A search for the volcanomagnetic signal at Deception volcano (South Shetland I., Antarctica)

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Abstract
After the increase in seismic activity detected during the 1991-1992 summer survey at Deception Island, the continuous measurement of total magnetic intensity was included among the different techniques used to monitor this active volcano. The Polish geomagnetic observatory Arctowski, located on King George Island, served as a reference station, and changes in the differences between the daily mean values at both stations were interpreted as indicators of volcanomagnetic effects at Deception. A magnetic station in continuous recording mode was also installed during the 1993-1994 and 1994-1995 surveys. During the latter, a second magnetometer was deployed on Deception Island, and a third one in the vicinity of the Spanish Antarctic Station on Livingston Island (at a distance of 35 km) and was used as a reference station. The results from the first survey suggest that a small magma injection, responsible for the seismic re-activation, could produce a volcanomagnetic effect, detected as a slight change in the difference between Deception and Arctowski. On the other hand, a long term variation starting at that moment seems to indicate a thermomagnetic effect. However the short register period of only two stations do not allow the sources to be modelled. The future deployment of a magnetic array during the austral summer surveys, throughout the volcano, and of a permanent geomagnetic observatory at Livingston I. is aimed at further observations of magnetic transients of volcanic origin at Deception Island.

Key words *Deception Island – volcanomagnetic signals – Antarctica*

1. Introduction

Volcanomagnetic signals have been observed in several volcanoes all over the world (Johnston and Stacey, 1969; Davis *et al.*, 1973; Zlotnicki, 1986; Zlotnicki and Le Mouel, 1988; Zlotnicki *et al.*, 1993; Yukutake *et al.*, 1990; Sasai *et al.*, 1990; Tanaka, 1993). Local variations of the Earth's magnetic field in volcanic areas can have different origins: thermal re-magnetization or demagnetization processes (thermomagnetic effect), changes in both the induced and the remanent magnetization of the rocks caused by a change in the local stress field (piezomagnetic effect) or variations in the fluid circulation system within the volcano (electrokinetic effect). The small amplitude of these signals (a few nT) compared with the rest of the components of the geomagnetic field

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makes it quite difficult to isolate and to identify the signals that are intrinsically linked to endogenous changes in the volcanic system.

Deception Island (62.93°S, 60.57°W) is a young volcano located over the spreading axis of the Bransfield Rift, near the Antarctic Peninsula, and it is one of the few foci of volcanic activity in Antarctica (fig. 1). Deception volcano has been very active throughout its evolution, although different periods of activity can be distinguished (González-Ferrán *et al.*, 1971; Baker and Roobol, 1975). The last eruptions took place in 1967, 1969 and 1970, destroying the British and Chilean scientific stations. Since 1986, a Spanish research group, supported by the National Program on Antarctic Research, and an Argentinean research group supported by the Argentinean Antarctic

