Magnetic anomaly map for Northern, Western, and Eastern Europe*

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ABSTRACT

All of the available data describing the Earth's magnetic field in Northern, Western, and Eastern Europe (c. 3×10^6 data points) are compiled and presented at a scale of 1:20 400 000. The compilation meets two requirements (i) that the total field intensity anomalies reflect a survey acquired at an altitude of 3000 m above m.s.l. and during the same epoch, 1980.0; and (ii) that the anomalies are residuals after subtracting the common reference field DGRF1980. As the data span many epochs, geomagnetic data recorded at observatories and repeat stations were used to determine the best model for estimating the secular variation in all data up to 1980. This yielded magnetic anomalies with wavelengths up to the order of 2000 km. The precision of the resultant anomalies (amplitudes about − 1700 nT to 8000 nT) differ between ± 10 nT in Central Europe and ± 20 nT in the outer parts of the compilation.

The resultant anomaly map contains a wealth of information to geoscientists studying global tectonic processes and the deep crustal composition of major continental crusts. It clearly shows the different anomaly patterns between the Palaeozoic and Precambrian crusts of Central and Eastern Europe. These anomalies are interpreted as lateral changes of magnetization in a horizontal plate. A comparison between the low-level compilation and maps derived from the MAGSAT satellite at about 360 km altitude allows the description of the two different crust types in Europe.

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Aim of the compilation

The aim of the compilation presented herein is a total intensity anomaly map that can be used as a basis for interpreting broad magnetic anomalies with wavelengths up to 2000 km. Such interpretations yield information about the composition of the upper lithosphere with respect to magnetic minerals. Magnetic data interpretation can resolve depths to 30 km, the Curie-isotherm of magnetite and, in some circumstances, even depths down to 70 km (Pilchin and Eppelbaum, 1997). However, the longest wavelengths of the broadest discernible anomalies in this compilation are at least 30 times longer than the thickness of the crust containing magnetic minerals. Magnetic anomalies of geological interest are relatively small, i.e. 30–100 nT in surveys acquired at 3000 m above mean sea level (a.m.s.l.). The amplitudes of long-wavelength anomalies of the magnetic field are expected to be in the order of ± 20 nT. This means that the individual geomagnetic surveys must be compatible over more than 1000 km within an error of ± 10 nT (Hahn, 1986).

Maps showing magnetic anomalies exist for every country in Europe, but they cover much smaller areas than necessary for interpreting broad anomalies. Simply fitting them together (as in Simonenko and Pashkevitch, 1990) does not provide a complete picture, because all surveys were conducted at different altitudes and epochs. Furthermore, different reference fields estimating the Earth's core field were employed for producing the various maps.

The map presented herein shows the crustal magnetic anomalies as if the total intensity field in Northern, Western, and Eastern Europe was measured at the same altitude 3000 m a.m.s.l. on 1 January 1980 (Fig. 1). The anomalies are residuals after subtracting the common reference field, Definitive Geomagnetic Reference Field DGRF 1980 (IAGA Division 1 Working Group 1, 1985), from the total field values. This parameter combination was chosen based on the following considerations and conditions:

- Long-wavelength anomalies are still recognizable at an altitude of **3000 m**. Datasets in areas of exploration or of other industrial interests are not available at lower altitudes.
- In 1980 the MAGSAT satellite opened up the first opportunity to determine the magnetic field of the entire Earth and also to identify all anomalies of the Earth's crust. Therefore, reference fields for the epoch **1980.0** are much more precise than for any other epoch.
- A comparison between the results of the four global reference field models DGRF 1980, GSFC 12/83 (Langel and Estes, 1985), CAIN M051782 (Cain *et al.*, 1984), CAIN M102089 (Cain *et al.*, 1989) and field observations recorded at 31 geomagnetic observatories in Central Europe yielded a best approximation of observed values for the **DGRF 1980** model (Wonik, 1990, 1992).

Progress in the compilation of this map can be trailed in numerous publications, some of which originate within the framework of the European Geotraverse (EGT) project: Wonik and Hahn (1989, 1990, 1991), Wonik *et al.* (1992), and Wonik (1992).

Available datasets

Appendix 1 and Table 1 list the contributing institutions and the

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*To achieve the required spread of data we made contracts with several institutions. We have agreed not to hand over the data to any third party. Everyone who is interested in the data should contact the first author, who will give help in contacting data owners.

sources of all data used in the compilation. The key parameters for each dataset are also listed. The present authors have acquired and compiled datasets from numerous organizations since 1986 in order to create a digital database of coherent magnetic observations.

Many of the datasets used result from surveys which were not only carried out at different flight altitudes and epochs, but also used different co-ordinate systems, profile spacings, instruments and processing. Moreover, the data were made available in a variety of formats. In most cases the compilation was started with digital magnetic anomaly values of total intensity ΔF or vertical intensity ΔZ. Where raw data of surveys were not available, it was necessary to use values obtained by digitization of maps showing anomaly values. For surveys 10, 17, 18, 20, 22, 25, 30, and 31 (see Appendix 1) only maps scaled 1:100 000–1:5 000 000 were available. Even punch cards (surveys 1 and 6) and lists taken from publications (surveys 11–13, 16, 26, 28, and 29) were used to amass the most complete dataset.

