Interpretation of CHAMP Crustal Field Anomaly Maps Using Geographical Information System (GIS) Technique

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Summary. Crustal field models from CHAMP magnetic measurements are increasingly stable and reliable. In particular, they now allow for quantitative geological studies of crustal structure and composition. Here, we use a forward modeling technique to infer deep crustal structure of continental regions overlain by younger sediments. For this, a Geographical Information System (GIS) based technique has been developed to model the various geological units of the continental crust. Starting from geologic and tectonic maps of the world and considering the known rock types of each region, an average magnetic susceptibility value is assigned to every geological unit. Next, a vertically integrated susceptibility (VIS) is computed for each unit, taking into account the seismic crustal thickness, as given by models 3SMAC and CRUST2.1. From this preliminary VIS model, an initial vertical field anomaly map is computed at a satellite altitude of 400 km and compared with the corresponding CHAMP vertical field anomaly map. We demonstrate that significant geological inferences can be made from the agreement and the discrepancies between the predicted and observed anomaly maps. In particular, the lateral extent of Precambrian provinces under Phanerozoic cover is revealed.

Key words: Global, magnetic, crustal, GIS

Introduction

Scalar magnetometers aboard satellites have been into orbit for more than three decades now. POGO (1965-1971) measured only scalar data, while Magsat (1979-1980) and ∅rsted (since February, 1999) missions measured the vector components as well. Though these missions led to the derivation of many crustal field models, the accuracy was limited due either to the higher orbital altitude of satellites (POGO and ∅rsted) or to the inaccuracies in the star cameras that corrupted the vector magnetic field components (Magsat). In July-2000, the CHAMP satellite (http://op.gfz-potsdam.de/champ/main_CHAMP.shtml) was launched into a low Earth orbit of 450 km. The present altitude of its almost circular orbit is 400 km and is particularly suited to map the crustal field anomalies much more accurately than any of its predecessors. Maus et al. (2002) derived a new global crustal magnetic anomaly map using the CHAMP satellite scalar and vector data. We use the first revision MF2 of this map (http://www.gfz-potsdam.de/pb2/pb23/SatMag/model.html) for all further analysis.

The aim of deriving these crustal field anomaly maps is to reveal new geological and tectonic information of the subsurface. The interpretation strategy followed here is not that of direct inversion, which is non-unique due to inherent ambiguities of the magnetic inverse problem.
The present method is a GIS based forward modelling technique, which takes geologic and tectonic maps of the world and considering the known rock types of each region, an average susceptibility value is assigned to every geological unit. Next, a vertically integrated susceptibility (VIS) is computed by taking product of average susceptibility value and the seismic crustal thickness, as given by global seismic models like 3SMAC (Nataf and Ricard, 1996) and CRUST2.1, the latest model by Mooney et al. (1998). From this VIS model, the vertical field anomaly map is predicted at a satellite altitude of 400 km and compared with the corresponding CHAMP vertical field anomaly map. Geological inferences are drawn on the basis of discrepancy between the extent of anomalies and their strength in the two maps.

GIS modelling

The sources of the continental magnetic anomalies primarily consist of rock types formed early in the geological history of the earth. These rocks are Precambrian in age. Our primary interest is to generate a global crustal magnetisation model based on the detailed information of the rock types exposed in the Precambrian provinces, their magnetic susceptibility values and a known stratigraphy for that region.

For this all the known rock types for a particular geological region are compiled and using their maximum volume susceptibility value (Clark and Emerson, 1991; Hunt et al., 1995) an average maximum susceptibility value is computed. The assigned susceptibility of the region is some percentage of this maximum value. This factor (0.55) is kept as a global constant for all the rock types. It was derived on the basis of minimum rms difference between the Gauss coefficients of predicted and the observed field. Next, the crustal thickness known from the stratigraphical information for each geological layer within a vertical column is multiplied with the average susceptibility of that layer. For regions where stratigraphical information are not available, the average maximum susceptibilities are multiplied with the crustal thickness of the upper crust known from the global seismic models like 3SMAC and CRUST2.1. The susceptibility value for the lower crust in any geologic region is computed by multiplying the average susceptibility of the upper crust with a factor accounting for the difference in the iron oxide content in the average composition of the upper and the lower crust (Taylor and McLennan, 1985). Integrating the product of susceptibility and thickness for various layers in a vertical column provides the vertically integrated susceptibility value for that region. Each geological province is modelled following the above steps and all of the VIS values are used to generate an initial VIS model (Fig. 1). The above modeling steps were done on the GIS ArcInfo 8.1 platform. One of the important

