Chapter 7

Conclusions

7.1 Summary

The aim of this thesis was to interpret the crustal magnetic anomalies observed at satellite altitude. Obviously, the target was to associate the magnetic anomalies with the geological sources in the crust. Eventually, the efforts were extended not only to interpret these anomalies but also to infer geological information from these maps. For this, a new simple way to model the geological units and their crustal structure on a GIS craton was derived. The magnetic potential was computed at satellite altitude and the Gauss coefficients were computed using two forward modelling methods, the Nolte-Siebert method and the equivalent dipole method. Equivalent dipole method was preferred over the Nolte-Siebert method because, the former method proved to be more accurate than the latter, though, the former method requires more computation time. Only final maps were prepared using the equivalent dipole method and initial computations were done using faster Nolte-Siebert method. Subsequently, *initial model* vertical field anomaly map was predicted based on the derived global vertically integrated susceptibility model. This predicted map was then compared with the corresponding observed vertical field anomaly. Interesting results churned out after the comparison for all the continents and oceanic plateaus. Exploiting the flexibility offered by the GIS based modelling method, to change the shape of a geological unit, as it is represented as a polygon on GIS craton, detailed analysis was carried out on 6 selected regions of the world. The *initial model* anomaly map disagreed with the observed magnetic anomaly map over these 6 continental regions of the world. Each of these regions had a distinct tectonic setup and hence, a different aspect of their unit was modelled to derive a new, *first iteration* model. The modelling results described in chapter 4 and chapter 5 illustrate the relationships between satellite magnetic anomalies and the surface geology. This indicates the power of the satellite magnetic method in understanding the nature and evolution of the crust. Later, the relevance and effect of continent-ocean boundary effect was discussed in chapter 6. It is concluded that this effect is negligible as the anomaly feature over the continent ocean boundary is absent even in the long wavelength dominated map of the crustal anomalies. Key issues relating to remanence and Curie-temperature isotherm which has not been a part of modelling in the present work, is also discussed.

The following conclusions are drawn on the basis of results discussed in previous chapters of this thesis:

- The geological extension below the Phanerozoic cover can be traced following the observed anomaly pattern of the region. The results for anorogenic granites of the mid-Proterozoic province of southwest USA and the deformed Kolyma block in east Siberia prove the usefulness of the modelling technique. Basement of the Phanerozoic covered Tarim basin is also confirmed following the same approach. It would be interesting to delineate more of such regions for further detailed analysis.

- In our VIS model, the composition of the lower crust was kept consistently at the same ratio with respect to the upper crust. The factor is within limits of the maximum value permissible for the composition of the lower crust following the work of Taylor and Mclennan (1985) and Clark (1999). The factor 1.2 for the lower crust below Archean units and 1.6 times below post-Archean rocks means that lower crust is 1.2 and 1.6 times more magnetic than the corresponding upper crust.

  The strong magnetic anomalies of Central Africa, however, require a more magnetic lower crust (basalts) unless one is willing to assume remanent magnetisation for this anomaly.

- The derivation of VIS model required a seismic model as one of the inputs. For most of the world, 3SMAC turned out to be best. This has been explained in detail in Chapter 4. However, the predicted anomaly over the eastern region of North America craton, especially over the Cordilleran region, did not match well with the observed anomaly pattern. In turn, the global crustal model CRUST2.1 showed a much better agreement with the observed pattern. Hence, CRUST2.1 model was preferred for modelling geological units of North American craton. Similarly, for Guyana shield regions, in South America, the seismic model of Schmitz et al. (2002) was included in place of 3SMAC model. For the rest of the world, VIS model derived using the 3SMAC seismic model showed a better agreement with observations. Thus, new seismic models do provide better results than the previous old seismic crustal models. A new seismic crustal model was also incorporated for Greenland.

- Although gaps in the seismic information for African craton was filled in by nonseismic information while deriving 3SMAC seismic model, the crustal structure is not well constrained yet. The results of our modelling in West Africa and Central Africa indicate that the crust could be still thicker than estimated by the 3SMAC model. As in these regions some part of the observed anomaly is yet unaccounted for.

