# High-resolution aeromagnetic survey of the Teide volcano (Canary Islands): a preliminary analysis

**Alicia García**[1], **Isabel Blanco**[1], **J. Miquel Torta**[1] **and Isabel Socías**[2]

[1] *Departamento de Volcanología, Museo Nacional de Ciencias Naturales, CSIC, Madrid, Spain*

[2] *Instituto Geográfico Nacional, Madrid, Spain*

**Abstract**

To contribute to our understanding of the structure of the Teide volcano, a detailed aeromagnetic survey was carried out covering the area of Las Cañadas caldera and the Teide-Pico Viejo complex. Taking into account the rugged relief of the area (altitude ranges from sea level to almost 4000 m), a terrain correction has been applied. As a first approximation, the topography has been characterized by a uniform magnetization of 5 $Am^{-1}$ (based on field and laboratory rock magnetic data). Several enhancement techniques have been applied to the residual map (original map minus topographic effect), such as reduction to the pole, pseudogravity integration and upward continuation. In the reduced-to-the-pole map the large positive anomaly that appears centered to the north of Pico Viejo is noteworthy and could be caused by a basaltic intrusion responsible for the last eruptions in this area. Also, a small magnetic low appears over Teide peak, which should be related to slightly-magnetized shallow phonolitic materials. The main tectonic direction of Tenerife, SW-NE, is also clearly reflected on the magnetic anomaly map. The comparison between the pseudogravity and the Bouguer anomaly maps indicates a good correlation between magnetic and gravimetric sources.

**Key words** *Teide – aeromagnetic anomalies – topographic correction*

## 1. Introduction

Teide, with a height of 3718 m, is the largest and only active stratovolcano of the Canarian Archipelago, with its last eruption in 1798. This volcano was constructed as the product of the most recent phase of central volcanism on Tenerife, and is located in the northern part of Las Cañadas caldera. To determine the internal structure, the evolution and the present state of its eruptive system, with the maximum possible accuracy, Teide was selected as one of the European Laboratory Volcanoes, as well as one of the Decade Volcanoes. Although Teide has been widely investigated, this project has been very useful to complete and integrate previous studies.

Among other research objectives, a detailed aeromagnetic survey of Las Cañadas caldera, including the Teide-Pico Viejo complex, was carried out. Previous structural studies never comprised a magnetic survey, which is first analysed in this paper. Since a detailed microgravimetric model of the area of Las Cañadas caldera exists (Camacho *et al.* 1991), a comprehensive structural model of the area is therefore envisaged with the joint analysis of potential field data. This work describes the

*Mailing address*: Dr. Alicia García, Departamento de Volcanología, Museo Nacional de Ciencias Naturales, Consejo Superior de Investigaciones Científicas, José Gutiérrez Abascal 2, 28006 Madrid, España; e-mail: mcngg92@pinar1.csic.es

preliminary analysis carried out with the aeromagnetic data. The first step has been the estimation of the average effect of the topography, which is very rugged, on the magnetic anomaly map. After the removal of the magnetic anomaly due to the relief, different enhancement techniques were applied to clarify the target magnetic anomalies and identify their sources. A first interpretation of these results is also proposed.

## 2. Geological background

Teide volcano is located in the centre of Tenerife, the biggest island of the Canarian Archipelago. Tenerife was originally constructed by fissure eruptions of ankaramites, basanites and alkali-basalts forming the Old Basaltic Series that ranges in age from 12 Ma to 3.3 Ma (Fuster *et al.*, 1968; Ancochea *et al.*, 1990; Martí *et al.*, 1995). Differentiated volcanics and basalts formed a large volcanic complex in the central part of Tenerife (from > 3.5 Ma to present, according to Martí *et al.*, 1994a), where the existence of evolved peralkaline phonolitic magmas indicates the development of high level magma chambers. At the same time, the Dorsal Series was formed as the result of basaltic eruptions along the SW-NE Dorsal Ridge or Cumbre de Pedro Gil (Fuster *et al.*, 1968; Ancochea *et al.*, 1990). On the rest of the island, a large number of monogenetic basaltic volcanoes constitute the Recent Basaltic Series (Fuster *et al.*, 1968).

The central volcanic complex of Tenerife is known as Las Cañadas edifice (fig. 1), a shield structure which culminates in the walls of a large elliptical depression measuring $16 \times 9$ km called Las Cañadas caldera. This is located at an altitude of 2000 m and its maximum depth is 600 m. Several periods of volcanic activity separated by periods of quiescence have been identified during the evolution of the Las Cañadas edifice (Martí *et al.*, 1994b). Each constructive-destructive cycle comprises a similar sequence of events: 1) continuous ascent of mantle-derived basaltic magmas; 2) formation of a discrete shallow phonolitic magma chamber, which implies a predominance of phonolitic eruptions and the existence of a shadow zone for basaltic eruptions in the central part of the island; 3) caldera-forming event, implying the destruction of the volcanic edifice and the partial/total destruction or cooling of the shallow magma chamber; 4) eruption of basaltic magmas in the central part of the island; and 5) construction of a new shallow magma chamber in a different location and, consequently, migration of the phonolitic volcanic activity to other sectors of the central part of Tenerife. This multicyclic process of caldera formation has developed over the last 1.2 Ma (Martí *et al.*, 1995).

In the northern part of Las Cañadas, the Teide-Pico Viejo complex was constructed as the product of the most recent phase of central volcanism on Tenerife. Teide and Pico Viejo are two large stratovolcanoes which have grown in close mutual proximity. They overlap to form an elongated double edifice, their summits being separated by a distance of 2.5 km. The highest altitude corresponds to the Teide youngest summit vent, El Pitón, at 3718 m. The main cone is approximately circular, with a basal diameter of about 5 km. A satellite vent known as Montaña Blanca is located on the eastern flank of Teide. The Western Las Cañadas caldera is occupied by Pico Viejo products, mainly mafic to intermediate lava flows. Products of Teide filled the central caldera and flowed northward to bury the northern slopes of the Las Cañadas edifice. The youngest phonolites from Teide cover much of the Teide-Pico Viejo edifice. Relatively recently, the eastern caldera became a focus for phonolitic volcanism (Ablay and Martí, 1995).