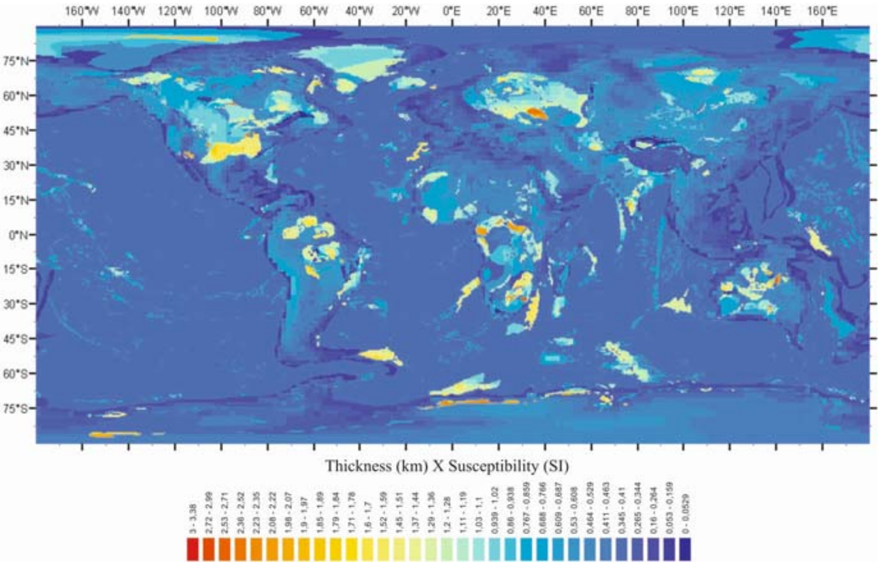

Fig. 1. The vertically integrated susceptibility (VIS) model.

assumptions in the present work is to consider the seismic Moho as a magnetic boundary (Wasilewski and Mayhew, 1992). Thus, the upper mantle is considered to be non-magnetic (Meyer et al., 1983; Purucker et al., 1998).

This VIS model is replaced with a distribution of equivalent dipoles on the Earth induced in the direction of the main field of the Earth. No remanent magnetization is considered here and the sources for the anomalies are considered to be induced magnetization. From the spherical grid of dipoles the magnetic field is computed at a height of 400 km and expanded into spherical harmonic to derive the Gauss coefficients of the predicted field. The vertical field anomaly map is computed from these Gauss coefficients and spherical harmonic degrees 1-15 are set to zero because this long wavelength crustal field is masked by the main field and therefore is not observable. Finally, only spherical harmonic degrees 16-80 of the predicted crustal magnetic field are compared with the corresponding degrees 16-80 of the observed crustal field.

Results

The CHAMP observed vertical field anomaly map for spherical harmonic degrees 16-80 at an altitude of 400 km is shown in Figure 2 and the corresponding predicted anomaly map or the initial model computed using the initial VIS model is shown in Figure 3. The two maps are compared visually. On comparison it is apparent that there are anomalies over the regions where the predicted and observed maps match well. Over some regions of the Precambrian provinces, the predicted anomalies display weaker amplitudes than the observation. The numbers referenced in parentheses discussed below correspond to circles in Figure 2. The shapes of the predicted anomalies agree well with those of observed anomalies over the Turkmenistan shield (1), partly over the Songliao massif (2), and eastern (3) and southern (4) shield regions of the Indian craton. Over the Siberian craton, the strong anomaly over the Anabar shield (5), in the north and Aldan shield (6), in the southeast, correlate well with the observations. Predicted anomalies over the Kiruna mines (7), Sweden, in the north and over the Kursk region (8), in the south of the European craton show a good agreement with observations. Along the western region of East European platform, a partial agreement in anomalies is seen along the Tornquist-Teisseyre Zone (TTZ) (9). The magnetic anomalies over the Superior (10) and Slave (11) province show a weak anomaly both in the observed and the predicted map but a strong anomaly is evident over the Ungava craton (12), in the northern region of North American craton. Regions of Guyana shield (13), in the north and Brazilian shield (14), in the north-central part of South American craton show moderate anomaly features in the observed map, which are in agreement with the predicted anomaly. Major anomaly features over the west African craton (15), central African region (16), and southern Africa (17), are reproduced well in the predicted map. Precambrian provinces of Australia, the Pilbara (18), and the Yilgarn craton (19) show weak anomalies, which are only partially reproduced, in the predicted map. However, strong anomalies over the largely buried Nullarbor block (20), in the south and Mt Isa inlier (21), in the north of Australian craton agree well with predictions. Observed anomaly over the Archean block in the southern Greenland (22), is largely in agreement with predictions. Antarctica is mostly covered with ice except at the periphery, hence, the observed anomalies agree only over some regions of the predicted map especially over the Rayner complex (23) and its surrounding Precambrian provinces. Much of results discussed above are consistent with the conclusions of various researchers and are summarized in Langel and Hinze (1998).

