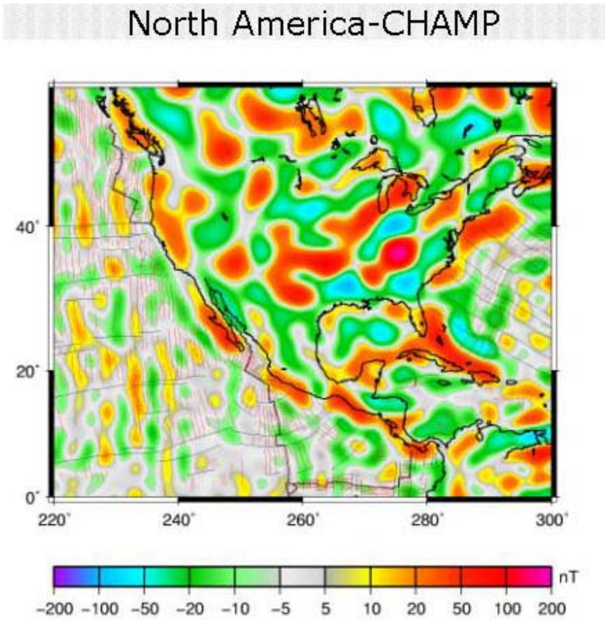

Figure 2.CHAMP's higher resolution, lower noise view better distinguishes contínen]tal from oceanic crust[2].

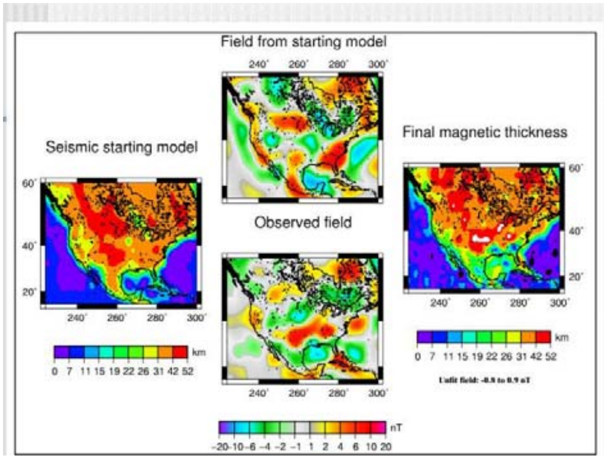

Figure 3. Combining seismic [3], thermal and material properties [4], and magnetic [5] models of the lithosphere has resulted in improved models of the lithosphere [6]..

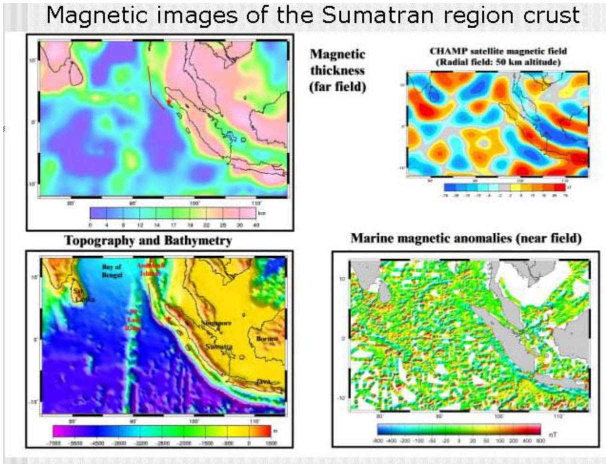

Figure 4. Near and far-field magnetic images of the Sumatran region crust, showing the magnetic features associated with the subduction zone here [7].

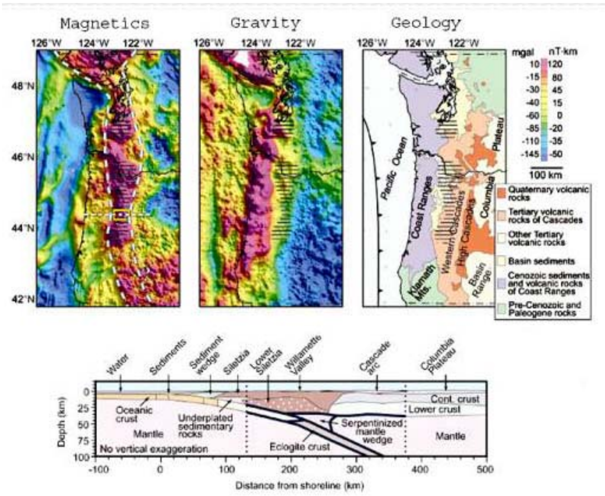

Figure 5. Some of the magnetic properties of the subduction zone region might be explained in terms of a serpentinized mantle wedge, as illustrated here for Cascadia [8].

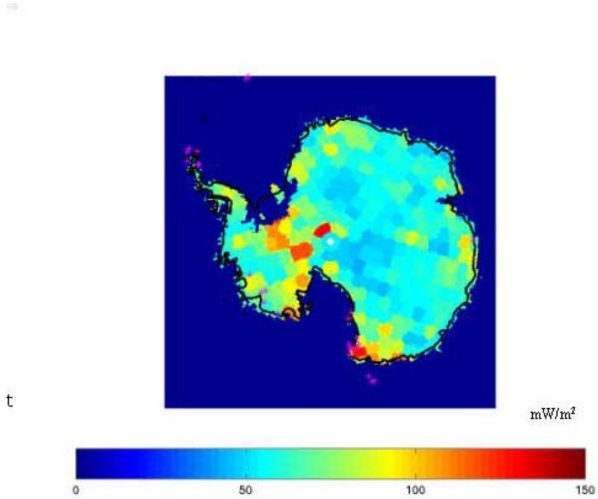

Figure 6. Satellite magnetics can also allow us to make inferences about the regional heat flux, as illustrated here in the Antarctic [9].

