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Tectonomagnetic field observations in central Italy 1989–1995

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Abstract

It has been reported that earthquakes and volcanic eruptions produce significant variations in the geomagnetic field. To investigate possible tectonomagnetic effects related to seismic activity, the Istituto Nazionale di Geofisica installed a seismomagnetic network in central Italy; the area was selected after a magnetic noise survey. Geomagnetic field intensity data are simultaneously recorded at four magnetometer stations and at L'Aquila Geomagnetic Observatory, which is located in the same area. The data are differentiated in order to detect local magnetic field anomalies. The present study reports geomagnetic field observations in central Italy from July 1989 to March 1995 and also discusses the detectability of a tectonomagnetic effect in this area. A variation of about 5 nT over a two-month period (January–February 1990) has been observed in the geomagnetic field. No other anomaly has been observed, although moderate seismicity occurred in central Italy during the study period. © 1998 Elsevier Science B.V.

Keywords: Tectonomagnetism; Seismomagnetic network; Seismic activity; Central Italy

1. Introduction

Magnetic field changes due to stress variations have been first observed by Stacey (1963) and Nagata (1969) who also introduced the term tectonomagnetism for this research field. The term seismomagnetism refers to geomagnetic field changes associated with earthquake occurrence. Rikitake (1976) reviewed historical seismomagnetic effects observed in early scientific research.

Two main phenomena have been suggested to explain the observed tectonomagnetic variations: piezomagnetic effects, resulting from variations of magnetic susceptibility in the rocks induced by local stress field changes, were proposed in the case of slow variations (weeks or months) (e.g., Stacey, 1964; Stacey and Johnston, 1972; Guseva et al., 1984), while electrokinetic phenomena, due to the build-up of electric currents in the crust, were proposed in the case of more rapid variations (seconds to days) (e.g., Mizutani et al., 1976; Fittermann, 1979; Dobrovol'skiy et al., 1989). Since the expected amplitude of change in the total field intensity due to a seismomagnetic effect is estimated to be a fraction to a few nanoTeslas (nT), modern tectonomagnetic research requires the use of highly accurate

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instruments, such as proton precession magnetometers (PPM) and optically pumped magnetometers (Packard and Varian, 1954; Usher et al., 1964; Parsons and Wiatr, 1982).

Networks of synchronous magnetometers have been set up in many seismogenic and volcanic areas of the world to detect anomalous magnetic field changes related to seismic and volcanic activity. Magnetic field changes of tectonic origin are detected by comparing data from adjacent sites. Examples can be found in Smith and Johnston (1976), Honkura (1978), Johnston (1978), Davis et al. (1980), Sasai and Ishikawa (1980), Shapiro and Abdullabekov (1982), Sumimoto and Noritomi (1986), Mueller and Johnston (1990), Johnston et al. (1994), among others. A recent review of observed tectonomagnetic effects is given by Park (1994) in a more general paper on earthquake precursors.

From a seismic point of view, Italy is one of the most active areas in central Mediterranean. The hypocenter distribution generally follows the Apennine mountain belt, with depths mostly ranging within the first 30 km. The area investigated by the present study lies in the central part of the peninsula (Fig. 1). It is characterized by carbonatic sequences and flysch belonging to the Apennine domain and by large sedimentary valleys filled with Plio–Quaternary continental deposits. Along the Tyrrhenian side of the peninsula large amounts of volcanic outcrop. Geologic units are extensively fractured at regional and local scale and evidence of active tectonics are reported (e.g., Bosi, 1975; Carraro et al., 1981). The Total Magnetic Field Anomaly Map of Italy shows that the magnetic field anomaly level in the study area, although quite variable, is characterized by a regional trend of medium amplitude, due to the presence of deep crustal layers of granulitic and titano–magnetite rocks (Molina et al., 1994). This indicates on average a medium-to-low crustal magnetization intensity.

In this paper we report seismomagnetic observations made in central Italy from July 1989 to March 1995 at four magnetic stations and L'Aquila Geomagnetic Observatory. With respect to a previous paper of Mele et al. (1994), three more years of magnetic field measurements are shown. Special attention is also given to the detectability of tectonomagnetic (seismomagnetic) effects in the study area.

