Shaded relief magnetic anomaly map of Italy and surrounding marine areas

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Abstract

Magnetic observations made onshore the Italian Peninsula, and across the adjacent seas, have been compiled in a new digital database that provides the first complete regional scale view of the crustal scale magnetic anomalies of the region at sea level. The offshore data were acquired between 1965-1972 by the Osservatorio Geofisico Sperimentale (OGS) while the ground measurements were performed within the framework of the Progetto Finalizzato Geodinamica of the Consiglio Nazionale delle Ricerche (PFG-CNR) between 1977 and 1981. The new shaded relief magnetic anomaly map of total intensity of the Earth's magnetic field for Italy and the surrounding seas has been produced at sea level, for the geomagnetic epoch 1979.0. The most remarkable result of this new map, with respect to the previous compilations and to the aeromagnetic map of Italy, is an unprecedented view of the magnetic signature of the major tectonic elements in their regional setting. There is good correlation between known structural geology and the magnetic anomalies, and now that the longer wavelength signatures have been corrected, deeper interpretations are possible.

Key words *magnetic anomalies – geomagnetism – potential fields*

1. Introduction

The purpose of magnetic surveying is to identify the shallow geological components of the Earth's magnetic field. When devoted to the definition of crustal origin magnetic fields, generally generated by unusual anomalous magnetization of crustal rocks, magnetic anomaly maps are produced to show this contribution. The Earth's magnetic field intensity is in fact not very high, but large enough to magnetize certain kinds of rocks containing iron, titanium and/or other minor magnetic minerals. In practice, however, almost all rock magnetic properties reflect the concentration of magnetite. As for gravity, all the geophysical work for magnetic anomalies relies on a two stage process: 1) near surface measurements of anomalies, and 2) interpretation of anomalies in terms of rock properties, adding knowledge to the geology of the investigated area, or at larger scales, leading to the definition of configuration and structure of the underlying magnetic basement.

In Italy, magnetic survey efforts only began on a national scale in the 1970's.

The Osservatorio Geofisico Sperimentale (OGS) had started a series of geophysical investigations in the Mediterranean Sea, which included magnetic data acquisition. They published a few sector maps for the seas surrounding Italy (Morelli, 1970, 1972; Morelli *et al.*, 1969). Only recently has Zanolla *et al.* (1998) published the raw magnetic data and the navigation for the whole of the Mediterranean area.

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Meanwhile a second order, ground magnetic network was set up for the determination of total field measurements and all magnetic field components across the Italian Peninsula and across the major islands. The Consiglio Nazionale delle Ricerche (CNR) funded the work under the framework of the Progetto Finalizzato Geodinamica (PFG). The survey work was carried out by several universities, coordinated by the Istituto Nazionale di Geofisica (ING). This work produced the first ground magnetic anomaly map for the onshore areas (Molina *et al.*, 1986, 1994).

A magnetic anomaly map for Italy and the surrounding areas was compiled by Pinna (1987) for the sea level. Despite using the same data set as previous compilations, there were remarkable discrepancies between the maps. One of the problems, for example, was related to the very different regional trend on land in Northern Italy in comparison to the CNR-PFG group map. As shown by De Santis and Meloni (1988), this was due to the inappropriate reference field that was subtracted by Pinna (1987).

The Italian national oil company AGIP commissioned a number of aeromagnetic surveys of Italy in the late 1970's. Total field magnetic data at various altitudes were collected. Two aeromagnetic anomaly maps for the Italian territory were produced: a colored version in 1981, and a later contour version of the same data set of 1981, superimposed on regional geological features, in 1994 respectively (AGIP, 1981; Servizio Geologico Nazionale, 1994). Due to the high measurement density and the large geographical extent, this map has been used for many years for magnetic interpretations and, to a larger extent, as a tool for integrated geodynamic interpretations of geophysical data.

An initiative was launched and coordinated by ING with the involvement of the Istituto di Geofisica Marina of Consorzio Universitario di La Spezia (CUNISPE) and the Osservatorio Geofisico Sperimentale (OGS), to compile a new digital database of magnetic anomaly data, for both on and offshore areas using modern processing techniques.