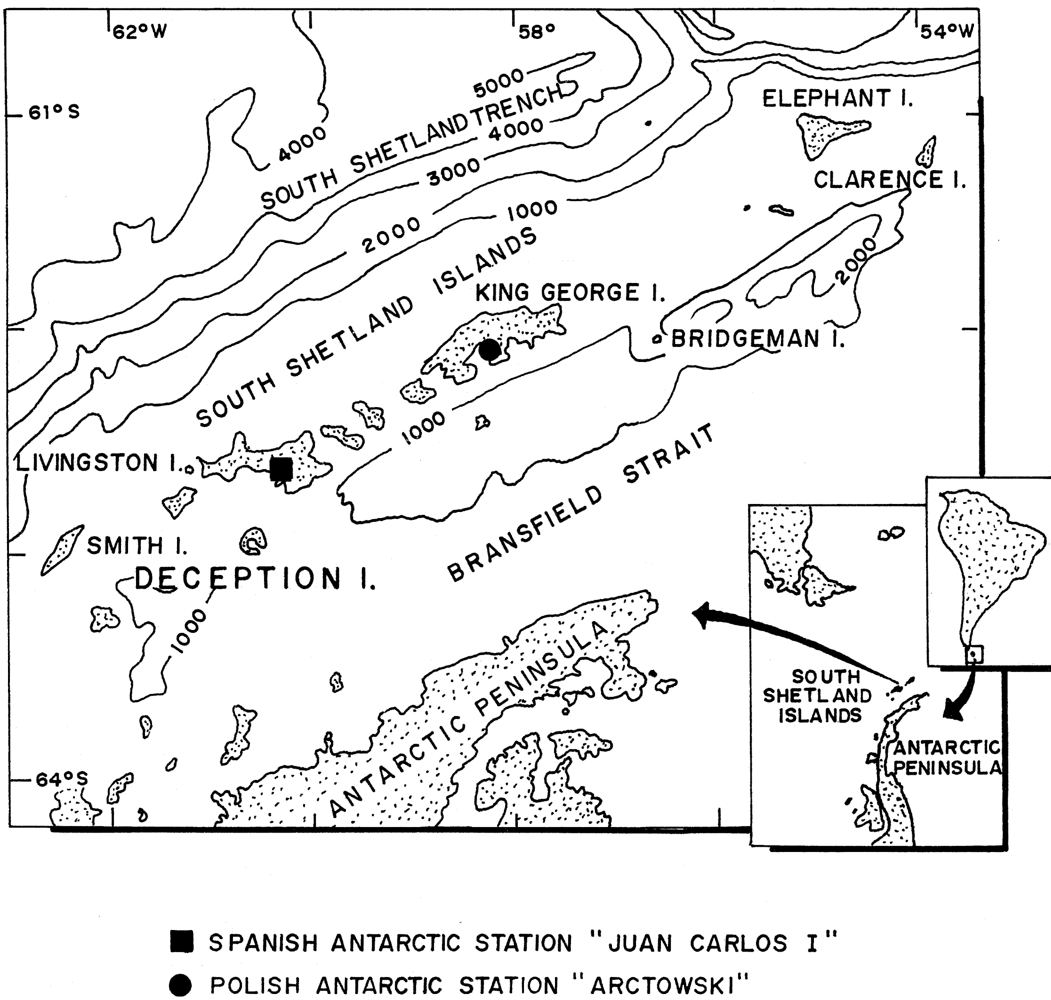


Fig. 1. Map of the Bransfield Sea and the South Shetland Islands (from Vila *et al.*, 1992). Locations of the Spanish Antarctic Station «Juan Carlos I», at Livingston I., and of the Polish Antarctic Station «Arctowski», at King George I., are indicated.

