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Piezomagnetic effects induced by artificial sources at Mt. Vesuvius (Italy): preliminary results of an experimental survey

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Abstract

In order to put new constrains on magnetic effects associated with mechanical stresses, high frequency monitoring of the geomagnetic field was carried out during a seismic tomography experiment (TOMOVES '96 project) at Mt. Vesuvius. Eight proton precession and one Cesium magnetometers were installed along a profile on the SW flank of the volcano to observe possible magnetic changes induced by explosions. Measurements were performed at different sampling frequencies (10 Hz, 0.5 Hz and 0.1 Hz). A remarkable change in the intensity of the magnetic field was observed in only one case. The magnetic transient lasted 12-13 min, reaching the maximum amplitude of slightly less than 15 nT.

Key words *piezomagnetic effect – artificial sources – Mt. Vesuvius*

1. Introduction

Early warning of eruptions is one of the main goals of volcanology and though the early diagnosis of the volcanic events started as a purely volcanological discipline, it now involves several others Earth science branches. Among the applied geophysical methods, continuous monitoring of telluric and magnetic fields are usually performed. It is generally accepted that an eruption is preceded by intensive crack formation which activates various types of mechano-electric counters and causes electro-magnetic signals (*e.g.*, Gokhberg *et al.*, 1995). If the mechanical energy involved in rock deformation may be the source of electromagnetic phenomena, detectable by measurable signals, these can contribute to the short-term prediction of seismic and volcanic hazards.

Magnetic changes associated with earthquakes and volcanic eruptions have been observed since historical times (*e.g.*, Tanakadate and Nagaoka 1893; Wilson, 1922). Particular attention was reserved to the detection and interpretation of the magnetic changes because of their intriguing nature. Moreover their small magnitude (from a few to tens nT), makes it difficult to single them out from diurnal and other natural magnetic time variations. During the last decades, several interesting results have been obtained using magnetic networks installed on volcanoes. Magnetic changes associated with the volcanic activity may have different nature, they were referred either to

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stress, temperature effects or ground water, or a combination of them. Thermal demagnetization is still considered the main factor for slow magnetic time variations, while piezomagnetic phenomena seem to have been gradually replaced by streaming potential (electrokinetic) effect in explaining swift changes in the magnetic field intensity. Despite so many mechanisms, it is important to distinguish which of them is the most effective for each volcano and for each stage of its activity.

In Italy the first experimental approach dates back to the end of 70s when two magnetic stations continuously recording worked for four years at Mt. Etna volcano (Budetta and Pinna, 1979). The large temporal anomaly (about 10 nT) retrieved in the total geomagnetic field series recorded in 1981 on Mt. Etna was associated with the March 17-23 eruption and was thought to be accounted for by the joint effect of piezomagnetism and thermal demagnetization engendered by a large intrusive dyke (Del Negro *et al.*, 1997a). Later, two tests were carried out at Vulcano: the first, between 1990 and 1992, with two proton precession magnetometers, the second, during the 1994 summer, with three scalar sensors. They aimed at developing a strategy for the elimination of disturbance and the enhancement of signal-to-noise ratios when processing volcanomagnetic signals (Budetta *et al.*, 1993). At present a network of continuous recording proton precession magnetometers is set up on the upper southern flank of Mt. Etna. Geomagnetic changes associated with the renewal of activity of the NE crater were detected during the period from September to December 1995. The center of the magnetic anomaly source, which was supposed to be the region heated by high-temperature fluids and gases originating from fresh magma, was estimated by the spatial distribution of the variation rate at a depth of about 500 m near the 1991-93 eruptive boccas (Del Negro *et al.*, 1997b).

In order to improve our knowledge of piezomagnetic effects associated with mechanical stress, we had the opportunity to undertake continuous magnetic recordings during the bursts provided by the three-dimensional seismic tomography carried out at Mt. Vesuvius, in 1996 summer. In this paper, we furnish an example related to the field research on volcanic-piezomagnetic effect and a preliminary elaboration and discussion of these data.