In this paper, the magnetic data used in the compilation and acquisition, and processing will be described, and compared with the previous compilation. All the magnetic data used in the present compilation and some details on their acquisition, reduction procedures and the processing techniques will also be described.

2. The digital database

Between 1965 and 1972, oceanographic campaigns were promoted by the CNR in the Mediterranean Sea. The cruises acquired bathimetric, gravity and magnetic data, and were performed by OGS. The R/V Bannock was used until 1971, when the R/V Marsili replaced her. During the measurements, a cruising speed of 10 to 12 knots was maintained. Positioning relied upon a Loran C navigation system. A proton precession magnetometer was used to make measurements of the total intensity of the Earth's magnetic field; the sensor was placed in a towed fish at 200-300 m from the ship. Figure 1 shows the marine track lines along which magnetic measurements were acquired. Preliminary contour maps of free-air gravity, Bouguer gravity and magnetic anomalies offshore were published for the Adriatic Sea area (Morelli *et al.*, 1969), the Tyrrhenian Sea (Morelli, 1970) and the Sicilian Channel (Allan and Morelli, 1971; Morelli, 1972).

Seven national institutions (coordinated by ING), set up a new national geomagnetic repeat station network (116 stations) and a second order network of more than 2700 stations. A secular variation model, magnetic maps of the total intensity (F), the vertical component (Z), and the horizontal component (H) of the Earth's magnetic field were produced. Details of the acquisition procedures can be found in Molina *et al.* (1985b). Figure 1 shows the locations of the ground stations. The average sample interval on the ground is one station every 100 km^2.

Offshore and ground data were reprocessed, reduced to a common geomagnetic reference field epoch and height datum and merged to produce a map. That means all the measurements were first mathematically adjusted so that it appears that the whole area was surveyed at the same time at the same altitude. Six different observatories were set up on Italian territory: four of them were permanent and two were

