Artificial and natural electromagnetic signals revealed during two years in the Amare cave (Central Italy)

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Abstract
In 1990, some instrumentation was set up in the Amare cave (southern slope of the Gran Sasso chain, L'Aquila) in order to pick up electric signals ranging from 0.3 to 300 kHz, magnetic signals from 0.3 to 30 kHz and seismoacoustic signals by means of three geophones with natural frequencies of 0.3 kHz, 25 kHz and 150 kHz. Data are recorded every ten minutes on a solid state memory. The analysis of the data allows us to establish the existence of electromagnetic fields of distant origin connected with broadcastings and with tropical lightning activity and the discontinuous presence of local electric and magnetic signals, coupled with seismoacoustic ones, connected with weather events. A qualitative explanation of these near fields is given.

Key words *electromagnetic signals – earthquakes precursors*

1. Introduction

In the last few years studies on electromagnetic emissions as precursors of earthquakes have been carried out by many authors (Gokhberg *et al.*, 1982, 1986; Warwick *et al.*, 1982; Rikitake, 1986; Bella *et al.*, 1987, 1989, 1992; Fraser-Smith, 1992). In this framework, since 1986 research works have been carried out at the «La Sapienza» University of Rome. During 1990, a multichannel piece of equipment was put into operation in the Amare cave, located in the Central Apennines (fig. 1). Here, the data recorded over a period of approximately two years are presented and analysed.

2. Equipment and measurement site

The Amare cave is placed on the southern slope of the Gran Sasso chain. This chain is one of the largest karst areas of the Italian Apennines and it is mainly formed by limestone of different geologic periods (Lucrezi and Villani, 1965). This cave extends more than one hundred metres from the mouth and reaches a depth of about eighty metres from ground level. The transverse section of the cave is shown in fig. 1. The roof of the «Sala dei Colossi», that is the largest room of the cave, consists of irregular wedge-shaped limestone blocks of different sizes from which short thin stalactites hang down. The floor is formed by huge blocks which have collapsed from the roof. These blocks are also in the zone overhanging the «Sala dei Colossi»; so it

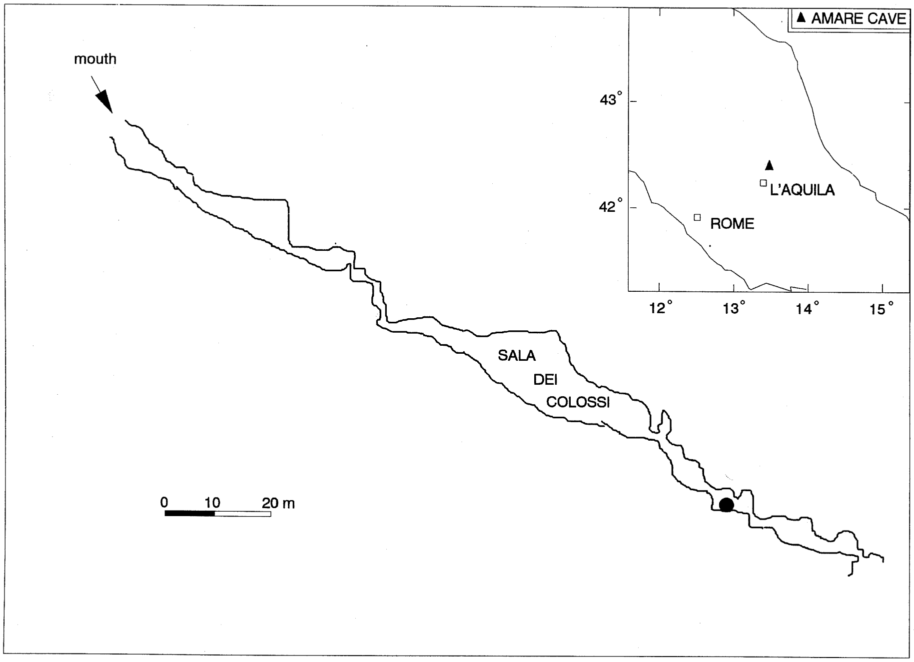

Fig. 1. Transverse section of the Amare cave. The full point indicates the place where the instruments are set up. The location of the cave is shown in the square.

is possible to get down among them without a rope-ladder. Water drips constantly in several parts of the cave.

