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Geophysical investigations in Southern Italian active volcanic regions

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Abstract: As part of the European Community project „TOMAVE" and the Italian national project *"Aeromagnetic Study of the Neapolitan Volcanic Area"*, airborne geophysical measurements were carried out in active volcanic regions in Italy, namely on Mt.Vesuvio and on the islands of Vulcano and Lipari. In this paper results of magnetic and gamma ray measurements are presented, including some first results of modelling of anomalous magnetic regions. Moreover, differences in the anomalous magnetic field of the campaign 1999 at Vulcano Island to a previous mapping, done 15 years ago by AGIP, were calculated to get an idea of the change of the magnetic field with time in that area.

1. Introduction

Southern Italy is characterised by several active volcanic regions like Mt. Vesuvio, Campi Flegrei, Etna and the Eolian Islands. Some of them are surrounded by some of the most densely populated areas in Europe like Napoli and Catania. Therefore it is very important to understand the structural and geological settings of these areas in view of possible hazards in the future.

In the frame of the European Community project TOMAVE (ENV4-CT-98-0697; Supper and Seiberl, 2000), different potential field methods were applied to investigate the physical structure of the volcanic areas, including airborne magnetics, VLF and gamma ray mapping at Mt. Vesuvio, Campi Flegrei and on the Islands of Vulcano and Lipari (Fig. 1). The corresponding airborne and ground geophysical (geoelectric and magnetic) measurements were carried out between 1998 and 2000. Within this paper mainly results of the airborne research program will be discussed.

The purpose of the airborne surveys was to map the geophysical anomaly structures of these areas from a regional point of view and to correlate them, including other potential field data, with recent volcanic activities to find significant geophysical anomaly patterns caused by these activities. Moreover these data sets should provide a basis for future research activities including volcanic hazard monitoring. Also a

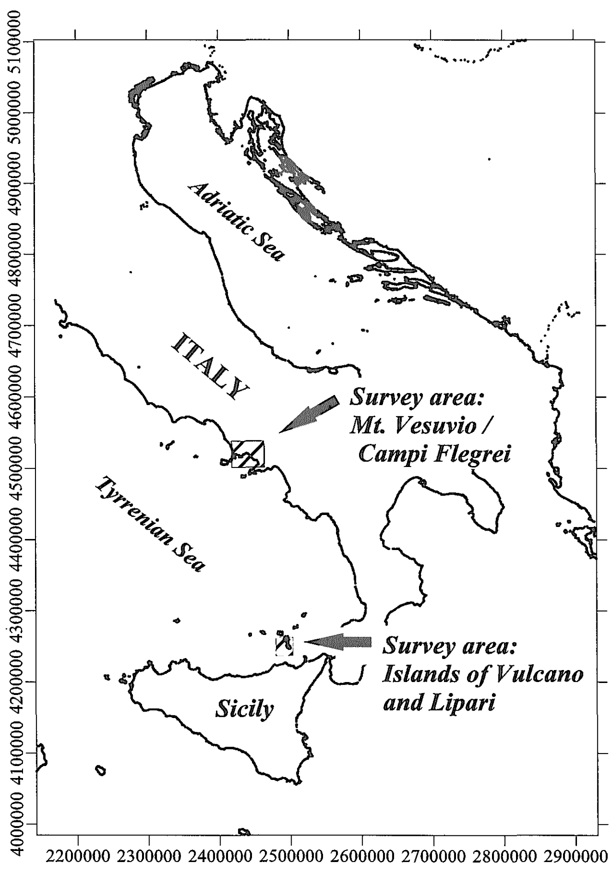

Fig. 1 Geographic overview showing the location of airborne survey areas in Italy.

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trial marine magnetic survey was carried out near the Island of Vulcano in June 1999.

In spring 2000 gravity measurements were carried out along the same profiles, covered in 1999 by geoelectrics and magnetics on the Island of Vulcano in the frame of an international co-operation with Japanese geophysicists from the Geological Survey of Japan.

2. The Airborne System

The measurements were done using an Ecureuil 350 helicopter rented from a local company.

Navigation and Flight Path Recording

The coordinates of the flight lines were recorded using a Global Positioning System (ASHTECH-GPS/GLONAS). This system was supplemented by an infrared video camera, which records the surface signature on videotape along the profile path. Unfortunately, due to an unknown and unidentifiable noise, positioning with GPS was not possible in a large area to the west of Mt. Vesuvio. In this case the recordings from the infrared camera had to be used to reconstruct the flight paths via topographic maps. This caused much more work during data processing and delayed the production of the final maps. This noise has also hampered the planned detailed survey of the central part of Mt. Vesuvio (planned line spacing 300 m).

Magnetic Measurements

For magnetic measurements an optically pumped magnetometer (Scintrex CS-2) was used. The recording rate of the instrument was 10 samples per second.

The magnetic sensor was fixed in a shell, which was dragged 30 m below the helicopter.

Gamma Ray Measurements

Due to the small helicopter used for the measurements in Italy, only one single NaI crystal (4.4 liters) was used. The crystal detectors were placed inside the helicopter itself. The energy of the gamma radiation is measured using a spectrometer with 256 channels to provide spectral data in the range from 0.4 to 3.0 MeV (channels 1-255). Channel 256 is used to record the cosmic background radiation (3.0 to 6.0 MeV). Usually the energy windows of potassium, uranium and thorium are considered in the interpretation of data. Since there were no calibration facilities available, no equivalent geochemical concentrations were calculated.