2. Station characteristics and data analysis

In this experiment the data acquisition system for the detection of a seismomagnetic effect consists of a network of PPM stations separated by a few tens of kilometers. The PPM station and the National Geomagnetic L'Aquila Observatory (AQU) locations are shown in Fig. 1. Magnetometers synchronously measure the total geomagnetic field intensity with a 4–15-min sampling rate; instrument accuracy (Geometrics G856AX model) is 0.1 nT and the expected drift is 0.2 nT yr^{-1}.

The amplitude of observable seismomagnetic effects is often reported to be less than 10 nT and, in populated areas, below the background noise level due to anthropic sources. As a consequence, even if high-amplitude tectonomagnetic effects, at least in the case of piezomagnetic origin, are expected where high crustal magnetization exists, a low level of electromagnetic noise is a strong advantage to unambiguously detecting seismomagnetic effects in this type of environment. Central Italy is both seismically active and relatively free from artificial sources of electromagnetic noise. Furthermore, the main Italian Geomagnetic Observatory is located in the area (see Meloni et al., 1984; Meloni and Palangio, 1990).

Synchronously sampled measurements from each of the recording sites have been collected and averaged on a daily basis; the magnetic field data for all stations are shown in Fig. 2. Gaps in the data set are primarily due to logistic problems, as is the case of TER that was moved to RIT, and LEO that was closed after the first half of 1992. Weather conditions, as well as technical problems, also affect the continuity of the recordings. Fig. 2 shows a uniformly increasing secular variation of the total field, at an average rate of 25 nT yr^{-1}. The average spatial gradient is estimated to be less than 1 nT yr^{-1} 100 km^{-1}. Synchronous spikes in the recordings are due to solar activity.

The geomagnetic field intensity recorded at L'Aquila Observatory was taken as a reference and differentiated with the PPM station measurements. Non-zero differences arise from four main sources: (1) magnetic field effects due to the Earth's external electric currents; (2) induced electromagnetic fields in the Earth's interior; (3) variations of the Earth's core electric currents (non-uniform secular variation);

