42. COMPILATION OF MAGNETIC ANOMALY CHART WEST OF IBERIA[1]

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ABSTRACT

A reduced-to-the-pole magnetic anomaly chart of the region west of Iberia, including the Ocean Drilling Program Leg 149 sites, has been produced at a scale of 1:2.4 million. Data from the Atlantic Geoscience Centre Magnetic Compilation Project database and recent Leg 149 site surveys were corrected for secular and diurnal variations, geomagnetic instability, and crossover errors. The resulting 424,777 data points were gridded at 5 km and processed to transfer the anomalies to the pole. The grid was contoured at 25-nT intervals and colored to produce the chart presented as a foldout in the back pocket of this volume.

INTRODUCTION

This paper describes the compilation, reduction, and processing of marine magnetic measurements for the production of a magnetic anomaly chart of the Northeast Atlantic Ocean adjacent to the Iberian Peninsula. The chart, Figure 1, is attached as a foldout in the back pocket of this volume.

Several magnetic anomaly compilations of the Northeast Atlantic have been published as contour charts during the last two decades (Guennoc et al., 1978; Roberts et al., 1985; Verhoef et al., 1986). The earlier two charts are manual compilations of analog data, designed to show the Late Cretaceous and Tertiary age seafloor-spreading magnetic anomalies, for which contours at 100-nT intervals were sufficient. Considering that some of these compilations did not include any crossover control, the 100-nT contour interval may have been unduly optimistic but did enable the linear anomaly sequences to be recognized and viewed in a regional context. This was of particular importance in visualizing the seafloor-spreading history west of Iberia where the major anomalies of Chron 33R (reversed polarity, 83-79 Ma; Harland et al., 1990) and J (within the youngest M-series of Early Cretaceous age; Rabinowitz et al., 1979) dominate the magnetic charts.

In order to better resolve the magnetic anomaly field, particularly as an aid to modeling, it was necessary to have available a greater density of tracks than those used by Guennoc et al. (1978) and Roberts et al. (1985). It was also desirable to be able to analyze and edit the large amount of data prior to processing and contouring. A project that collected geophysical data from ships on passage between Europe and South America, the Kroonvlag-Project (Collette, 1984), generated a significant amount of new marine magnetic data across the area west of Iberia. This prompted a comprehensive compilation initiative by a team at the Vening Meinesz Laboratorium, Utrecht (Verhoef et al., 1986), who extrapolated the International Geomagnetic Reference Field (IGRF 1980) (IAGA Division 1 Working Group 1, 1981) back to 1956 in order to process all available data in the Atlantic Ocean between 35°N and 50°N as far as 32°W. The crossover analysis of Verhoef et al. (1986) showed deficiencies in the accuracy of the reference fields, which, when approximated by long-wavelength time-dependent corrections, produced mean crossover errors close to zero with a standard deviation of about 60 nT, although this varied across the area. The worldwide average of daily diurnal variation at 40°N measured by Reagan and Rodriguez (1981) is about 50 nT. This accounted for part of the standard deviation of the crossover errors, which also included errors derived from navigation inaccuracies. The data were gridded to a spacing of 5.5 km, and the total magnetic field anomaly was contoured at 50 nT (Verhoef et al., 1986).

New data were added to a segment of the Verhoef et al. (1986) grid in compiling a revised 50-nT contour chart of the area 39.5°N to 42°N, 14°W to 10°W, for magnetic modeling associated with the regional interpretation of crustal seismic refraction lines obtained off western Iberia in 1986 (Whitmarsh et al., 1990). The revised chart did not reveal any new magnetic anomalies of wavelengths less than those of the previous chart but it provided additional control for modeling the J and M-series anomalies, which were used to identify oceanic crust in the region of the ocean/continent transition.

Subsequent studies in the Tagus Abyssal Plain (Pinheiro et al., 1992) and the Iberia Abyssal Plain (P.R. Miles, unpubl. data) compiled magnetic anomaly contour charts using a least-squares crossover adjustment that, in these small areas, brought crossover errors down to less than 20 nT. This permitted contouring at the 25-nT interval. These compilations revealed the presence of low-amplitude (~50 nT) north-south-trending linear magnetic anomalies that were interpreted to be generated by magnetization variations and basement relief related to continental rifting and the onset of seafloor spreading. These results made an important contribution to the choice of Ocean Drilling Program (ODP) Leg 149 drill sites and prompted us to compile magnetic anomalies for the whole region off western Iberia to a resolution compatible with a contour interval of 25 nT. This would support scientific interpretation of the drilling results and produce a new detailed magnetic anomaly chart, which is presented here.