As only one NaI crystal was used in these airborne surveys only relative low countrates were recorded. To improve the performance of the system, different window settings for uranium and thorium were used in comparision to the usual published energy ranges (e.g.: In the uranium-window, the Bi-214 peak at 2.2 MeV was also included). In Figs. 2a and 2b, these three windows are marked.

To demonstrate the major differences in the geochemical distribution of the above mentioned three radioactive isotopes between the research areas, averaged sum spectra of the Mt. Vesuvio area (23500 single spectra) and of the Vulcano area (2500 single

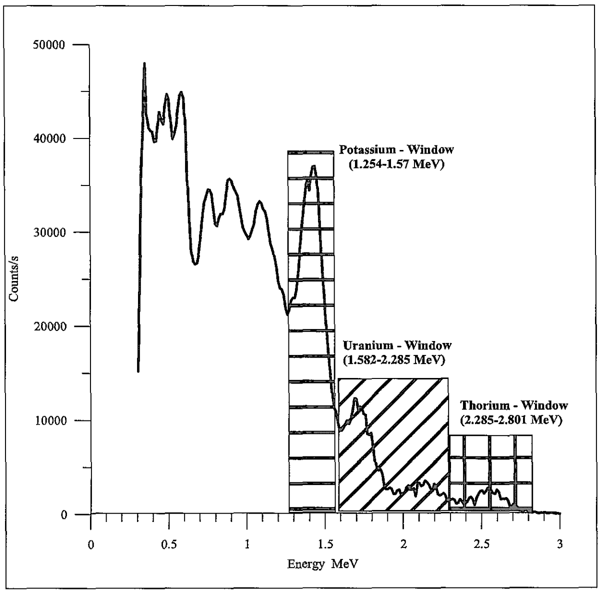

Fig. 2a Summarised gamma ray spectrum (23500 single spectra) after Compton correction from the Mt. Vesuvio area; rectangles indicate energy windows used for data processing;

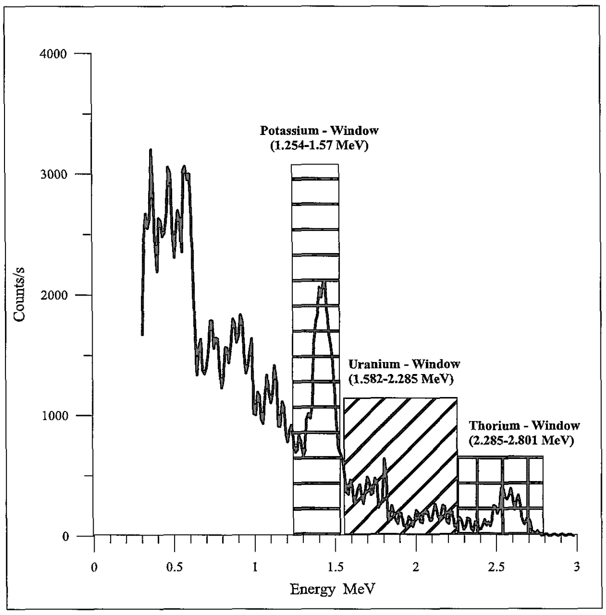

Fig. 2b Summarised gamma ray spectrum (2500 single spectra) after Compton correction from the island of Vulcano; rectangles indicate energy windows used for data processing;

spectra) are shown in Figs. 2a and 2b, respectively. Most striking is the relative high uranium-concentration in the top soils of the Mt.Vesuvio area in comparison to that one on the Island of Vulcano. Also the potassium concentration is somewhat higher at Mt. Vesuvio, whereas the thorium distribution is rather similar in both survey areas.

VLF Measurements

The so-called VLF method (Very Low Frequency) was used as a supplementary method. The VLF method is based on observations of electromagnetic fields in a frequency range of 15-30 kHz transmitted for communication with submarines. The passive receiver coils, contained in small shells, were dragged along 20 m below the helicopter. The results are used to delineate electrical conductive bodies. An installation useful for the VLF method is the "Gradiometer" configuration. Thereby two sensors are towed along at a vertical distance of 2 to 3 m, increasing the resolution of the data. As the VLF-signals were too low (transmitter too far away, high cultural noise), no meaningful data were recorded.

Ground Equipment

The ground equipment consisted of a GPS reference station and a variometer recording the earth magnetic field during the survey flights. Due to the large cultural noise near the base station for the flights on Mt. Vesuvio, data from the magnetic observatory at L'Aquilla were used in this case.

3. Airborne Measurements on Mt. Vesuvio

In the Mt.Vesuvio area, 31 profiles in north-south direction, 8 tie-lines in east-west direction and one profile following the geoelectric profiles measured in 1998, were surveyed. Profile separation was approximately 600 m. As already mentioned above, no positioning with GPS was possible in an area to the west of the volcano itself.

3.1 Results of Magnetic Measurements

After applying corrections for daily variation, IGRF and heading error and adjusting some minor mismatch of adjacent profiles (micro levelling) a map of magnetic data, reduced to the pole, was produced (Fig. 3).

The magnetic anomaly map is dominated by the large anomaly of Mt. Vesuvio with an amplitude of about 2000 nT. Only small anomalies of maximum 100 nT exist in its vicinity, except the one near Pompeii with an amplitude of 250 nT and a southern minimum. This anomaly probably indicates remanent magnetization. Due to the high number of anthropogenic magnetic sources, the data in the densely populated area around the volcano is rather noisy. It is difficult to distinguish here between cultural noises and anomalies caused by geologic sources.

A double minimum can be recognised in the mountainous area of Mt.Vesuvio: a large magnetic low can be observed in the north of the Mt. Somma complex, which is overlapped by a smaller minimum in the Valle dell Gigante.