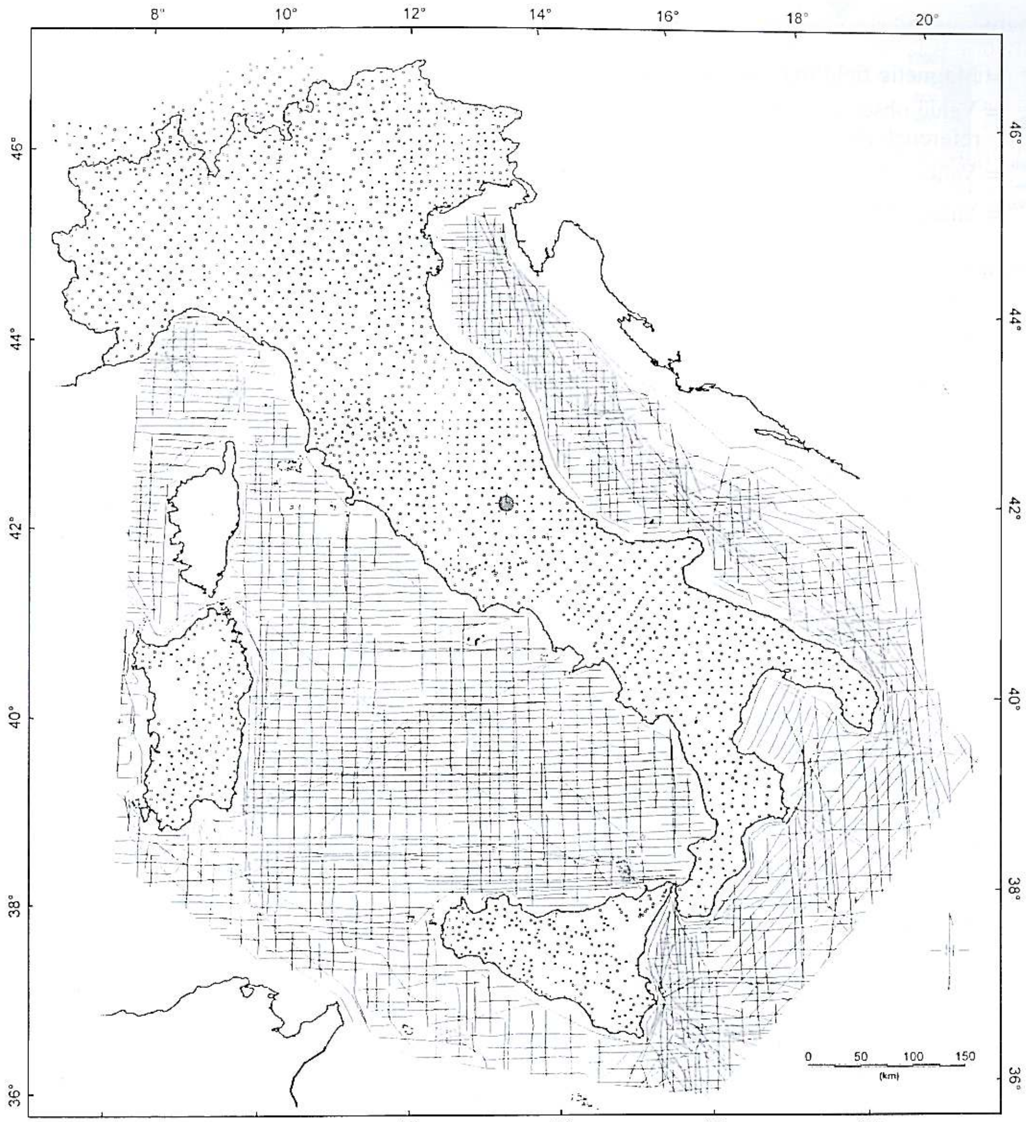

Fig. 1. Distribution of the marine track lines in the form of profiles, and location of the ground magnetic stations reprocessed, compiled, and merged. Latitude and longitude are North and East from Greenwich respectively. The black symbol indicates the location of L'Aquila geomagnetic observatory.

installed on a temporary basis (Molina *et al.*, 1985a, 1994). The observatory data were used in preference to remove the diurnal variation of the Earth's magnetic field from the ground data.

The geomagnetic epoch 1979.0 was used using the following equation

$$E_s^{79.0} = E_{obs}^{79.0} + (E_s^t - E_{obs}^t)$$

where

E_s^t = Magnetic field (nT) at station s at time t;

E_{obs}^t = Value observed at the same time t at the reference observatory;

$E_{obs}^{79.0}$ = Value at the observatory at 1979.0;

$E_s^{79.0}$ = Value at station s reduced to 1979.0.

During the marine cruises (1965-1972), only the geomagnetic observatory of L'Aquila was operational; these hourly mean values have thus been digitized and used for the diurnal variation correction. This observatory was particularly suitable for use as a ground station because of its central location in the survey area. The shipborne survey data were then all reduced to the 1979.0 geomagnetic epoch to produce a coherent data set.

All ground data were then reduced to sea level, to be consistent with the marine data. The magnetic field (E) at elevation h is corrected at sea level, by adding the dipolar contribution only, as follows:

$$\Delta E = 3Eh/R$$

where R is the ideal spherical earth radius R = 6371.2 km.

3. The computation of the magnetic anomaly field

To compute the magnetic anomalies and apply the secular variation correction, the correct geomagnetic reference field model needs to be considered. A detailed comparison of geomagnetic planetary reference fields for the Italian area was undertaken by Molina *et al.* (1985b) at the time of the PFG-CNR magnetic anomaly map compilation. All reference fields available at that time were used and finally a normal field in the form of a polynomial was suggested to draw the anomaly map. This procedure was improved and a particularly suitable model for the Italian and the Mediterranean regions was found by Molina and De Santis (1987) in order to maintain the spatial gradients of IGRF, but constraining its secular variation to the one observed at L'Aquila geomagnetic observatory. This model was called the Italian Geomagnetic Reference Field (ItGRF) and its analytical expression is a 2nd order polynomial in latitude (ϕ) and longitude (λ), in the form

$$F(\phi,\lambda) = a_{00} + a_{10}\,\Delta\phi + a_{01}\,\Delta\lambda + a_{20}\,\Delta\phi^2 + a_{02}\,\Delta\lambda^2 + a_{11}\,\Delta\phi\Delta\lambda.$$

All coordinates are referred to the central point (42°N; 12°E) and expressed in degrees. The coefficients were calculated by means of a least squares procedure from the experimental data, by Molina and De Santis (1987), and are reported in table I.