2. Magnetic data acquisition and analysis

Since its last eruption, in March 1944, Mt. Vesuvius has been in a state of total quiescence, and there are no indications of a possible renewal of its activity. However, during its long eruptive history it recorded many long inactivity periods, in some cases lasting for centuries, followed by Plinian eruptions, and small-sized effusive-explosive episodes (Santacroce, 1987). To understand its future dynamics and the associated risk, a variety of exploration techniques have been performed on Vesuvius. The most recent among them was an experiment of seismic tomography (TOMOVES project) carried out between June 18 and July 2, 1996. Elastic waves were produced by 14 explosions located off-shore and on-shore at distances ranging between 1 and 20 km from the crater of Mt. Vesuvius. The most powerful explosions were executed with 800 kg of explosive. The depth of the latter inside wells was about 100 m.

In order to monitor the magnetic time variations during the land explosions (see table II), magnetic stations continuously recording were in operation on the volcano. Eight Proton Precession Magnetometers (PPM) were installed along a NW-SE profile, at a mean distance of 600 m (fig. 1) for total field measurements.

The station sites along the profile, located on the western side of Mt. Vesuvius at about 600 m a.s.l., were selected by considering the array of explosions, and the local magnetic features of the area; in particular the sites with the lowest noise level were chosen. Magnetic data acquisition was performed at high frequency sampling rate (0.5 Hz and 0.1 Hz)

On June 29, an optically pumped Cesium magnetometer was also installed at CT1 site (fig.1). The day after, the position of this magnetometer was changed in CT2 site close (about 300 m) to B3 and C4 explosion points. The final installation sites are reported in table I