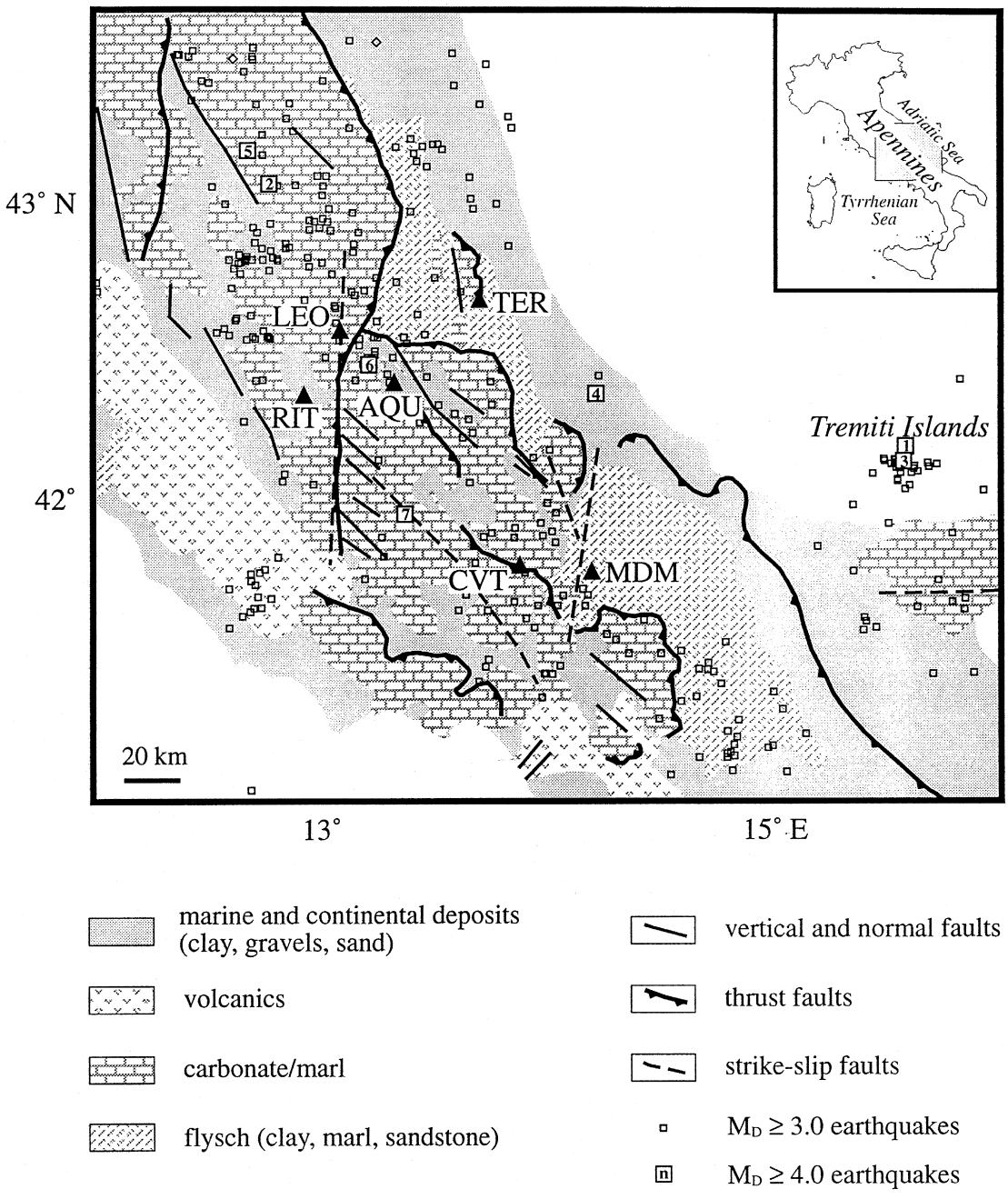


Fig. 1. Map of the study area (shaded in the inset) showing the main geologic and tectonic units (after Carraro et al., 1981). The epicenters of the magnitude $M_D \geq 3.0$ earthquakes occurred during the study period (open squares) and the seismomagnetic station location (filled triangles) are shown. Earthquakes with $M_D \geq 4.0$ are numbered following Table 1.

(4) changes in crustal magnetization due to variations in the stress field or to electrokinetic effects (tectonomagnetic effect).

To isolate local magnetic anomalies generated by crustal stress field variations, the first three effects must be eliminated from the data. Most of the noise