Topographic elevation information was required to compile surveys measured on the ground and airborne surveys carried out at constant ground clearance. Mean values estimated from a map published by Schleusener (1959) were used for surveys 3–5, 11–13, 16, 26, and 28–30, and are given in Appendix 1. Additionally, mean topographic heights for the Finnish survey were published by Mikkola (1983). A dataset comprising the heights of Norway and parts of Sweden in a 1-km grid was purchased from the Norwegian Mapping Authority, while the British Geological Survey made available a detailed digital topographic dataset for Great Britain. For the Harz mountains area (Germany) a dataset comprising heights in a 70-m grid were given by the University of Clausthal-Zellerfeld, Germany.

Fig. 1 Total magnetic anomaly map for Northern, Western and Eastern Europe.

Appendix 1 also gives a list of the many reference fields used for the calculation of anomaly values. They vary from polynomials (e.g. BGR, 1976), presentations in a map form (e.g. György, 1966), special reference fields published in papers (e.g. Galdeano *et al.*, 1980), to global reference fields such as DGRF or IGRF.

A total of about 3 000 000 input magnetic data were used in this compilation.

Procedures for processing & merging the datasets

Figure 2 shows the calculation steps necessary to obtain anomaly values at a common altitude of 3000 m a.m.s.l. for the epoch 1980.0. As an example, the procedure used to compute anomaly values from the southern part of the German airborne survey at 1500 m a.m.s.l. and the epoch 1967.5 is shown.

Step 1: Values of total intensity F (1500 m 1967.5) are obtained by adding the 'old' reference field (quadratic

Table 1 The institutions listed below provided magnetic data for the compilation project

Country	Town	Institution	Contact
Austria	Vienna	Geologische Bundesanstalt	GATTINGER, T. & EICHBERGER, H.
	Vienna	Institut für Meteorologie und Geophysik der Universität Wien	GUTDEUTSCH, R. & SEIBERL, W.
Canada	Dartmouth	Geological Survey of Canada	MACNAB, R.
Denmark	Copenhagen	Danish Meteorological Institute	LAURIDSEN, E.K.
	Copenhagen	Geological Survey of Denmark	DINESEN, A. & HANSEN, C.F.
Finland	Espoo	Geological Survey of Finland	KORHONEN, J. & KORPELA, K.
France	Paris	Centre National de la Recherche Scientifique	
	Paris	Institut National d'Astronomie et de Géophysique	
	Paris	Institut de Physique du Globe	GALDEANO, A.
Former GDR	Berlin	Heinrich-Hertz-Institut für Atmosphärenforschung und Geomagnetismus	MUNDT, W.
	Leipzig	Geophysik GGD Leipzig	SCHEIBE, R. & LINDNER, H.
Germany	Hamburg	Deutsches Hydrographisches Institut	VOPPEL, D.
	Hannover	Bundesanstalt für Geowissenschaften und Rohstoffe	SENGPIEL, K.P. & BOSUM, W.
	Hannover	Institut für Geowissenschaftliche Gemeinschaftsaufgaben Hannover	PUCHER, R.
	Hannover	Niedersächsisches Landesamt für Bodenforschung	
	Clausthal-Zellerfeld	University of Clausthal-Zellerfeld	
Great Britain	Keyworth	British Geological Survey	LEE, M. & SMITH, I.F.
Ireland	Dublin	Geological Survey of Ireland	INAMDAR, D.
	Dublin	Petroleum Affairs Division	CROKER, P.
	Galway	National University of Ireland	MURPHY, C. & BROCK, A.
Luxembourg	Luxembourg	Service Géologique Luxembourg	BINTZ, J.
The Netherlands	Utrecht	University of Utrecht	COLLETTE, B.J.
Norway	Trondheim	Geological Survey of Norway	HÅBREKKE, H.
Poland	Warsaw	Polish Geological Institute	WYBRANIEC, S.
Sweden	Stockholm	Svenska Petroleum Exploration AB	LINDER, F. & STRÖM, R.G.
	Uppsala	Geological Survey of Sweden	BORG, K. & HOLDAR, B.
Switzerland	Zurich	Schweizerische Geophysikalische Kommission	KLINGELE, E.

TOTAL MAGNETIC ANOMALY MAP
Northern, Western and Eastern Europe
1 : 10,000,000

by Thomas Wonik, Klaus Trippler, Helmut Geipel, Siegfried Greinwald, Inna Pashkevich