Only five historic eruptions are precisely dated (García Moral, 1989). All of them took place in the central part of the island and were of basaltic nature. The last eruption within Las Cañadas caldera was Las Narices del Teide or Chahorra eruption, which took place in 1798, and its lava flows cover the southwestern slopes of Pico Viejo.

The Canary Islands region is affected by various fault systems, which could be classified into two different families or groups depending on their relationship with the opening

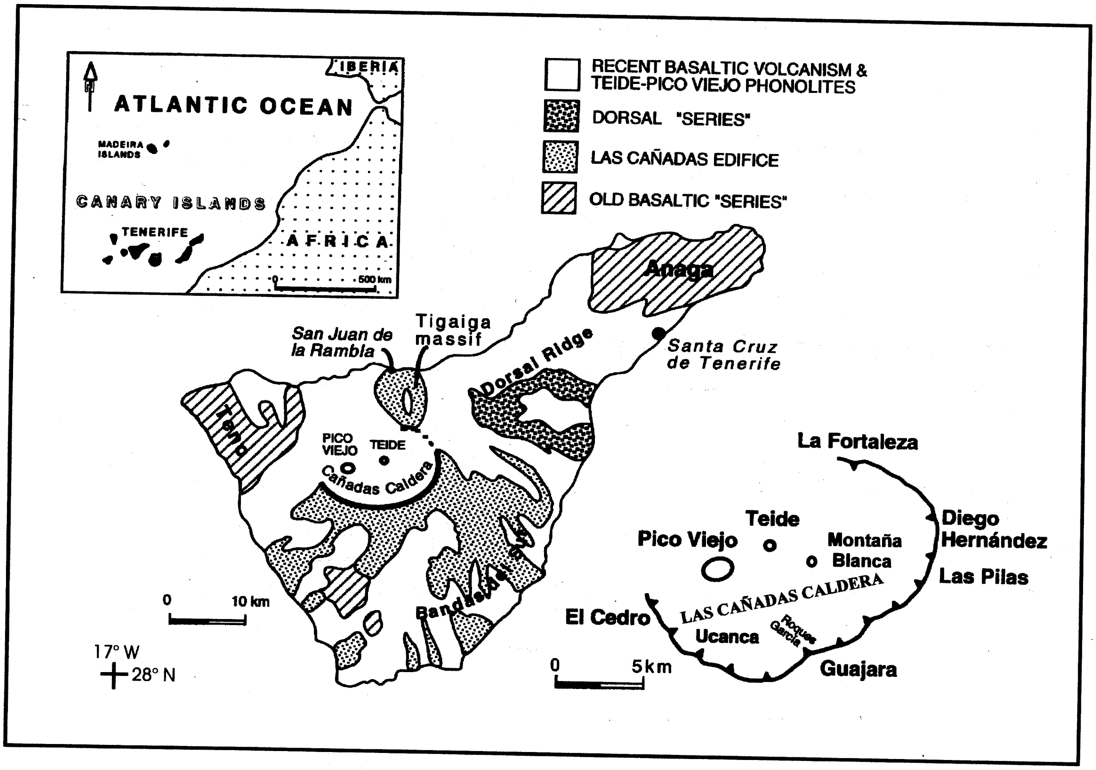


**Fig. 1.** Simplified geological map of Tenerife Island and location of the Las Cañadas caldera and Teide-Pico Viejo complex (from Martí *et al.*, 1995).

of the Atlantic or the tectonics of the Atlas range in the African continent. For the African family of fractures the orientations are approximately ENE-WSW and NNE-SSW, while the Atlantic follow the direction WNW-ESE (parallel to the transform faults of the Mid-Atlantic Ridge) (*e.g.*, Emery and Uchupi, 1984; Araña and Ortiz, 1991; Mezcua *et al.*, 1992). The tectonic framework of Tenerife is determined by these regional fault systems. In fact, the main volcano-tectonic alignments of the island follow these directions, the Atlantic trend being related to salic eruptive vents and the African trend related to basic vents (Coello and Bravo, 1989). The most active faults of Tenerife are oriented NW-SE and NE-SW (the direction of La Dorsal), and converge in the central part of the island (Araña and Ortiz, 1991; Ancochea *et al.*, 1995).

## 3. Data acquisition and reduction

In 1993, and within a regional aeromagnetic survey of the Canarian Archipelago, the Spanish IGN carried out a detailed survey of Teide-Las Cañadas. The size of the area is 26×26 km$^2$ (fig. 2). The main flight lines were flown in a N-S direction with a 500 m spacing at an altitude of 3810 m. The corresponding spacing for tie lines, flown in an E-W direction, was 5000 m. The aircraft speed was approximately 285 km/h that, with a sampling rate of 0.1 s, implying a data point every 10 m. Magnetic total intensity was measured with a stinger mounted Magnetometer-Scintrex cesium vapour with a sensitivity of 0.001 nT. Altitude was measured with both a barometric and a radar altimeter. A GPS receiver was used for the positioning. Two base stations were installed at La Esperanza (Tenerife Island) and Tahiche (Lanzarote) for the purpose of removing external field variations.

The calibration of the equipment included: a magnetic lag test (computation of the time elapsed from the instant a point is recorded on the video and the one in which the corresponding magnetic field value is recorded on the tape); a heading effect test (to estimate the effect due to the ferromagnetic materials of the aircraft which depends on the sensor position and on the geomagnetic field intensity and direction; the correction was 0.07 nT for the main lines and 1.85 nT for the tie lines); a calibration of the altimeter; a navigation test (to calculate the accuracy of the positioning system, which was under 10 m); and a test of repeatability (to check the stability of the acquisition system).