In the south of the cone, a smaller minimum/maximum structure strikes WNW-ESE, parallel to the coastline. This anomaly could be correlated with a fault zone known from seismic surveys (Bruno, 1998). Surprisingly, the expected NE-SW and NW-SE regional fault system is not clearly visible.

The general anomaly pattern shows a rather concentric anomaly spread around the Mt. Vesuvio cone. More detailed information can be obtained looking directly into the profile data. The mountainous area shows multiple maxima and minima that are not so apparent in the gridded plot. These anomalies could be interpreted further in more detail.

3.2 Radiometric Results

Processing of gamma ray measurements was already described above. Once again it should be mentioned that only one NaI crystal was used in the instrument and only flight altitudes of minimum 150 m were possible in densely populated areas. Due to these circumstances very low count rates were recorded.

Fig. 4 a-d shows the results of the gamma ray mapping. Around the summit of the volcano a large anomaly can be realised due to the outcrop of recent lava. Moreover a lineament anomaly of low amplitude exists reaching from the summit towards ESE. The thorium content is very low, showing no prominent anomaly in the Vesuvian area except one low on the eastern flank. Interpretation of this data is in work in co-operation with rock physicists.

4. Measurements over the Islands of Vulcano and Lipari

At the Eolean Islands, 19 profiles were measured covering the Island of Vulcano, the western part of Lipari and the submerged western flank of Lipari. The separation of flight lines was 250 m.

Fig. 5 shows the results of the aeromagnetic survey after applying corrections for main field (IGRF80), heading error, daily variations and micro levelling. The data has been reduced to the pole. The anomaly pattern shows many different anomalies which may be targets for further interpretation. Here only the main features will be discussed. Several magnetic maxima can be recognised in the western part of Vulcano.

The region of Piano shows a large NW-SE trending structure correlating partly with topographic

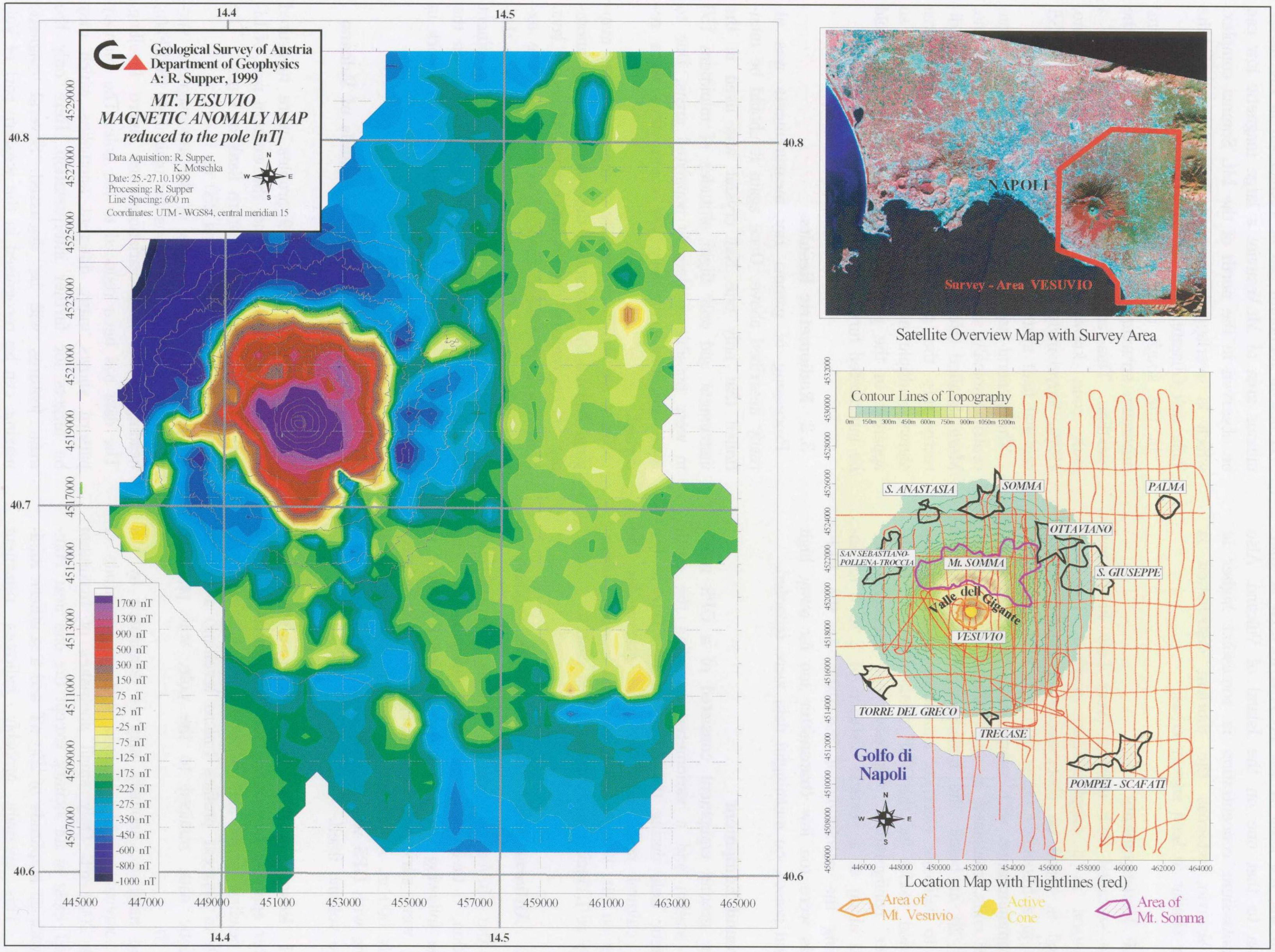

Fig. 3 Airborne magnetic map of Mt. Vesuvio; Right up: Overview of region; Right down: Location Map with flight lines (red).

