ANNALI DI GEOFISICA, VOL. 41, N. 3, August 1998

# An experimental aeromagnetic survey in the Volturno valley area (South-Eastern Latium)

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**Abstract**
A helicopter-borne experimental aeromagnetic survey, covering an area of 200 km$^2$, was performed in the Volturno valley area north of the Roccamonfina volcano and south of Venafro in November 1994. Although severe logistical, instrumental and meteorological conditions significantly reduced the planned coverage, the processed magnetic image still shows a remarkable improvement in the description of the geological and structural features of the area in comparison with previous regional aeromagnetic data. A multi-directional shaded relief anomaly map displays two moderately positive NW magnetic bands associated with lavas, pyroclastics and dykes of the Roccamonfina volcanic district together with N-S, NNE-SSW and NE-SW lineations. A comparative magnetic-geologic map allows correlation with known Pleistocene faults and reveals the existence, especially in the area between Sesto Campano and Presenzano, of a larger presence of high susceptibility dykes than seen in the outcrop, which is dominated by non-magnetic carbonatic rocks. We interpret the curvilinear and intricate pattern of magnetic lineaments as suggestive of an extensional setting along the main NW structures with previous strike slip components and of tectonic activity along a N-S fabric; the latter has no superficial evidence and has also been used for magma upwelling. Overall, this local scale investigation shows both the utility and the need for further efforts in high resolution aeromagnetics in Italy both for geological and environmental purposes similar to those successfully carried out in many other countries throughout the world.

**Key words** *aeromagnetic survey – Roccamonfina volcano – magnetic lineations – structural interpretation*

## 1. Introduction

In November 1994 an aeromagnetic experimental study was carried out in the Volturno valley area, north of the Roccamonfina volcano and south of Venafro (fig. 1) by the Istituto Nazionale di Geofisica and by the Dipartimento Scienze della Terra of Genoa. The investigated area, which is located at the intersection of tectonically significant regional scale apenninic and anti-apenninic extensional fault systems is magnetically characterised by a well developed recent volcanic activity of relatively high susceptibility emplaced in a weakly magnetic carbonate stratigraphic succession. Previous AGIP regional aeromagnetic data (AGIP, 1981) showed the existence of a prominent magnetic anomaly over the Roccamonfina volcano but was not useful in the study of the secondary volcanic eccentric manifestations (lavas, pyroclastics, dykes) nor in

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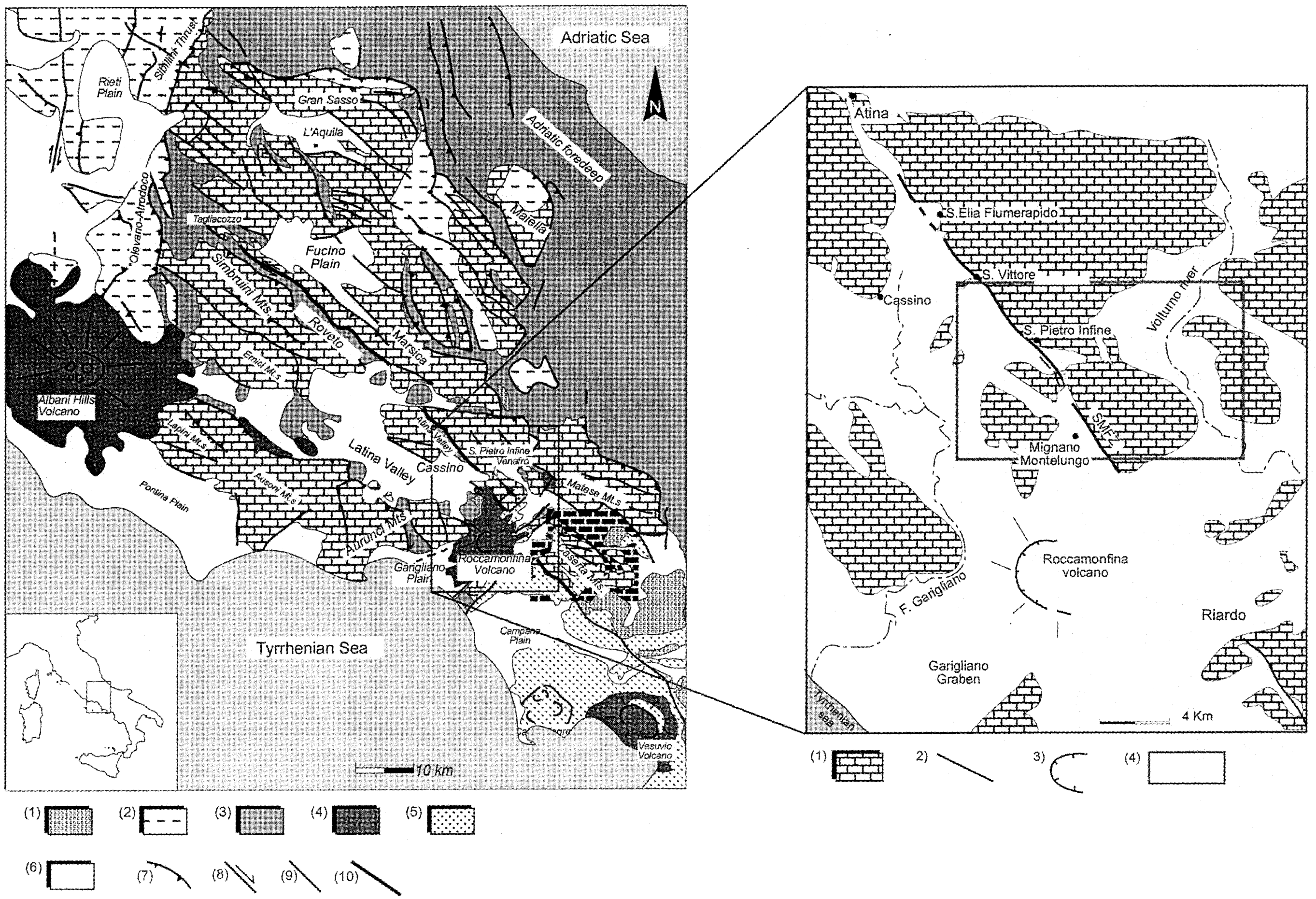