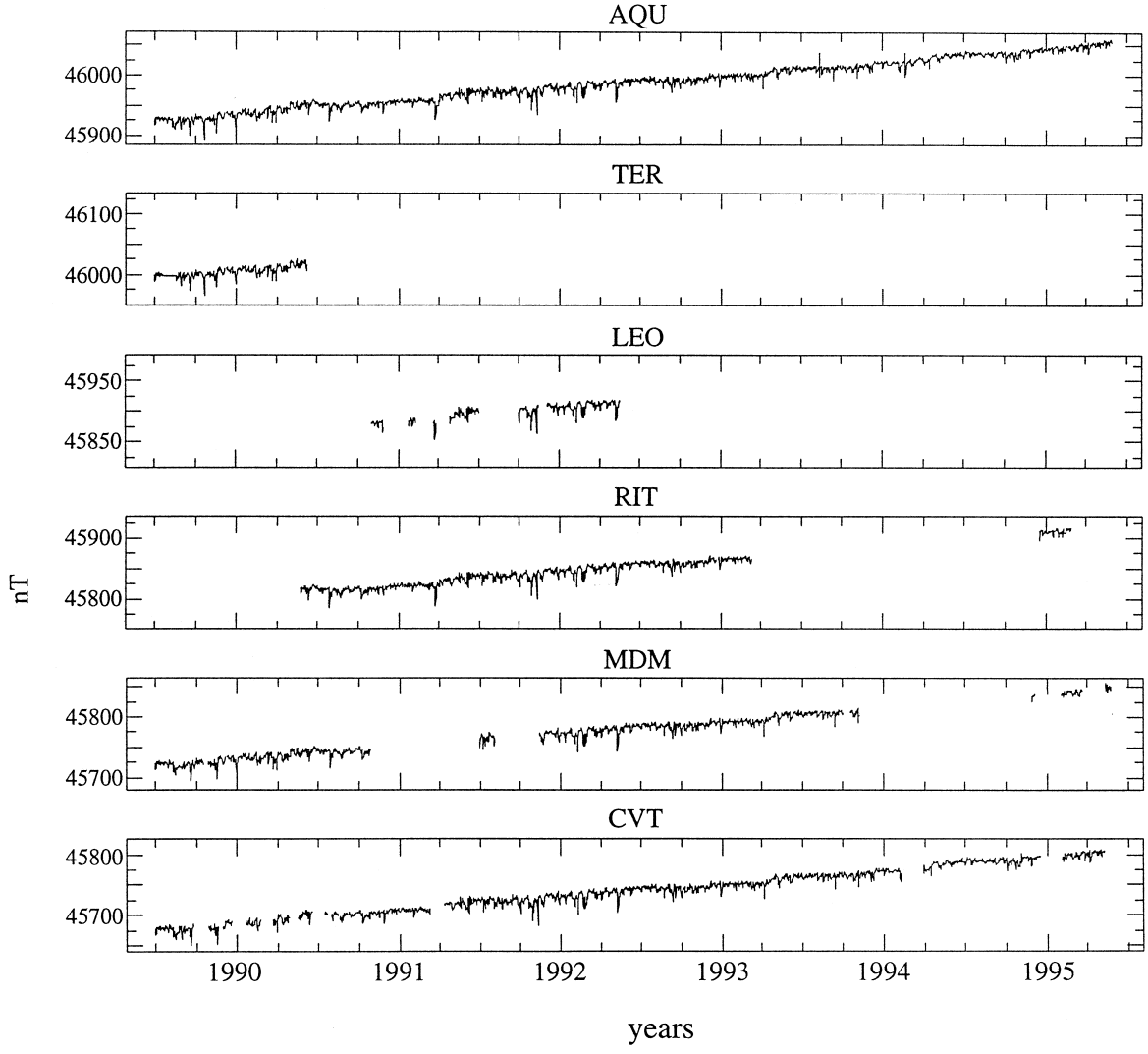


Fig. 2. Daily mean values from L'Aquila Geomagnetic Observatory (AQU) and the seismomagnetic stations. A steady increasing secular variation of 25 nT yr^{-1} is observed in the study area. Synchronous spikes are due to solar activity.

derived from external electric currents is removed by filtering out the higher frequencies; induction effects of iono–magnetospheric currents can also be eliminated by a low-pass filter, since the time scale of ionospheric and magnetospheric variations is short compared to tectonic stress accumulation (Rikitake, 1976). On the contrary, non-uniform secular variation is characterized by frequency and wavelength similar to those observed for seismomagnetic effects, and for this reason it is more difficult to eliminate. For example, variations of more than 1 nT yr^{-1} 100 km^{-1} in latitude, with some small dependence in longitude, have been found along the San Andreas Fault (Johnston et al., 1985). However, in the study area a uniform secular variation rate is observed (see Fig. 2), so that it can be easily removed to detect a local effect.

Five-day averaged differences between L'Aquila Observatory and the available measurements at TER, LEO, RIT, MDM and CVT stations are shown in Fig. 3; vertical lines indicate the occurrence of magnitude $M_D \geq 4.0$ earthquakes in the study area (see