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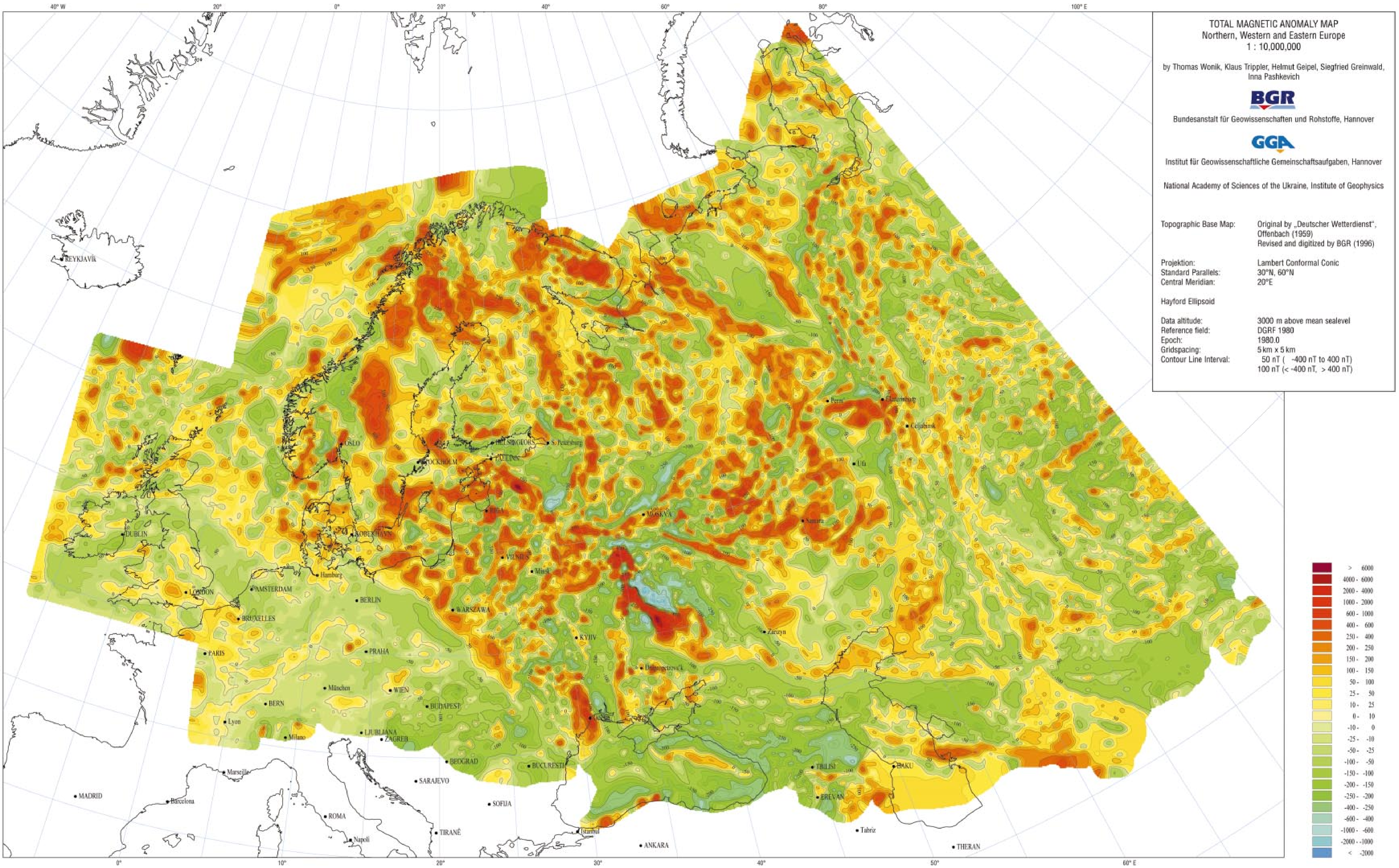
Topographic Base Map:	Original by „Deutscher Wetterdienst“, Offenbach (1959) Revised and digitized by BGR (1996)
Projektion:	Lambert Conformal Conic
Standard Parallels:	30°N, 60°N
Central Meridian:	20°E
Hayford Ellipsoid	
Data altitude:	3000 m above mean sealevel
Reference field:	DGRF 1980
Epoch:	1980.0
Gridspacing:	5 km x 5 km
Contour Line Interval:	50 nT (-400 nT to 400 nT) 100 nT (< -400 nT, > 400 nT)



anomaly values ΔF (1500 m; 1967.5)

Step 1 + reference field (1967.5)

F (1500 m; 1967.5)

Step 2 + secular variation (1980.0 - 1967.5)

F (1500 m; 1980.0)

Step 3 - DGRF 1980 (1500 m; 1980.0)

ΔF (1500 m; 1980.0)

Step 4 upward continuation
1500 m --> 3000 m

ΔF (3000 m; 1980.0)

Fig. 2 Procedure for converting anomaly values from the southern part of Germany to a common altitude of 3000 m a.m.s.l. and epoch 1980.0.

polynomial) used for producing the anomaly map (BGR, 1976) to the anomaly values of the map ΔF (1500 m, 1967.5).

Step 2: To transform the F-values to the epoch 1980.0, a representation of secular variation (here: 1967.5–1980.0) in the area under consideration is necessary.

Global reference fields describe the magnetic field and its secular variation across the Earth as a whole. The International Association of Geomagnetism and Aeronomy (IAGA) tries to consider the magnetic field variations by publishing a new model of the DGRF every five years (DGRF 1965, DGRF 1970,…). Because the focus here is Europe, it is obvious that data from geomagnetic observatories and repeat stations are more detailed and realistic than computed values from a global reference field model.

For the epochs 1965.0 and 1982.5, Wonik and Hahn (1988) compared the results of 10 Central European observatories (Golovkov *et al.*, 1983) and 78 repeat stations in Germany (Voppel and Wienert, 1974; Schulz *et al.*, 1997) and France (e.g. Gilbert and Le Mouel, 1984) with the field values computed from the reference fields DGRF 1980 and DGRF 1965 at these sites. The data from the observatories and repeat stations show a secular variation (1965.0–1982.5) of 475 nT for southern Germany and of 530 nT for northern Germany. The secular variation computed from the differences between DGRF 1980 and DGRF 1965 varies from 500 to 525 nT. A difference of about 30 nT (– 25 nT to + 5 nT) over a period of 17.5 years is observed between the results of the two methods of calculating secular variation within a distance of about 1000 km. Coles (1979) made similar investigations for Canada and obtained maximal errors of 50 nT yr^{-1} in secular variation for several reference fields.

