A web-based utility to highlight the role of remanent magnetization in Australian magnetic field data

Clive Foss
CSIRO
Sydney
clive.foss@csiro.au

Phil Schmidt
CSIRO
Sydney
phil.schmidt@csiro.au

Peter Milligan
Geoscience Australia
Canberra
Peter.Milligan@

Robert Musgrave
Industry & Investment NSW
Maitland
Robert.Musgrave@industry.nsw.gov.au

SUMMARY

Magnetic field data forms the most detailed and comprehensive geophysical coverage of Australia but at present there are challenges in reliable interpretation of that data. One major concern is the recognition and correct treatment of remanent magnetization which can result in mislocation of drill targets. To both reduce hazards of incorrectly interpreting magnetic field data and also to derive new geological information we have developed a web-delivered database of Australian magnetic anomalies recognised as being at least in part due to remanent magnetization. The database is linked with databases of model studies, magnetic moment analyses (MMA) and palaeomagnetic and rock magnetic investigations. These linked databases presented in the context of magnetic field imagery provide geoscientists with a rapid means of recognising the expression of remanent magnetization and of accessing information about that magnetization to assist in their interpretations. The databases have been lightly populated and can be accessed with a web utility. Community involvement is sought to further populate the databases with information currently distributed through geological survey, company and academic records.

Key words: magnetic anomaly, remanent magnetization, rock magnetism, palaeomagnetism, database.

INTRODUCTION

Much of onshore Australia is covered with aeromagnetic data at a line spacing of 400 metres or less. This data is of strategic importance for geological mapping and provides many of the drill-targets for mineral exploration. A national grid has recently been compiled from regional surveys by Geoscience Australia at a cell size of 80 metres and forms the basis for the 5th Edition Magnetic Anomaly map of Australia (Milligan et al., 2010). The grid is primarily compiled from regional aeromagnetic data acquired by Federal and State Geological Surveys that is freely and readily available for download over the web using the Geoscience Australia GADDS utility. Despite the importance of this data and its widespread use, the mineral exploration industry does not at present have corresponding convenient access to information about the distribution of magnetization in Australian rocks, nor a comprehensive suite of interpretation tools to address specific problems such as recognising and correctly treating the influence of remanent magnetization in magnetic field data. At present, magnetic field interpretation is commonly based on unqualified assumptions that magnetization is parallel to the local geomagnetic field. With the present trend towards drilling deeper targets ever more subtle remanent magnetization effects become significant and errors through incorrectly addressing remanent magnetization effects become more costly.

Many rocks have a remanent magnetization of similar strength to their induced magnetization, but the ratio of these magnetizations (the Koenigsberger or 'Q' ratio) is highly variable. Magnetic field anomalies range from conspicuous examples due to resultant (remanent plus induced) magnetizations rotated considerably from the present geomagnetic field direction, to much more common examples of smaller but still significant rotations that may pass undetected on cursory inspection of the magnetic field data. Remanent magnetization is acquired in various igneous, metamorphic, alteration, weathering and mineralisation events and also records structural processes. Remanent magnetization should therefore not be seen merely as a hazard to interpretation but should be recognised as a source of geological information to substantially enhance the value and application of magnetic field interpretation. Over the last few years there has been a considerable interest in recovering estimates of resultant magnetization from magnetic field data both through staged inversion and MMA (for example Schmidt and Clark, 1998, Phillips 2005, Foss and McKenzie 2011a, 2011b).

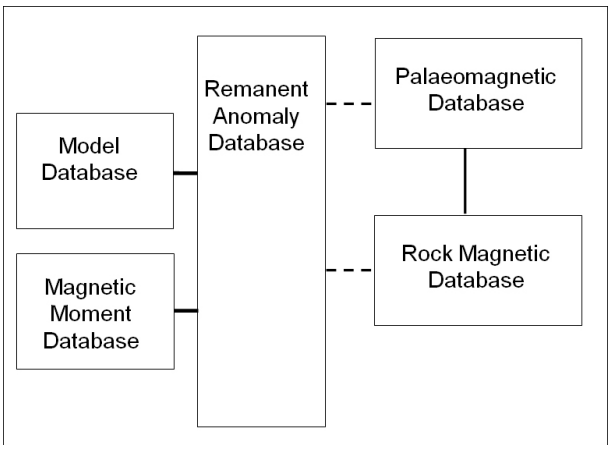

Figure 1. Linked database relationships

CSIRO and Geoscience Australia have developed a preliminary set of linked databases (as shown in Figure 1) to further the recognition of the expression of remanent magnetization in Australian magnetic field data and to assist in