**Fig. 1.** Schematic geological map of the Lazio-Abruzzi region and the neighbouring areas. 1) Carbonatic units of the Lazio-Abruzzi platform (Upper Triassic-Upper Miocene); 2) Umbro-Sabina and Maiella transitional units (Late Triassic-Late Miocene); 3) terrigenous deposits of the Lazio-Abruzzi carbonatic units (Tortonian-Messinian), Adriatic Foredeep (Messinian-Pleistocene) and Molisan Basin (Late Cretaceous-Messinian); 4) deposits of the Vesuvio (Upper Pleistocene-Holocene), Roccamonfina (Middle-Upper Pleistocene) and Colli Albani (Middle-Upper Pleistocene) volcanos; 5) pyroclastic deposits of Campi Flegrei eruption (Upper Pleistocene); 6) continental and marine deposits of the coastal and intramountain basins; 7) thrust faults; 8) strike-slip faults; 9) normal faults; 10) «Marsica fault». The aeromagnetic survey area is also enlarged.

the identification of faults indicative of the structural framework and kinematical regime of the area which was the main objective of this more detailed study. After a brief geological setting, we thus describe in the following sections, both the technical aspects and problems and the interpretative elements derived from an integrated magnetic and geological approach. It is also noteworthy that this study represents the first non industrial example of a local scale high resolution aeromagnetic survey performed in Italy which employs techniques already widespread in other countries worldwide and that have been successfully applied for geological exploration purposes by Italian researchers in Antarctica (Bozzo *et al.*, 1997) in a somewhat similar extensional tectonic environment but clearly highly different as far as anthropic ambient is concerned.

## 2. Geological framework

Starting from the Late Miocene, the western margin of Central Apennines, which is located between the uplifting chain and the subsiding Tyrrhenian area (fig. 1), underwent strong geodynamic processes that produced the present day structural setting.

According to several authors (*e.g.*, Faccenna *et al.*, 1994; Hyppolite *et al.*, 1995), two different extensions have been interacting in this area since the Lower Pliocene, during the concomitant migration of the eastern thrust front towards E-NE. A NE extension accommodated by NW-trending normal faults caused NW-trending basins which were filled by thick marine and continental deposits. These basins were after cut by NE-trending strike slip and normal faults (NW extension). In the chosen area two lithospheric discontinuities, with a complex and controversial significance, converge: the N and NE-trending Ortona-Roccamonfina tectonic lineament (Patacca *et al.*, 1990) and the E-trending «41° parallel» line (Finetti and Del Ben, 1986; Sartori *et al.*, 1990). Despite this, the most evident superficial structures are instead NE- and NW-trending normal faults which set the topographic and structural boundaries between the mountain ridges and the main depressions. The activity of these faults ranges between Lower and Upper Pleistocene, and their interaction is not yet completely understood, being probably much more complex than what is expected. Bosi (1994), on the basis of structural and neotectonic analysis, suggested much recent activity along the NW-trending normal faults, and in particular along the South Marsica Fault Zone (SMFZ in fig. 1; Parotto and Praturlon, 1975), which probably acted as a left-lateral strike-slip fault in previous times (Pliocene-Lower Pleistocene) as described, *e.g.*, by Mattei *et al.* (1993) and Salvini (1993).