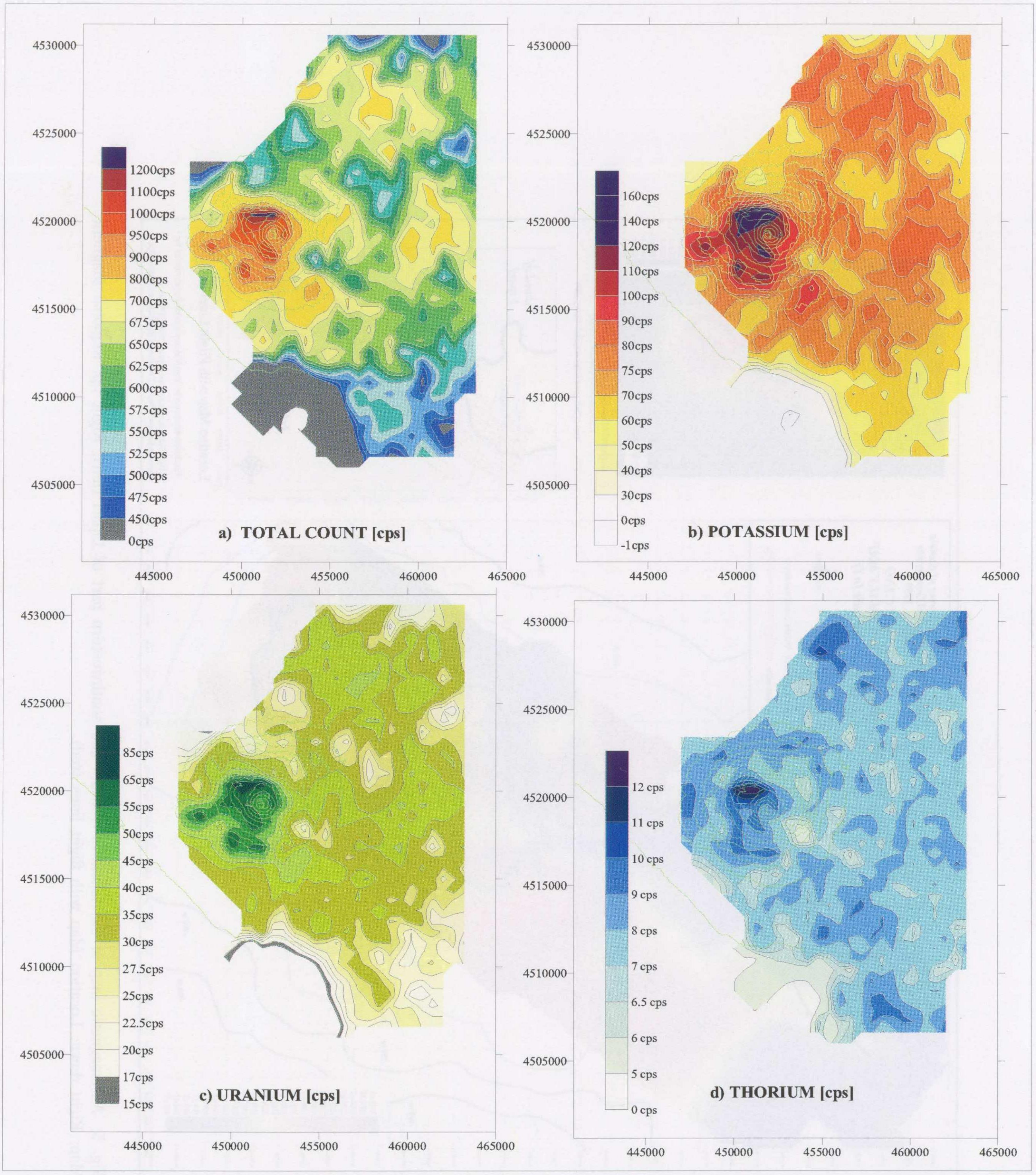

Fig. 4 Results of airborne gamma ray mapping [in counts per second = cps] at Mt. Vesuvio showing total count (a) as well as Potassium (b) Uranium (c) and Thorium (d) count rates distribution. The topography is shown with faint green lines.