Once the anomaly values were obtained for the total field by subtraction of the reference field from the reduced values, the problem of repositioning of the marine paths arose. As it is clearly seen in fig. 1, the line paths do not represent a systematic survey nor uniformly cover the whole area. The main orientations are North-South and East-West plus some additional oblique profiles. One of the most time-consuming processing steps was to visually inspect every single survey line, to detect the presence of spikes and missing values. This operation was applied to the whole marine data set, and several spurious and/or missing records detected. A careful selection of valid lines and the elimination of double records are the major outcome of the repositioning and data visual scanning procedures.

Crossover analysis showed various leveling errors, statistically adjusted. The gridded data

Table I. Numerical coefficients of the 2nd order polynomial in latitude (ϕ) and longitude (λ) used to calculate the Italian Geomagnetic Reference Field model (ItGRF) (Molina and De Santis, 1987).

a_{00}	=	45386.500	nT
a_{10}	=	342.120	nT
a_{01}	=	69.034	nT
a_{20}	=	– 4.438	nT
a_{02}	=	1.457	nT
a_{11}	=	– 1.867	nT

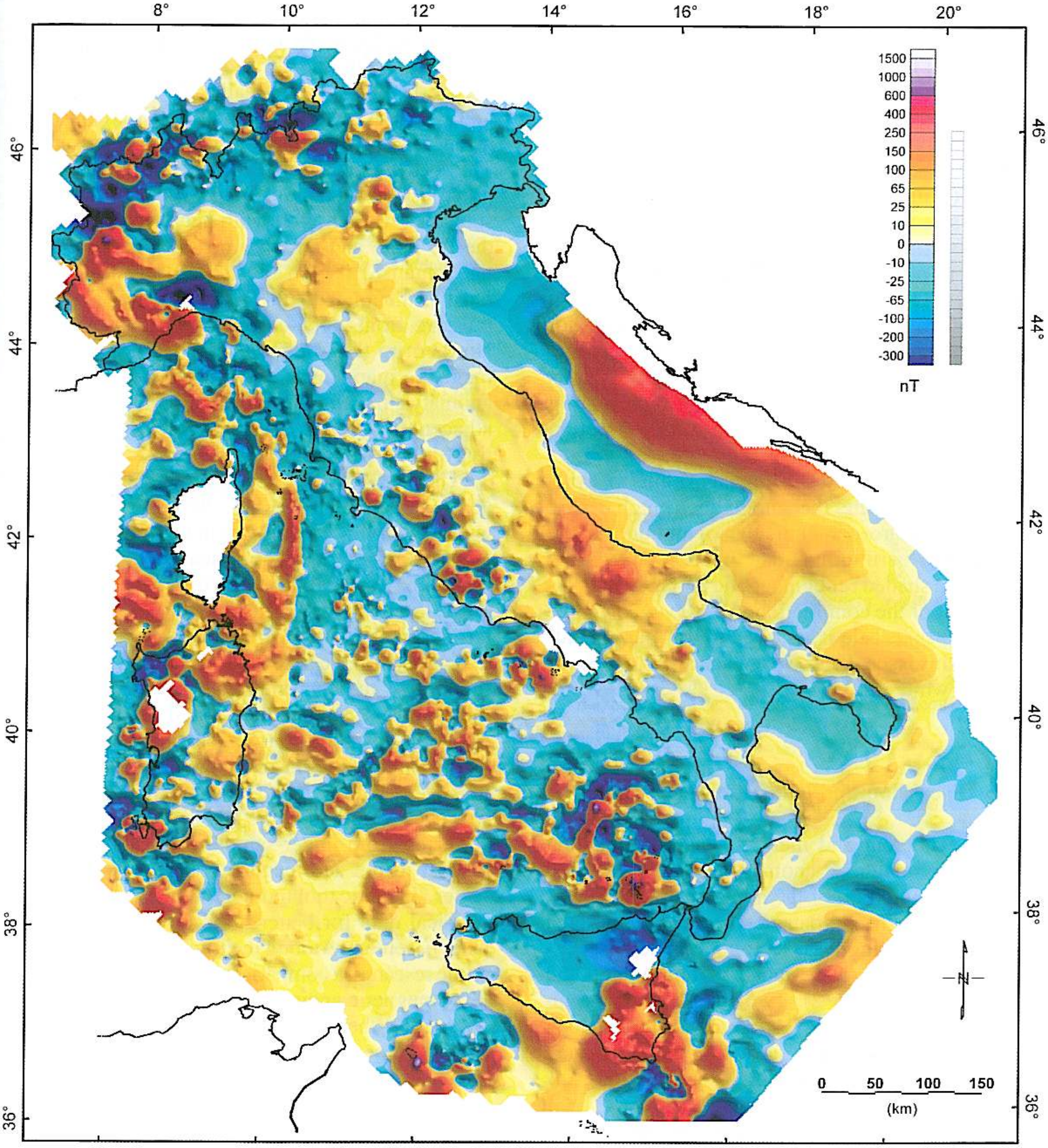

Fig. 2. Merged shaded relief magnetic anomaly map of Italy and surrounding marine areas at sea level, for the total intensity of the Earth's magnetic field. Latitude and longitude are North and East from Greenwich respectively.

further showed residual errors, shown as elongated anomalies parallel to the marine line directions; these errors exhibited a distinct spectral signature but did not have any physical meaning. The strategy has been to use multidimensional directional grid filtering methods to remove the leveling-related effects from the grid (Minty, 1991). The filtering method was used selectively, according to the spectral signature of the anomaly features in the investigated area, to pass or reject linear features of various strikes. The data set was properly windowed, to restrict the filtering and to ensure that it does not affect the anomalies with a geological meaning. The quality of the data processing was thus dramatically improved, avoiding representing wavelengths in the shipborne tracks direction less than the tie-line spacing.

We then applied shading algorithms to artificially illuminate the anomalies, emphasizing those that are perpendicular or oblique to the direction of illumination. Figure 2 shows the merged shaded relief magnetic anomaly map, as a result of the compilation. An A0 version at the 1:1 500 000 scale is reported in the map included in this issue. Unsurveyed areas are represented in white on the map.