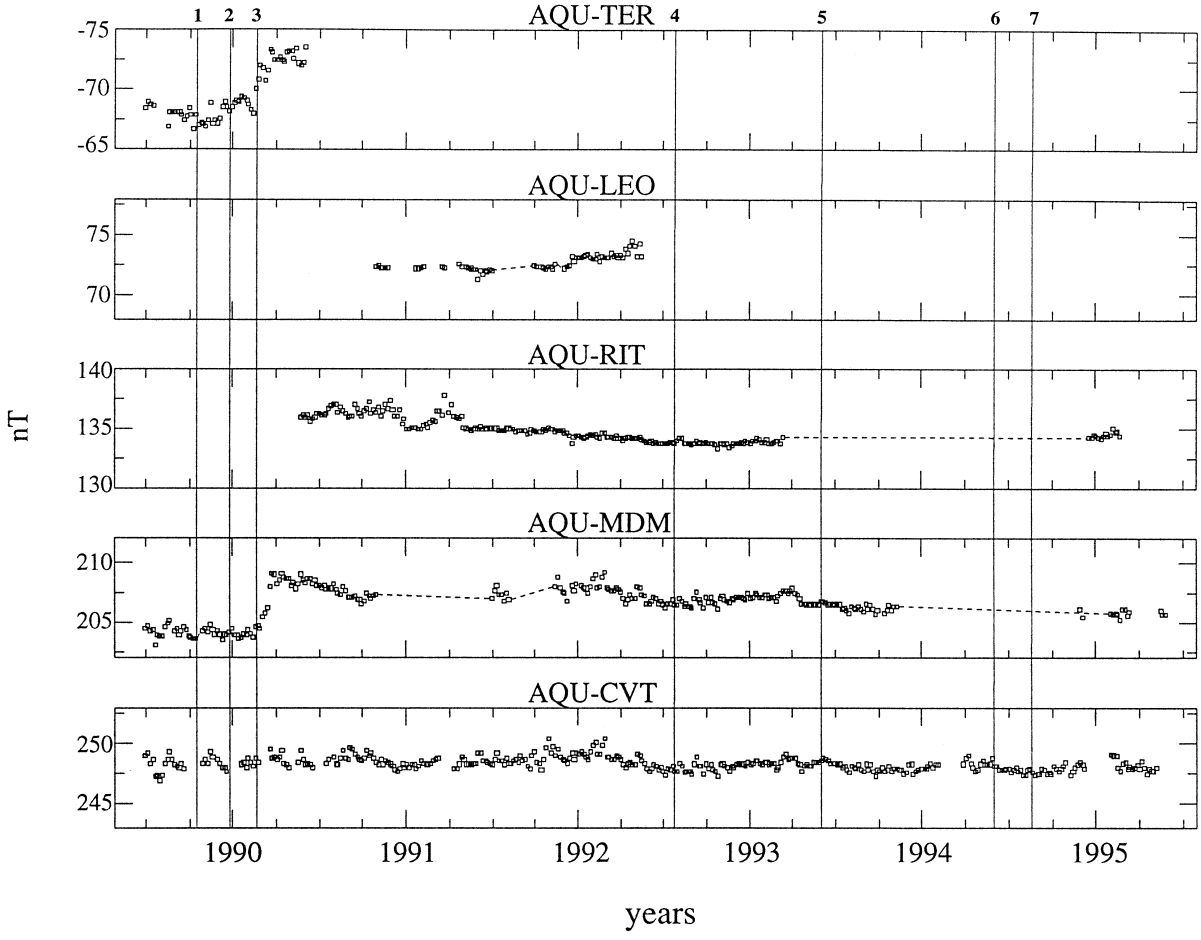


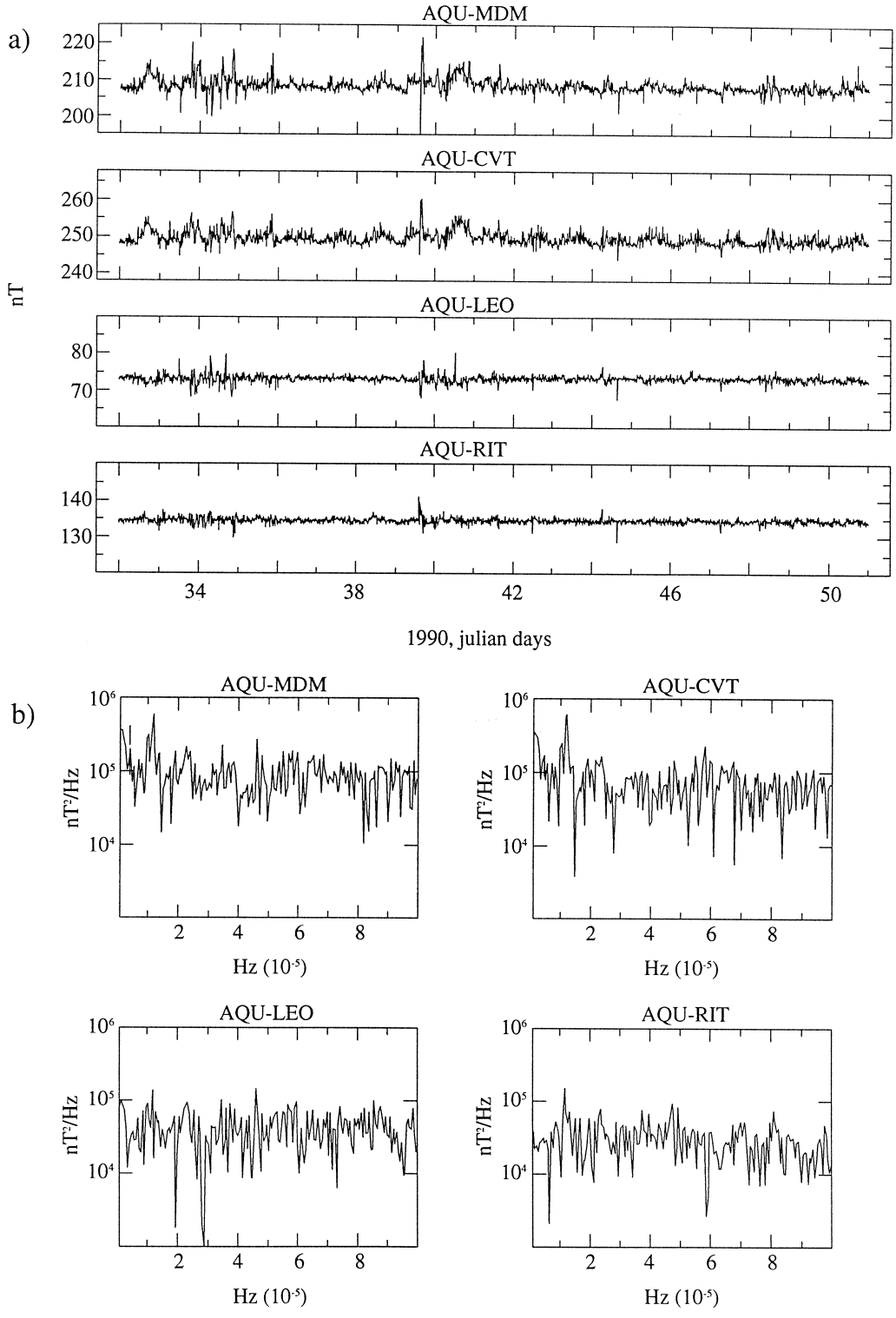
Fig. 3. Five-day means of simple differences for the total geomagnetic field between the AQU reference stations and TER, LEO, RIT, MDM, CVT stations. Vertical lines indicate the occurrence of the most intense earthquakes ($M_D = 4.0–4.1$); earthquake parameters (numbered from 1 to 7) are listed in Table 1.

Table 1). An anomalous decrease of a few nT in the absolute field level is observed at stations MDM and TER: this increasing trend occurred during January and February 1990 and has been already reported by Mele et al. (1994). At station MDM this variation seems to be recovering toward the original level. Averaged values at 0200 UT and daily mean differences between AQU and MDM and between AQU and TER, not shown here, show similar changes.

Table 1
Parameters of the $M_D \geq 4.0$ earthquakes that occurred in central Italy during the study period