The equipment is set near the bottom of the cave; the location is shown in fig. 1. The power is supplied by a 12 V battery, located near the mouth of the cave, connected with a solar panel. A bipolar rubber cable, 150 m long, connects the battery to the equipment. The monitoring system set up in the cave consists of: a) one rectilinear antenna for detecting electric signals; b) one circular antenna for detecting magnetic signals; c) three geophones for detecting seismoacoustic signals; d) one absolute pressure transducer to measure atmospheric pressure; e) one temperature sensor to measure room temperature. The geophones are moving-coil type (one) and piezoelectric type (two), with natural frequencies of 0.3, 25 and 150 kHz. The equipment has three very similar data recording systems: one for electric signals (EME), one for magnetic signals (MAG) and one for seismoacoustic signals (ACU) and atmospheric parameters. The paper by Bella *et al.* (1989) details the equipment for electric data recording. All the data are recorded with sampling every ten minutes. The MAG signals are filtered in two frequency bands, *i.e.* (0.3-3) kHz and (3-30) kHz. The EME signals are filtered in three frequency bands, *i.e.* (0.3-3) kHz, (3-30) kHz and (30-300) kHz. From now on we denote these bands as LF, IF and HF, respectively. The same labels are used for ACU data revealed by the three geophones. The ACU data are recorded as number of pulses over a threshold from a counting module; the EME, MAG and atmospheric data as voltage in output of an integration module. As concerns atmospheric data, we have calibrated the response. As concerns EME and MAG fields, the instrumentation is not calibrated. However, as regards the order of such fields, we can evaluate that response of 1 mV corresponds to 1 mV/m, if it is referred to electric signals and to 10^{-6} Asp/m, if referred to magnetic signals.

The spot where the instruments are located in the Amare cave is well thermostated. The diurnal thermal variation is contained within 0.1 °C; the yearly periodic variation ranges from 7.8 to 8.2 °C. The minimum value occurs in February-April and the maximum in July-September, according to the season. The atmospheric pressure revealed in the Amare cave is in a good agreement with that measured in the Preturo weather station, located 20 km from the cave.

3. Results

The EME, MAG and ACU signals collected up to now in the Amare cave seem to identify two different situations, that we call «quiet» or «perturbed» state.

A quiet state is characterized by the absence of significant seismoacoustic and LF electric-magnetic signals. On the contrary, a continuous signal appears on the electric (IF and HF) bands and on the IF magnetic one. An example of this situation is shown in fig. 2. Simply, in the figure we report only one ACU trend; however, a similar behaviour appears in the other two ACU bands.

A perturbed state is characterized by the sudden appearance of significant seismoacoustic signals in all three ACU bands, simultaneously. On this occasion there are also always clear electric signals and sometimes magnetic ones. In the LF bands the phenomenology appears simple because such signals are the only ones present at these frequencies. In the other bands such signals are superimposed upon the quoted continuous one; in such a way, their evidence is a little indistinct. Figure 3 shows an example of a perturbed state. As usual, we show only one ACU trend.

At first we looked carefully for the pattern of the continuous electric and magnetic signal.