DATA COMPILATION

The Atlantic Geoscience Centre (AGC) of the Geological Survey of Canada in Dartmouth, Nova Scotia, has for some time been developing a project to compile magnetic data in the Arctic and North Atlantic Oceans (Macnab et al., 1992). Apart from the international collaboration established to access data from all sources, the project is based on a specialized computer facility, which enables compilation and processing of large potential-field data sets and the generation of

gridded data sets. In particular, the system permits the user to assess the relative contribution of each possible source of error in the data of each survey by using a statistical analysis of crossover errors. The application of a subsequent minimization and final adjustment through a least-squares algorithm applied to the crossover errors, with a repeated statistical analysis, allows the monitoring of improvements at each step.

Data Set

The boundary of the compilation area (Fig. 2) was chosen as 36°N to 46°N and 6°W to 19°W in order to give a regional perspective to the Leg 149 drilling area. It is also advisable when compiling data for grid manipulation to avoid high-amplitude linear anomalies at grid boundaries that can generate aliasing during subsequent processing. In this area the mid-Biscay anomalies and anomalies 33N to 34N in the west are significant (~700 nT) and contributed to the choice of the above boundaries. A subset of the AGC North Atlantic magnetic database for this area consists of 177 cruise legs operating between 1956 and 1990. To these were appended three new data sets from recent cruises in the Iberia and Tagus Abyssal Plains. A list of institutions that contributed cruise data to this compilation is included on the foldout chart in the back pocket. These data sets were concatenated into a working format system file for processing. The cruise track segments used in the compilation are shown in Figure 2. Figure 3 shows the age distribution of these ships' tracks in the AGC database, after the elimination of poor data segments.

Data Processing

The initial operation was to reduce the observed total magnetic field measurements to magnetic anomalies using the IGRF 1990 (IAGA Division V Working Group 8, 1992), which includes the secular variation model. The IGRF and Definitive Geomagnetic Reference Field (DGRF) are coefficients describing a model of the main geomagnetic field, with forward-extrapolated and linearly interpolated models, respectively, of the secular variation. These are normally reassessed every 5 years; the IGRF is a forward extrapolation used until the geomagnetic secular field model can be defined from models of actual observatory data to generate a DGRF. As a rule, shipboard magnetic data are not corrected for diurnal (daily) variation. However, we applied a latitude-dependent daily variation model that was extracted from all available magnetic data in the North Atlantic (J. Verhoef et al., unpubl. data).

The usefulness of a measurement of the total geomagnetic field is dependent on the general behavior of the external magnetic field and its disturbances during the time of observation. When processing large amounts of marine magnetic data for which shore-based monitoring is absent, some technique is required to control decisions on time periods when the geomagnetic field was disturbed. Geomagnetic fluctuations have regular and irregular components. The former can normally be accommodated by secular variation reference fields (IGRF) and daily diurnal corrections. The latter requires a measure of planetary irregular variations as a whole. A general way to describe this activity and disturbance level of the Earth's magnetic field is by using geomagnetic indices, which have been compiled from observatory data and summarize the complex time-varying phenomena related to the activity of the magnetic field. Although there are many indices in use (Mayaud, 1980), the Kp index is used here as it is appropriate for mid-latitude regions. Three-hour intervals from a network of observatories are standardized and averaged to produce a value for Kp as a continuous variable between 0.0 and 9.0 for any date and time during data collection. The index is normally expressed as N-, N, or N+ giving 27 values. Statistical parameters from crossover analysis change and improve by elimination of data based on the criteria of the Kp index.

Crossover Errors

A track segment is defined as a straight line between two successive data points with a maximum separation limit nominally set at 5 km to avoid erroneous interpolation across large data gaps. At each crossover point between two track segments, two magnetic anomaly values were calculated by interpolation. This was achieved by creating a table of track segments by scanning the database and sorting each segment by ascending longitude. Straightforward comparison detected segment pairs that intersected, and the times and anomaly values were interpolated. These times and values were stored in another table with the positions of the crossovers and the two local magnetic gradients. The gradients were used to estimate the significance of the errors, as high magnetic gradients magnify the effect of navigation errors, particularly for older data with poor navigation.