correctly addressing remanent magnetization in magnetic field interpretations. The primary database is a spatial database of magnetic field anomalies recognised to be due in part to remanent magnetization. Related databases contain the results of any magnetic field model studies or MMA conducted on these anomalies. Direct measurement of magnetizations and magnetic properties of rocks are of course of particular value to the interpretation of magnetic field data and additional associated databases of remanent magnetization studies and of rock magnetic studies have also been created. The rock magnetic properties database may at a later stage be replaced by access to a more comprehensive rock properties database currently under design and construction at Geoscience Australia. The palaeomagnetic study database has been developed from an earlier IAGA global database for which the Australian sector has been updated in a study by Phil Schmidt of CSIRO and Sergei Pisarevsky of the University of Western Australia. A prototype web delivery system to test the ease and process of interrogating and downloading information from the different databases was developed in association with Intrepid Geophysics. Following tests with this prototype the database structures have been finalised, a working version of the web delivery tool has been built and the databases have been lightly populated.

THE REMANENT ANOMALY DATABASE

The remanent anomaly database has a simple spreadsheet structure. Minimum entry requirements are the longitude and latitude of the anomaly together with details of the author and contributing organization. This minimum entry is sufficient for anomalies to be flagged as being suspected expressions of remanent magnetization even if no further information is immediately available. Additional, optional data for the anomalies include assigned resultant and remanent magnetization directions, magnetization age and the petrology of the rock carrying the magnetization, together with minimum and maximum anomaly amplitude values, anomaly shape and orientation. These statistics support comprehensive interrogation of the database to locate similar anomalies elsewhere. Where a resultant magnetization direction has been estimated or where susceptibility and remanent magnetization have been measured, an apparent resultant rotation angle (ARRA) is also derived. This is the angle between the resultant magnetization and local geomagnetic field directions and is the single most appropriate statistic with which to rank the deviation of a magnetic anomaly from that expected for an equivalent induced-only source.

THE MODEL AND MAGNETIC MOMENT ANALYSIS DATABASES

Inversion and MMA are the two principal means of recovering information about magnetization from magnetic field data. Inversion without knowledge of the magnetization direction (and without assumption that it is in the direction of the local geomagnetic field) is challenging but nevertheless can be performed successfully for many compact sources by a suitable staged inversion process. One such process (Foss and McKenzie, 2011a, 2011b) is to first approximately locate the source body with an inversion to minimise the data misfit for a transform such as the analytic signal amplitude (ASA) which has low sensitivity to magnetization direction, then to use that located source in an inversion of the TMI data to find the corresponding best-fitting magnetization. With approximate estimates for both the location and magnetization, subsequent inversions that allow simultaneous position, shape and magnetization changes commonly show stable and repeatable convergence to provide estimates of both geological structure and resultant magnetization. For anomalies over compact sources, magnetic MMA is an alternative means of recovering an estimate of magnetization direction. Unlike inversion, MMA does not require resolution of the shape of the source body, although it is dependent on correct location of the centre of magnetization. Two variations of the analysis are an analytic solution (for example Helbig (1963), Schmidt and Clark (1998)) using magnetic field components which can be derived from FFT of TMI data, and an approximate solution (Phillips et al, 2007) using tensor elements. Tensor data can be directly measured by magnetic tensor gradiometers or derived from FFT of TMI data. There are different advantages and drawbacks to these two MMA methods with the tensor method providing particular advantage where overlap of anomalies from other sources renders outer parts of an anomaly unavailable for analysis.

