Generating a high-resolution global magnetic model for oil and mineral exploration

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Summary

This is the final contribution to the trilogy of articles on global potential-field data compilations. Getech's continental and national magnetic data compilations commenced in 1989 and were designed specifically for use in petroleum and mineral exploration. These studies complemented the continental-scale gravity-compilation studies that were the subject of the *TLE* "Meter Reader" contributions in March and May of this year. The success of these projects resulted from strategic partnerships, especially with Paterson, Grant and Watson Ltd. (PGW), and links to a wide range of national organizations. Early compilations covering the whole of Africa, South America, and China were followed by large-scale, small-scale, and national compilations and continue to this day with compilations of U. S. surveys. The projects spawned a range of technical developments, including approaches to remove survey-line noise, the integration of survey grids and disparate ship-track data, and the preservation of the longest-wavelength anomalies associated with the crustal magnetic field. The resulting global gravity and magnetic grids now form an invaluable resource for resource exploration.

Origins of the projects

The success of the continental-gravity compilations for Africa and South America provided an opportunity and demand for similar magnetic-compilation studies. To this end, an initial partnership was developed among Getech, PGW, and the International Institute for Aerospace and Earth Sciences (ITC). PGW had a history of working with major funding agencies such as UNESCO, the World Bank, and mining companies for aeromagnetic surveys. ITC had a history of academic links with geological surveys in Africa, and Getech had successfully completed two continental-scale gravity projects with oil-company funding. The partnership among Getech, PGW, and ITC was a key to success in the initial task of finding, recovering, and processing the vast collection of vintage aeromagnetic surveys that were known to exist across Africa.

Specifications chosen for the initial compilation products were a 1-km grid at a constant terrain clearance of 1 km. This meant oil companies could use the data for quantitative analysis, but at the same time, the data sets were manageable using computer equipment available in the early 1990s. This resolution was adequate to represent most pre-1990 oil-exploration and regional government or mining surveys, which typically had line spacing of 2 to 4 km.

Magnetic data do not have the military connotations associated with gravity data, which facilitated their relative ease of release into the compilation studies. Furthermore, release of study products at 1-km resolution commonly fitted with the remit of data providers because many of the surveys had been acquired with the intention of stimulating investment in individual countries.

The magnetic compilations

The first compilation was the African Magnetic Mapping Project (AMMP, 1989–1992) undertaken by Getech, PGW, and ITC. The first task was to identify what aeromagnetic surveys had been flown, by whom, and for which organization. Links with BRGM (France), Hunting Technical Services (U. K.), UNESCO, the World Bank, and many others generated a wealth of information, as did our oil- and mining-company sponsors. For some companies, this provided the impetus to sort out their analog archives and the opportunity to convert at least parts of them into digital archives.

After accessing the aeromagnetic survey data and metadata, the prime task was to recover the digital flight-line profile data or, if those was not available, the analog map data for digitizing. For many surveys, only total-magnetic-intensity (TMI) maps had been archived, so the digitizing priority was to recapture the TMI data along the original flight-line paths superimposed on the maps or along regular line patterns simulating the flight-line coverage. Doing this allowed us to apply a range of postprocessing applications to improve the consistency of the data prior to merging surveys.

The second study, the South American Magnetic Mapping Project (SAMMP, 1993–1995), resulted in very good coverage for the northern half of South America, with continuous data coverage over the length of the subandean basin system from Venezuela into northern Argentina (Figure 1). For Brazil, the initial release to SAMMP was a 1-km grid from Serviço Geológico do Brasil (CPRM) and a decimated 20-km grid

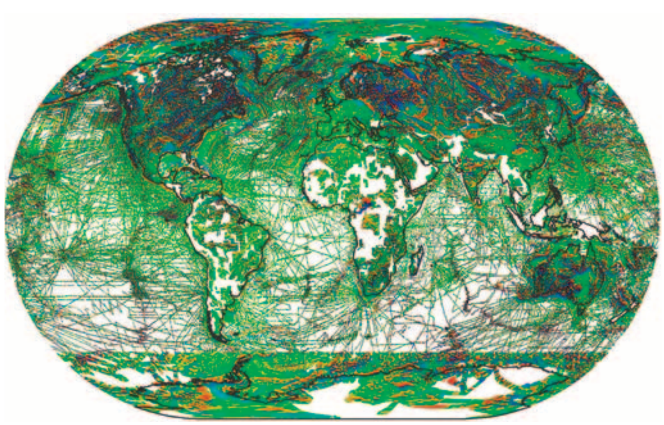

Figure 1. Getech magnetic compilations integrated with public-domain data grids.