	Date	Origin time	Latitude°(N)	Longitude°(E)	M_D
1	06/10/89	17:38:27.2	42.17	15.59	4.1
2	22/12/89	06:48:14.9	43.02	12.77	4.0
3	01/02/90	06:24:15.8	42.13	15.58	4.1
4	16/07/92	05:38:55.2	42.34	14.22	4.0
5	05/06/93	19:16:18.4	43.13	12.67	4.3
6	02/06/94	17:38:15.1	42.44	13.21	4.0
7	07/08/94	06:31:12.4	41.95	13.37	4.0

The ability to resolve magnetic field variations of crustal origin using station pairs critically depends on the cancellation of other magnetic variations. This cancellation becomes progressively less effective as station separation increases (see Davis and Johnston, 1983). In the study area this cancellation ability was tested, for a selected period of 19 days in 1992, by comparing the time variations of the difference values between each of the PPM stations and AQU. The


a)
AQU-MDM
220
210
200
AQU-CVT
260
250
240
nT
AQU-LEO
80
70
AQU-RIT
140
130
34
38
42
46
50
1990, julian days
b)
AQU-MDM
AQU-CVT
AQU-LEO
AQU-RIT
10^6
10^5
10^4
nT²/Hz
2
4
6
8
Hz (10^{-5})