THE PALAEOMAGNETIC AND ROCK MAGNETIC DATABASES

Direct measurement of magnetizations and rock magnetic properties are of course invaluable for magnetic field interpretation and every effort should be made to undertake such measurements or to locate any earlier measurements that may have been made. There is fortunately a strong publication culture for palaeomagnetic studies and many palaeomagnetic investigations within Australia carried out by universities or government groups (CSIRO and formerly Geoscience Australia) are published. These publications generally provide strength and direction of NRM (natural remanent magnetization) but not always accompanying magnetic susceptibility measurements that would allow the resultant magnetization to be computed. Palaeomagnetic measurements allow the direct and relatively precise determination of magnetization direction together with the ability to understand the mechanism and possible timing of its acquisition such that it can be related to geological processes. Generally however the palaeomagnetic samples represent a very small proportion of the rock body and are rarely well distributed in three dimensions. Magnetic field interpretation provides estimates of resultant rather than remanent magnetization but provides that estimate for bulk rock bodies including those that may be totally buried without ready access for palaeomagnetic sampling. The combination of magnetic field interpretation and palaeomagnetic studies is therefore very powerful. In a study with Sergei Pisarevsky of the University of Western Australia we have updated the Australian section of the IAGA global palaeomagnetic database. Key statistics of this database relevant to magnetic field interpretation are the direction and strength of NRM, the lithology and age of the rocks measured, ages assigned to the magnetization, the mode of acquisition of the magnetization and any susceptibility measurements made. The geographic range of individual palaeomagnetic studies is highly variable and unfortunately the global database provides only summary statistics. We have designed a daughter database to be populated with site statistics where available. This additional level of information will enable palaeomagnetic measurements to be linked more specifically to individual magnetic field anomalies and to individual source bodies that may have been generated to model or invert the anomalies. Not all palaeomagnetic studies have site

information available and population of this daughter database will be an ongoing task.

Rock magnetic measurements (particularly of susceptibility) have also been made in many geological mapping and mineral exploration and development programs but unfortunately this data is rarely published and in many cases the information is either lost or is available only in printed tabulations. We investigated various existing rock magnetic databases. The palaeomagnetic and rock magnetic databases may contain some common data (particularly susceptibility and Koenigsberger ratio values) but the general data structures differ sufficiently that it is more effective to maintain separate databases rather than to try and combine them into a single, less easily managed database. We have initially populated the rock magnetic database with a number of historic project databases from CSIRO. On entering this test data it was soon obvious that it is not feasible at a national or regional scale to present individual sample measurements, only summary statistics of individual studies and/or boreholes. Various organisations and companies may have compiled in-house databases that could be added to this rock magnetic property database. There is a considerable volume of data acquired opportunistically, particularly in drilling projects that provide samples from areas that may have no fresh material available at surface, but this data is often difficult to locate. Some data may be recoverable through data-mining of state geological record databases but in many cases the information is tabulated in reports that may be available only as scanned images requiring considerable effort to locate and extract. With available resources we will only be able to recover a small proportion of this data, but nevertheless even sparse rock magnetic property data may be invaluable for magnetic field interpretation studies. We also hope to accumulate data through community effort by supplying forms to enable web-based upload of data.

WEB DELIVERY OF THE DATABASES

Ready access to the various databases is essential to encourage their widespread use. The key to strengthening the database relationships illustrated in Figure 1 is to provide access to those databases in a common, spatial interface as shown in Figure 2. This is the main map component for web delivery of the databases. Icons mapping entries in each database are displayed in a common map space over an image of total magnetic intensity. A secondary window displays key information relating to the currently selected icon. Figure 3 shows an example entry for the magnetic anomaly database. Each magnetic anomaly entry has a supplied kmz file for direct download that can be displayed in Google Earth for visualisation in context with topographic features and other vector and image files. At present we use this secondary window simply to display selected information but we plan to later introduce more sophisticated capabilities to interrogate the databases and their relationships.

The magnetic anomalies, model and MMA databases all contain information which is by its nature interpretational. It is therefore not feasible to verify entries in these databases in the same way that, for instance, primary magnetic field survey data can be verified. Our approach to this problem is that we intend to maintain a lightly modulated database with many entries, rather than a more heavily modulated database that would contain the most reliable information but with a much smaller number of entries. We also plan to encourage public upload as well as download of data to and from the databases. In this way we hope that the database will be widely used as a community resource.

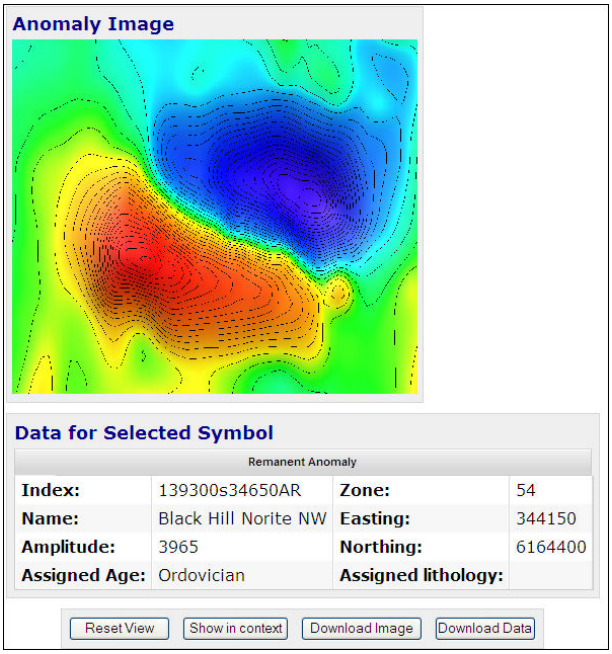

Figure 3. Example display of key data for a selected anomaly database entry. The displayed image can be downloaded in kmz format