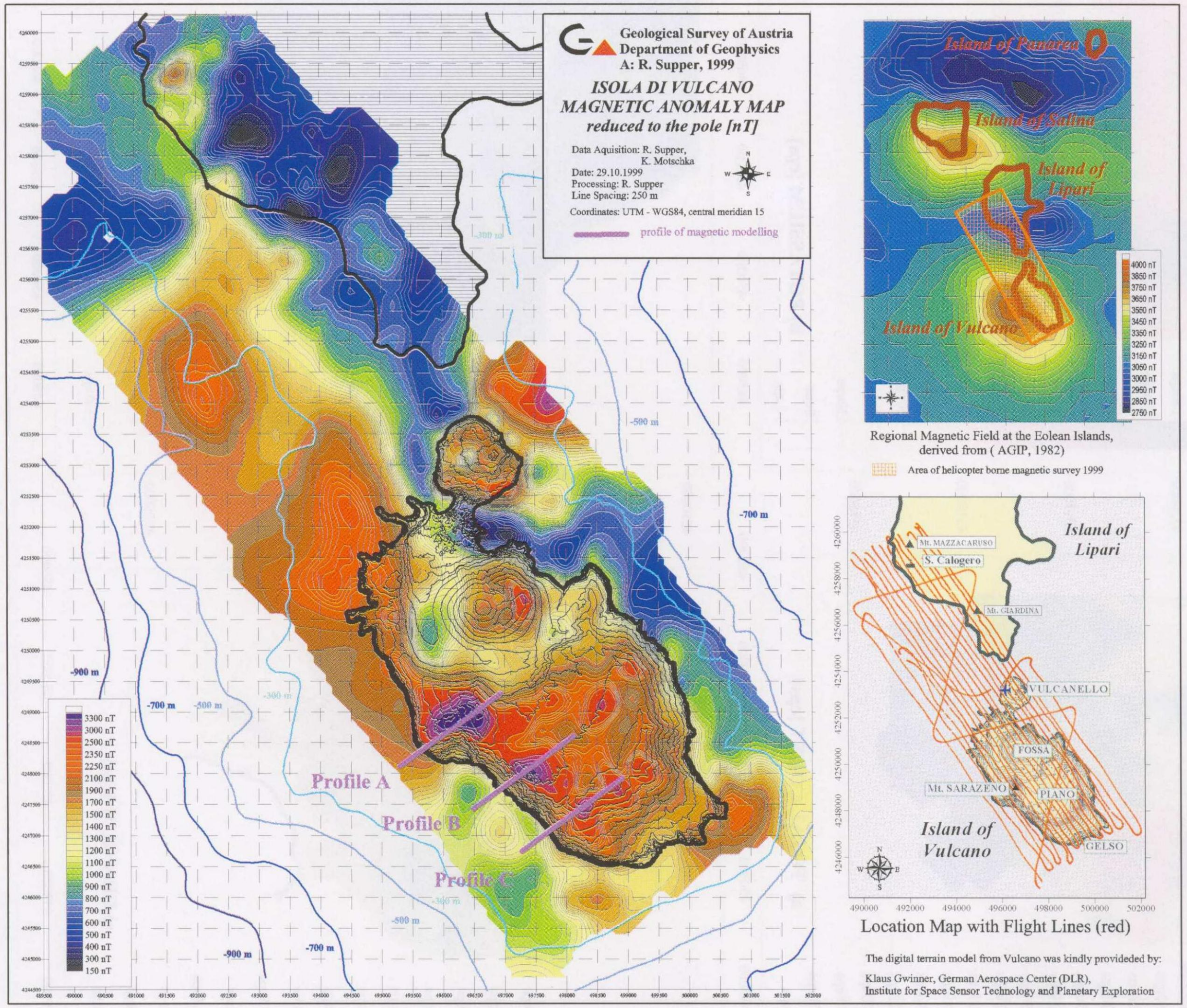

Fig. 5 Aeromagnetic map of the Island of Vulcano and southwestern part of Lipari (left); Right up: Regional Magnetic Map; Right down: Location Map with flight lines (red).