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from Petrobras. After the end of the project and with Petrobras' approval, this 20-km grid was upgraded to a 1-km grid.

The China Aeromagnetic Mapping Project (CHAMP, 1996–1999) was the result of collaboration with China Aero Geophysical Survey and Remote Sensing Centre for Land and Resources (AGRS). Kaxia Lei (Getech) managed the three-year study in Beijing with a workforce of 10 AGRS employees. The purpose of the study was to recover and reprocess all the aeromagnetic surveys from all provinces of China at full resolution to generate a 1-km grid. This involved the reprocessing of approximately 7 million line-km of data because much of eastern China is covered by 0.5-km flight-line-spaced surveys.

Regional magnetic compilations then were undertaken independently of PGW for

- Russia; by linking with the Russian Academy of Sciences, access was given to a major part of the digitized 2-km line-spaced magnetic-profile data (~ 8 million line-km) covering Russia west of the Lena River; these map-sheet profile data were reformed into their original surveys prior to microleveling and merging the data
- East and Southeast Asia by linking with Coordinating Committee for Coastal and Offshore Geoscience Programmes in East and Southeast Asia (CCOP) and working closely with Takemi Ishihara (Geological Survey of Japan) to generate an updated compilation
- global continental margins out to 500 km from the coast, using all available NGDC/NOAA ship-track and airborne survey data. This complements the previous satellite-derived gravity study over the same area.
- Europe and the Mediterranean, bringing together data sets that span more than 60 years of acquisition and include ground vertical field data where total field land or airborne data are not available

Alongside these compilations, Getech undertook a series of country compilations and further regional compilations. The country compilations included Iran, Pakistan, Tanzania, Bangladesh, Iraq, Philippines, and PNG. The Iraq compilation was unique in that the tapes of the 1974 national survey had remained stored within the air-conditioned archive of the State Company of Geology and Mining of Iraq (GEOSURV) in Baghdad. This facility suffered a break in the power supply in 1990, resulting in poor tape condition (sticky-tape syndrome). In 2011, the USGS and Frontier Processing Company of Denver, Colorado, recovered 99% of the original digital data from the tapes by carefully baking them. Getech used these recovered data, along with digitized flight-line profile maps for the areas of unrecovered data, to generate the final digital products.

On a larger scale, Getech recently has systematically reprocessed the public-domain magnetic surveys for the western United States, integrating them with proprietary data sets to generate a new coherent exploration data set.

Development of processing techniques

Producing integrated 1-km magnetic grids over areas the size of a continent and its margins required the development of processing techniques to aid both the efficiency and quality of the output. The timescale of the initial projects was sufficient to allow such developments to take place.

The draping microleveling technique was refined through these studies to effectively microlevel any line-based data set (Figure 2). The method drapes each flight line onto a stable low-pass-filtered grid; several iterations can be used for optimal effect. A major attraction of this technique over other available techniques is that it can be tuned to remove only noise associated with the survey lines; it will work whether or not tie lines are available. Some map data sets were contour representations of poorly leveled surveys, with leveling problems forming part of the map. A combination of careful digitizing and draping generated a coherent gridded data set with leveling errors removed.