Starting from the Middle Pleistocene a strong volcanism related to extensional tectonics and driven mainly by N-S and NE-SW trending fault systems (D'Argenio, 1966), developed in the Garigliano graben, where the subsidence rate abruptly increased. The volcanic process is evidenced by the building up of the Roccamonfina apparatus which was active from about 630 to 50 ky (Ballini *et al.*, 1989 and references therein).

At Roccamonfina, highly explosive eruptions occurred between 385 and 230 ky (Luhr and Giannetti, 1987), after a previous initial stage of widespread magma intrusion and of strombolian to subplinian pyroclastic flow. During the early activity (630-400 ky) uprising magma intruded along pre-existing fractures causing the formation of dykes and eccentric cones of Presenzano and Sesto Campano, respectively (Di Girolamo *et al.*, 1991). The final stage of the volcanic activity (230-54 ky; Radicati di Brozolo *et al.*, 1988) was represented mainly by a period of strong phreatomagmatic activity, which also occurred from many parasitic centres aligned along N-trending lineaments, and by effusive and explosive eruptions.

## 3. The airborne magnetic system

The airborne magnetic system adopted for the survey belongs to the PNRA (Progetto Nazionale Ricerche in Antartide) and had already been employed in Antarctica by the GITARA (German Italian Aeromagnetic

Research in Antarctica) aeromagnetic group (Bozzo *et al.*, 1997). It is composed of three different parts: a) towed magnetic apparatus; b) aeromagnetic rack; c) magnetic and GPS base stations. The towed magnetic apparatus includes the caesium optical and electronic sensor with a sensitivity of $10^{-3}$ nT at a sampling rate of 10 Hz. It is mounted on orienting gimbal placed in a bird towed with a 25 m cable fixed to a barycentric hook to the helicopter (an Agusta A 109A) so as to minimise the magnetic effects. The signals coming from the two sensors are thus conveyed to the acquisition system, which is part of the aeromagnetic rack. The rack also includes the GPS positioning system, the navigation computer, the barometric sensor and the power supply. A proton precession magnetometer and a GPS receiver were installed close to the survey area at Aquino airport and were used as magnetic and GPS base stations respectively.

## 4. Survey layout

Since the survey area was placed at the intersection of NW and NE trending geological structures, contributing to the emplacement of volcanic bodies of the Roccamonfina apparatus, a widely spaced grid with E-W profiles (spacing 1 km) and N-S tie lines (3 km line interval) was planned. In order to study the small secondary eccentric structures, as well as the main edifice of the volcano, we designed a more detailed survey over Sesto Campano and Presenzano.

The above mentioned AGIP regional magnetic survey, flown at two different altitudes (1500 and 2600 m), showed a prominent anomaly over the volcano, but was not designed to display shorter wavelength magnetic features over the secondary magmatic manifestations. On the other hand susceptibility measurements indicated quite a large contrast between the «lavas» ($30\ 10^{-3}$ SI) and the carbonatic rocks ($0.016\ 10^{-3}$ SI). The previous considerations led us to perform a feasibility study, by using forward magnetic modelling techniques, applied to theoretical bodies along outcropping dykes to improve the effectiveness of planning a detailed grid. In order to obtain clearly detectable anomalies over the smaller features (over 10 nT), this study indicated that terrain clearance had to be 200-400 m (1200 barometric height); line spacing was also to be reduced to 500 m. The anthropic electromagnetic noise was not considered a major problem since the area is only relatively urbanised. An electrified railway line flanks a main road crossing the survey (SS. N. 6) and was estimated to cause a very intense variation in the magnetic field at a small distance, clearly distinct from the very weak anomalies related to the geology.

