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An Electric Precursor:

Laboratory Field & Earthquake Observations

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A perspective electric earthquake precursor observed in the Apennines

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ABSTRACT We present the data on particular electric signals in the frequency band around 8 kHz emitted by various types of rocks that are subject to pressure and fracture in the laboratory and recorded in the surrounding air. A similar type of electric signal was recorded as an electric precursor of the earthquake with magnitude 5.0 that occurred on September 14, 2003 at $22^h\ 42^m\ 50^s$ in the Tosco-Emiliano Apennines (lat. 44.22° N, long. 11.35° E). The precursor was recorded with an instrument called radio-geophone installed in an experimental station located near Cascia (PG) (lat. 42.8° N; long. 13.1° E; 900 m a.s.l.).

1. Earthquake predictions

To forecast earthquakes is one of the major issues of science. It is extremely important for the number of lives it may save; it is also a major scientific challenge for the difficulties it has encountered theoretically and experimentally. Many important books have been written on the state of art of earthquake prediction in various times beginning with the classics of Rikitake (1976), Asada (1982), Mogi (1985), Keilis Borok and Soloviev (2003), where the different observational approaches are presented.

Today there are two major tentative solutions of the problem: the observation of precursors of the earthquakes in the field and in the catalogues. The experimental method is based on the observations of physical, chemical, electric, magnetic and tectonic phenomena that may precede the earthquakes; a typical example is the well known VAN method (e.g. Varotsos and Alexopulos, 1975). Another method is based on precursors detected with sophisticated analyses of earthquake patterns that may precede the earthquakes, typical examples being that of the M8 and CN algorithms (e.g. Keilis Borok and Soloviev, 2003; Peresan *et al*., 2005).

The topic has also raised questions on the possibility solving the problem mostly concentrated on criticisms of the various methods used to observe the precursors and on the meaning of the precursors (Geller *et al*., 1997; Kagan, 1997; Wyss, 1997; Geller, 1999).

The debate was very useful and did not discourage the community of those who pursue the goal of predicting the earthquakes. In the most authoritative scientific journals, articles with suggested methods for the observation of precursors or of actual intermediate or long term forecasts appear now and then.

It was De Rossi (1879) who perhaps was the first to indicate in his book, where the earthquakes are considered as phenomena of an endogenous meteorology, a list of phenomena occurring prior or during earthquakes**.** The observation of phenomena precursory to earthquakes had also several encouraging successes, as for instance the VAN method, but no systematic uncontested result has so far been obtained. Often the laboratory confirmation of the observed phenomena was lacking.

2. Earthquake predictions in Italy

The Italian seismic region is subject to moderate, seldom intense, seismic activity and scientific and popular interest in this phenomenology goes back many centuries. Scientific interest in forecasting earthquakes however began only several decades ago. The first observation of a precursor in Italy was made by Caloi. He installed horizontal pendulums in a grotto near the River Ambiesta (Tolmezzo) to monitor the deformations of the rocks near a dam under construction; when the earthquake of October 11, 1954 occurred, Caloi noted an anomalous large variation in the direction of the horizontal pendulums that occurred over several days before the earthquake struck and concluded that it was due to the preparation of the earthquake (Caloi and Spadea, 1955).

Mid-term predictions of earthquakes in the Italian and neighbouring regions are currently made at ICTP, in Trieste with the numerical algorithms CN and M8S. Among others, we quote the 5.5 magnitude earthquake of March 29, 2003, offshore the Italian – Croatian border (Peresan *et al*., 2005); the regions covered and time duration of the alarms are still wide (of the order of more than 100,000 km^2 and many months, respectively) and do not allow to sound a red alarm for population evacuation, however they do allow an alert for preparedness. For more on this type of prediction see Keilis Borok (1996), Keilis Borok and Soloviev (2003). For an updated and exhaustive report see Peresan *et al*. (2005).

Another prediction was made in 1982 for the earthquakes of May 5 and 11, 1984 in the Parco Nazionale dell'Abruzzo (Caputo, 1983, 1988) with a numerical method different from the CN and M8S algorithm. However, also this prediction covered an area too large and too large a time interval and could probably only allow an alert for preparedness.

3. Experiments in the laboratory and in the cave

In order to record the electromagnetic emission during the compression and fracture of rocks, a particular receiver of the electric component of the electromagnetic field was built sensitive in 80 Hz to 12 kHz with a dynamic range of 60 dB.

In laboratory experiments, we compressed 42 samples of rocks uniaxially with different lithology [calcare massiccio (massive limestone) arenarie argillosa (clay sandstone) metamorphic rocks and also beton] with dimensions $8 x 8 x 10$ cm^3 and recorded the E-VLF emission.

We used a 500-ton hydraulic press whose metallic mass was grounded, together with all the other surrounding metallic masses, and it gave a good electric insulation from the surrounding environment. Preliminary experiments made by compressing steel cubes showed that the press would not emit any EM signal even with stresses larger than those used for the rock samples. These were subject to a constant stress rate increase which took the sample to fracture in 3 – 8 minutes, depending on the lithology of the rock.

The signals recorded before and at the fracture are formed by a sequence of microimpulses with structure similar to that of the perspective precursor but of shorter duration. The band of emission of these signals is about 3 kHz wide (in the lab the centre of the band is from 6 to 11 kHz, in the cave it is from 0.5 to 8 kHz, in the presumed precursor it is from 8 to 10 kHz) with a tendency to drift towards the radio-frequency band spectrum but always remaining in the band 0.5 -11 kHz as shown in Figs. 1 and 2. These electric emissions could be assimilated to preseismic signals.