The pre-processing of the magnetic data consisted of: correction for altitude variations; corrections for diurnal variations; levelling (based on the comparison between the corrected total magnetic field values at the intersections of main lines and tie lines); IGRF subtraction and minimum curvature gridding with a spacing of 200 m. The resulting magnetic anomaly map is shown in fig. 3.

A ground survey was carried out during April 1995 where magnetic susceptibility was measured with a portable susceptibility meter on 63 outcrops (shown in fig. 2).

## 4. Data analysis

Several techniques of analysis were applied to the magnetic data, in order to obtain some information on the anomalous bodies. With the exception of the calculation of the topographic effect, the processing was carried out with the program TRSMAP (Gibert and Galdeano, 1985).

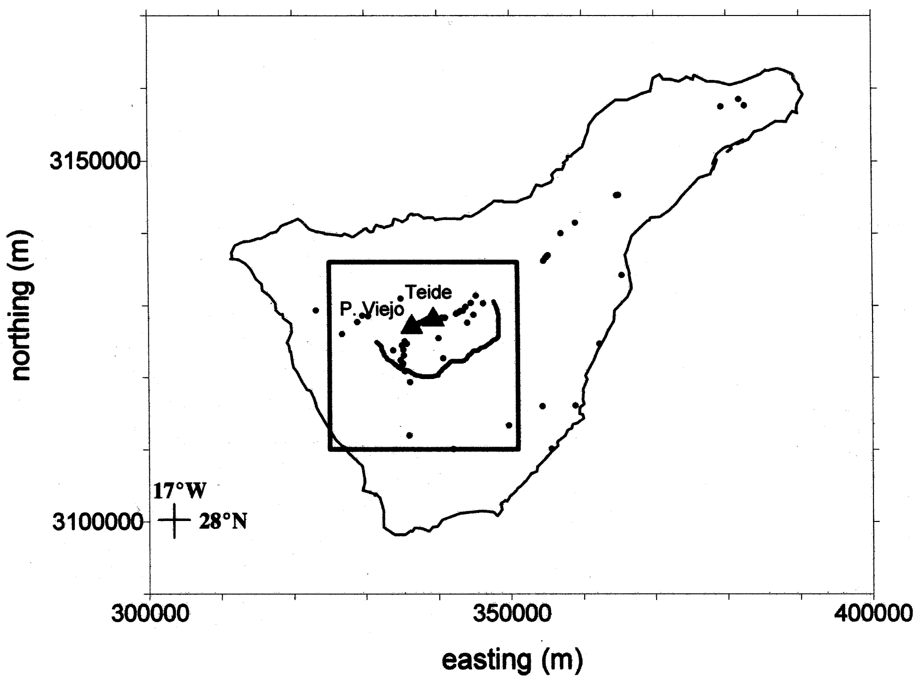


**Fig. 2.** Location of the area covered by the aeromagnetic survey and of the outcrops where magnetic susceptibility was measured (dots). Coordinates are UTM (m).

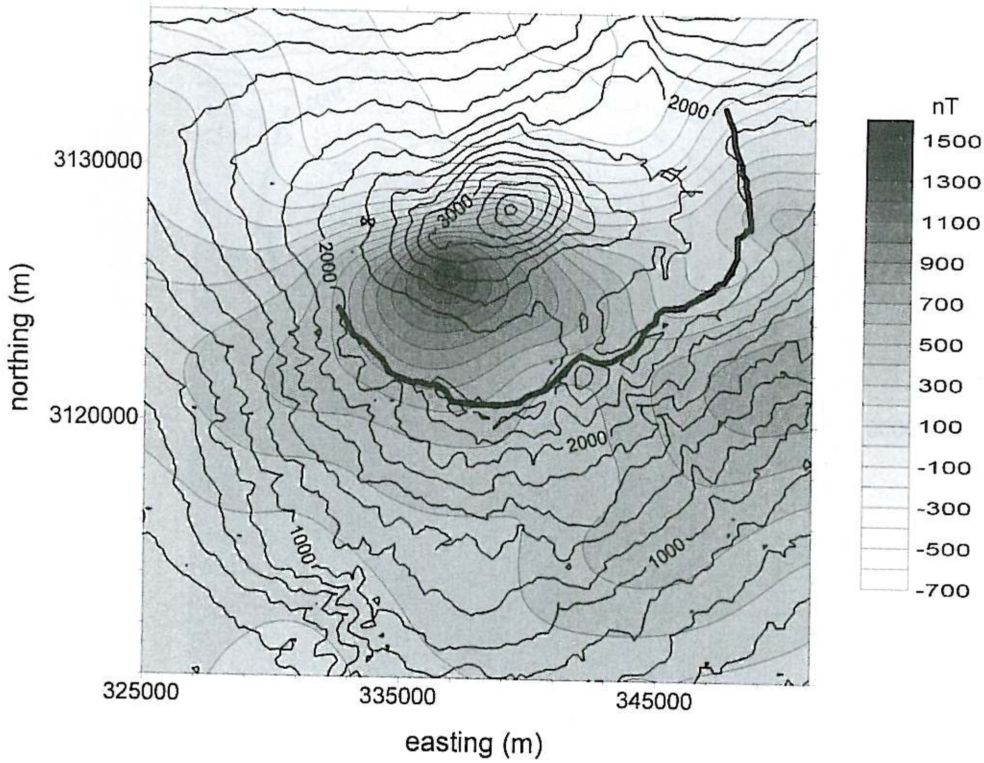


**Fig. 3.** Aeromagnetic anomaly map of Las Cañadas caldera and the Teide-Pico Viejo complex, superimposed on the topographic relief (black contours with some labels corresponding to altitude in m). The thick line marks the caldera boundary. Coordinates are UTM (m).