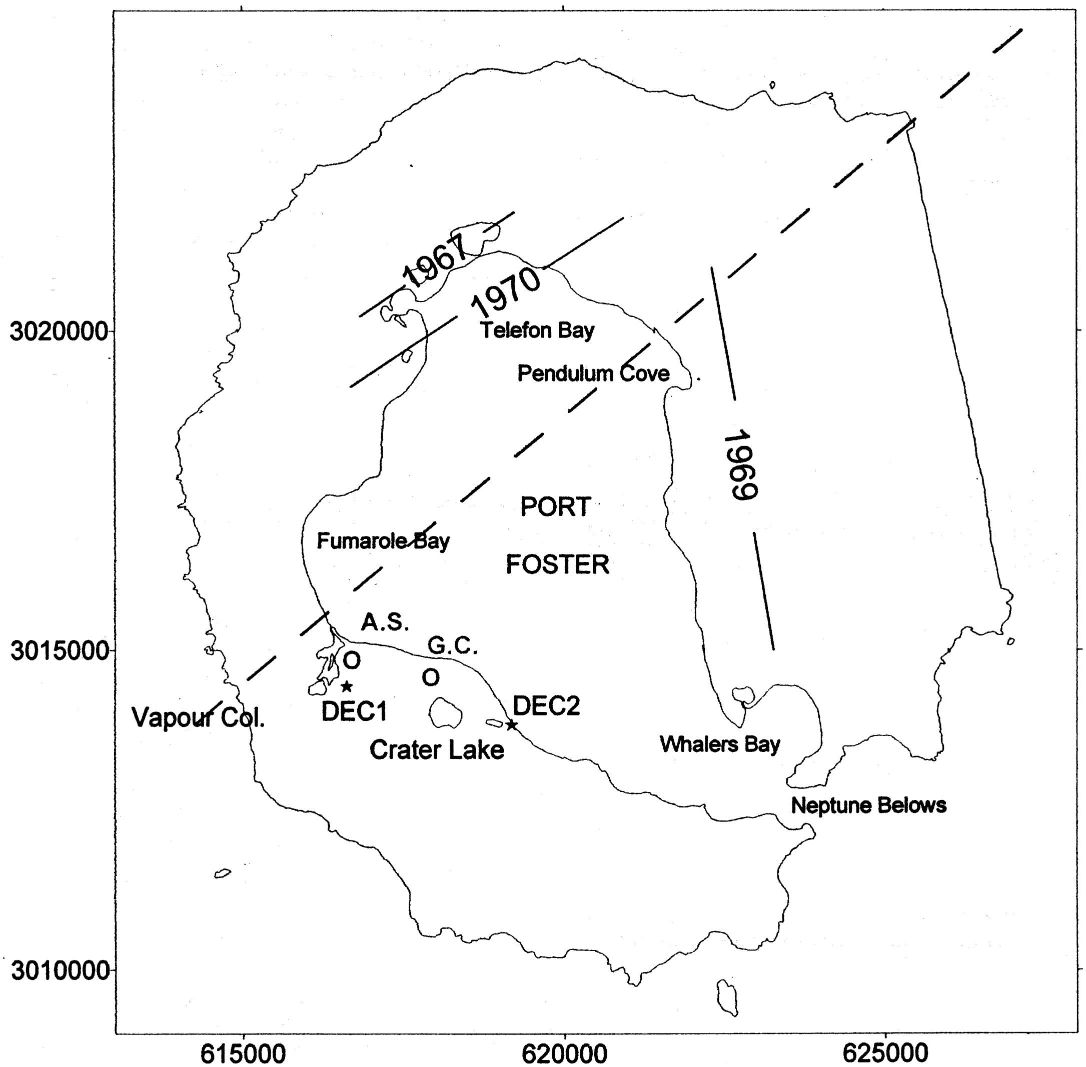
Institute, have been responsible for geophysical and volcanological research at Deception, which is typically carried out every summer (from December to March). Monitoring of volcanic activity comprises the study of the seismic activity, the sampling and analysis of the fumarolic gases, the continuous recording of Earth tides, the estimation of the deformation and the control of the superficial thermal anomalies (see SEAN *Bulletin* vol. 16, No. 5 and vol. 17, No. 1). During the 1991-1992 survey, an abnormal increase in seismic activity was detected compared with the earlier campaigns. From that time, the continuous recording of the total magnetic intensity was included among the monitoring techniques. The objective was to find out if the changes that were taking place in the volcanic system would be the source of volcanomagnetic signals that could be detected with our instruments. In this paper, we present the first results obtained after an analysis of the magnetic data recorded during the 1991-1992, 1993-1994 and 1994-1995 antarctic surveys.

2. Geo-volcanological setting

Deception Island (fig. 2) is a young horseshoe-shaped stratovolcano (< 0.75 Ma), 25 km in submerged basal diameter and about 15 km in diameter for the emerged zone (Smellie, 1988). The present-day tectonic structure of Deception Island is defined by a nearly orthogonal normal fault system. The set of faults oriented NE-SW can be interpreted as a result of back-arc spreading in the Bransfield Strait, whereas the N-S normal faults could be the consequence of the previous tectonic situation combined with compression exerted by subduction at the South Shetland Trench (Martí and Baraldo, 1990). This fault system seems to have been a significant controlling factor on the distribution of volcanic activity during the evolution of the island. Most of these faults are still active, as deduced from microseismicity analyses (Vila *et al.*, 1992). The geophysical features of the island are based on gravimetric and magnetic studies. Gravimetric and magnetic anomalies do not show the circular structure typical of classic volcanic calderas. Otherwise they reveal linear trends over the NE-SW direction (minimum gravimetric anomaly) and over a NNW-SSE conjugate direction (large minimum magnetic anomaly) (Ortiz *et al.*, 1992).