Survey linking methods developed during the projects trimmed and adjusted adjacent surveys to produce nearly seamless joins. Multiple links produced grids that were coherent over large areas and effectively imaged features crossing from one survey (and often one country) to another. However, the result lacked control on wavelengths bigger than individual surveys (Figure 3a). For AMMP, a magnetic grid derived from the Magnetic Field Satellite (Magsat), downward-continued to 1-km elevation (Figure 3b), was used to define the longest wavelengths onto which the magnetic-compilation data were draped to generate a

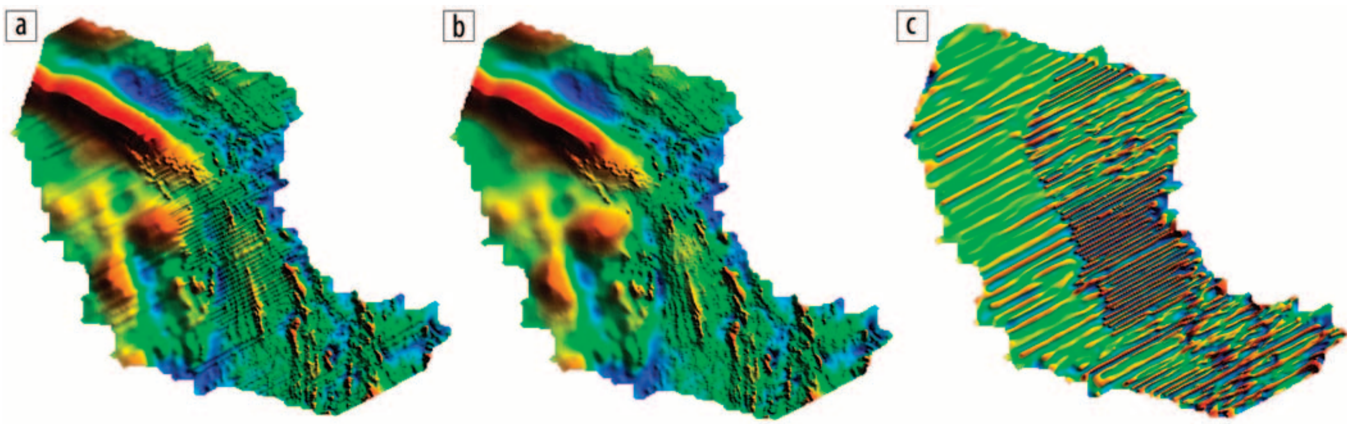

Figure 2. Drape microleveling of California aeromagnetic survey: (a) original magnetic-anomaly grid showing artifacts from lines with varying spacing; (b) magnetic anomaly after draping microleveling; (c) line noise removed (autocolor-scaled).