- Remanence does not appear to be important in modelling continental anomalies. This result is in agreement with the recent work by Purucker et al. (2002). It is also not possible to distinguish whether the observed anomaly pattern is really due to induced or remanent magnetisation. On the other hand, our modelling results suggest that remanence may be required to model a few oceanic plateaus especially in south Atlantic ocean and around Australia. Magnetic stripes of oceanic crust are known to be magnetised in alternately normal and reversed direction. However, these strips are thin and the alternate polarization cancels at satellite altitude. In the present work, these strips of alternate magnetisation are not considered in the modelling.

- The modelling results provide no indication of magnetisation in the upper mantle, except for West Africa, where the magnetisation may extend below the Moho discontinuity, in to the upper mantle. Generally, the magnetisation of the upper mantle could be of long wavelength and thus be masked by the main magnetic field.

- The oceanic region has a more generalized and simple crust but the lower crustal composition of the oceanic plateaus is largely inferred on the basis of seismic studies. The plateaus were represented here by a 3-layered model. The thickness of some of the plateaus in south Atlantic ocean may need to be redefined. The modelling results suggest that the thickness of the crust of the Maud rise, in Antarctica region and South Georgia, east of Falkland islands, South America is thicker by 6.0 km and 10.0 km respectively, than indicated by the 3SMAC model.

Considering the inherent uncertainties in the interpretation of magnetic anomalies, the *initial model* derived above shows a very good correspondence with the observed magnetic anomaly map. It is encouraging to note that the predicted anomaly of most of the tectonic features and their trends have correspondence to the observed anomaly pattern. Large scale anomaly pattern observed at the satellite altitude does not mean a corresponding large scale source in the crust, but often, most of the small-scale anomaly features coalesce together to form a large anomaly, indicating several small sources in the crust. Nevertheless, the results of the interpretations are useful in limiting the range of permissible geological models and in isolating regions for more intense geophysical investigations.

One of the most important conclusions of this thesis is confirmation of the anomalies observed by CHAMP satellite to be real. Each anomaly, positive or negative amplitude reflects ancient or present-day processes that have altered the magnetisation of the crust. The challenge inherent in the interpretation is to deconvolve the multiple sources of anomalies of the crust. The modelling results discussed in previous chapters have demonstrated that most of these anomalies do have a corresponding geological source and can be reproduced following a suitable modelling methodology as presented here in this thesis. Having established that the observed anomalies can be modelled and can be predicted following a simple geological model, this should provide a new basis for interpreting increasingly accurate satellite data measured by the CHAMP satellite from decreasing orbital altitudes. Another important outcome of this modelling work is that using the *first iteration* VIS model, long wavelength component of the crustal anomalies can be predicted which is difficult to see in the observed magnetic anomaly maps as it is masked by the main magnetic field. Such long wavelength dominated map helps us to study the long wavelength features like continent-ocean boundary. However, the modelling result suggests that continent-ocean boundary is not a long wavelength feature (Fig. 6.1). Forgoing discussions of the interpretation of individual observed anomalies using the present modelling method shows the way for increasing use of satellite magnetic anomalies for the study of the crust and lithosphere.

7.2 Outlook

In future work, the modelling method should include heat flow models though at present, their inaccuracy limits their usefulness. Remanence has not been a part of our present modelling and may not be important for continents. But for modelling the oceanic anomalies, it should be included. Aeromagnetic and gravity surveys have always provided detailed information of a region. The modelling results of such surveys can be used to improve our *initial model* by improving geological and tectonic boundaries and susceptibility of the region. This may help to predict the anomalies at satellite altitude much more accurately. New seismic crustal model needs to be consistently included in our *initial model*. Inclusion of new crustal models for North America, Guyana shield in South America and Greenland led to improved predicted anomaly maps. Incorporating heat flow, improved seismic models, aeromagnetic and gravity data and further information on the lower crust should improve our *initial model* significantly and help in producing an improved initial crustal magnetic field.

With the availability of new data from decreasing measurement altitude of the CHAMP satellite, coupled with a better understanding of the various contributions to the measured field, we will see further significant improvements in the accuracy and resolution of the observed magnetic anomaly maps.