Secular variations were estimated in this compilation by calculating a quadratic polynomial for the whole of Europe using geomagnetic observatory data (Golovkov *et al.*, 1983). Different quadratic polynomials are calculated for surveys referred to other epochs. These are based on the above-mentioned sources or the annual mean values published by the European geomagnetic observatories (e.g. IPGP, 1987).

Step 3: The Definitive Geomagnetic Reference Field 'DGRF 1980', altitude 1500 m, epoch 1980.0 (IAGA Division Working Group 1, 1985) is subtracted.

The determination of a reference core field is necessary, although somewhat arbitrary. This is because its spectrum partially overlaps the spectrum of the crustal field. Because sources in both the crust and core are unknown, the two components are impossible to separate and the shape of the magnetic anomalies depends on the reference field and its truncation level. It should be noted, however, that even the use of different DGRF models causes varying anomalies at the same location (Pucher and Wonik, 2001). Four reference fields were examined by Wonik (1990 and 1992): DGRF 1980, GSFC 12/83 (Langel and Estes, 1985), CAIN M051782 (Cain *et al.*, 1984) and CAIN M102089 (Cain *et al.*, 1989). The mean values of 31 European observatories were compared with the mean values calculated using the four reference field models for the same locations and epochs. The differences between these and the DGRF 1980 model proved to be minimal for Europe and therefore, DGRF 1980 was selected as the appropriate reference model.

Step 4: The anomalies ΔF (1500 m, 1980.0) are upward-continued to 3000 m using an algorithm published by Gibert and Galdeano (1985).

A comparison between Gibert and Galdeano (1985)'s algorithm and three further methods of upward continuation published by Hahn (1965), Hartmann (1963), and Rudman and Blakely (1975) results in only slight differences (Wonik, 1992) at grid margins. The algorithm of Gibert and Galdeano (1985) was chosen because of its ability to handle large datasets in one run, thus minimizing the amount of error at grid margins.

For those areas where measurements were carried out at constant ground clearance – as was the case in most parts of Norway, Finland, Sweden north of 66°N, Ireland, and Great Britain – the method published by Grauch (1984) and applied by Cordell and Grauch (1985) was used. The method is based on a Taylor series algorithm and allows the upward continuation of data measured on an irregular surface to a horizontal plain.

The topographic elevations in the Harz mountain area in Germany show differences between 250 m and 850 m a.m.s.l. Therefore, an airborne survey (survey 2 in Appendix 1) was conducted resulting in anomalies of total intensity at 50 m above the ground. These data were upward-continued to 3000 m using the algorithm of Gibert and Galdeano (1985) and assuming a mean altitude of the Harz mountains of 400 m. For comparison the same dataset was upward-continued to 3000 m using the Grauch (1984)'s algorithm. The resulting anomaly patterns clearly differ. The maximal difference in anomaly amplitude is about 15%, which cannot be ignored in terms of long-wavelength anomalies. Therefore, for the final dataset, the data measured at constant ground clearance were upward-continued using the Grauch's (1984) program.

Before upward-continuing the ΔF-data, the data were transformed onto a rectangular kilometric grid. The Lambert conformal conic projection with a central meridian of 20°N and standard parallels 30°N and 60°N was chosen. The projection allows a direct comparison between the magnetic anomalies and the International Tectonic Map of Europe (Bogdanov *et al.*, 1973). Data with Gauss–Krüger or UTM co-ordinates were first transformed into geographical co-ordinates using an algorithm published by Grossmann (1964), and those with Swiss rectangular kilometric co-ordinates were converted into geographical co-ordinates using Bolliger (1967). These geographical co-ordinates were then transformed into Lambert co-ordinates using Snyder (1987).

All data were gridded using the UNIRAS interpolation subroutine GINTP1. The grid spacing was adjusted to the respective profile spacing and varied between 0.2 km and 10 km.

The map: production and precision

The final dataset is gridded at 5 km and presented at a scale of 1:20 400 000 (see flyout). The final grid comprises a 1351 × 891 matrix 58% filled with data and with a mean value of 16 ± 176 nT. The values vary between – 1689 nT and 8036 nT.

The grid node distance of 5 km corresponds to 0.5 mm on the map. Contouring and shading was performed with the subroutines GCRN2V and GCRN2S. The contour interval is 50 nT. However, below – 400 nT and above + 400 nT the interval is 100 nT. The 27-colour scale is quasi-logarithmic to show anomalies in areas without strong gradients.

About 70% of the final processed anomalies meet the requirement that the values of two adjoining surveys differ by less than 10 nT in the overlapping area. For some parts of the compiled area, errors increase but they do not exceed 20 nT. This decrease in precision occurs for the following reasons.