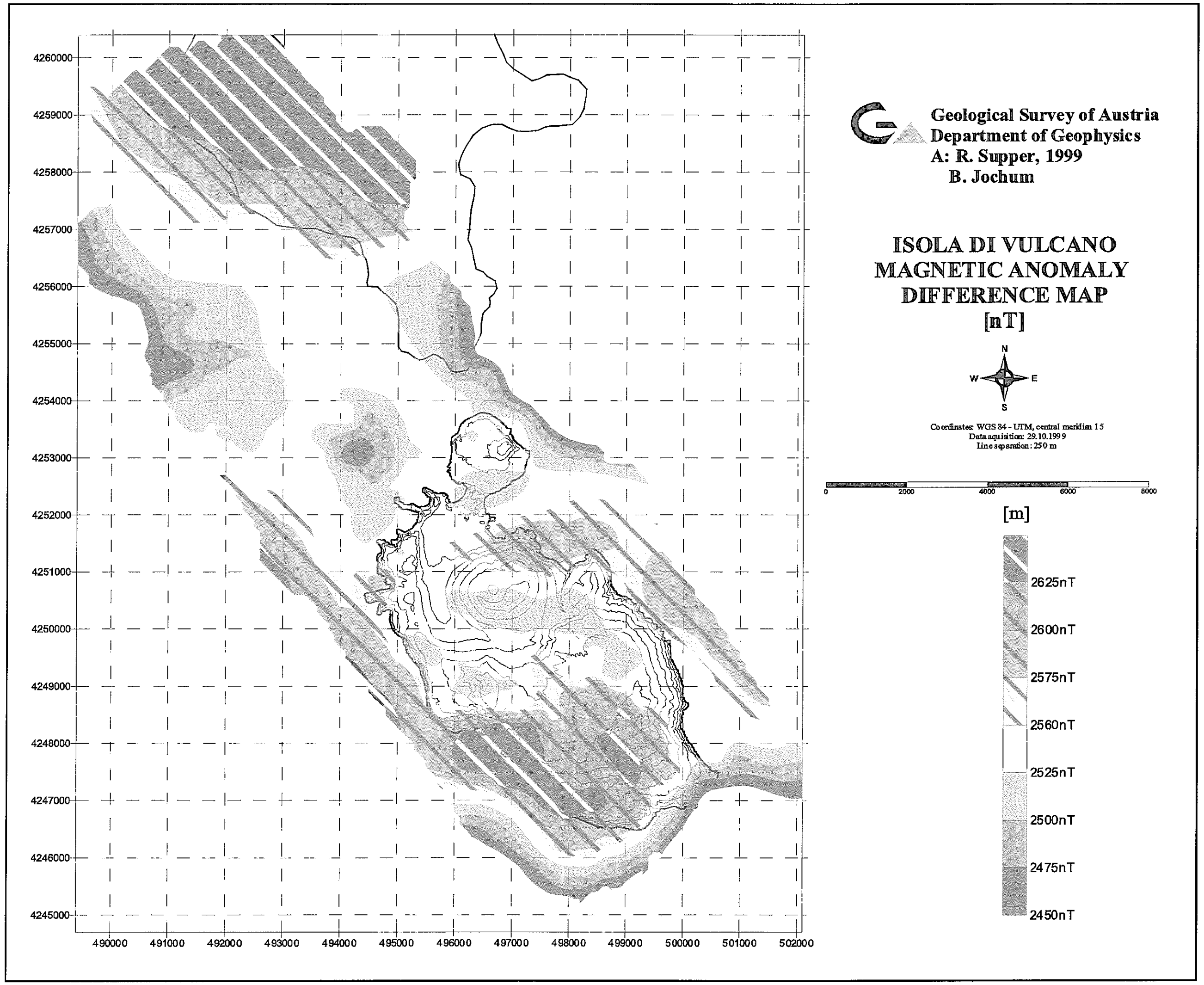

Fig. 6 Differences in the magnetic anomaly field between the AGIP survey (Barberi, 1994) and the 1999 survey (upward continued to 900m).

heights of Vulcano (e.g. Mt. Sarazeno). Also, three smaller anomalies can be seen off the shoreline to the south of Vulcano.

The caldera of Fossa shows a minimum halo structure with a maximum at the eastern rim of the crater.

Two large anomalies can be observed towards northwest in the open sea. The one further to the north correlates with a known active volcanic zone. This magnetic structure extends further north to the S. Calogero geothermal area on the Island of Lipari, showing some smaller anomalies like the one at an ancient crater near Mt. Mazzacaruso. A second anomaly in the southern part of Lipari corresponds with Fossa di M. Giardina.

Another anomaly structure can be seen on the southern flank of Vulcanello and in the sea to the northeast of it.

One might expect that due to the geodynamics of this area, corresponding changes of the magnetic anomaly pattern may occur with time. Therefore data from previous airborne measurements by AGIP (Barberi, 1994), measured in 1985, were digitised. To compare the two data sets, the new data set obtained in 1999 was upward continued to 900 m altitude as the average flight altitude in the AGIP survey was 1000 m a.s.l. Thereafter, the new data was subtracted from the AGIP data (Fig. 6).

A decrease of the magnetic field during this 15 year period can be recognised in the Piano area on Vulcano and in the NW-part of Lipari, whereas in the central area a general increase in the magnetic field can be observed along a NW-SE striking structure. As the survey lines were not the same in both surveys and measurements were carried out at different altitudes, one has to be careful in looking into this result. Despite of this fact, changes of the magnetic field may be monitored for further structural investigations. But, in our mind, detailed information can only be derived if the survey is done on nearly the same profiles and at the same altitude. So further investigations are needed to verify time dependent changes in the magnetic field caused by a change in volcanic activity in that region.

Additionally marine magnetic measurements were conducted in the West of Vulcano. Three profiles were selected (location see Fig. 5) to investigate a magnetic structure in the SW of Vulcano using two-dimensional (2D) modelling. Profile A was chosen to pass a deep drilling site for calibration purpose. This drilling is situated at the foot of the south flank of the "Fossa di Vulcano" crater and reached a depth of about 2200 m b.s.l. at maximum.

Because of the rough topography on Vulcano and strong variations of the magnetic anomaly in volcanic areas (some 100 nT), it was necessary to reduce the influence of the near-surface strata (topographical correction). For that reason a layer with a maximum thickness of 1200 m under the highest peak of the island (Barberi, 1994) and a susceptibility of $\kappa = 0.01$ SI-units was assumed. This assumption is based on the results from drilling data (Barberi, 1994) and field measurements of the magnetic susceptibility (Gehring *et al.*, 2000a; Gehring *et al.*, 2000b).

Magnetic bodies (Österreicher, 2000) with depth extents from approximately 1200m down to 3000 m below surface, preselecting a magnetic susceptibility of 0.06 SI-units, were obtained using a 2.5D-Talwani algorithm (Shuey and Matthews, 1972; Hübl, 1993). These model parameters correspond well with the results of Barberi (1994) and the findings in the borehole. Especially the high temperature gradient found in the latter one limited the depth to lower boundary of the magnetic bodies to approximately 3000 m.

The reason for choosing a maximum depth of 3 km to the lower boundary of the bodies was that magnetic bodies normally loose their ferrimagnetic characterisation at temperatures of about 600 ℃ (Curie point temperature) which is reached in that depth in this area. The results of the calculation along these 3 profiles are shown in Figs. 7, 8 and 9.

5. Conclusions

Within a two years project, different airborne geophysical methods, supplemented by a detailed terrestrial geophysical program, were carried out by the Geological Survey of Austria and the Institute for Meteorology and Geophysics, University of Vienna, in volcanic regions of southern Italy, namely Mt. Vesuvio and the Islands of Vulcano and Lipari.