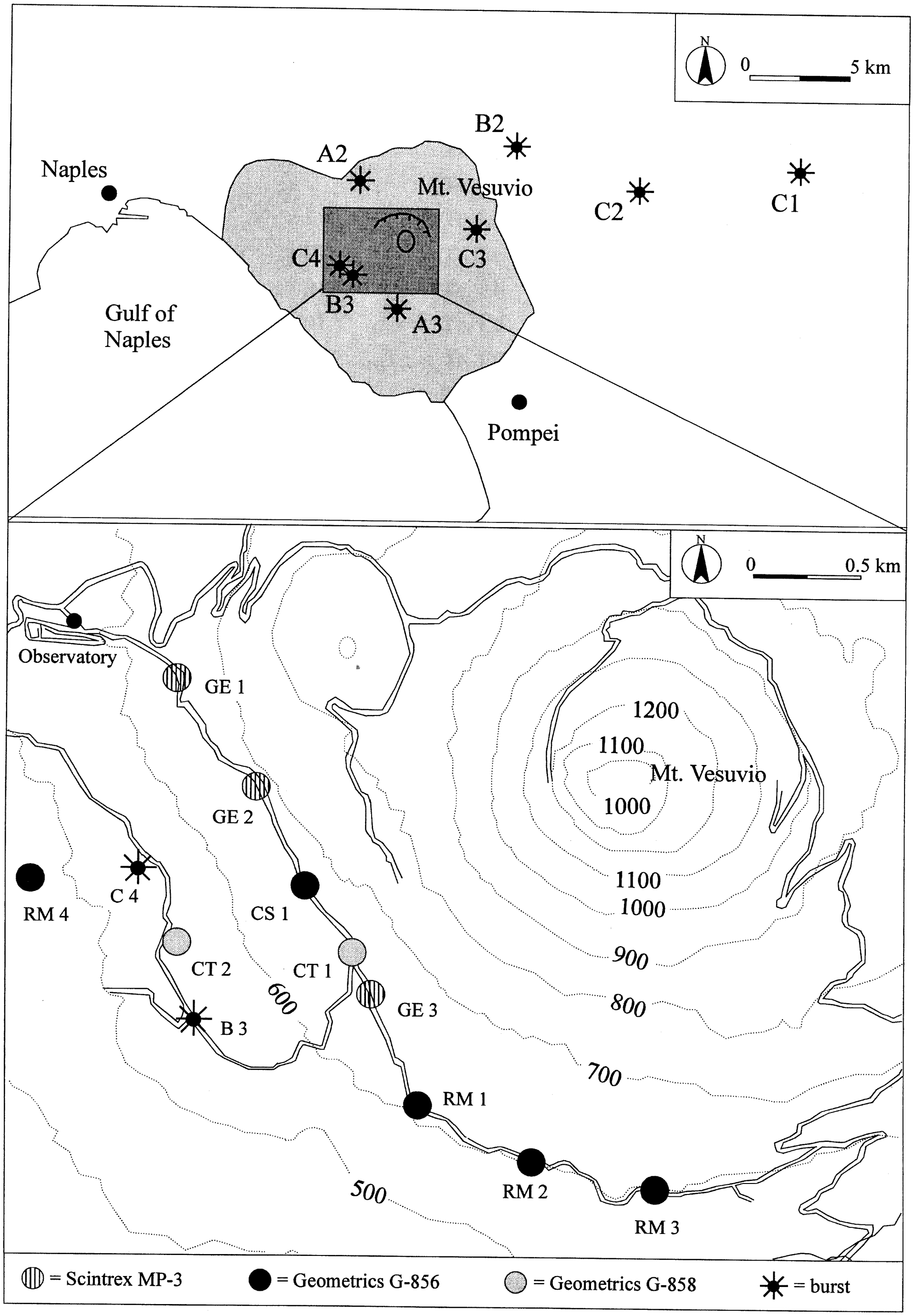

Fig. 1. Location map of bursts and continuously recording stations run on Mt. Vesuvius.

Table I. Magnetic data acquisition system.

Station	PPM magnetometer type	Sensitivity	Sampling rate	Institutions
CS1	Geometrics G-856	0.1 nT	10 s	University of Calabria
GE1	Scintrex MP-3	0.2 nT	2 s	University of Genoa
GE2	Scintrex MP-3	0.2 nT	2 s	University of Genoa
GE3	Scintrex MP-3	0.2 nT	2 s	University of Genoa
RM1	Geometrics G-856	0.1 nT	10 s	ING
RM2	Geometrics G-856	0.1 nT	10 s	ING
RM3	Geometrics G-856	0.1 nT	10 s	ING
RM4	Geometrics G-856	0.1 nT	10 s	ING
CT1/2	Cesium Geometrics G-858	0.001 nT	0.1 s	IIV

Table II. TOMOVES'96 project: calendar of land explosions.

Solar time	18:00	19:30
June 28, 1996 – Friday	C2 (500 kg)	C1 (800 kg)
June 29, 1996 – Saturday	A3 (500 kg)	A2 (500 kg)
June 30, 1996 – Sunday	B2 (250 kg)	B3 (500 kg)
July 1, 1996 – Monday	C3 (500 kg)	C4 (500 kg)

together with the magnetometer characteristics. The measurements lasted four days, from the afternoon of June 28, some hours before the C2 explosion, to the night of July 1, some hours after the C4 explosion (table II).

The magnetic field total intensity values measured along the profile and corrected by the time variations, using as reference the Geomagnetic Observatory of L'Aquila (Central Italy), are shown in figs. 2, 3, 4 and 5. Because of instrumental problems and/or unexpected anthropic noise, only high quality recordings were reported in these figures. This data processing disclosed that an anomalous change of magnetic field took place simultaneously to only one explosion. In particular, at each station of the profile in correspondence to the A2 explosion (7:30 p.m. of June 29) a rapid increase of about 10-15 nT in the total intensity of the magnetic field (fig. 3) and a recovery to the primitive range of values after 10-13 min was clearly observed.

Figure 6 shows the measurements executed on June 29, 30 and July 1 with the high sensitivity Cesium magnetometer. The performance of this instrument such as high resolution (0.001 nT), high gradient tolerance (25 μT/m) and high frequency (0.1 s), furnished a signal of high quality. Also in this case a remarkable change was observed only associated with the A2 explosion.