One significant aspect in the geology of Deception Island is the existence of several shallow and confined water-saturated layers. These aquifers have been inferred from the presence of hydrothermally altered lithic clasts in the pyroclastic deposits (Martí and Baraldo, 1990) and by the study of the chemical composition of low-temperature fumaroles and thermal springs which occur at different points of the island (Martini and Giannini, 1989). The formation of these aquifers would be favoured by the existence of sea water in the central part of the island, and also by the high thermal gradient characteristic of Deception, which favoured the melting of snow and percolation and accumulation of fresh water through the pyroclastic deposits.

Fumarolic emissions, thermal springs, hot soils and constant seismic activity are witness to Deception's present volcanic activity. These phenomena are mainly extended over the main fracture, which crosses the island in a NE-SW direction (from Fumarole Bay to Pendulum Cove). The distribution of seismic events clearly emphasizes the activity of this fracture. Successive surveys have shown that seismic activity has almost remained stationary from 1987, but two exceptions are noteworthy (see SEAN *Bulletin* vol. 13, No. 2; vol. 14, No. 3; vol. 15, No. 3, vol. 16, No. 5; vol. 17 Nos. 1,2 and vol. 20, No. 4). In January 1992 an important increase in the number and magnitude of the events was detected. A total of 766 seismic events were recorded by a three component and vertical seismic equipment emplaced close to the Argentinean Station. The temporal distribution of the events shows how these appear in clusters which may last for several days. More than half of the recorded events were followed by another event of similar characteristics in less than an hour. About the location of the swarm, it is only possible to say that the events were superficial and close to the stations, due to have very impulsive arrivals. During the sur-



--- 1967 --- Location of the last eruptions
A.S. Argentinean Station
G.C. Spanish Station "Gabriel de Castilla"
DEC1 Location of magnetic station Deception 1
DEC2 Location of magnetic station Deception 2
— — Main tectonic direction

Fig. 2. Map of Deception Island.

vey four seismic events were felt, all of them with a magnitude higher than 3 (Ortiz *et al.*, 1997). The crises started on 31 December and ended on 25 January. Gravity recordings showed an increase (0.5 mgal) until the 30 January and a decrease from that time till the end of the campaign, on 22 February. Small gravity irregularities correlated with successive seismic swarms. The area covered by the hot soils seems to have become more extensive since 1992, comparing it with the observations of earlier surveys. In Fumarole Bay an enrichment of sulphur compounds has been noted. Also, an important deformation process seems to have taken place in the Fumarole Bay area, although it has not been possible to measure it accurately. All these factors lead to the conclusion that a magmatic injection took place during this period, giving rise to an intrusion which did not reach the surface (Ortiz *et al.*, 1992, 1997). During the 1992-1993 and 1993-1994 surveys, the seismic activity decreased to the level before 1991-1992 (Risso and Ortiz, 1994). However, in the last campaign 1994-1995, the number of events was similar to that in 1991-1992. Although no earthquake was felt, the events recorded during this last survey are thought to be more energetic than the events recorded during 1991-1992 (see SEAN *Bulletin* 1995, vol. 20, No. 4), but relevant magnetic changes have not been observed.

Taking into account the geo-volcanological characteristics of Deception, it is worth accounting for all the mechanisms which are usually the source of volcanomagnetic signals. Thermal magnetization or demagnetization processes may take place as the result of a shallow magmatic injection or as a consequence of the cooling of the hot magmatic body responsible for the last eruptions, for example. The former, in addition, would produce a change in the stress field, probably giving rise to a piezomagnetic effect. On the other hand, the presence of shallow water-saturated layers implies that an internal change in the volcanic system could be reflected as a variation in the distribution of electric charges within this fluid, producing an electrokinetic signal. All these signals would cause a change in the total magnetic intensity, which is the parameter that was measured.