### 4.1. *Removal of the topographic effect*

The rugged topography of the Teide-Pico Viejo edifice (the caldera floor is at approximately 2000 m while the Teide summit is at 3718 m) leads to the belief that many of the observed anomalies are directly related to the unevenness of the relief. As the purpose of this study is to define the internal structure of the volcano in terms of magnetization, it is necessary to quantify and remove the anomaly created by the topography in order to clarify the anomalies caused by deeper sources.

As a first approximation, we calculated the magnetic anomaly due to a uniformly-magnetized terrain (fig. 4). For this, we used the program PFMAG3D (Blakely, 1981), an implementation of Parker's algorithm (Parker, 1972), who obtained the magnetic anomaly over an uneven source by summing a converging series of Fourier transforms of the magnetization and powers of the top and bottom surfaces. The input of the program was a portion of the digital elevation model of Tenerife which includes the area of the aeromagnetic survey. To avoid edge effects, the terrain anomaly was obtained over a grid of $36\times36$ km$^2$, while the original magnetic map covers an area of $26\times26$ km$^2$. It is necessary, of course, to assign a value to the magnetization of the rocks. For simplicity, we assumed a constant magnetization of 5 Am$^{-1}$ for the subaerial volume of the volcano (from sea level to the Teide summit). This selection was based on the

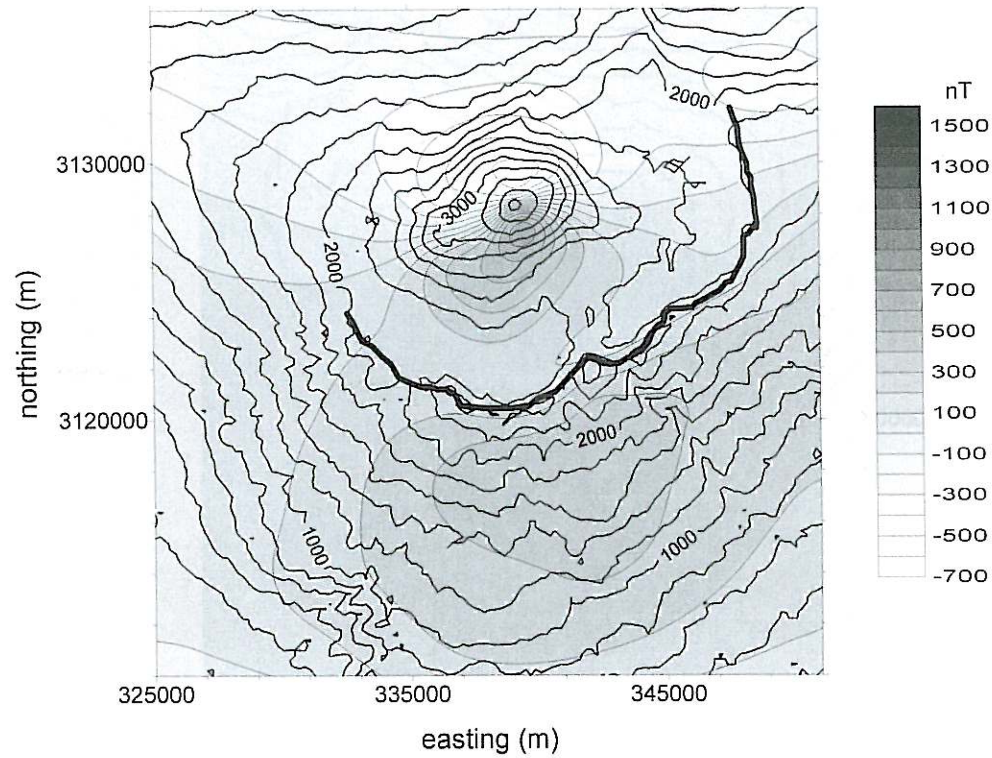


**Fig. 4.** Magnetic anomaly caused by the topography assumed to be characterized by a uniform magnetization of $M = 5\ Am^{-1}$ parallel to the present field ($D = -8°$, $I = 38°$).

values of total magnetization obtained from field susceptibility data and the values of remanent magnetization published by Carracedo (1979) (see table I). As a large portion of the subaerial volume of Tenerife corresponds to basalts and trachybasalts (about 70% in the central part and more than 90% in the rest of the island) (IGME, 1968; Araña, personal communication) the values that characterize this type of rock were considered for the modelling of the topographic effect. The magnetization vector was assumed to be parallel to the present geomagnetic field provided by the IGRF ($D = -8°$, $I = 38°$).

The anomaly due to the uniformly-magnetized relief was removed from the original magnetic anomaly map. The residual map is shown in fig. 5.

### 4.2. *Reduction to the pole*

The transformation that converts the original magnetic map (measured in a place characterized by a declination and an inclination of the main field) into the one that would be obtained at the north magnetic pole is widely applied in magnetics (Baranov, 1957). The result is a map where the relation between anomaly and source is more direct. Magnetic anomaly maps are usually very complex, especially in young volcanic areas, and reduction to the pole is a useful tool in the simplification of the maps. However, some assumptions must be adopted to perform this transformation. First of all, a constant direction for the magnetization vector is needed, and in some cases this may not be realistic. On the other hand, it is neces-

**Table I.** Magnetic properties of representative rocks of Tenerife. $\chi_M$ is average magnetic susceptibility, $M_{IND}$ is induced magnetization (assuming a magnetic field intensity of 30.7 Am$^{-1}$), *NRM* is natural remanent magnetization (data from Carracedo, 1979), $M_{TOT}$ is the sum of induced plus remanent magnetization, if they are assumed to be parallel, and $Q$ is the Koenigsberger ratio.

| Rock Type | $\chi_M$ ($10^{-3}$ SI) | $M_{IND}$ (Am$^{-1}$) | *NRM* (Am$^{-1}$) | $M_{TOT}$ (Am$^{-1}$) | $Q$ |
|---|---|---|---|---|---|
| Basalt | 22.0 | 0.68 | 5.41 | 6.08 | 7.9 |
| Trachybasalt | 9.8 | 0.30 | 4.04 | 4.34 | 13.5 |
| Phonolite | 4.4 | 0.13 | 0.66 | 0.80 | 5.1 |
| Trachyte | 5.7 | 0.17 | – | – | – |
| Basanite | 28.0 | 0.86 | – | – | – |