Despite the accurate planning quite a few problems were encountered. The logistic restrictions were mainly due to the impossibility of refuelling close to the survey area at Aquino, where the base station was located; this made it necessary for the helicopter to fly a very long distance to refuel, thus limiting operational range to approximately 30 m, compared to nearly 3 h of normal aeromagnetic helicopterborne flights. Heavy rains, the strict time schedule (4 days), combined with problems to the magnetic sensor and GPS navigation system, both on board and at the base station, reduced the planned coverage drastically. Due to the above drawbacks only 3 flights were performed (thus objectively transforming the survey in an «experimental study») for a total of 15 profiles corresponding to 250 km of line data covering an area of 200 km$^2$ with a spacing of 500-1000 m and a 50 m accuracy in positioning. As clearly shown in the following sections, however, the quantitatively reduced magnetic data we acquired turned out to be of good quality and useful for the structural interpretation of the surveyed area.

## 5. Processing procedures

A series of processing steps were applied to the raw aeromagnetic and positioning data to produce the magnetic anomaly image displayed in fig. 2b: i) filtering of magnetic data and spikes removal; ii) recovery and repositioning of flight paths; iii) diurnal variation removal; iv) removal of a regional reference

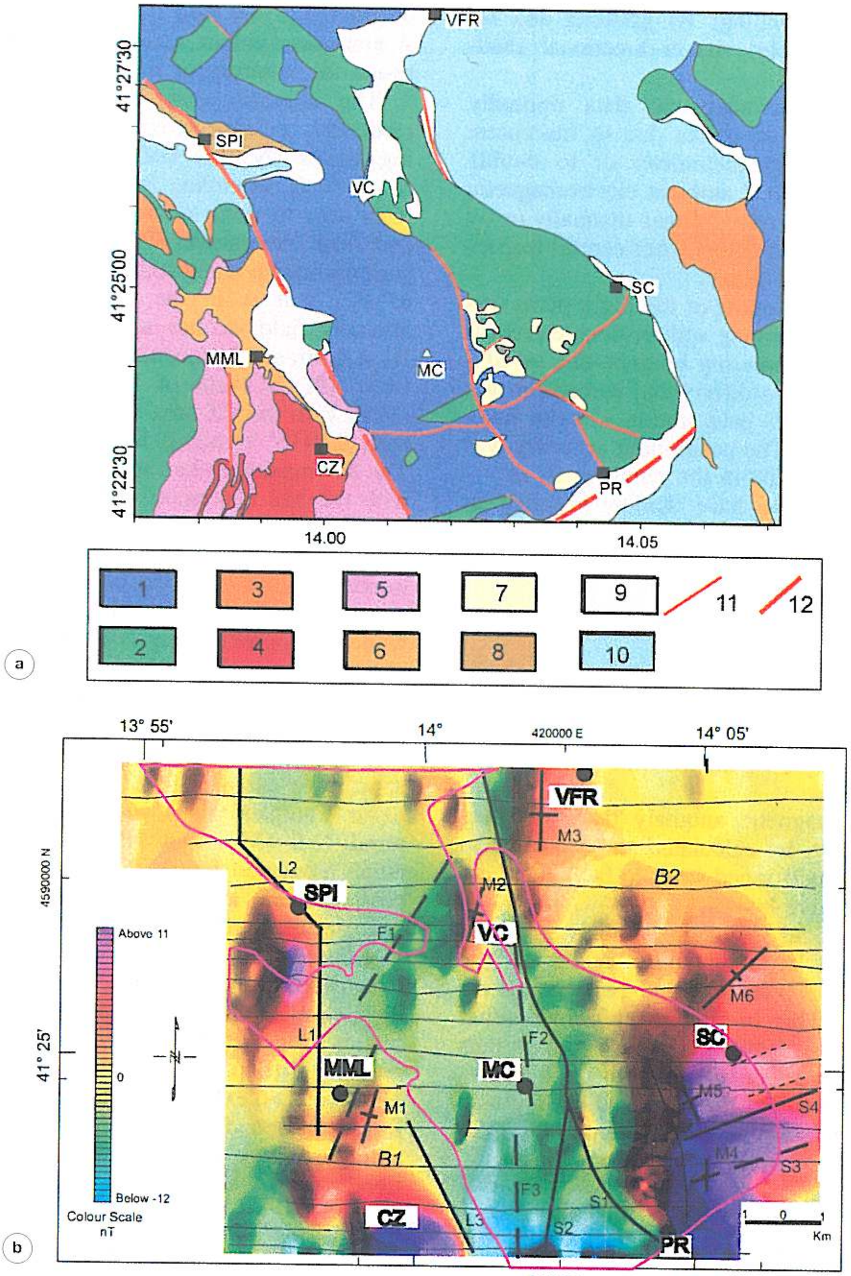

**Fig. 2a,b.** Comparison between (a) the reduced geological base and (b) the magnetic map. 1) Jurassic carbonate; 2) Cretaceous carbonate; Upper Miocene-Lower Messinian Terrigeous deposits; 4) Lavas; 5) Pyroclastic deposits; 6) Campanian Ignimbrite; 7) Residual deposits; 8) Upper Pleistocene breccias; 9) Debries slope and alluvial deposits; 10) Recent alluvial deposits; 11) Main fault system; 12) South Marsica Fault Zone (SMFZ).

field; v) microlevelling; vi) gridding and reduction to the pole; vii) bi-directional shading.

i) The raw aeromagnetic data normally contains a series of spikes due to inaccurate readings of the magnetometer or to double records and/or to real ambient electromagnetic noise, which is removed either manually or by adopting non linear filters, after careful inspection of the profile data.

ii) The repositioning of the flight paths was performed by removing spikes, double records and interpolating missing sections due to GPS gaps and errors; no differential correction was applied as the GPS base station was not functioning properly. The positioning accuracy was thus estimated to be in the range of 50 m.

iii) A magnetic base station installed at Aquino (near the survey area) was used to correct for long term magnetic time variations along the profiles.