As described before, it is likely that the 1991-1992 crisis was produced by a shallow intrusion of magma somewhere beneath the Fumarole Bay area. The emplacement of a body at high temperature would be reflected as a decrease in total magnetic intensity (F), while its progressive cooling would cause a relative increase in F as the rocks acquire a thermoremanent magnetization. The sign and amplitude of these anomalous variations depend, of course, on the location of the magnetic station. The optimal way to monitor them is that of deploying a magnetic network.

3. Data acquisition and reduction

In January 1992, a further occurrence of seismic crises led to the control of total magnetic field intensity variations as a one of the geophysical parameters used to monitor of volcanic activity. A proton precession magnetometer, with a resolution of 0.1 nT, was deployed in continuous recording at a sampling rate of 1 datum per minute. For the selection of its emplacement several criteria were considered. First, the proximity to the active area. Second, the accessibility, since the harsh weather conditions in Antarctica often prevent servicing of the instruments for long periods of time. Taking this into account, the magnetometer was installed relatively close to the Argentinean station in the place referred to as DEC1 (62° 58.72 S; 60° 42.05 W) (fig. 2). The quality of recordings is adequate from 25 January till February 20, the last day of the survey, although some gaps exist within this period. In the 1992-1993 survey, logistic problems prevented the magnetometer being installed again. In the 1993-1994 campaign, continuous recording was carried out between December 17 and February 9 at approximately the same location (200 m) as the first time. During the 1994-1995 survey, three magnetometers were available: one of them was installed at the usual location near the Argentinean station; a second one (fig. 2) was deployed at a distance of approximately 3 km southeast of the first one