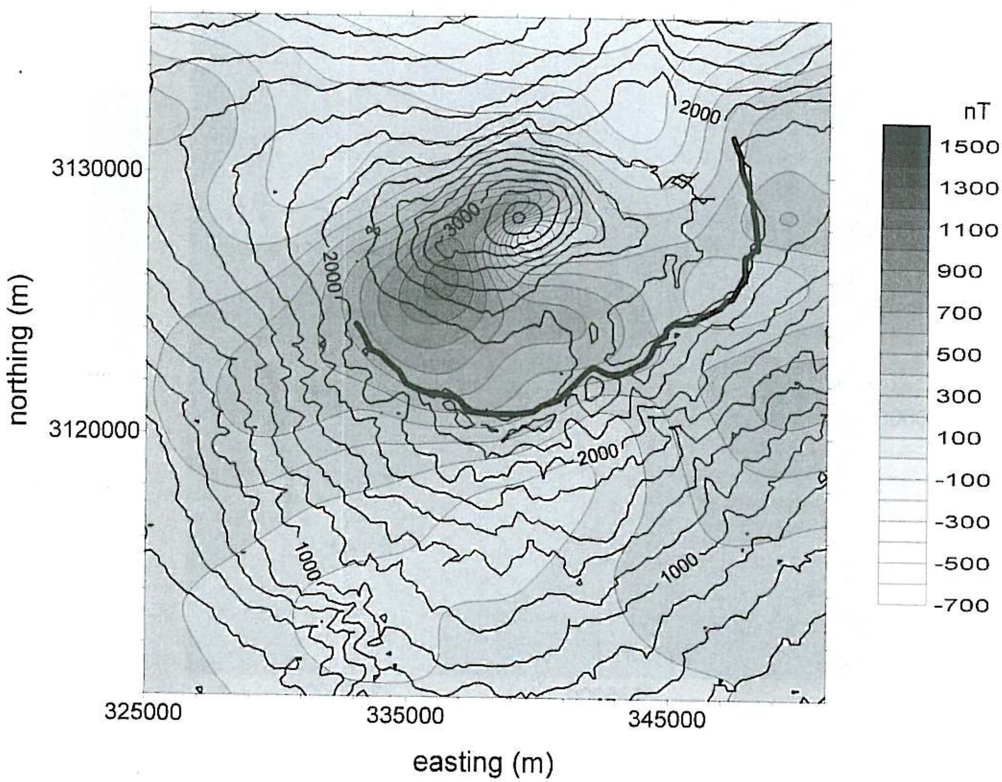


**Fig. 5.** Residual map obtained after subtracting the effect of the relief from the original anomaly.

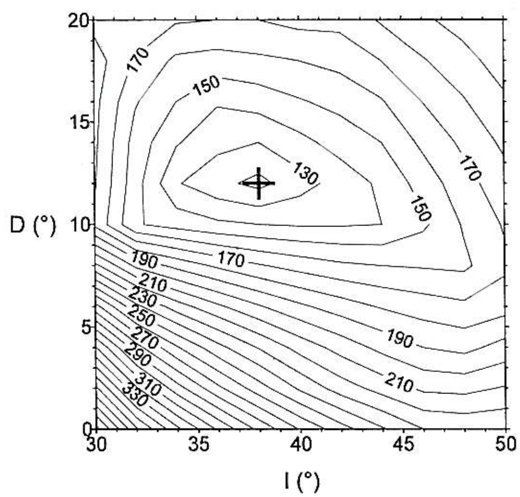


Fig. 6. Distortion analysis of the magnetic anomalies to estimate the direction of the magnetization. The cross mark indicates the obtained values of declination and inclination which correspond to the lowest absolute value of the minimum of the anomaly ($D = 12 \pm 2°$, $I = 38 \pm 2°$).

sary to assign a certain constant direction to the Earth's main field, that is usually valid for studies of local scale. To estimate the direction of the total magnetization vector, a distortion or shape analysis of the magnetic anomalies has been made (Fedi *et al.*, 1994): when the reduction to the pole is calculated using the correct values of inclination and declination of the magnetization, the low of the anomaly created