3. Discussion and conclusions

The existence of magnetic changes associated with the explosions might be ascribed to two different effects related to piezomagnetism and electrofiltration. These effects are indeed strictly connected to each other: a change of stress field can modify both natural and induced rock magnetization (piezomagnetic effect, Martin *et al.*, 1978; Zlotnicki *et al.*, 1981), and nets of interconnected pores (microcracks,

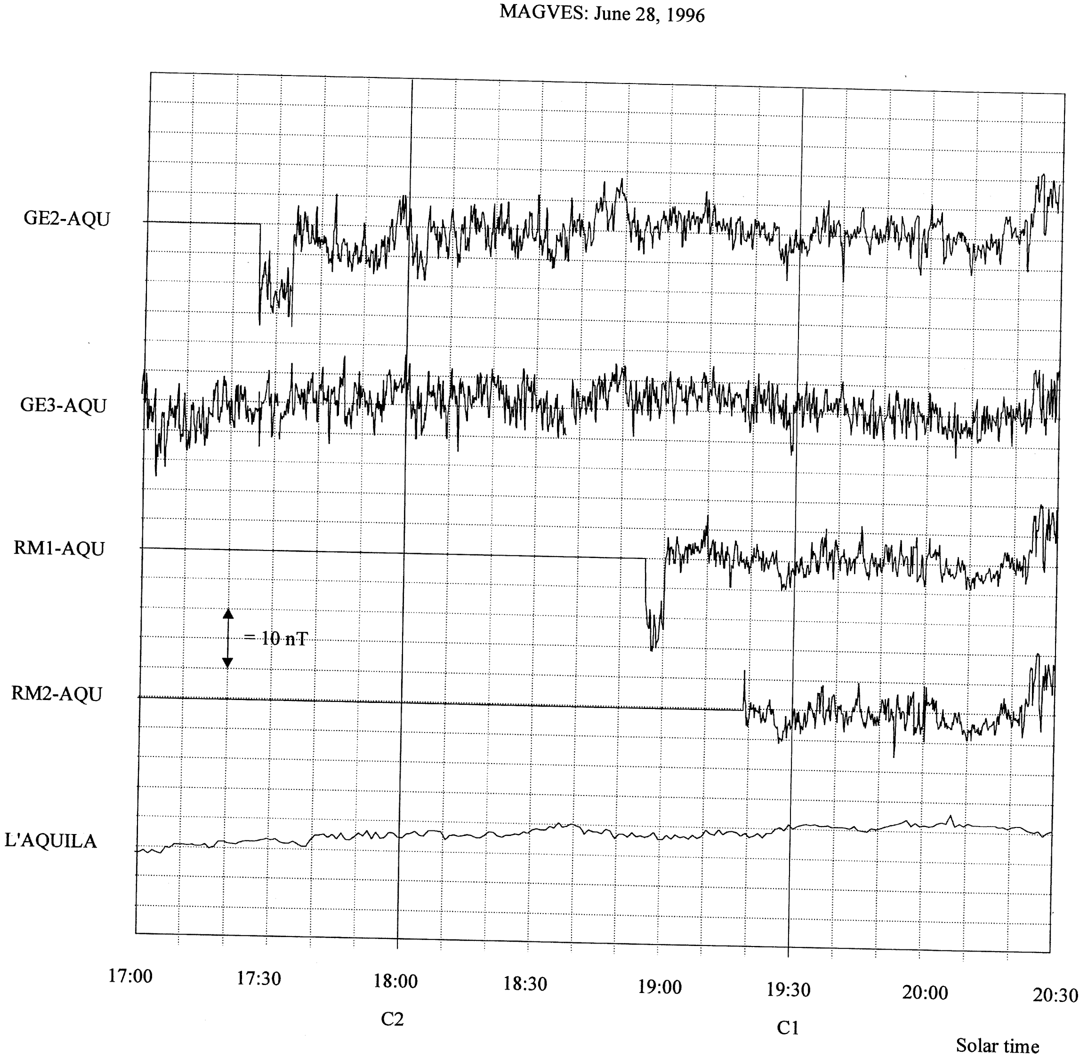

Fig. 2. The magnetic field total intensity values measured on June 28 at stations, GE2, GE3, RM1 and RM2. Signals are corrected by the temporal variation using as reference station the magnetic Observatory of L'Aquila, whose signal is displayed at the bottom of figure. C1 and C2 represent explosion time.

faults, acquifers). On the other hand, resistivity changes in crustal volumes affected by dilation phenomena are related to variations of pores net (Nur, 1972), while mechanical distortion of these structures can induce magnetic changes. Finally, in these areas, water flows, interstitial pressure gradients can generate electrofiltration currents causing magnetic anomalies (Mitzutani *et al.*, 1976; Fitterman, 1979) and consequently these two sources of magnetic anomalous variations may co-exist.