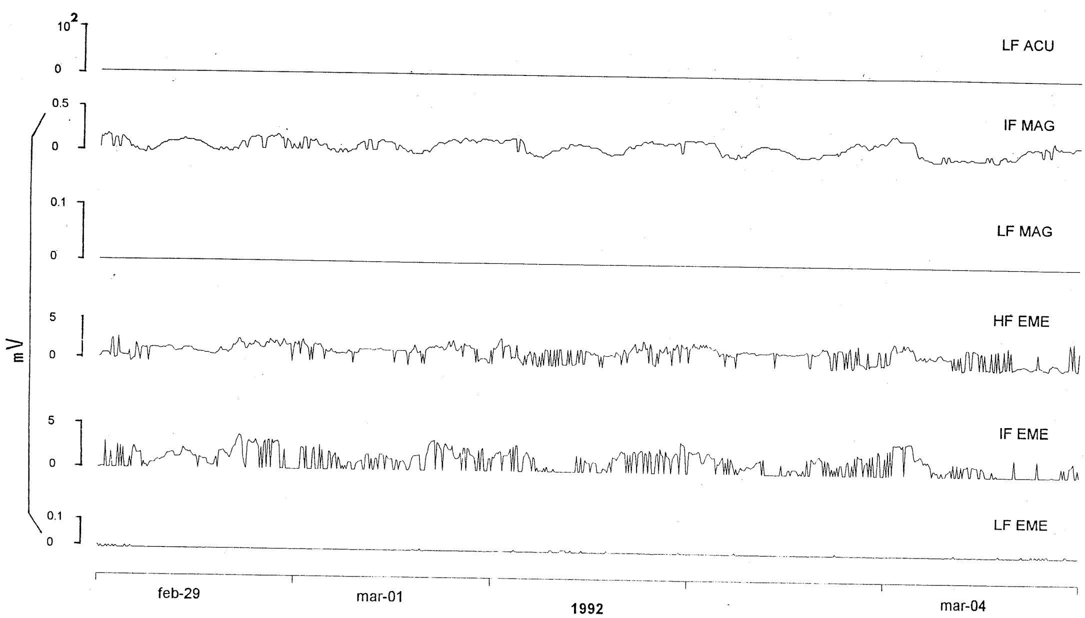

Fig. 2. Trends of EME, ACU (only LF band) and MAG signals revealed in the Amare cave during a «quiet» state.

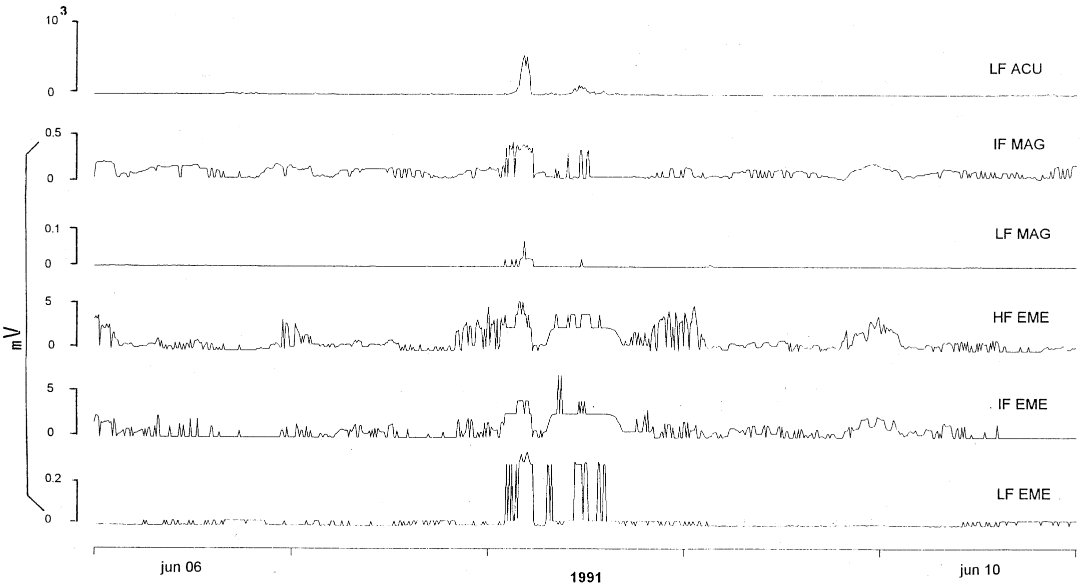

Fig. 3. Trends of EME, ACU (only LF band) and MAG signals revealed in the Amare cave during a «perturbed» state.