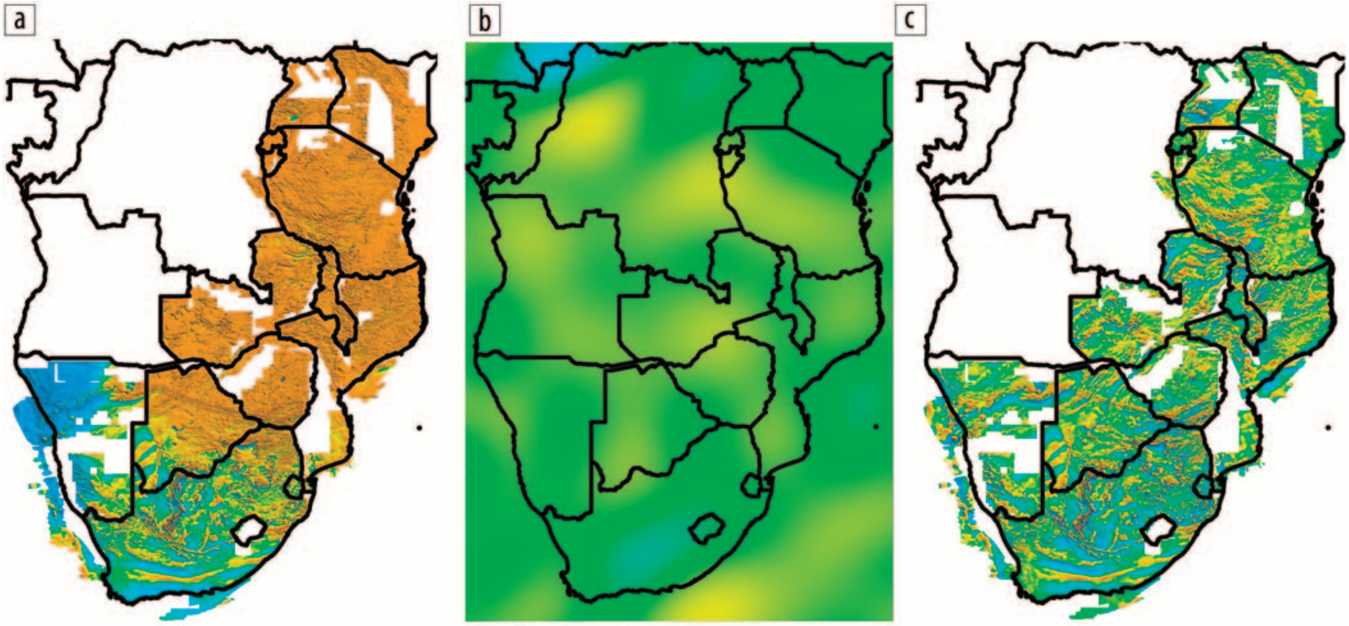

Figure 3. Draping linked grid onto satellite grid: (a) original linked surveys from South Africa to Kenya — note long-wavelength trends from survey linking; (b) Magsat satellite-derived crustal magnetic field; (c) linked surveys draped onto Magsat.

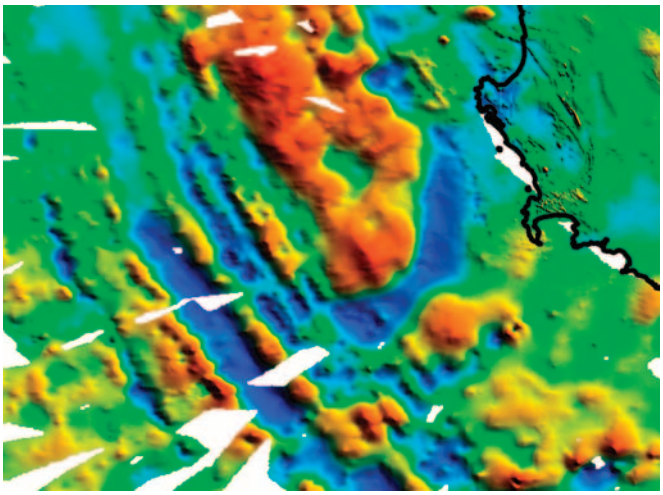

Figure 4. Magnetic map offshore South Africa, based in significant part on academic-survey ships entering and leaving Cape Town. After leveling, the magnetic map images oceanic isochrons and other features.

better representation of the crustal field (Figure 3c); currently, the CHAMP MF7 crustal field would be used.

Shipborne magnetic data from academic cruises form a crisscrossing and incoherent network of tracks, which are nevertheless quite dense in some near-shore areas. Careful processing, editing, leveling, and gridding of these disparate data sets enhanced the coverage, revealed interesting geologic features (Figure 4), and helped to tie together more densely sampled magnetic surveys.

Global magnetic grids

Magnetic grids from Getech's continental, marine, and national-scale compilations have been integrated with public-domain data sets (including major compilations for the North Atlantic and Arctic, Australia, Canada, and Antarctica) to generate a global compilation (Figure 1), which reveals major large-scale geologic variations. Our driving force in grid generation has been to allow users to make reliable estimates of depths at 1 km or deeper and delineate structures at those depths. Because of the 1-km resolution of this global grid, this is achievable over much of the globe.

Other global magnetic grids exist, but they are not necessarily useful for basin interpretation. These include the satellite-derived MF7 field and EMAG-2, which incorporates some lower-resolution onshore data sets and ambitious ocean-filling algorithms to generate a 4-km grid at 4-km elevation. Figure 5 shows how these grids compare over an area of East Africa. Figure 5b shows that in the north and west of the area, EMAG-2 can be based on similar data to the Getech grid but has been excessively smoothed by presentation at 4-km elevation; in the SE area, the grid is based on data of much lower quality. The MF7 satellite grid (Figure 5c) is smooth. Although it is provided as an ~ 11-km grid at 2.5-km elevation, the resolution will always be limited by the original acquisition at ~ 300-km altitude.