- Seven datasets comprise surveys with only wide-spaced profiles or large data spacings. Aeromagnetic data measured on profiles 35 km apart had to be used for Central and Southern Sweden (survey 24). The shipborne survey of the Dutch North Sea (14) was carried out with a profile spacing of 20 km. For Belgium, the former Czechoslovakia,Hungary, The Netherlands, and Romania, only irregularly distributed ground measurements with mean data spacings of about 6–20 km measurements were available.
- For some parts of Belgium, the former Czechoslovakia, small parts of Western Germany (surveys 3–5), Hungary, The Netherlands, and Romania no topographic elevation data were available. Mean altitudes had to be estimated, which cause a decrease in precision, especially in areas with higher gradients in elevation.
- The airborne data for onshore and offshore Denmark (surveys 17 and 18, acquired in 1963) were obtained with a fluxgate magnetometer, which in 1963 measured only relative values and showed large drifts. Results from a ground survey (survey 16) could be used to adjust and to improve the precision of these data.
- The datasets available for Eastern Germany, Great Britain, Ireland, Poland, and the former USSR (27, 32–36) are already amalgamations of various surveys conducted for only parts of the respective country. These surveys vary in their parameters like epoch, profile spacing, and altitude. The processing methods used for the compilation of these surveys are partly unknown and possible distortions in terms of long-wavelength anomalies cannot be eliminated.

Owing to the great heterogeneity of the datasets, not all parts of the compilation reach its aim of resolving the long-wavelength component of the magnetic field. The data presented for Austria, Finland, France, Germany, Luxembourg, Norway, Northern Fennoscandia, and Switzerland are of best quality in terms of long wavelength anomaly detection. Such anomalies with amplitudes smaller than 10 nT should be detected in this area. However, distortions inherent in the datasets from Belgium, the former Czechoslovakia, Hungary, The Netherlands, and Romania lead to a decrease in data precision to 20 nT. All of the other datasets not mentioned are of medium quality.

Interpretation of the magnetic anomalies

The map contains a wealth of information useful to geoscientists studying global tectonic processes and the deep crustal composition of major continental cratons.

This compilation enables comparison between the nature of the anomalous magnetic field and geological mega-structures. It will benefit international projects such as EUROPROBE and their subprojects TESZ, Uralides, and Eurobridge or the Palaeozoic Amalgamation of Central Europe (PACE network), in that it may lead to a better understanding of amalgamation processes of terranes to the East European Craton and the structure and evolution of the Uralide orogen.

A lot of studies have revealed the good correlation between magnetic anomalies and tectonic structures on a regional scale. The results of these studies are not repeated here, but the most important are:

- for the crystalline rocks of Scandinavia: Henkel *et al.* (1986, 1990), Eriksson and Henkel (1980) and Riddihough (1972);
- for The East European Platform: Bogdanova *et al.* (1996), Orlyuk and Pashkevich (1996), and Pashkevich *et al.* 1990, 1997);
- for the Palaeozoic platform of Central Europe: Bosum and Wonik (1991); and
- for the Trans-European Suture Zone between the Palaeozoic platform of Central Europe and the Precambrian platform of Eastern Europe: Dabrowski *et al.* (1984), Pashkevich *et al.* (1989), Grabowska and Dolnicki (1994), and Thybo *et al.* (1999).

Wonik (1992) interpreted European magnetic anomalies by considering lateral changes of magnetization. He used an algorithm introduced by Hahn (1965 and 1985) that computes the distribution of magnetization in a horizontal plate by means of 2D Fourier analysis. He was able to predict differences between the Precambrian and Palaeozoic crust within Europe. The product ‘magnetization (A/m) times thickness of the crust (km)’ is on average 80 kA for the Precambrian and 35 kA for the Palaeozoic crust.

Assuming that magnetic sources are only present in that part of the crust between the Moho and the undeformed sediments, we determined a mean thickness and magnetization for the Precambrian and Palaeozoic Europe. The results indicate a mean thickness of 40 km for the magnetized crust with a mean magnetization of 2.0 A/m for the Precambrian vs. 23 km and 1.5 A/m for the Palaeozoic Europe. For the Precambrian crust rock magnetic investigations by Krutikhovskaya *et al.* (1980) show a great variability in magnetization between 0 and 4 A/m. Moho depths and thickness of the undeformed sediments are taken from Hurtig *et al.* (1992). The difference in magnetic anomaly pattern between Eastern and Central Europe can therefore be explained by a variable crustal thickness and magnetization.