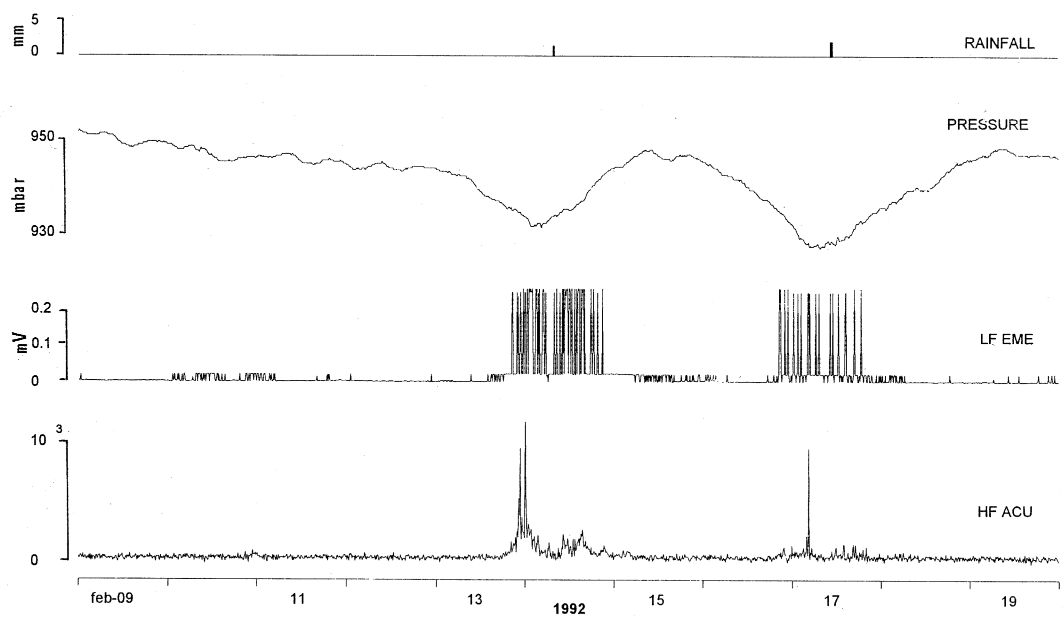

Fig. 4. Trends of HF ACU and LF EME signals during a «perturbed» state. Atmospheric pressure revealed inside the cave and rainfall provided by the Preturo weather station are also reported.

In the HF EME band a nightly enlargement was detected; in the IF bands this signal also shows a further enlargement at dawn.

Then, we looked for the circumstances that change a quiet state into a perturbed state. We found that when the atmospheric pressure changes and during rainfalls, the quiet state changes into a perturbed one. As an example, in fig. 4 a perturbed state connected with atmospheric pressure changes and probably rainfall, is shown. In figure we report LF electric and HF acoustic trends only, for optimal graphic quality.

4. Discussion

Here, we suggest a qualitative explanation of the phenomenology described in the previous section.