iv) A first order trend was subtracted from the data as a reference field.

v) In this study microlevelling techniques (Minty, 1991) played an important role; normally this procedure is regarded as an improvement in the signal to noise ratio parallel to flight lines.

vi) The magnetic anomaly data was thus gridded, FFT were calculated and reduction to the pole was performed so as to facilitate location of causative bodies.

vii) The final magnetic anomaly image is thus obtained by overlaying three grids: the reduced to the pole grid and two shaded relief images. This bi-directional shaded relief (Broome *et al.*, 1990) magnetic anomaly map displays in an effective way both the high frequency features and the low gradient regional structures orthogonal to the direction of illumination as well as the intensity of the anomalies.

## 6. Magnetic interpretation

The high resolution magnetic image (0.1 nT colour interval) was originally produced at a 1:25 000 scale so as to superimpose the map on the topographical sheets to facilitate correlation with the main features of the area: a reduced 1:125 000 map is shown here (fig. 2b). A non-linear colour scale was adopted to represent the intensity of the anomalies.

The anomaly map clearly displays two moderately positive (average 12 nT) NW trending bands (N320°) defined as B1 and B2 respectively extending from the Campozillone (CZ) area to north of San Pietro Infine (SPI) and from Presenzano (PR) to Venafro (VFR) surrounding an elongated broad minimum. East of B2, that is in the Volturno valley, the anomaly field is once again negative. Within B1 a north-south lineament named L1 extends from SPI to south of Mignano Montelungo (MML); in the CZ area it appears to converge with a N15° trending local maximum (M1). The M1 maximum lies approximately on strike with the M2 maximum in the Vallecupa area (VC), while further north the M3 axis at VFR is N-S. Within the broad minimum a N30° trending fabric (F1) can be recognised in the minimum extending in width from SPI to VC, while an approximately N-S trend (F2, F3) is seen to the east. The B1 band seems to be bordered by two linear segments (L2 and L3) at its eastern side; B2 at its western side, is limited by a curvilinear feature named S1, which appears to cut a N10° structure S2. Between Sesto Campano (SC) and PR magnetic axis trend N-S (M4) and NNW (M5); however N65° elongated trends (S3, S4) also seem to crosscut them and are sub-parallel to the M6 axis further north.

Mutual crosscutting relations and offsets between the magnetic trends, which could be indicative of relative timing of motion and kinematics along geologically documented faults, are very difficult to interpret from this image. However two extensional directions can be inferred (NE and NW approximately), further complicated by the existence of N-S and NNE trends.