Value of magnetic compilations

The magnetic compilations are widely used along with the gravity compilations because they provide complementary and readily synthesized information. Both data sets image major features of the geology on scales not available previously, which enables structural mapping over large areas. Gravity images lateral density variations at all depths, including within sedimentary basins at the basement boundary and at the Moho. However, isostatic compensation means that large-scale gravity anomalies from basins can be canceled to a significant extent by the deep-crust and upper-mantle anomalies. Magnetization varies in a more complex manner, but sediments are often virtually nonmagnetic; hence, the magnetic grids can be used to directly estimate basement depths. The

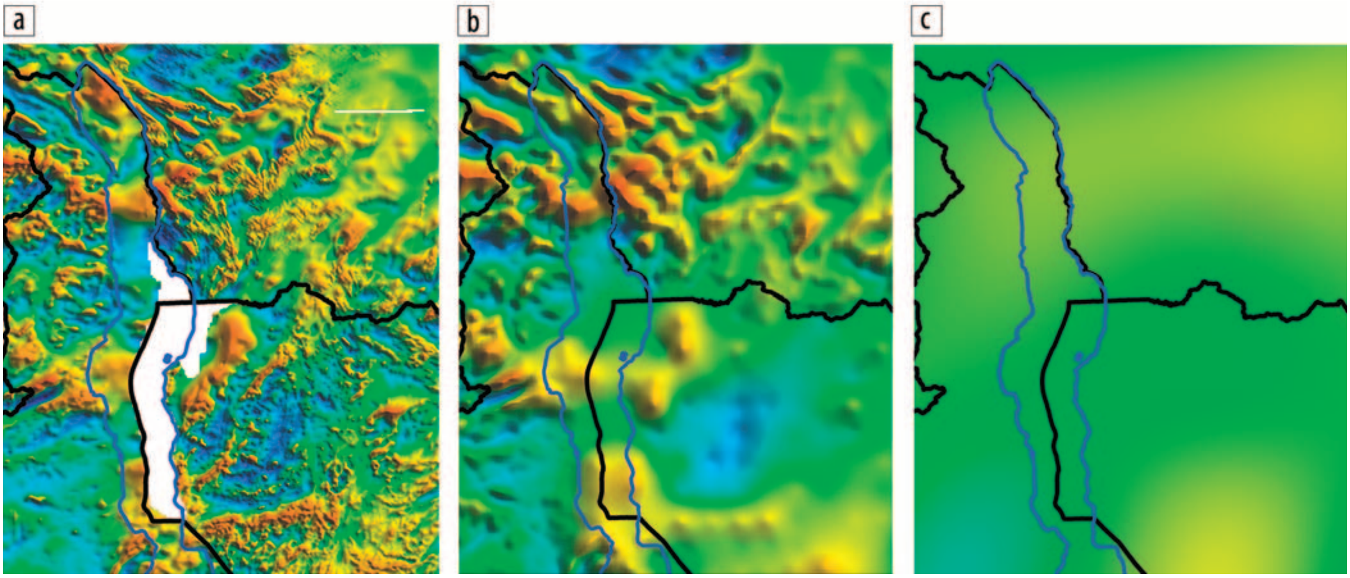

Figure 5. Comparison of magnetic grids for part of East Africa centered on Lake Malawi: (a) Getech compilation: 1-km grid at 1-km elevation; (b) EMAG-2: ~ 4-km grid at 4-km elevation — note data void smoothed across; (c) CHAMP crustal field: continued to 2.5 km above earth surface.

Curie isotherm, at which rocks become nonmagnetic because of temperature, commonly lies deep in the crust and can be mapped using large-scale magnetic compilations based on studying the long wavelengths of the crustal magnetic field. This Curie depth is not only an input for basin modeling but it also can provide critical additional information to tune depth-to-basement estimates. In cases in which the Curie isotherm is shallow and the basement is deep (e.g., in many continental margins), the basement depth otherwise would be significantly underestimated.

The gravity and magnetic compilations together are now used widely in large-scale geologic mapping and to define potential oil-exploration structural targets. TLE

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Suggested reading

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