In this paper we have shown that a significant change in the local magnetic field, about 10-15 nT, appears to be correlated with explo-

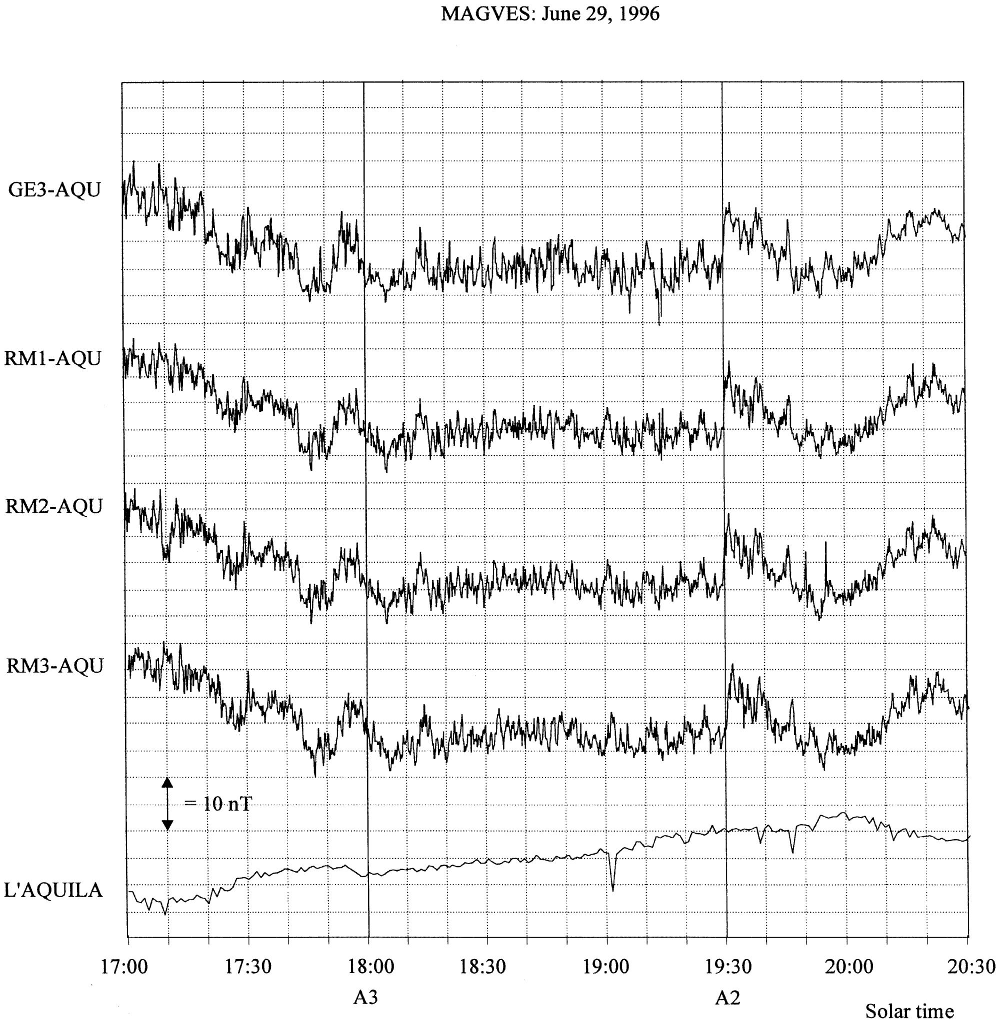

Fig. 3. The magnetic field total intensity values measured on June 29 at stations, GE3, RM1, RM2 and RM3. Signals are corrected by the temporal variation using as reference station the magnetic Observatory of L'Aquila, whose signal is displayed at the bottom of figure. A3 and A2 represent explosion time.

sion A2 executed in June 29. However, among the eight explosions executed with magnetic measurements available only one produced a distinct and marked magnetic time variation. This result is not easily explainable but several factors may be considered responsible.