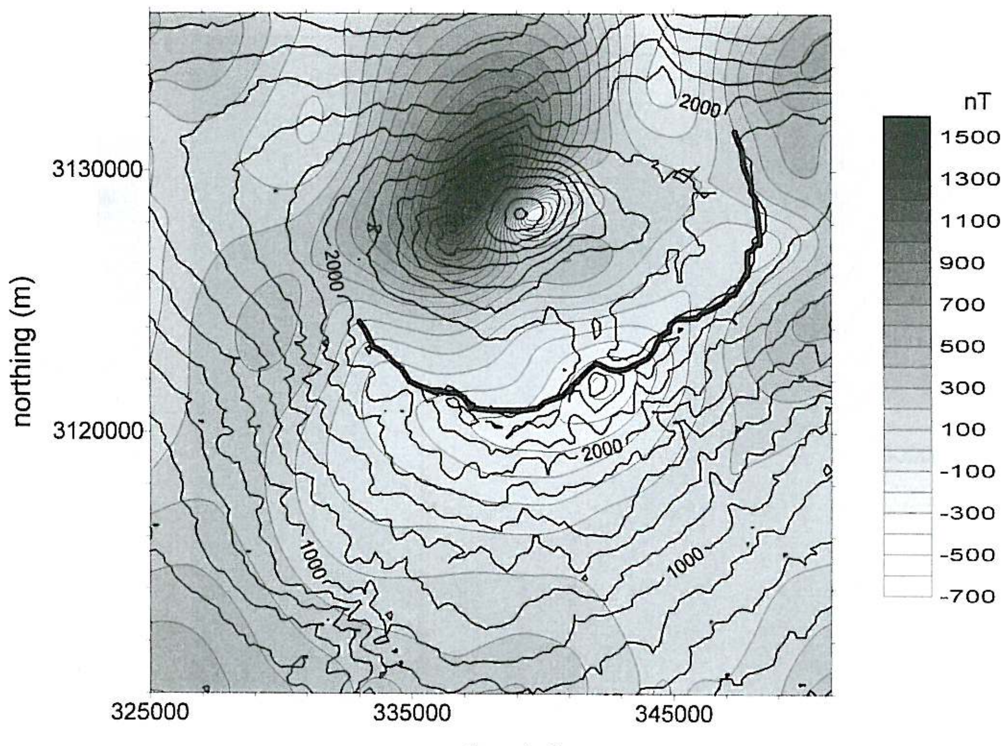


Fig. 7. Reduced to the pole residual magnetic map when the direction of the magnetization is given by $D = 12°$ and $I = 38°$ (obtained through the shape analysis of the anomalies).

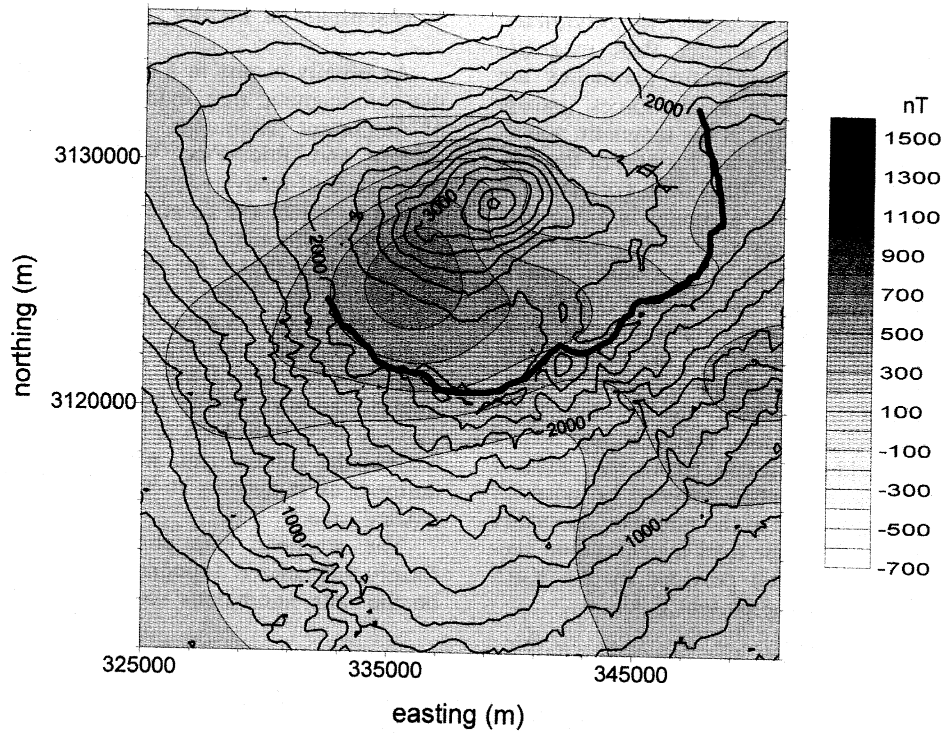


**Fig. 8.** Upward continuation to 5 km a.s.l. of the magnetic anomaly map.

by a body characterised by a positive magnetization contrast reaches its minimum absolute value. Therefore, the calculation of the reduction to the pole for different declination-inclination pairs will provide the real direction of the magnetization vector when the minimum absolute value for the low is found. The main anomaly, that is, the one that presents a high to the south of Pico Viejo and a low to the north of Teide (see fig. 3) was considered for this analysis. The result is that the magnetization vector is characterised by a declination of $12 \pm 2°$ and an inclination of $38 \pm 2°$ (fig. 6). For the Earth's field, we assumed the direction provided by the IGRF ($D = -8°$, $I = 38°$). Reduction to the pole was applied to the residual map (fig. 7). By *residual* we mean the difference between the original anomaly and the anomaly due to the relief characterized by a constant magnetization of 5 $\mathrm{Am^{-1}}$.

### 4.3. *Upward continuation*

The continuation of a potential field anomaly map to a height which is more distant from the source filters short-wavelength anomalies, usually linked to shallow structures. Therefore, the anomalies due to larger and deeper sources appear more clearly. In order to enhance these anomalies, we performed the upward continuation of the residual anomaly map to a height of 5 km a.s.l. (fig. 8).

### 4.4. *Pseudogravity*

This transformation, first introduced by Baranov (1957), provides the «gravity» map under the assumption that gravimetric and magnetic anomaly sources coincide, and is based on Poisson's relation. The interpretation of the resulting map is easier, as gravimetric anomalies are much simpler than magnetic ones. For example, magnetic anomalies are shifted with respect to their sources (except when they are measured at the magnetic poles), while gravity anomalies are located in the vertical of their sources. This shift correction is also obtained when the anomaly is reduced to the pole. Pseudogravity is indeed useful when a gravity anomaly map of the same area is available. The comparison between gravity and pseudogravity may help to determine if magnetic and gravity sources are the same or not. This transformation was applied to the residual magnetic data (fig. 9). As for the reduction to the pole, the direction of total magnetization and of the Earth's field are needed. Again, the values of declination and inclination obtained by means of the distortion analysis of the magnetic anomalies were considered for the total magnetization vector, while the direction provided by the IGRF was considered for the present field.

## 5. Discussion of results

As usually occurs in a recent volcanic area, the aeromagnetic map evidences the existence of important anomalies over Las Cañadas caldera and Teide-Pico Viejo complex. The techniques of analysis applied to the data have helped to relate the anomalies to the volcanic structures, although it is necessary not to neglect the hypotheses we made to simplify the real situation and the limitations they imply.