Detailed aeromagnetic and radiometric mapping was done in all areas. In the Vesuvian area the results are dominated by the large anomaly of the Mt. Somma-Vesuvio complex itself, showing a smaller anomaly with northern minimum in the Valle dell Gigante area, superimposed on a large positive anomaly with northern minimum. The shape of the anomaly is circular with an extension to the South. The results in the surrounding lowlands are dominated by high frequency anomalies partly caused by anthropogenic noise showing a diffuse star-like anomaly pattern with its centre at the cone. Remarkable is a smaller anomaly in the Pompei region with a southern minimum. But it is hard to decide if it is caused by geologic sources or cultural noise. A more detailed consideration of these anomalies should be subject to further investigations. The results of the radiometric mapping also show high concentrations of potassium and uranium centred at the cone.

The magnetic mapping of the Vulcano-Lipari area gives a much more detailed picture of the anomaly pattern in comparison to the results of the AGIP survey done in 1985. The anomaly pattern of the Vulcano-Lipari region shows many medium to small

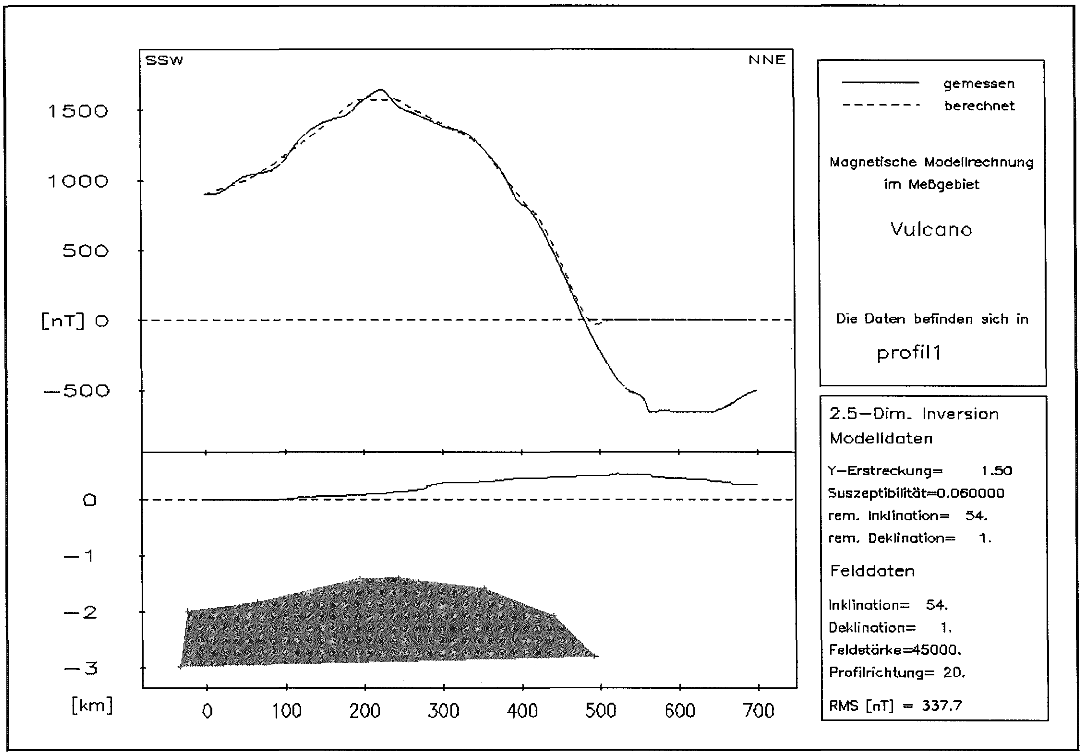

Fig. 7 Modelling results of the magnetic anomaly along profile A on Vulcano Island (see Fig. 5 for location of profile).

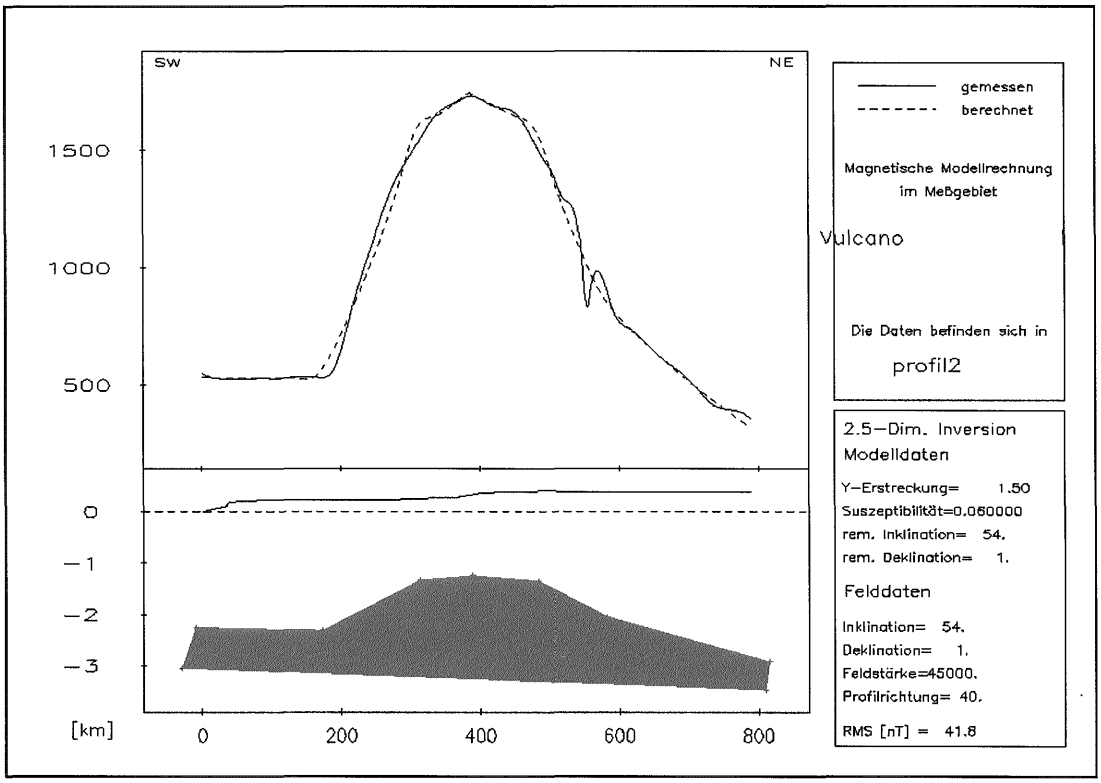

Fig. 8 Modelling results of the magnetic anomaly along profile B on Vulcano Island (see Fig. 5 for location of profile).