1) The explosions were executed at too shallow depth. In this case the generated shock wave could be spread only in the most volcanic superficial layers which are strongly fractured and altered. Therefore, even in the presence of strong mechanical stresses it is most unlikely that remarkable magnetic variations can take place. This hypothesis would be in agreement with observations on June 30 and July 1. Indeed, even though on these days

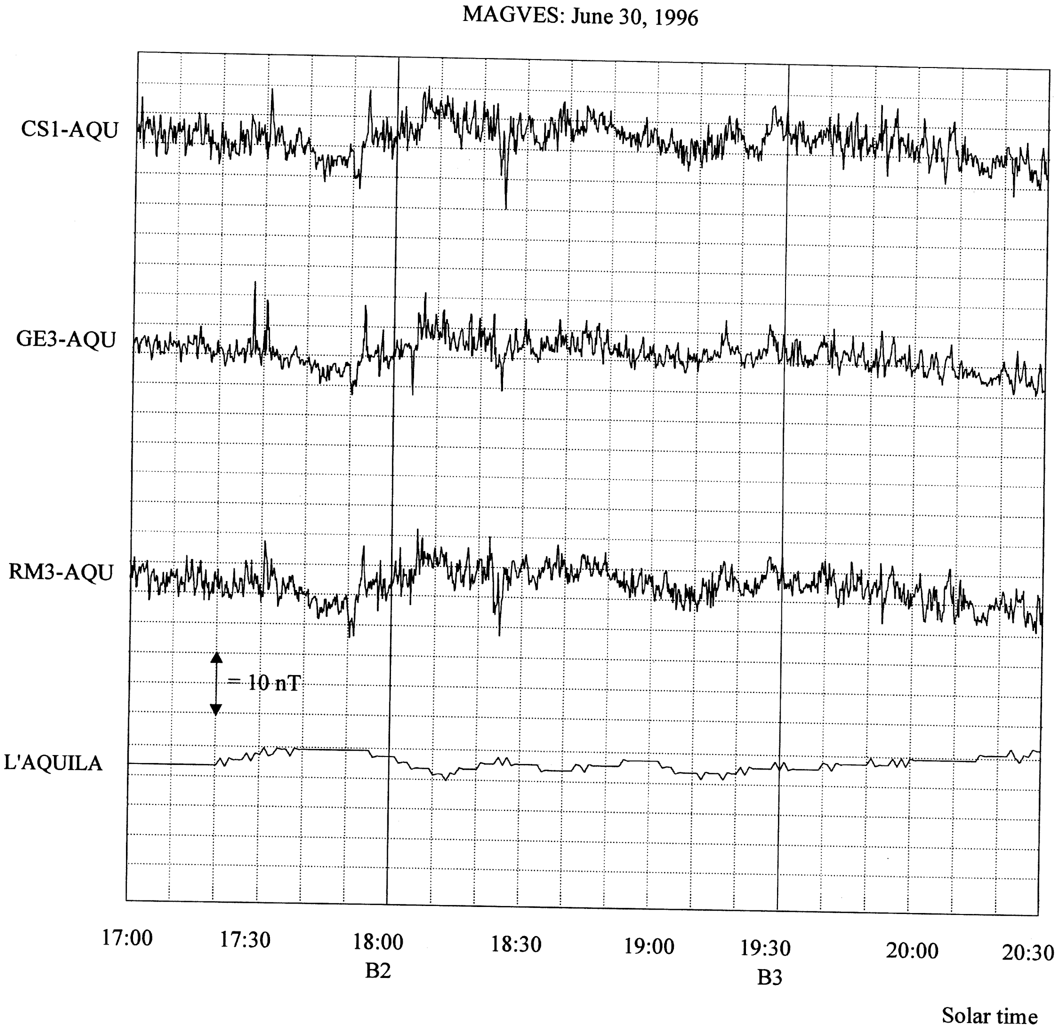

Fig. 4. The magnetic field total intensity values measured on June 30 at stations, CS1, GE3 and RM3. Signals are corrected by the temporal variation using as reference station the magnetic Observatory of L'Aquila. B2 and B3 represent explosion time.

recording stations were located very close to the explosion sites, no significant magnetic variation was recorded by magnetometers.