In the original aeromagnetic map (fig. 3) it is easy to distinguish a large maximum in the southwestern part of the caldera and a minimum to the north of the Teide-Pico Viejo complex. A secondary high is detected to the east, outside the caldera rim, which is not as well defined, as it appears in the boundary of the studied area.

The magnetic map obtained when a uniformly-magnetized topography is assumed to be the only anomalous source shows the im-

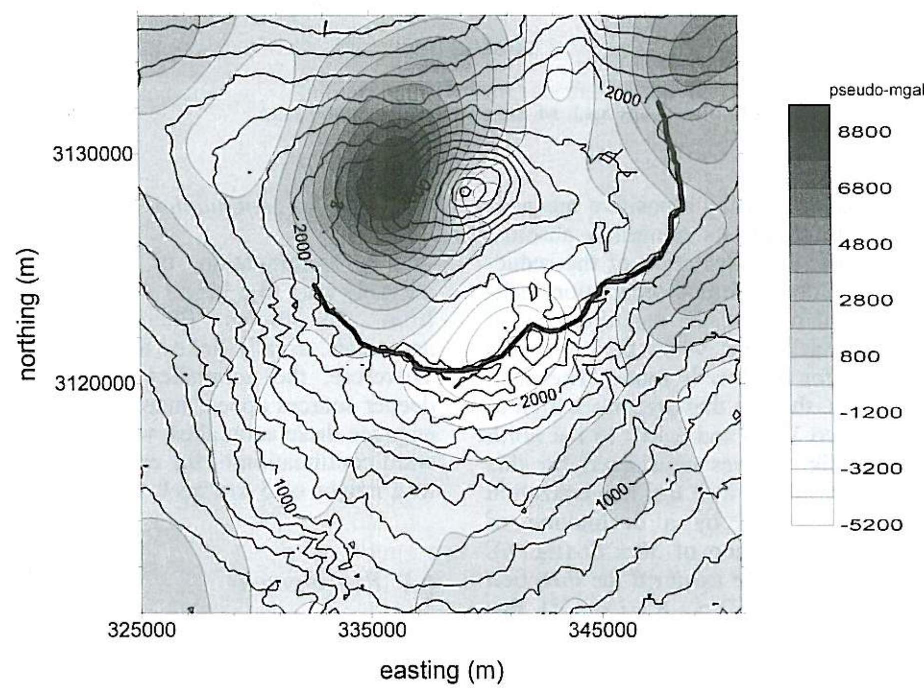


**Fig. 9.** Pseudogravity integration of the residual magnetic anomaly map when the direction of the magnetization is given by $D = 12°$ and $I = 38°$ (obtained through the shape analysis of the anomalies).

portance of the relief of the Teide-Pico Viejo complex (fig. 4). Therefore, it is likely that some of the anomalies not directly related with the topography are masked by the relief effect. In fact, when this is removed the magnetic map changes considerably (fig. 5). The residual anomalies are due to deep structures and to shallow bodies with magnetizations different from 5 $Am^{-1}$, which was taken as reference. It is essential to take into account during their interpretation that the aeromagnetic survey was carried out at a constant altitude of 3810 m. This means that the aircraft passed at 100 m over Teide peak, but at more than 1800 m over the caldera floor. Consequently, a shallow structure within the Teide cone will be reflected in the magnetic map as an anomaly much more intense than if it were emplaced beneath the caldera floor. It is shown, for example, that the major part of the northern minimum could be explained by the unevenness of the relief. However, the large anomaly of the southwest of the caldera is still present, although its magnitude has logically decreased. The direction of the La Dorsal fracture, SW-NE, is clearly observed. It is interesting to note that a small magnetic low appears near the summit of Teide.

When the magnetic map is reduced to the pole, anomalies are shifted to the vertical of their sources (fig. 7). The small minimum mentioned is now located over the Teide peak. Its short wavelength and intensity seem to indicate a very shallow origin. We had seen, from field measurements and other author's data, that phonolites are characterized by very low susceptibility and remanent magnetization compared with other types of rocks (table I). The shallowest materials of Teide-Pico Viejo are phonolitic (Ablay and Martí, 1995). The small negative anomaly over Teide indicates that very slightly-magnetized phonolites (with a magnetization much lower than 5 $Am^{-1}$) are present and that, in some way, they must be different from those overlying Pico Viejo. On the other hand, the strong maximum appears now centered over the northern slopes of Pico Viejo. Both its intensity and size imply a strongly-magnetized source buried at some depth. The upward continuation of the magnetic map confirms these conclusions (fig. 8). On one hand, the small anomaly over Teide peak disappears, and this is proof of its shallow character. On the other hand, the large high near Pico Viejo is still present, although logically smoothed. This anomaly covers the northern part of the caldera and could be related to the basaltic intrusion responsible for the last eruptions in Tenerife. We can also see that the southern caldera boundary is clearly outlined by a linear magnetic high centered over the caldera wall, reaching its maximum value over the peak of Guajara.

Regarding pseudogravity (fig. 9), the resulting map is very similar to the reduced to the pole one, although anomalies have been smoothed (this is expected as pseudogravity attenuates high wavenumbers). The caldera limit is not so clearly marked, but a broad low appears in the zone of Guajara. As a preliminary approach, the qualitative comparison between the pseudogravity and the Bouguer anomaly map of Las Cañadas area (Camacho *et al.*, 1991) yields a good correlation between magnetic and gravity sources.