First of all, we looked into the quiet state. The mutual features of electric and magnetic signals in the IF frequency band, in particular, the fact that the ratio seems to remain constant, lead us to think that they represent a formed electromagnetic wave. According to the Maxwell equations, we are in the situation of far field. It is natural to assume that the same situation occurs for HF EME signal. The frequencies in the range (30-300) kHz are normally used in broadcasting for radio navigation and broadcasting by long waves. In particular, in Central Italy radio programmes from the RMC (f = 216 kHz) station (Principality of Monaco) are well received. So, it is natural to connect HF EME signals with this kind of broadcasting. It is well known that long period radio waves propagate as terrestrial waves along the Earth's surface and as spatial waves reflected by the ionosphere. Then, the enlargement in HF EME signals that appears nightly finds its explanation in the fading ionospheric effect. The frequency range (3-30) kHz is rarely used for broadcasting; so, it is unlikely that electric and magnetic signals recorded in the IF band are related to broadcasting. An energy of different origin exists that propagates as electromagnetic waves transmitted in this frequency band, *i.e.* the energy released by lightning. In fact, lightning behaves like huge antenna systems that radiate electromagnetic energy in the range from some hundred Hz to one hundred kHz, with a maximum around 10-20 kHz (Volland, 1984). Since about 100 strokes of lightning a second occur in the tropical area of the Earth, it is possible to describe this situation as continuous broadcasting with a source randomly in space. So, it seems accurate to consider IF EME and MAG signals connected with these sources. The enlargement of these signals we pointed out previously is related both to the ionospheric fading effect and to more lightning activity at dawn and dusk on each day.

The screen above the cave does not seem to cut off the electromagnetic energies associated with the quoted human and atmospheric disturbances.

Now let us consider the perturbed state. Seismoacoustic signals with frequencies ranging from some hundred Hz to some hundred kHz have a maximum estimated range in rock or in air of a few hundred metres (Armstrong, 1969); so, we consider these seismoacoustic signals to be of local origin. Besides, it must be noted that the mutual features of the electric and magnetic signals, recorded on the same occasions, seem to indicate changes in their ratio, according to a situation of «near field», where the electromagnetic waves are not formed and the electric and the magnetic field are connected with the nature of the sources. The temporal coincidence between the appearance of seismoacoustic signals with the quoted frequencies and electric and magnetic signals (when these latter exist) suggests a common genesis for such phenomenology. It is reasonable to assume that such phenomenology is produced just inside the cave. On the other hand, from the previous section, it seems clear that these signals are connected with atmospheric pressure variations and rainfall.

Here, we have to explain the mechanism that allows these weather agents to produce seismoacoustic, electric and magnetic signals inside the cave. Let us pay attention to the roof of the cave: we can consider the roof as a blocks system with viscoelastic boundaries. The potential energy of the system is to be attributed to gravity and elastic forces. The relative displacements of the blocks are restrained by friction at the boundaries. Viscosity at the boundaries depends on the atmospheric pressure, temperature and dilution (Balasauyan, 1990). Then, rainfall and atmospheric pressure variations can change the characteristics of friction between blocks. So it is possible for instability in some blocks groups to be produced, thus triggering local relative displacements. Such frictional sliding of some blocks of rock can produce acoustic emissions (Armstrong, 1969). Now, we have thought of two possible mechanisms able to produce EME and MAG signals.

According to a first hypothesis, during the mechanical processes, electric charges will redistribute in the roof of the cave, so that a charged capacitor can occur with respect to the floor of the cave. The roof of the cave is covered by a moisture film. This film can behave as an inductance and/or a resistor. In such way an equivalent RLC or RC circuit can be adopted. Electric and magnetic signals, recorded in the cave during a perturbed state, can be connected with the electric and magnetic energy stored in these circuits.

According to a second hypothesis, during the displacements of the blocks an electrification of contacting surfaces will occur, due to triboelectric and electrokinetic phenomena. In such a way, a charged capacitor can occur in the boundary layer: the moisture film in this zone can behave as a resistor and an inductance. So, an equivalent RLC series or parallel circuit can be adopted. The electric and magnetic signals recorded in the cave during a perturbed situation can be connected with the electric and magnetic energy radiating from these circuits.

5. Conclusions

The measurements we have been carrying out in the Amare cave have the practical aim of detecting and studying electromagnetic precursors of earthquakes. During recent years no earthquake characterized by a sufficient deformation parameter (Dobrovolsky *et al.*, 1979) has occurred. The data collected in the Amare cave in this period offered much information on the electric and magnetic events that characterize the measurement site. These phenomena must be considered the «background». We think that these preliminary findings play a fundamental role in accurately detecting the electric-magnetic anomalies connected with earthquakes.

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