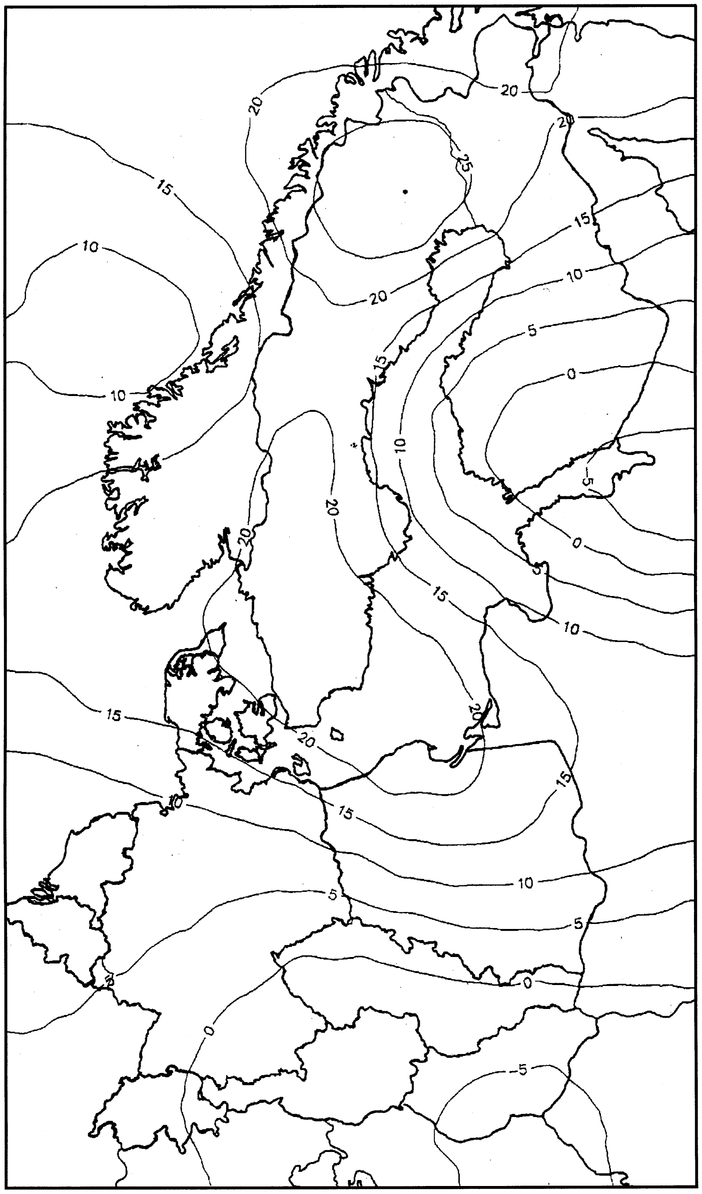


Fig. 3 Anomalies of total intensity in Central Europe from MAGSAT data at 360 km a.m.s.l. Reference field: CAIN M102089 (Cain *et al.*, 1989), degree and order 1–14; epoch 1980.0. Numerical values in nT.

Comparison of magnetic anomalies between the 'low-level' compilation & MAGSAT data

A number of magnetic anomaly maps for Europe produced from the MAGSAT satellite data (*c.* 360–500 km altitude) were published by various investigators: Coles *et al.* (1982), Cain *et al.* (1984), De Santis *et al.* (1989), Wendorff (1990), Nolte and Hahn (1992), Arkani-Hamed *et al.* (1994), and Taylor and Ravat (1995). The maps differ slightly in the shape and amplitude of the main European anomaly caused by the different magnetic properties of the Palaeozoic and Precambrian crust. They all show a maximum for Northern Europe (Central Sweden) and a minimum for Central Europe (Southern Germany). The amplitude of this anomaly is 10–20 nT in all of the above-mentioned maps. As an example the map by Nolte and Hahn (1992) is presented in Fig. 3.

A comparison between the MAGSAT-based maps and an earlier version of the low-level compilation presented in this paper is given by Wonik (1992). He upward-continued the 3000 m-data to 360 km using the algorithm by Grauch (1984), which accounts for the Earth's curvature (Fig. 4). The dimension of the field sector was 2900 km in the N–S direction and 1720 km in the E–W direction. The shape of the European anomaly caused by the differences of the Palaeozoic and Precambrian crust in both datasets coincides. However, they differ in anomaly amplitude where it is 45 nT in the map based on low-level data. Similar observations were made by Pashkevich and Orlyuk (1997) for the Precambrian crust. Arkani-Hamed and Hinze (1990) who compared MAGSAT anomalies and upward-continued aeromagnetic anomalies from North America obtained a maximal anomaly amplitude of 23 nT from the MAGSAT data and 33 nT for the low-level data. Furthermore, peak positions of matching anomalies did not always coincide and many anomalies were detectable in only one of the maps.

The difference in anomaly amplitude in Europe (10–20 nT vs. 45 nT), both at 360 km altitude, may be explained by some or all of the following:

- electromagnetic fields of ionospheric currents are present at an

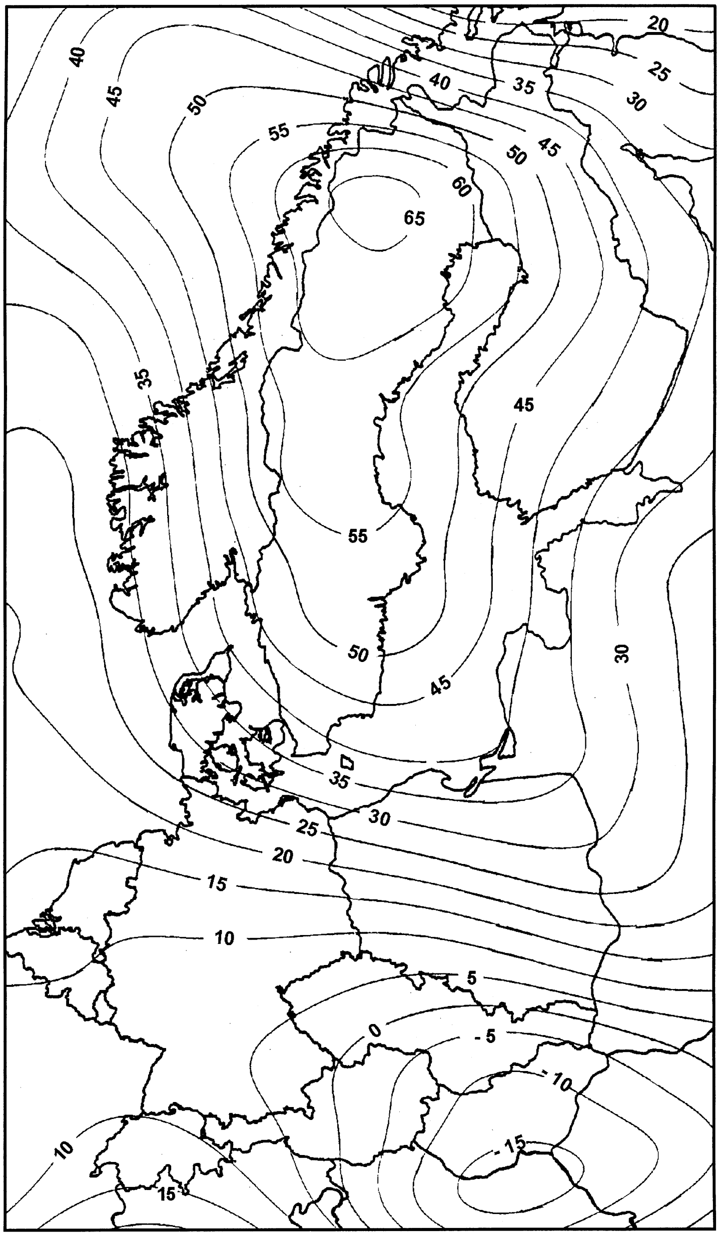


Fig. 4 Anomalies of total intensity in Central Europe at 360 km a.m.s.l. based on the compilation of 'low-level' data. The 3000-m data were upward-continued to 360 km using the algorithm by Grauch (1984). Reference field: DGRF1980 (IAGA Division 1 Working Group 1, 1985), degree and order: 10; epoch 1980.0. Numerical values in nT.

altitude of *c.* 100–280 km. The effect of this on MAGSAT data quality is difficult to approximate (Yanagisawa and Kono, 1985), and so, is not considered in the above-mentioned MAGSAT based anomaly maps.

- anomalies with wavelengths longer than the upward-continued sector (2900 × 1720 km) are not included in the upward-continued data, while the MAGSAT based maps contain this component of the magnetic field.
- Long-wavelength anomalies are strongly effected by core field components that have not been completely removed from the European dataset. It should be noted, that the MAGSAT anomaly maps and the low-level compilation do not include anomalies with wavelengths longer than *c.* 4000 km, because these are eliminated while correcting for the magnetic field of the Earth's core (e.g. DGRF 1980, degree and order 1–10).

These differences between the amplitudes of anomalies at an altitude of *c.* 360 km derived from MAGSAT data and that from upward-continued low-level data in Europe also have an effect on the interpretation of MAGSAT data. Nolte and Hahn (1992), Taylor and Ravat (1995), and Pucher and Wonik (1998) computed model bodies based solely on MAGSAT anomalies. Therefore, the computed lateral changes of magnetization or the thickness of magnetic layers are much smaller than they would if derived from model calculations based on low-level data.

Conclusions

Approximately 3×10^6 magnetic data for Northern, Western, and Eastern Europe were compiled and displayed in a 1:20 400 000 scale map. Detailed processing was applied to present the map showing magnetic anomalies of total intensity at an altitude of 3000 m a.m.s.l. Secular variations in respect to the common epoch 1980.0 were estimated by using measurements recorded at European geomagnetic observatories. The global reference field, DGRF 1980 was then used to eliminate the effect of the Earth's core magnetic field from all data.

The procedure provides the opportunity to view the longer wavelength anomalies ($>$ 300 km) evident in the data. However, these long-wavelength anomalies are contaminated partly by the great heterogeneity of the original data.

The compiled magnetic data enable us to calculate differences in the magnetic properties of the Precambrian and Palaeozoic crust within Europe. The mean thickness of the magnetized crust and the mean magnetization for Precambrian and Palaeozoic Europe are: 40 km and 2.0 A/m vs. 23 km and 1.5 A/m.

The compiled data were upward-continued to 360 km and compared with the MAGSAT-based maps for Europe. The shape of the anomalies, especially the anomaly caused by the two different crust types, coincides in both datasets. However, they differ in anomaly amplitude by a factor of *c.* 3. This may be caused by interference resulting from electromagnetic fields induced by ionospheric fields not corrected in the MAGSAT data. Other factors that may account for this are removal of the very long wavelength component in the compilation of the low-level data. Whatever the cause, this difference in anomaly amplitude may lead to misinterpretation of the satellite data, suggesting that the low level data compilation is more suited for determining the causes of the long wavelength anomalies across Europe.

The compilation presents another piece in the jigsaw of the still incomplete magnetic anomaly map of the world. Such a map will help resolve uncertainties about the early histories of opening of continents and the processes involved in the accretion of terranes. The magnetic anomalies will help provide new constraints on the pre-drift plate configurations and break-up motions. The geometry and timing of these events are a key to understanding the processes that shape the passive continental margins, their sedimentary basins and their related economic potential.

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Appendix 1 Available magnetic datasets and their parameters