Analysis of the crossover errors with respect to the geomagnetic stability enabled data adversely affected by high Kp values to be excluded and track segments eliminated. Figure 4 shows the percentage of crossovers with an absolute error < 25 nT for each value of Kp. A balance of improving crossover statistics while avoiding elimination of large sections of data required determination of a pragmatic Kp-limiting value. This was selected at Kp = 6 (Fig. 4). This percentage drops off for Kp > 6+, and data with values greater than this were eliminated (Fig. 5)

A powerful application of the processing facilities is the ability to interrogate crossover information for various combinations of cruise characteristics, particularly time. At each data-editing stage, where an improvement in the mean and standard deviation of the crossover errors was generated, the data could be regridded and color imaged with shading to give a visual perspective of the grid and the integrity of the data. This approach highlighted inconsistent track segments that were not apparent in the crossover analysis and enabled individual track crossovers to be reassessed against all other data, or any subset of data, based on time or track segment. These statistics, which were typically large and nontrivial, enabled eliminating rogue data. It was evident that some data made no contribution to the integrity of the magnetic anomaly field. Figure 6 shows the standard deviation of the crossover errors of the data as a function of a cutoff year (all data collected since that year; Verhoef et al., 1991). The final stage in preparing the data for gridding was the minimization and final adjustment of the crossover errors through the application of a least-squares algorithm (Fig. 6).

PREPARATION OF THE CHART

The final data set used in the generation of the grid consists of 424,777 data points representing 192,685 line km collected on 176 surveys between 1960 and 1993. Data prior to 1960 were eliminated on the basis of crossover analysis. Figure 6 shows that the final data set has a standard deviation of crossover errors between 17 and 40 nT dependent on age of the data.

The gridding routine applied by the AGC software produces on average one value per grid cell. This value is obtained by averaging all data points that fall inside a grid cell and locating the average at the center of distribution of all the points in the cell. This preprocessed data then has a surface-fitting program applied, based upon a minimum curvature algorithm that can include "tension" to prevent overshooting of the solution. In most cases, with well-controlled track lines, only a minimal tension is used (Smith and Wessel, 1990). The choice of grid size depends on a combination of the original data distribution (the denser the data tracks, the more unbiased detail can be obtained in directions perpendicular to the track) and the shortest wavelength of the magnetic data chosen to be retained. For this compilation, the data distribution was sufficiently dense to get unbiased

Figure 2. Limits of the magnetic chart showing the ships' tracks used in the compilation after the deletion of unreliable data.

data with a wavelength of about 10 km. However, the depth to basement is 5 to 7 km in the area of the Leg 149 sites (Whitmarsh et al., this volume), and a cell size of about 5 km would not significantly eliminate magnetic wavelengths that contain information about the source layer.

Observed magnetic anomalies are skewed or phase shifted by the noncoincidence of the present and remanent geomagnetic magnetic vectors. Reduction of these anomalies to the pole (RTP) transfers these anomalies to those equivalent to both magnetic vectors being vertical. This has the advantage of placing the magnetic anomaly directly above its causative body. This is achieved through processing the observed magnetic anomaly grid using paleomagnetic vectors. Ideally, an individual paleo-pole vector would be used for each grid

node, but here a single remanent vector for the Early Cretaceous, the general age of the crust in the vicinity of the Leg 149 sites, was used with inclination 46° and declination 0° derived for the period 98 through 144 Ma (Van der Voo, 1990). The effect of this reduction was the resolution of several north-south-trending magnetic lineations in the vicinity of the Leg 149 sites, in particular the magnetic low extending from 40°N to 43°N east of the J anomaly.

To continue the de facto standard for marine geophysical charts in the Northeast Atlantic (Laughton et al., 1975), a scale of 1:2.4 million at 41°N was chosen for the Mercator projection. Color infill shades every 25 nT and line contours at 100-nT intervals delineate the RTP magnetic anomalies. The location of Deep Sea Drilling Project (DSDP) and ODP sites, plus the J anomaly, was added for reference.

