MAGNETIC STRUCTURE OF THE CRUST

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Unique interpretive problems emerge when one tries to model the large scale crustal magnetic anomalies. The full thickness of the magnetic crust by areal dimensions of a craton may be the crustal volume to be modeled, or perhaps the geometric volume of a subduction zone. Embodied in some volumes may be a billion years of earth history with consequent lithologic additions and modifications, all complicated by numerous tectonic events. It is apparent that the non-uniqueness aspect of geophysical interpretation must be constrained by geological insight in order to limit the range of theoretically possible models. However, an additional step is required, namely, an in depth understanding of the relationship between rock magnetization and geological circumstances on a grand scale. Typical block models on this scale are quite deficient and inappropriate.

Emerging views about crustal structure and the distribution of lithologies certainly suggests a complex situation with lateral and vertical variability at all levels in the crust. Volcanic, plutonic, and metamorphic processes together with each of the observed anomalies. Certain important questions become prominent and are being addressed currently.

- Where is the magnetic bottom?

- Is the source a discrete one or are certain parts of the crust cumulatively contributing to the overall magnetization?

- If we localize the anomaly to some recognizable surface expression, then how do we arrive at a geologically realistic model incorporating magnetization contrasts which are realistic?

- In what way are the primary mineralogies altered by metamorphism and what are the resultant magnetic contrasts?

- What are the effects of temperature and pressure on magnetization?

There is no direct way to access the deeper regions of the crust. However, xenoliths brought to the surface in kimberlite and alkalai basalt, tectonically exposed crustal sections, Precambrian amphibolite/granulite metamorphic terrain, the ophiolites, and dredged oceanic rocks from fracture zones do provide access to lower crustal lithologies, though one must be careful in evaluating the magnetic properties.

The classical seismic refraction velocity discontinuity (Figure 1A) locates the Moho. Is this boundary a magnetic boundary? We asked this question (Wasilewski et al., 1979) and (a) surveyed the literature (see for example, Haggerty, 1977) to find overwhelming evidence suggesting that Fe^{2+} and Cr in non-magnetic normal spinels dominated the oxide components in upper mantle rocks, with Fe^{3+} and Ti in magnetic inverse spinels partitioning to the crust, and (b) we measured the magnetic properties of upper mantle xenoliths and found them to be virtually non-magnetic except in cases where decompression melt is obvious. From this evidence it became apparent that the Moho as defined in the classical sense was indeed a magnetic boundary, except where the magnetite isotherm surface resides above the Moho and correspondingly becomes the magnetic bottom. The reason for the choice of the magnetite isotherm ($\sim$550°C) became obvious when an extensive study and review of exsolution, oxidation, serpentinization and metamorphism was concluded. Magnetite with minor impurities appears to be the dominant magnetic mineral in the crust.

Reports of detailed seismic reflection studies emphasized the lithologic complexity of the lower crust. The Moho is best defined as a position of the maximum velocity gradient after a gradational lower crustal profile. Laminations may be present at the crust-mantle boundary due to cumulate layering or other causes (see Figure 1B). However, in this modified classical model there does not appear to be any reason to modify the magnetic source conceptualization developed earlier. However, the gradational nature of the lower crustal velocity profiles indicates increasing rock basicity with depth, allowing a potential source of increased magnetization.
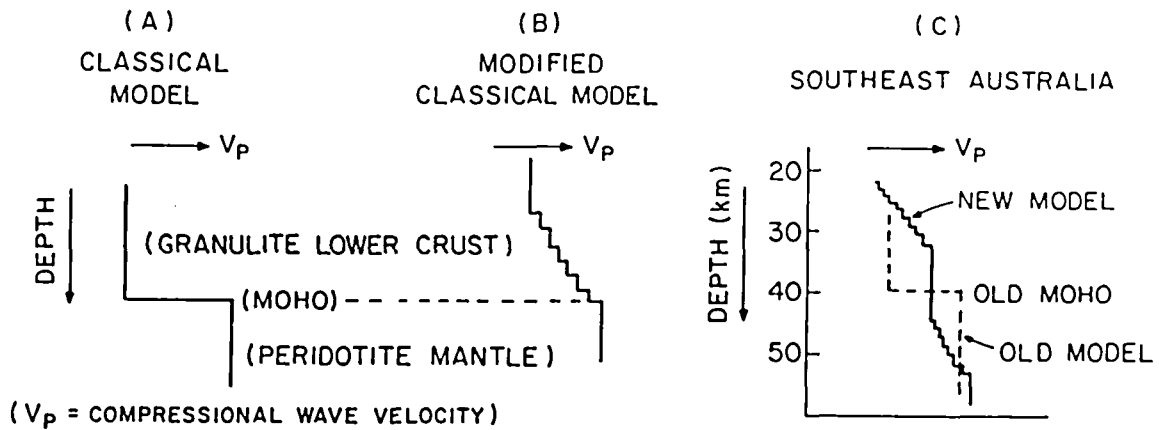
In Figure 1C a specific case (SE Australia) is presented to demonstrate the contrast between the old seismic refraction model and the new model based on more recent detailed studies (Ferguson et al., 1979, Wass and Hollis, 1983, Griffin et al., 1984). The laminated transition zone is attributed to mafic/-ultramafic interlayering associated with extensive underplating. This region has anomalously high heat flow and regardless of the implications of the new model, the region of crust below 20 km is non-magnetic.