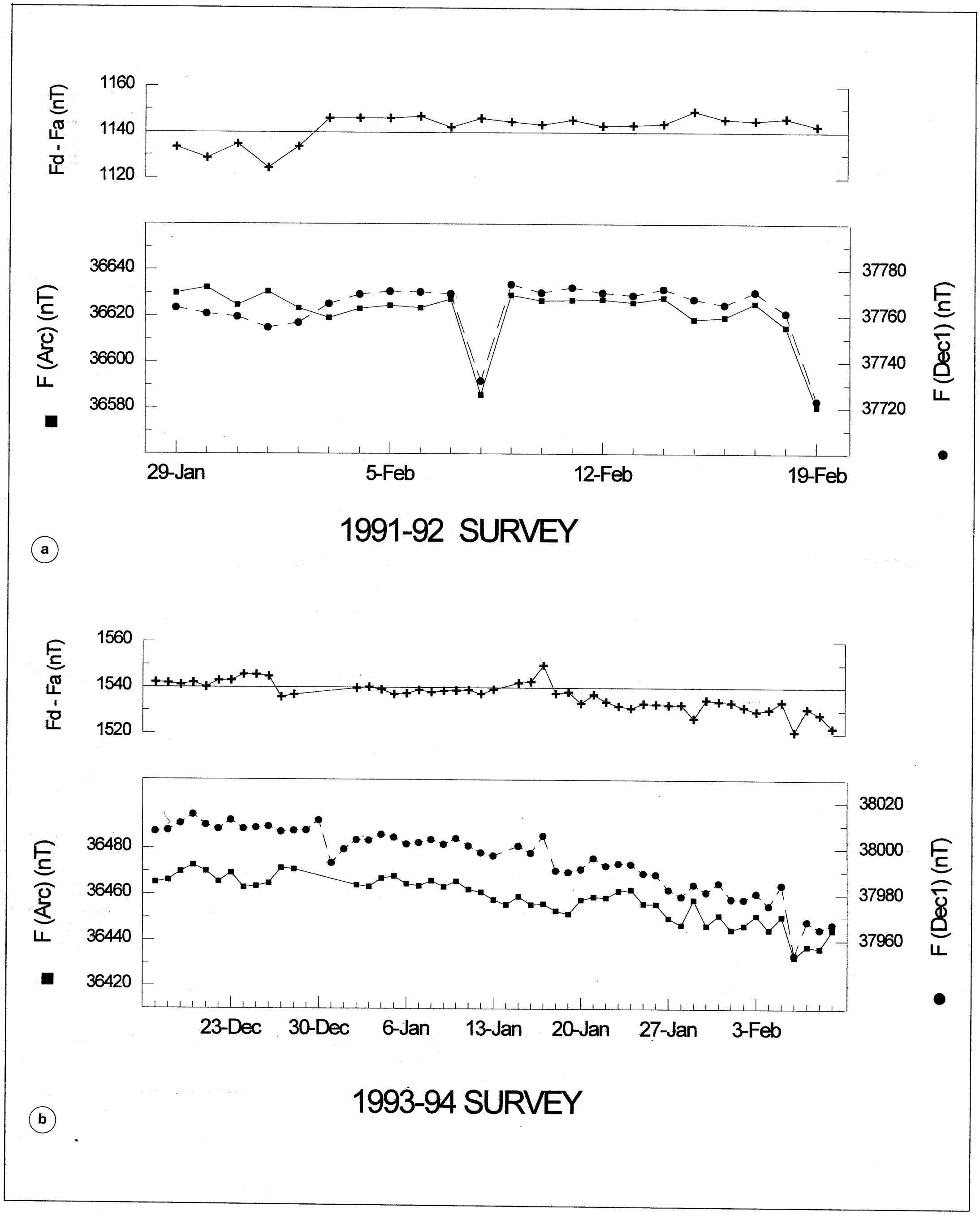


Fig. 3a.b. *F* daily mean value differences between DEC1 and ARC during the 1991-1992 survey (a) and 1993-1994 survey (b).