ACKNOWLEDGMENTS

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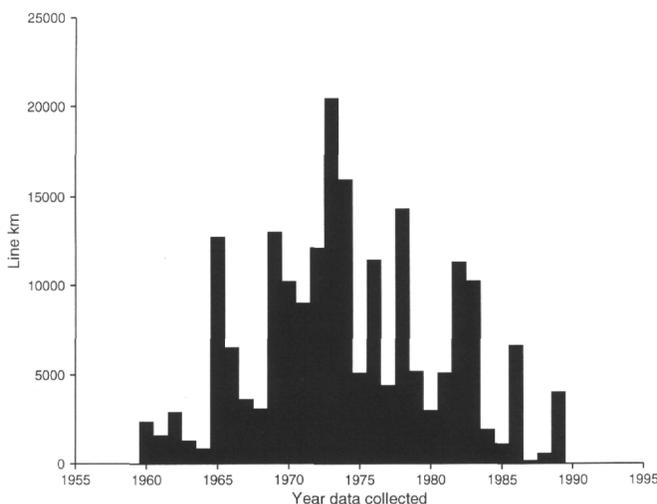
Figure 3. Histogram of the AGC database used in the compilation for each year of acquisition.
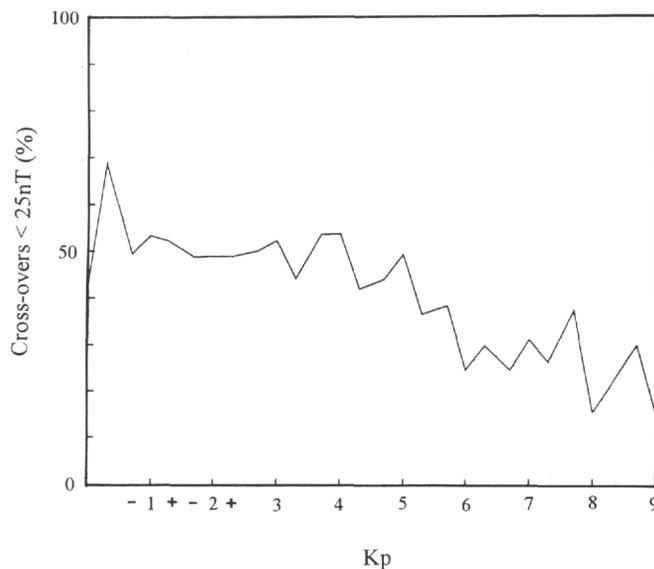
Figure 4. The percentage of good crossovers (those with an absolute error < 25 nT) decreases with increasing Kp. The Kp cutoff value for data editing was chosen at 6+, where the relationship drops off.
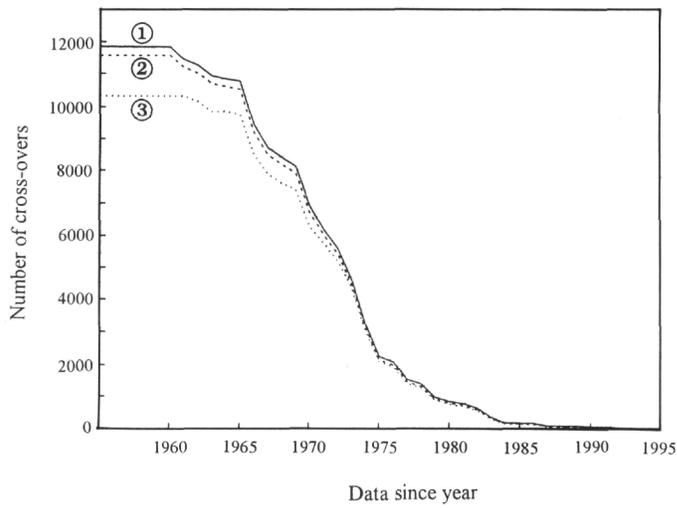
Figure 5. The number of crossovers at each data-reduction stage plotted against cutoff start year. (1) = raw data; (2) = after correction for Kp and diurnal variations; (3) = after the elimination of bad tracks and application of least-squares adjustment.
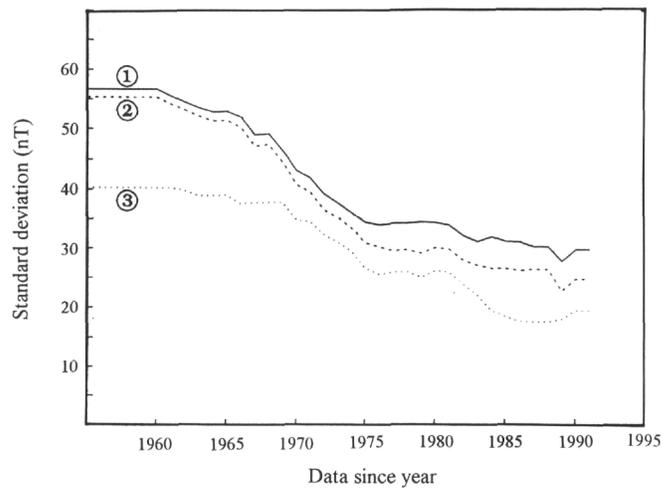
Figure 6. Standard deviation of crossover errors plotted against cutoff start year. (1) = raw data; (2) = data corrected for Kp and diurnal variations; (3) = after the elimination of bad tracks and application of least-squares adjustment.