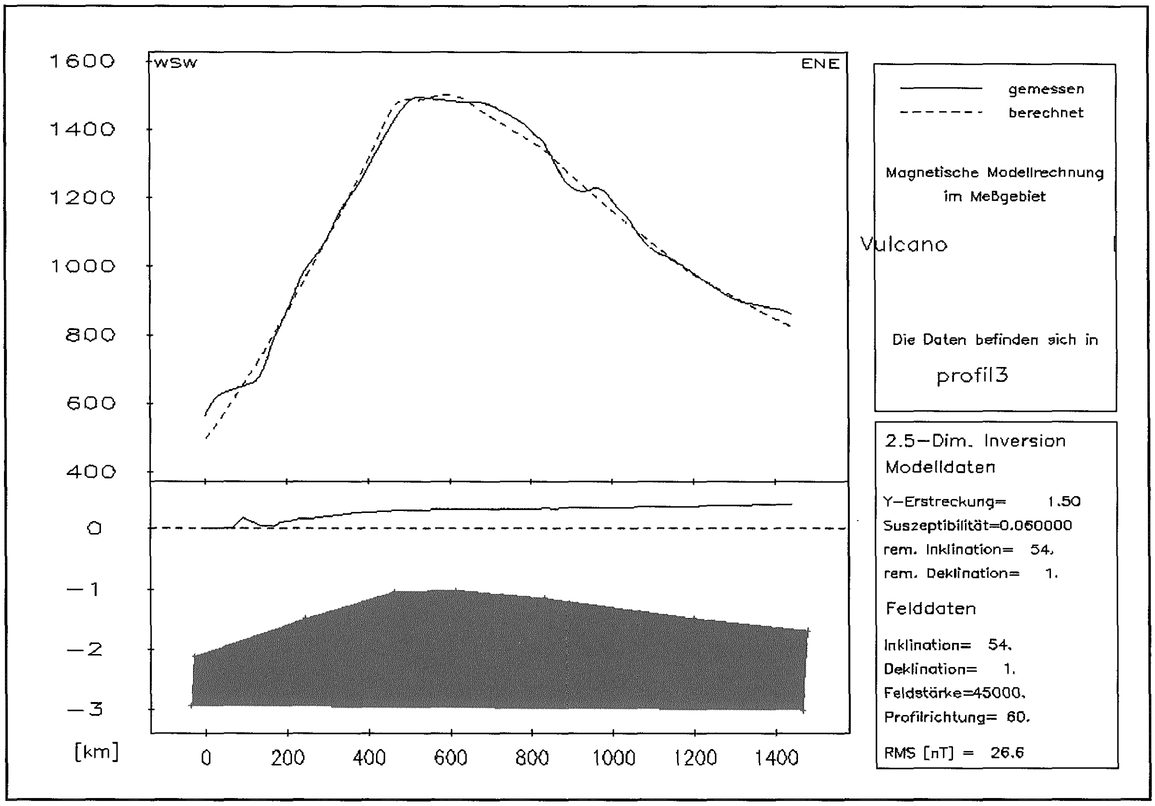

Fig. 9 Modelling results of the magnetic anomaly along profile C on Vulcano Island (see Fig. 5 for location of profile).

sized anomalies representing the response of complicated magnetic structures. Very interesting are two anomalies in the open sea. One of them correlates with a zone of current fumarolic activity, whereas the sources of the other is so far not known. Also remarkable are small but elongated anomalies at the southern flanks of Vulcanello. They also correspond to fumarolic activity in hot areas like another one at the region of Bagni Thermali di S. Calogero on Lipari. As mentioned above the anomaly pattern in the Vulcano-Lipari area is very complex. First attempts were made to discuss the origin of these anomalies within this project.

The differences in the magnetic field pattern between the present and the former survey done by AGIP may be indicators for the geodynamic behaviour of the volcanic area. Although the data were not measured along the same flight paths lines and at the same altitudes, it can be concluded that at least some changes took place during the period of the last 15 years. Monitoring this change could be very important information forecasting dangerous volcanic hazards. Periodical mapping of the magnetic field (and of other parameters, e.g. geoelectrics) are suggested for further research.

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南イタリア火山地域における物理探査

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要　旨

EC（European Community）の共同研究TOMAVEとイタリア側の研究「ナポリ火山地域での空中磁気探査」によって，イタリアの活火山地域（ベスビオ火山，ブルカノ島およびリパリ島）において空中物理探査を実施した．本論では，磁気探査と放射能探査の結果について地磁気異常の予備的な解析結果を含めて記述する．さらに，ブルカノ島における1999年の地磁気異常測定結果とAGIPによる15年前に行われた測定結果とを比較し，当該地域における地磁気異常の時間変化について検討する．

（要旨翻訳：大熊茂雄（地殻物理部））