The comparisons made above between predicted and the observed magnetic anomalies for the vertical component show agreement over many Precambrian provinces of the world but the discrepancies between the two maps are also evident in some regions. For instance, most of the negative anomaly pattern and its extent over the Himalayan fold belt and the Tibetan plateau are in agreement with observations, however, the observed anomaly shows a more intense negative anomaly. Some of the regions like southwest USA show a large stretch of predicted anomalies but it does not completely match with the extension of the observed anomalies. Similar disagreement in extent and shapes of anomalies are also seen over the Kolyma-Omolon regions in the eastern Siberia, Tarim craton in China and north-central Greenland. Over the west African craton and central African region, the trend of the predicted anomalies are largely in agreement with observations but the predicted anomaly is comparatively much weaker in strength than the observed anomaly. Another significant disagreement between the anomalies in the predicted and observed map lies in the northwestward region of Anabar shield. The observed map shows the anomaly over the known geological boundary of Anabar shield to extend northwestward over the Phanerozoic sediments filled Khatanga trough. This extended anomaly is absent in the predicted map as this strong anomaly cannot have a source in the upper crust of Khatanga trough filled with 15 km of sediments (Goodwin, 1991). The regions shown in ovals in Figure 3 show some of the regions mentioned above.

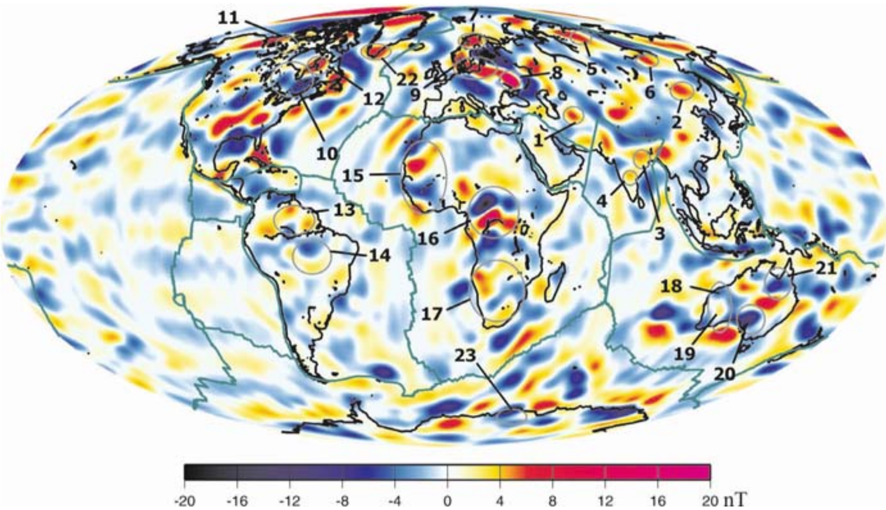

Fig. 2. Lithospheric field model (MF2) for vertical component derived from CHAMP scalar and vector data at 400 km for degrees 16-80 (http://www.gfz-potsdam.de/pb2/pb23/SatMag/model.html). Numbers marked represent some of the major Precambrian provinces which are described in the text.

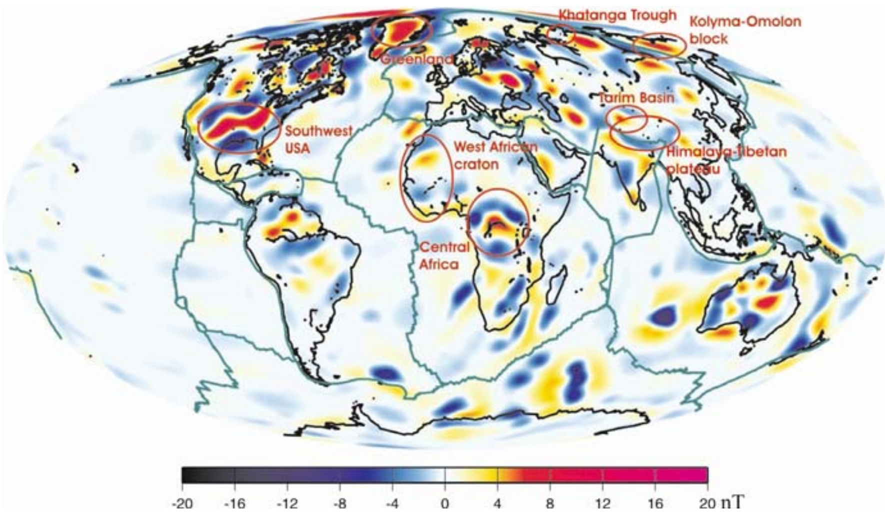

Fig. 3. Predicted vertical field anomaly map for spherical harmonic degrees 16-80 at an altitude of 400 km. Marked provinces are described in the text.

Conclusion

Our GIS based magnetic modelling technique demonstrates the possibilities of this technique of inferring geological and tectonic information from the differences between the predicted and the observed magnetic anomaly maps. The overall agreement in the predicted and the observed maps show that sources to magnetic anomalies are indeed geological in origin. This also supports our assumptions employed during the derivation of vertically integrated susceptibility map. The discrepancies between the magnetic anomalies of the predicted and the observed map over certain regions have shown that the assumptions used in the present VIS map may not be true globally. This provides the basis for further investigation especially in the context of extent of subsurface Precambrian provinces, the composition of the lower crust, accuracy of the seismic crustal models and even the variation of Curie-isotherm in the Earth's crust. Remanent magnetisation model of the oceanic crust should also be included to study their effect on anomalies near the continental edges. These studies could be helpful in getting insights in to the nature of the crust in regions which are poorly covered by surface geophysics.

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