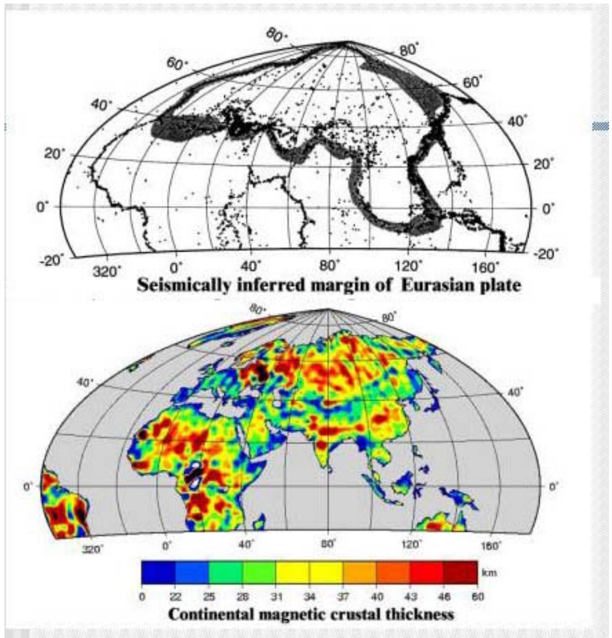

Figure 7. Diffuse plate boundary zones seem to have a distinctive magnetic signature, with magnetic thicknesses between 22-31 km [10]. These thicknesses are significantly less than those of the adjacent rigid plate. The diffuse NE Asia plate boundary zone [11] is especially well-expressed as a zone with magnetic crustal thicknesses some 10 km thinner than adjacent crust. Satellite data are crucial to obtaining this result- aeromagnetic and ground based data do not resolve the required 'intermediate' wavelengths.

2. RESOLVING INTERPRETATIONAL AMBIGUITY

Recent progress on the important issue of resolving interpretational ambiguity has included the use of annihilators [12], ideal body analysis [13], Monte Carlo simulations, and, of course, the use of prior information, as for example from seismology.

3. SUMMARY

Mapping of the lithospheric magnetic field provides a 3rd dimension to surface observations of the earth's composition and geologic structure. The Decade of Geopotential Research was envisioned as an attempt to break new ground in our understanding of the magnetic and gravity fields from space. What are the accomplishments to date in the area of lithospheric and related fields, and what new accomplishments can we reasonably expect? Since 1999, the development of new approaches to modeling has led to an increase in the resolution of those models from spherical harmonic degree 42 to 65, and locally higher. With CHAMP still descending, we expect that the best is yet to come, with models exceeding spherical harmonic degree 100 by mission end. Of equal importance is the increase in the number of fields that are described by these models, and improvements in the way that they are estimated. Prior to 1999, the lithospheric field was estimated in a sequential fashion. Because of the overlap of the lithospheric and external fields, and the way that our satellites take data, a coestimation approach has now proven to be a superior way to estimate the lithospheric field. The recognition of the magnetic signature of the oceanic tidal signal from the CHAMP observations stands out as one of the premier accomplishments of the decade, as it ushered in an era in which magnetics could be considered a remote sensing tool for oceanic studies. The first attempts to integrate seismic and thermal models of the lithosphere with our new magnetic field maps has shown abundant promise, and we expect that these synergistic approaches will yield new insights as the techniques mature, and as lithopsheric magnetic maps improve. In particular, the imaging of many subduction zones by CHAMP, and the marked difference of continental and oceanic crust in some places, means that new insights are sure to come from a synergistic approach incorporating magnetics, seismology, thermal, and gravity studies.

Looking beyond our discipline to related fields, we find that the discovery and systematic mapping of the remanent magnetic field on Mars has energized our community as few other events have done, and led to a reconsideration of questions long thought closed. The role of Martian remanence, it's strength, and antiquity, still baffle us. But those discoveries will lead to new insights. Some have already come, such as the role of ilmenite-hematite intergrowths in producing large, stable remanent fields. The systematic mapping of the lunar magnetic field in 1999 by Lunar Prospector has not yet generated as much interest from researchers, but I predict that as we are better able to sort out the host of fields in the lunar environment, the lithospheric field will be recognized for the insights it can provide into the nature of the lunar crust. And the upcoming mapping of the magnetic field of Mercury at the end of the decade is sure to provide surprises and insights into the lithosphere of Mercury. Finally, looking to our colleagues who have been mapping the earth's lithospheric magnetic field from aircraft for 75 years now, we are delighted to see that they have joined us in a project to produce the first ever high-resolution, global map of the lithospheric field, integrating our two efforts. The Swarm satellite constellation, by providing the best-ever survey of the lithospheric magnetic field, will both markedly improve our knowledge of the deep crust, and allow us to begin to integrate our far and near-field views of the earth's magnetic field.

Complementary views of the magnetism of the crust of Mars, the Moon, and (soon, perhaps) Mercury are challenging widely held assumptions about the magnetism of our planet's crust, while also providing insights into igneous and tectonic processes acting in those solar system bodies in the distant past.

4. REFERENCES

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