Ref. no.	Survey	Coordinates central meridian	Height (m) a.m.s.l.	Epoch	Profile/ (data) spacing (km)	Grid (km)	Available data map scale	Reference field (height; epoch)
1	Western Germany	Gauss–Krüger 9°E	700/1000/1500	1967.5	2.2 (N–S) 11.0 (E–W)	2.2 × 2.2	56 700 ΔF-values	quadratic polynomial
2	Harz Mountains	Gauss–Krüger 9°E	50 above ground	1983.9	0.2 (N–S)	on profiles	195 400 ΔF-values	IGRF 1980 (0 m;1983.9)
3	Eichsfeld	geogr.	ground [250]	1987.8	1.0 (N–S) 1.0 (E–W)		1000 stations F	
4	Tirschenreuth	Gauss–Krüger 9°E	50 above ground [615]	1977.3	0.3 (N–S)	on profiles	84 300 ΔF-values	IGRF 1975 (0 m;1977.3)
5	Pfalz	geogr.	ground [550]	1985.9	1.0 (N–S) 1.0 (E–W)		800 stations F	
6	Western Austria	Gauss–Krüger 12°E	3000/4000	1977.5	2.2 (N–S) 11.0 (E–W)	2.2 × 2.2	5500 ΔF-values	linear polynomial
7	Eastern Austria	Gauss–Krüger 13°20′E	various	1978.0	2.0 (N–S)	2.2 × 2.2	19 000 F-values	
8	Switzerland north of Alps	Swiss rectangular kilometric	1829	1980.5	5.0 (N–S) 20.0 (E–W)	on profiles	86 000 F-values	
8	Switzerland Ticino	Swiss rectangular kilometric	3000	1981.5	5.0 (N–S) 20.0 (E–W)	on profiles	6500 F-values	
8	Switzerland entire country	Swiss rectangular kilometric	5000	1981.5	5.0 (N–S) 20.0 (E–W)	on profiles	160 000 F-values	
9	Eastern France	Lambert France II	3000	1964.5	10.0 (N–S) 100.0 (E–W)	1 × 10	33 400 ΔF-values	quadratic polynomial
10	Luxembourg	Gauss–Krüger 6°E	1000	1967.5	2.2 (N–S) 11.0 (E–W)	2.2 × 2.2	800 ΔF-values 1:100 000	quadratic polynomial
11	Belgium	geogr.	ground [200]	1960.5	irregularly distributed (6.6)		700 stations F	
12	Brabant Massif	Gauss–Krüger 6°E	ground [20]	1979.0	irregularly distributed (2.2)		500 stations F	
13	The Netherlands	geogr.	ground [20]	1945.0	irregularly distributed (11.2)		320 stations H, Z	
14	Dutch North Sea	geogr.	sea	1980.0	20.0 (N–S)	on profiles	35 000 ΔF-values	IGRF 1980 (0 m;1980.0)
15	North Sea	Gauss–Krüger 9°E	sea	1960.5	irregularly distributed	10 × 10	400 F-values 1:250 000	
16	Denmark	geogr.	ground [20]	1975.5 1980.0	irregularly distributed (8.5)		600 stations F	
17	Denmark	geogr.	760	1963.0	3/6 (N–S) 6.0 (E–W)	5′ × 6′	2200 F-values (fluxgate magnetometer) 1:100 000	
18	Danish North Sea	geogr.	300	1963.0	3.0 (E–W)	3′ × 5′	2800 F-values (fluxgate magnetometer) 1:200 000	
19	Norway	UTM 32°E	various	1965.0	various	1 × 1	670 600 F-values	DGRF 1965 (0 m;1965.0)
20	Offshore Norway	geogr.	180	1965.0	5.0 (N–S) 50.0 (E–W)	15 × 15	1800 ΔF-values 1:1 500 000	IGRF 1965 (180m;1965.0)
21	Northern Fennoscandia	Lambert 18°E	various	1965.0	various	1 × 1	90 500 F-values	DGRF 1965 (0 m;1965.0)
22	Offshore southern Sweden	geogr.	600	1970.5	1;2;4	2′ × 4′	3700 ΔF-values 1:200 000	IGRF 1965 (600m;1970.5)
23	Finland	gauss–Krüger 27°E	150 above ground	1965.0	0.4 (N–S)	2.5 × 2.5	65 700 F-values	DGRF 1965 (0 m;1965.0)
24	Scandinavia	geogr.	3000	1965.0	35.0 (NW–SE)		9600 F-values	
25	Offshore Norway	geogr.	300	1965.0	18.0 (E–W)		1250 ΔF-values 1:5 000 000	(Hurwitz *et al.* 1966)
26	Eastern Germany	geogr.	ground [250]	1957.5	irregularly distributed (7.9)		1750 stations F	
27	Eastern Germany	Gauss–Krüger 12°E	ground/100 above ground	various	various	1 × 1	160 000 ΔF-values	various
28	Former Czechoslovakia	geogr.	ground [700]	1958.0	irregularly distributed (20.9)		300 stations F	
29	Former Czechoslovakia	geogr.	ground [700]	1967.5	irregularly distributed (32.6)		120 stations F	
30	Hungary	geogr.	ground [150]	1950.0	irregularly distributed		3800 ΔZ–values 1:500 000	(György, 1966)
31	Romania	geogr.	ground [300]	1967.5	irregularly distributed		4600 ΔZ–values 1:1 000 000	quadratic polynomial
32	Poland	geogr.	500 above ground	1980.0	various	5 × 5	13 000 ΔF-values	IGRF1980 (0m;1980.0)
33	Offshore Ireland	geogr.	305 above ground	1990.0	various	2 × 2	35 000 ΔF-values	IGRF1990 (0m;1990.0)
34	Onshore Ireland	geogr.	305 above ground	1990.0	various	2 × 2	25 000 ΔF-values	IGRF1990 (0m;1990.0)
35	United Kingdom	geogr.	305 above ground	1990.0	0.4 – 2.0	2 × 2	250 000 ΔF-values	IGRF1990 (0m;1990.0)
36	Former USSR	geogr.	various	1965.0	various	3′ × 3′	500 000 ΔF-values	various

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