4. Discussion and conclusions

A coherent and merged shaded relief total intensity magnetic anomaly map was obtained after compilation of the above mentioned shipborne and ground data sets for the Italian area and surrounding seas. The anomaly field is characterized by a wide range of amplitudes and wavelengths (fig. 2). Two major domains appear: high frequency anomaly features along the Tyrrhenian Coast and within the Tyrrhenian Sea, and a long wavelength pattern along the Apennines and over the Adriatic Sea.

The new map shows many signatures of the major tectonic elements over the Italian Peninsula already recognized especially in the AGIP aeromagnetic map. However some different magnetic anomaly patterns are recognized. The most remarkable difference between the new map at sea level and the aeromagnetic one appears along the Apennine mountain chain that acts as a rough sector of separation between the two Tyrrhenian and the Adriatic domains. On the Tyrrhenian side, anomalies start from a generally negative level while on the Adriatic basin a generally positive large-scale trend is present. This behaviour is not recognized at all on the previous aeromagnetic map. The AGIP map showed a residual field with negative values on the Po plain and strongly positive values over the Ionian Sea, with the isoanomaly lines almost orthogonal to the main Apennine compressive fronts, gradually increasing from the Northern to the Southern Apennines. The new magnetic map shows a low amplitude positive anomaly along the whole external Apennine belt, adjacent to a negative residual field in the nearby Adriatic/Apulian foreland areas.

The NNW-SSE trending feature on the AGIP aeromagnetic map that has always been in disagreement with ground magnetic maps as well as with many other geophysical data and interpretations especially on the on shore areas, is now clearly defined. This is likely to be due to an incorrect magnetic reference field removal undertaken on the aeromagnetic data set that, as reported by the same authors, was only based on the removal of a «magnetic field gradient» for the whole covered area (see Cassano *et al.*, 1986). This dramatically masked the low amplitude magnetic features. The new magnetic map at sea level described in the present paper, despite suffering from under-sampling on shore (with respect to the aeromagnetic survey), is now a better magnetic tool to integrate with other geophysical data for better definition of the magnetic basement. Among the future developments of the research, a comparison between the ground level magnetic anomalies and the aeromagnetic data set for the whole area will be attempted for the first time.

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