## 6. Conclusions and future work

This preliminary analysis carried out with the aeromagnetic data of Las Cañadas caldera, including the Teide-Pico Viejo complex, has provided a new insight into the structure of this interesting active volcanic area. The main results obtained to date are the following:

– the rugged topography of the area is responsible for many of the measured magnetic anomalies;

– a large magnetic high appears centered to the north of Pico Viejo and covering the northern part of the caldera. This anomaly could be related to a basaltic intrusion responsible for the last eruptions of the Pico Viejo area (*e.g.*, Las Narices del Teide);

– a small magnetic low is located over the summit of Teide. This seems to be caused by very low-magnetized shallow phonolites, different from the ones of Pico Viejo;

– the SW-NE tectonic direction, parallel to the La Dorsal fault, is reflected on the magnetic maps;

– a secondary magnetic high appears outside the eastern caldera limit. It seems to be caused by a structure characterised by a positive magnetization contrast, although it is not well defined, as it coincides with the boundary of the magnetic map;

– the comparison between the pseudogravity and the Bouguer anomaly map indicates a good correlation between magnetic and gravity sources.

Future work will take into account the correction of the topographic effect considering different magnetizations for each area. Also, the magnetic data of Las Cañadas area will be completed with those of the entire island and of the marine survey that has recently been carried out. Finally, the joint interpretation of both magnetic and gravimetric anomalies will provide an integrated geophysical model of the subsurface structure of Teide.


## Acknowledgements

The authors are indebted to A. Galdeano for providing his routines to transform the anomaly maps and to S. Macmillan and D.R. Barraclough for their adapted version of the same routines. R.J. Blakely is also acknowledged for providing his program PFMAG3D to estimate the terrain effects.


*REFERENCES*


ABLAY, G.J. and J. MARTÍ (1995): Stratigraphy and structure of the Teide-Pico Viejo volcanic complex, in *A Field Guide to the Central Volcanic Complex of Tenerife (Canary Islands)*, edited by J. MARTÍ and J. MITJAVILA, Serie Casa de los Volcanes No. 4, Cabildo Insular de Lanzarote, 47-80.

ANCOCHEA, E., J.M. FÚSTER, E. IBARROLA, A. CENDRERO, J. COELLO, F. HERNAN, J.M. CANTAGREL and C. JAMOND (1990): Volcanic evolution of the island of Tenerife (Canary Islands) in the light of new K-Ar data, *J. Volcanol. Geotherm. Res.*, **44**, 231-249.

ANCOCHEA, E., J.L. BRÄNDLE and M.J. HUERTAS (1995): Alineaciones de centros volcánicos en la isla de Tenerife, *Geogaceta*, **17**, 56-59.

ARAÑA, V. and R. ORTIZ (1991): The Canary Islands: tectonics, magmatism and geodynamic framework, in *Magmatism in Extensional Structural settings. The Phanerozoic African Plate*, edited by A. KAMPUNZU and P. LUBALA (Springer-Verlag, London), 209-249.

BARANOV, V. (1957): A new method for interpretation of aeromagnetic maps: pseudo gravimetric anomalies, *Geophysics*, **22**, 359-383.

BLAKELY, R.J. (1981): A program for rapidly computing the magnetic anomaly over digital topography, *U.S. Geological Survey Open-File Report*, 81-298.

CAMACHO, A.G., R. VIEIRA and C. DE TORO (1991): Microgravimetric model of the Las Cañadas caldera (Tenerife), *J. Volcanol. Geotherm. Res.*, **47**, 75-88.

CARRACEDO, J.C. (1979): *Paleomagnetismo e Historia Volcánica de Tenerife*, Aula de Cultura de Tenerife, Sta. Cruz de Tenerife, pp. 82.

COELLO, J. and T. BRAVO (1989): Lineamientos volcanotectónicos en la región central de Tenerife, in *Los Volcanes y La Caldera del Parque Nacional del Teide (Tenerife, Islas Canarias)*, edited by V. ARAÑA and J. COELLO (ICONA, Madrid), 127-135.

EMERY, K.O. and E. UCHUPI (1984): *The Geology of the Atlantic Ocean* (Springer-Verlag, New York), pp. 1020.

FEDI, M., G. FLORIO and A. RAPOLLA (1994): A method to estimate the total magnetization direction from a distortion analysis of magnetic anomalies, *Geophys. Prospecting*, **42**, 261-274.

FÚSTER, J.M., V. ARAÑA, J.L. BRÄNDLE, M. NAVARRO, U. ALONSO and A. APARICIO (1968): *Geología y Volcanología de las Islas Canarias: Tenerife*, Instituto «Lucas Mallada», CSIC, Madrid, pp. 218.

GARCÍA MORAL, R. (1989): Erupciones históricas en Tenerife, in *Los Volcanes y la Caldera del Parque Nacional del Teide (Tenerife, Islas Canarias)*, edited by V. ARAÑA and J. COELLO (ICONA, Madrid), 235-249.

GIBERT, D. and A. GALDEANO (1985): A computer program to perform transformations of gravimetric and aeromagnetic surveys, *Comput. Geosci.*, **11**, 553-588.

IGME (1968): Mapa geológico escala 1:100000 de la isla de Tenerife.

MARTÍ, J., J. MITJAVILA and V. ARAÑA (1994a): Stratigraphy, structure and geochronology of the Las Cañadas caldera (Tenerife, Canary Islands), *Geol. Mag.*, **131**, 715-727.

MARTÍ, J., G.J. ABLAY, L. REDSHOW and R.S.J. SPARKS (1994b): Experimental studies on collapse calderas, *J. Geol. Soc.*, **151**, 914-929.

MARTÍ, J., J. MITJAVILA and V. ARAÑA (1995): The Las Cañadas edifice and caldera, in *A Field Guide to the Central Volcanic Complex of Tenerife (Canary Islands)*, edited by J. MARTÍ and J. MITJAVILA, Serie Casa de los Volcanes No. 4, Cabildo Insular de Lanzarote, 19-38.

MEZCUA, J., E. BUFORN, A. UDÍAS and J. RUEDA (1992): Seismotectonics of the Canary Islands, *Tectonophysics*, **208**, 447-452.

PARKER, R.L. (1972): The rapid calculation of potential anomalies, *Geophys. J. R. Astron. Soc.*, **31**, 447-455.