2) The structural-geological complexity of this area and the bidimensional variability of the subsoil structure (lavic and pyroclastic intercalations) as well as the different lithologic characteristics of the outcrops (lavic body, pyroclastics products, alluviums) can strongly condition wave paths and/or the generation of possible magnetic signals.

3) The magnetometers network in the Vesuvian area was not adequate to observe the studied phenomenon. Magnetometers were in fact concentrated on a limited area of the S-W side of the volcano.

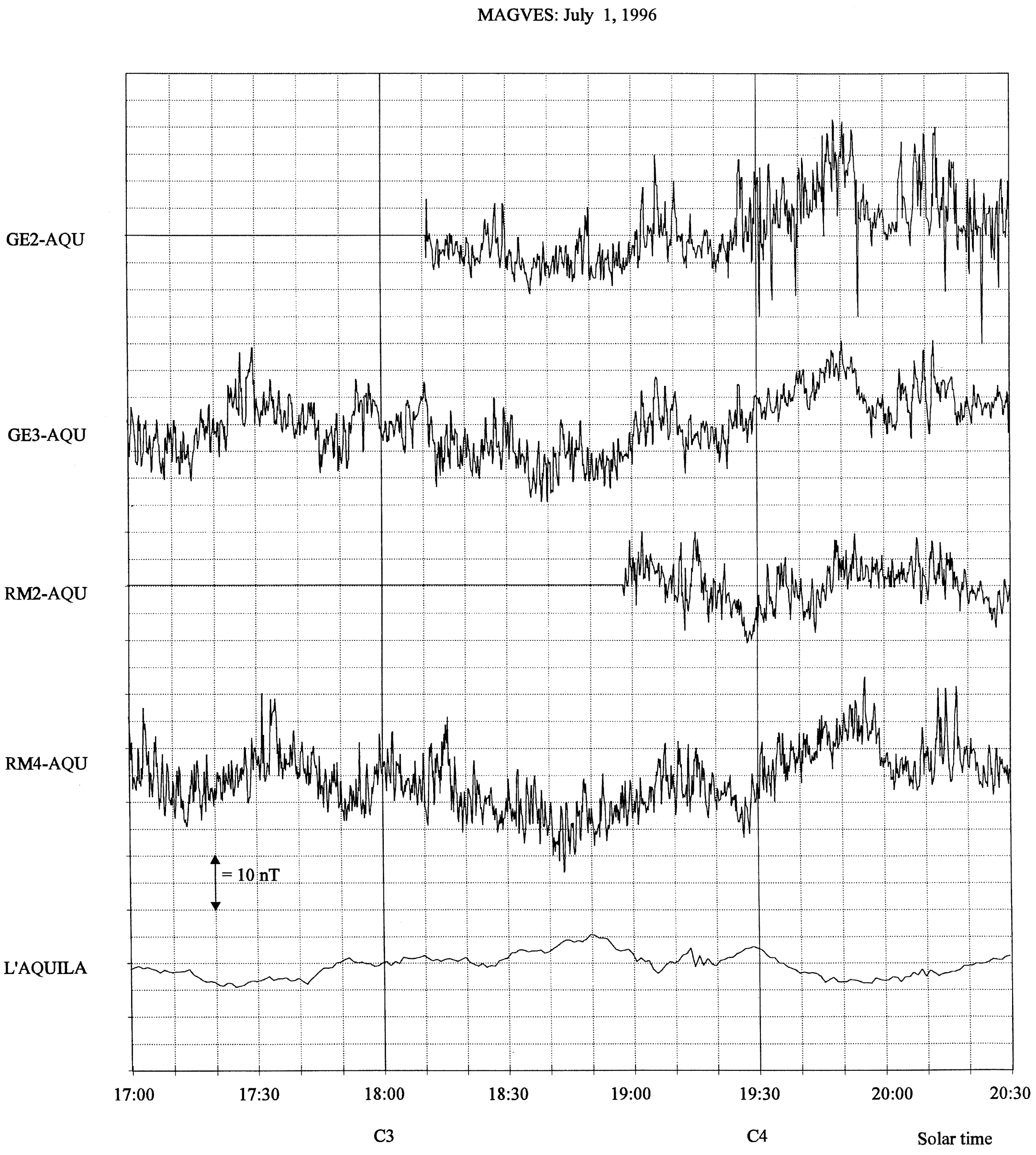

Fig. 5. The magnetic field total intensity values measured on July 1 at stations, GE2, GE3, RM2 and RM4. Signals are corrected by the temporal variation using as reference station the magnetic Observatory of L'Aquila, whose signal is displayed at the bottom of figure. C3 and C4 represent explosion time.