CONCLUSIONS

Assistance is required for interpreters to be able to correctly address issues with remanent magnetization in the interpretation of Australian magnetic field data. We are providing such assistance through release of a web-base utility to present linked databases of magnetic anomalies interpreted to be due in some part to remanent magnetization, magnetic moment analyses of those anomalies, source model inversions of the anomalies, and palaeomagnetic and rock magnetic studies. Lightly populated versions of these databases have been generated and we encourage community involvement in the further population and usage of this resource.

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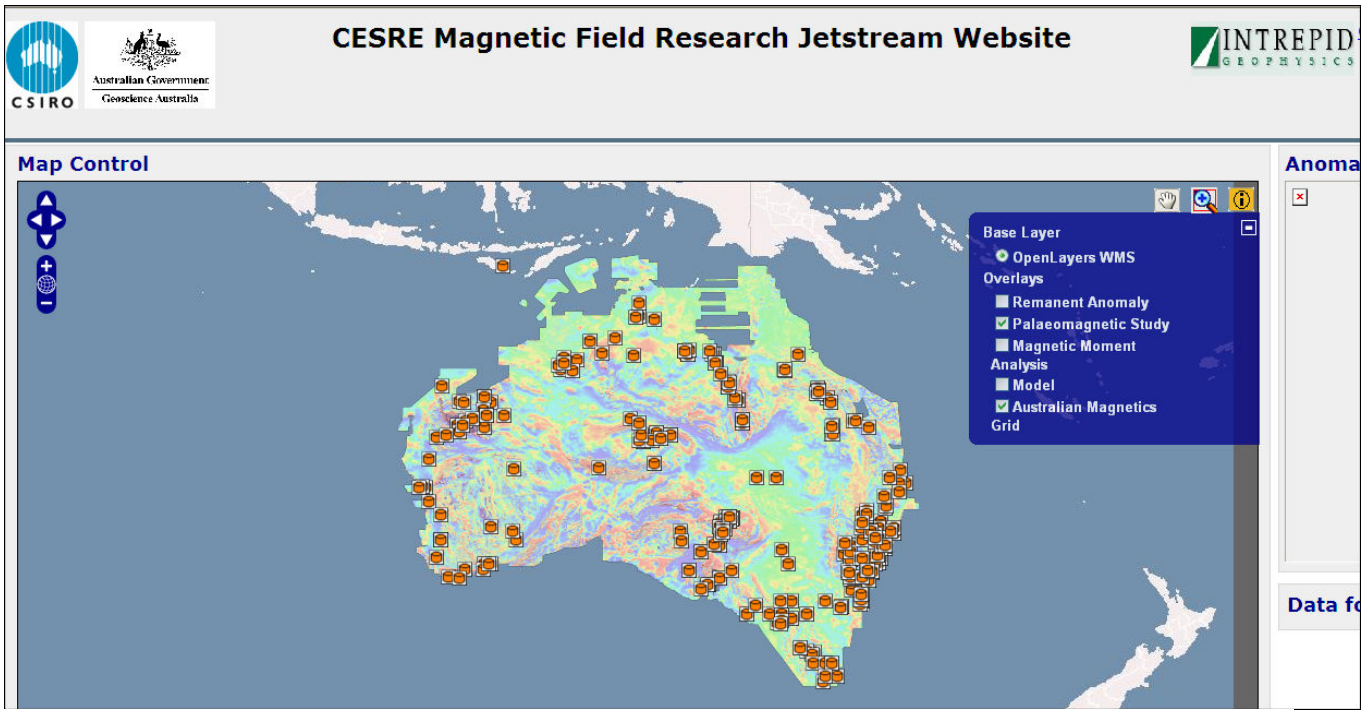

Figure 2. Main map window with the palaeomagnetic study icons overlaid on the TMI image