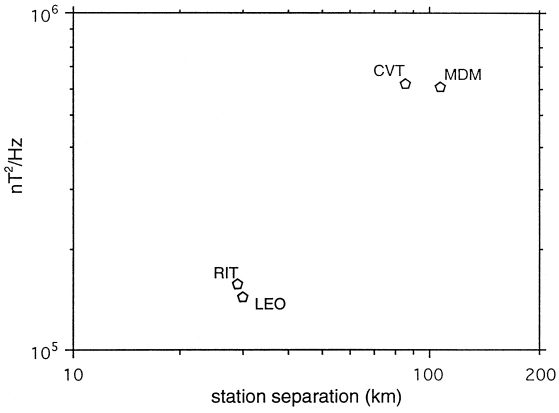


Fig. 5. Differential geomagnetic field power for a 24-h period vs. the distance from the reference station AQU.

results of this test are shown in Fig. 4, where power spectral analysis on the different geomagnetic field data shows that peak noise levels do have a spatial dependence. For example, diurnal variations of the geomagnetic field and/or tidal effects exhibit a remarkable increase of about 3 nT per 100 km of increasing distance between each station and the AQU Observatory. In Fig. 5 the spatial dependence of magnetic field daily variation noise power is shown for MDM, CVT, LEO and RIT stations with respect to AQU.

3. Discussion and conclusions

Central Italy is characterized by active faulting and by a rather intense seismicity (I.N.G., 1995), indicating that tectonic stresses are significantly accumulated in the study area. Several destructive earthquakes are documented to have occurred in historical times within the L'Aquila area and its surrounding regions, including the $M_s = 6.9$ Avezzano earthquake in 1915.

Magnetic field measurements were undertaken in central Italy from July 1989 to March 1995 in order to detect tectonomagnetic changes related to the seismic activity. During this period, more than three hundred earthquakes with duration magnitude M_D ranging from 3.0 to a maximum of 4.1 have been recorded in the study area by the seismic stations of the Istituto Nazionale di Geofisica. In particular, seven earthquakes with 4.0 to 4.1 magnitude occurred in the Apennine region and the Tremiti Islands area (see Table 1, Figs. 1 and 3).

An anomalous variation of about 5 nT simultaneously detected at TER and MDM stations during January and February 1990 (Mele et al., 1994) could be related to crustal stress perturbations following the Tremiti Islands events (earthquakes #1 and 3) or, more probably, it could be due to a tectonomagnetic aseismic effect. In fact, the events occurred at the Tremiti Islands are rather small and distant from both the recording sites TER and MDM and probably involve tectonic structures not directly related to the recording site areas. Moreover, the Tremiti Islands seismic events should have triggered some variation also at CVT station, which is located as far as MDM from the epicentral area. On the other hand, a $M_D = 4.0$ earthquake (event #6 of Table 1) occurred about 11 km far from AQU did not give local magnetic field changes, as shown by the AQU–CVT differences in Fig. 3. In order to hypothesize an electrokinetic effect, some correlation between the observed geomagnetic field variation and ground water flow in the study area is necessary. Unfortunately, hydrogeological investigations are not available on this purpose during the study period.

As a final consideration, the absence of significant magnetic field changes at our seismomagnetic stations in central Italy during the observation period indicates that magnetic or long-term electric fields of crustal origin, i.e., tectonomagnetic effects of piezomagnetic or electrokinetic origin, do not frequently occur in this area. Furthermore, the moderate-energy seismic activity that occurred in the past few years does not allow us to find evident correlation between local magnetic field variations and earthquake occurrence.

Fig. 4. (a) Magnetometer pair differences for a selected period of 19 days. From the lower to the upper part of the diagram data are shown for MDM, CVT, LEO and RIT stations with increasing distance from the reference station site AQU. (b) Power spectral analysis of the geomagnetic field difference for the 19-day time interval.

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