Curie points in the the crust are dominantly magnetite, however, in principle any phase from Fe_3O_4 to Fe_2TiO_4 is possible. It turns out, as mentioned earlier, that oxidation and exsolution invariably produce magnetite ($\sim$540-575°C) Curie points. In regions of high heat flow, such as rift zones and certain subducting regimes where conditions are anhydrous, reduction prevails and ilmenites and ulvospinel rich titanomagnetite are the dominant oxides. In the study of xenoliths care must be exercised as partial fusion during decompression can result in oxide phase reduction, garnet and other silicate decomposition, thereby producing magnetite, hercynite and even metallic iron (as reported by Haggerty at the Magsat investigators meeting).

Most xenoliths from the lower crust are in the granulite facies. In the crustal cross section considered in some detail by Fountain and Salisbury (1982) the lower crustal material is in the granulite facies and is overlain by amphibolite facies. The significant vertical zonation in the crust from a magnetic viewpoint may be metamorphic zonation. Granulite facies rocks usually contain discrete ilmenite and magnetite, while retrogression to amphibolite facies may produce more or consume magnetite. There is little systematic information about magnetization contrast in progressive or retrograde metamorphism.

Considerable laboratory work is required to understand the origins of magnetization contrasts in the context of crustal evolution, a prerequisite for effective modeling of long wavelength magnetic anomalies. In the context of potential field mapping a correspondence must be established between the origins of density and magnetization contrasts since this capability will refine our interpretive skills. This presentation will review our state of knowledge about:

- The distribution of minerals and Curie points in the crust,

- The location of this magnetic bottom,

- The distribution of lithologies and associated magnetization contrasts,

- The effects of metamorphism on magnetization contrasts, and

- The development and modification of magnetization contrast due to crustal processes such as metamorphism, oxidation, reduction, exsolution and serpentinization.

(A)
CLASSICAL
MODEL

(B)
MODIFIED
CLASSICAL MODEL

(C)
SOUTHEAST AUSTRALIA

DEPTH → V_P

(GRANULITE LOWER CRUST)

(MOHO)

(PERIDOTITE MANTLE)

(V_P = COMPRESSIONAL WAVE VELOCITY)

DEPTH (km) → V_P
20
30
40
50

NEW MODEL
OLD MOHO
OLD MODEL

• Fe Ti OXIDES IN GRANULITE FACIES LOWER CRUST (MAGNETIC)
• CHROMIUM SPINELS AND MAGNESIAN ILMENITES IN MANTLE PERIDOTITES (NON MAGNETIC)
• NORMAL CONTINENTAL LOWER CRUST DOMINATED BY Fe_3O_4 (CURIE POINT 550-580°C)

MOHO IS THE MAGNETIC BOTTOM UNLESS TEMPERATURES ABOVE THE MOHO EXCEED ~550°C; THEN THE ~550°C ISOTHERMAL SURFACE IS THE MAGNETIC BOTTOM

Figure 1 - Simple and more complicated views of the crust-mantle boundary.