## 7. Structural interpretation

The comparison between the magnetic map and the reduced geological base map obtained from the 1:100 000 sheet of Geological Map of Italy is shown in fig. 2a,b. The most evident feature is the positive magnetic anomaly in the area between Presenzano (PR) and Sesto Campano (SC), which is dominated by non-magnetic carbonatic units formed by Cretaceous limestones. The anomaly field in the area is thus due to the secondary manifestations of the Roccamonfina volcano. Specifically the Presenzano outcrop is a massive lava flow with a maximum thickness of 15 m, while the Sesto Campano one is reported as a peripherical cone, now eroded, forming a small lacustrine basin, then filled by the Roccamonfina trachytic products (Di Girolamo *et al.*, 1991). In the same area, a series of dykes are reported to have been emplaced along N65° anti-apenninic faults and to outcrop at the intersection with the NW apenninic fault systems.

The comparison between the two maps seems to suggest:

a) That the volumetric entity of the magmas constituting these dykes and eroded cones is greater than what is apparent in outcrop.

b) The S3 and S4 elongated magnetic features could indeed be interpreted in terms of dyke swarms uprisen along the NE trending fault system.

Other remarkable anomalies, not readily correlated with outcrop are:

i) The N-S trending S. Pietro Infine anomaly, related to unexposed volcanics, partially under alluvial cover. This anomaly is located exactly along the northward extension of the Campozillone (CZ) – Mignano Montelungo (MML) outcrop of lavas due to the last phase of the Roccamonfina Volcano.

ii) The N-S Venafro anomaly (VFR), probably induced by volcanic rocks under recent alluvial deposits of the Volturno river, is aligned with the F2 and F3 magnetic fabric, possibly indicating structural control of these anomalies along an unexposed tectonic fault or fracture.

From the structural point of view the L2-L3 magnetic lineaments correlate with the geologically mapped NW trending normal faults indicative of NE extension; the B1 band is interpreted as being controlled by the regional scale SFMZ lineament. The NW trending curvilinear S1 magnetic structure, which cuts Mt. Cesima relief, is correlable with a NW striking normal fault, displacing Middle Pleistocene deposits. The image also displays another NW feature with opposite convexity just west of the M4, M5 anomalies. Within the SE corner of the map, at east of M4 and M5, pervasive SE-NW aligned magnetic structures are observed. These features may be interpreted as a dyke swarm induced structure, connected with one of the main volcanotectonic elements peculiar to the Tyrrhenian margin. The N30° magnetic fabric F1 may correspond to a deeper fault at an angle with the S3 and S4 dyke swarms; the geologically unrecognized F2, F3 trends are much harder to explain. They could be indicative either of faults accommodating the displacement along the NW and NE structures or, more probably, the magnetic expression of N-S trends, related to those geologically recognised in Venafro Basin by (Naso *et al.*, 1997, personal communication). The NNE S2 structure does not seem to control the location of the volcanics and could be due to an unrecognized NNW extension.

## 8. Conclusions

This study allowed us to discuss a variety of problems which are involved in aeromagnetic field work as well as the specific results derived from an integrated interpretative approach of magnetic images with some geologic data. Despite the fact that many problems were encountered during the survey, we believe that this experimental study can also be regarded as a useful first experience for further high resolution aeromagnetic work in Italy. Experiences in other countries indicate that the aeromagnetic method is a cost effective approach for geological and environmental studies in a variety of tectonic and geologic settings and anthropic conditions. The use of differential GPS techniques, of new processing steps and, as a consequence, the production of high resolution magnetic images has greatly enhanced the capabilities of aeromagnetics, which has recently been applied also to sedimentary environments.

In our specific case, despite the scale of the secondary manifestations of the Roccamonfina volcanic apparatus and the coarseness of the flight grid, the aeromagnetic study has led to a remarkable improvement in the structural and geologic description of the area. Above low susceptibility outcropping units in the Sesto Campano-Presenzano area magnetic anomalies are related to small presently eroded volcanic cones (structurally controlled by the NW and N-S trends) and to dyke swarms aligned along the N65° anti-apenninic faults. As well as previously recognised NW and NE faults, linked to the youngest extensional episodes, accompanied by previous strike slip movements, we imaged N-S and NNE trends. In particular the N-S trend contributed to magma upwelling and has been highlighted in an area which has similar evidence in northern surrounding sectors, the Venafro Basin (Naso *et al.*, 1997, personal communication).

Overall, this local scale investigation shows both the utility and the need for further efforts in high resolution aeromagnetics in this and in other areas throughout Italy, both for geological and environmental purposes.

## Acknowledgements

The experimental aeromagnetic study was financially supported by the Dipartimento della Protezione Civile. The authors also wish to thank the Compagnia Aeronautica Italiana for the effective collaboration during the survey. The useful discussions with M. Gambetta have been greatly appreciated.

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