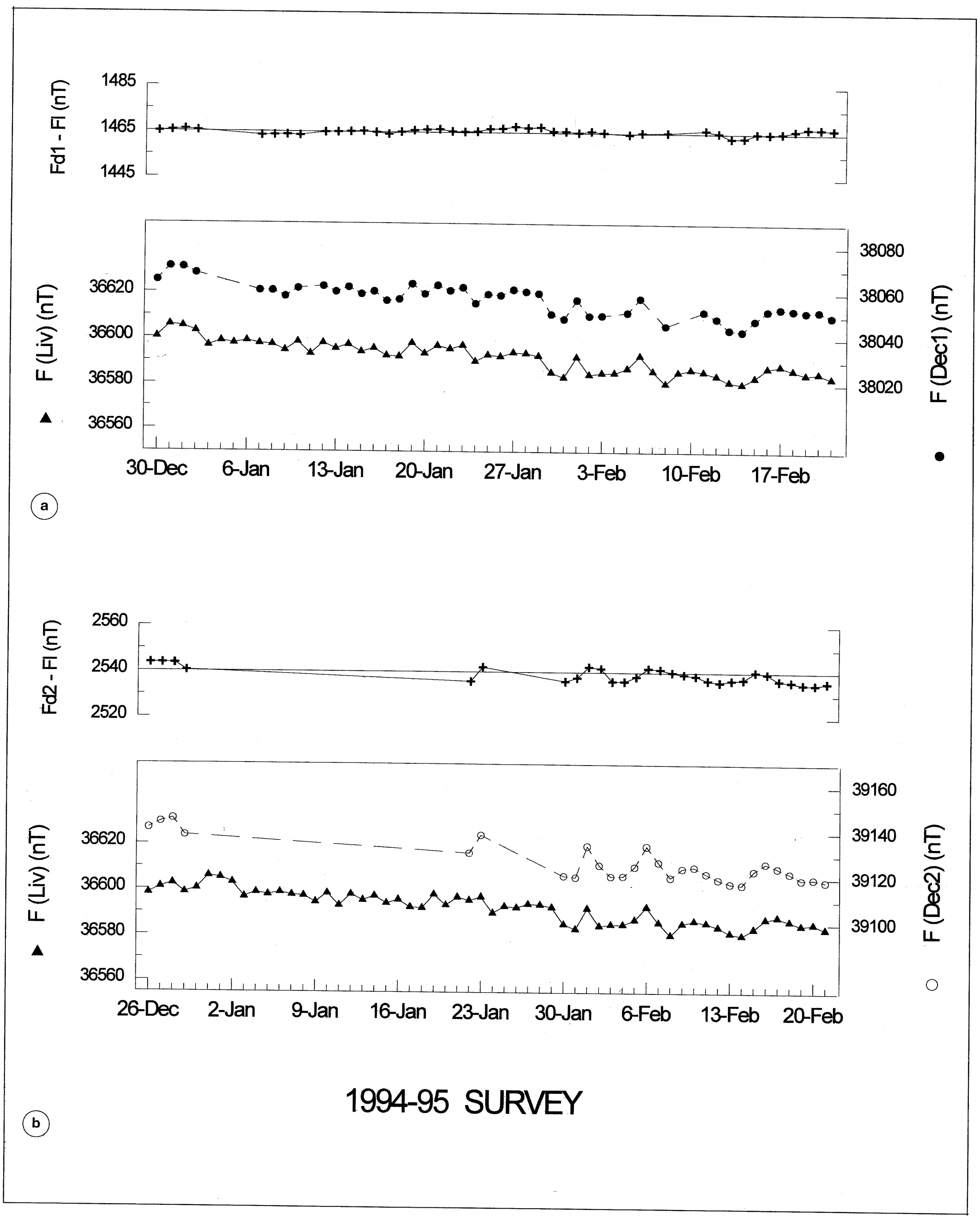


Fig. 4a.b. *F* daily mean value differences between DEC1 and LIV (a), and DEC2 and LIV (b), during the 1994-1995 survey.

(DEC2, 62° 58.84 S, 60° 39.38 W), and the third one was .installed in the immediate vicinity of the Spanish Antarctic Station Juan Carlos I, at Livingston Island, at a distance of 35 km (LIV) (fig. 1). The recorded period for each of these stations was: DEC1: from December 14 to February 21; DEC2: from December 23 to February 21; LIV: from December 26 to February 21.

For the reduction of the magnetic recordings in the first two surveys, we used the data from the Polish observatory Arctowski (ARC), on King George Island, at approximately 150 km from Deception (fig. 1). The processing of the data comprised: the detection and removal of low signal-to-noise ratio periods (detected by comparison with the reference station); the computation of the F daily mean values at each station; the linear fit of the F daily mean value evolution through time (considering the magnetically quiet days only); computation of the F daily mean value differences between DEC1 and ARC and between DEC1, DEC2 and LIV.

4. Discussion of results

During the 1991-1992 survey, a change in the F daily mean value differences between Deception and Arctowski was detected from February 3rd (fig. 3a), nine days after the end of the seismic activity increase, but our data do not allow to distinguish between the possible processes. The period of available records in the 1993-1994 survey (fig. 3b) is longer. Here we can appreciate a long term descending trend in the measured differences, which could indicate a thermomagnetic effect, which seems to finish towards the end of January 1994. Some sporadic increases in activity at Deception were also detected. During the 1994-1995 survey, no significant differences were detected between Deception 1 and Livingston (fig. 4a), but the comparison between Livingston and Deception 2 (fig. 4b) shows different trends especially during the periods of high external geomagnetic activity. Although during this period a large number of earthquakes were recorded, no direct short-term correlation seems to exist between the occurrence of seismic events and the magnetic variations.

The results obtained to date certainly suggest the existence of volcanomagnetic effects on Deception Island, which could be associated with a reactivation of the seismic activity and the likely occurrence of a magma injection. Both long-term (approximately two years) and short-term (several days) variations have been observed. Some logistic difficulties, such as the impossibility of deploying a magnetometer array on the island (to date) and the shortness of the periods (two or three months each year), have prevented accurate characterization of the source bodies and the mechanisms of these effects. For the next summer survey it is planned to install a third fixed station at Deception and a mobile one which will operate for 8-10 days at different points throughout the island. The 1995-1996 and 1996-1997 new data sets will give more realistic results. On the other hand, our project includes the deployment of a magnetic observatory in the Spanish Antarctic Station «Juan Carlos I» at Livingston Island which will be put into operation in 1996. The location of this observatory is the most favourable one for the control of future eruptions in Deception, and will be integrated on the Worldwide Network of Magnetic Observatories

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