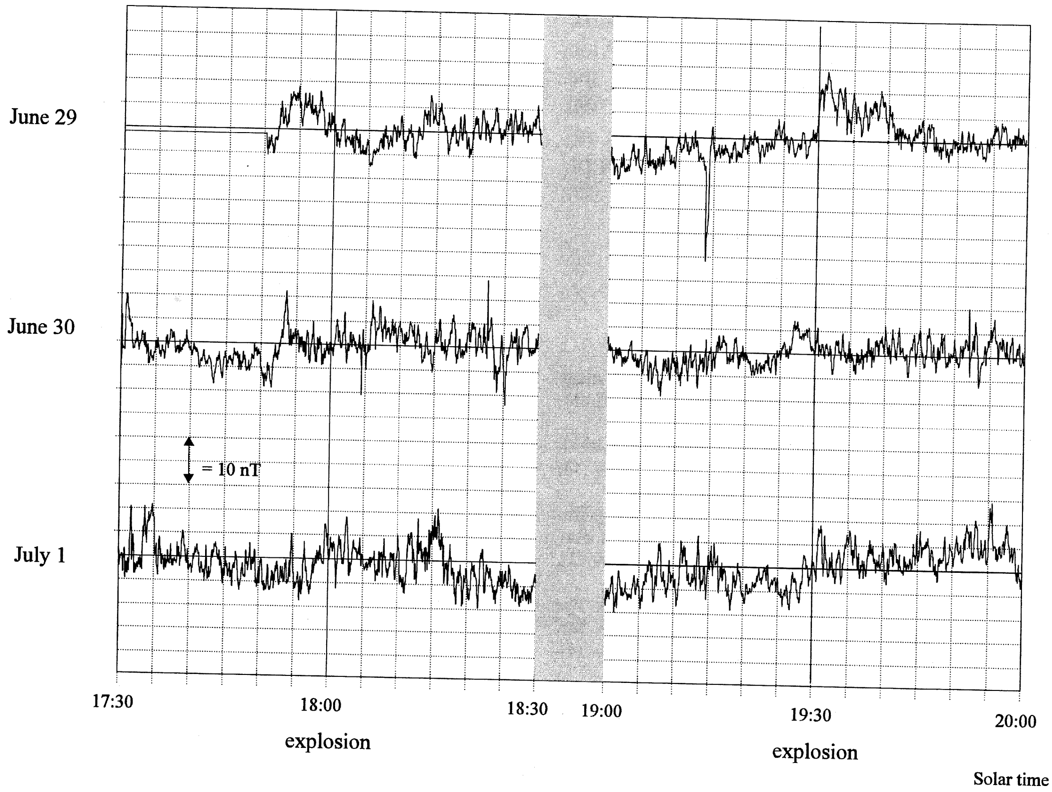

Fig. 6. Time variations in the magnetic field observed during the explosions of June 29, 30 and July 1 at station equipped with Cesium Geometrics G-856 magnetometer.

However, considering the explosion locations and observational sites, the polarity of the observed anomaly simultaneous to the A2 explosion, is in perfect agreement with that expected, according to piezomagnetic calculations based on Mogi's (1958) model (Sasai, 1991). Of course other physical and mathematical models are indispensable for understanding the physics of volcanic associated effects and consequently for any interpretation of field data.

Finally, the anomalous magnetic time variations appear an interesting feature; they cannot be discussed, however, here separately from other geophysical data (as well as seismic-tomographic, geoelectrical and magnetotelluric, simultaneously acquired but not yet available to the authors), deformation characteristics and geological properties of the media involved. Our effort has to be considered among those attempts addressed to single out and study anomalies in any parameters related to the early warning of eruptions. A following multidisciplinary approach, to produce a reasonably accurate experimental contribution for the development of this new field of research, will be attempted later on.

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