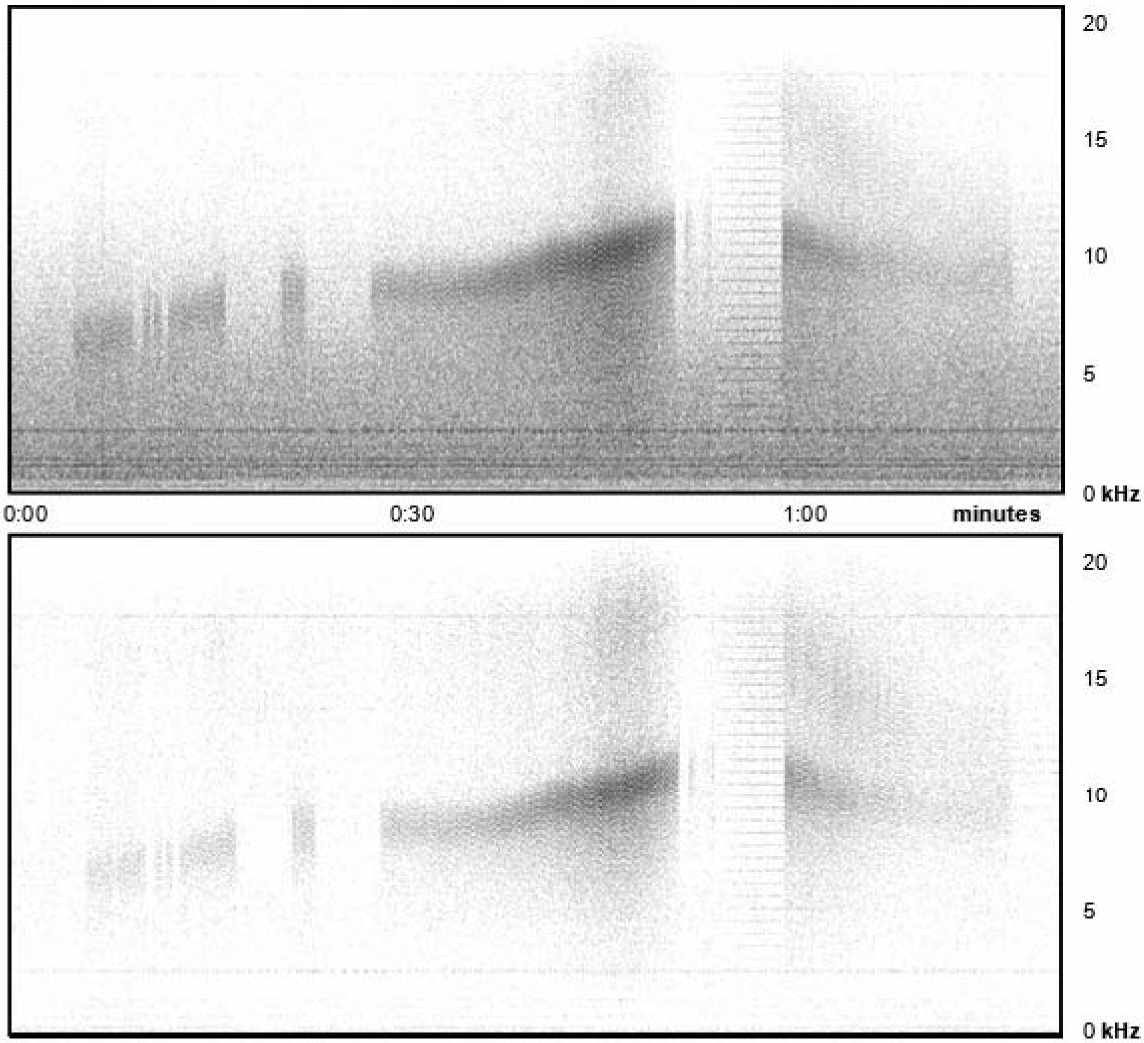

Fig. 1 - Spectrogramme recorded during the laboratory fracture of a sample of calcare massiccio (massive limestone). Each spectral line is on a time interval of 0.012 seconds with sampling rate of 44.1 kHz . The top figure is the unfiltered signal, that on the bottom is filtered for the noise spectrum with a band pass filter from 80 Hz to 12 kHz. The time window used is a portion of the first half of the experiment which lasts about 5 minutes. Note that the band 3 kHz wide of the spectra initially drifts from about 7 to 12 kHz then decreases to about 9 kHz.

Fig. 2 - Spectrum of 2 seconds of the signal recorded in the laboratory during the compression of a sample of calcare massiccio (massive limestone). Note the hump in the frequency range 7 – 10 kHz with a peak of 6 dB above the noise level.

We note that the set of signals emitted as a shower typically precedes the fracture of the sample, in practice they occur at half time, between the beginning of the pressure and the fracture.

Apparently, the difference between the scale of the signals recorded in the laboratory and the perspective precursor concerns mostly the separation between the trains of impulses and not the frequencies revealed by the spectral analysis.

In both cases, the signal is composed by the repetition of a characteristic train composed by impulses with the shape of wavelets whose period determines the position in the band of emission which is always 3 kHz wide.

In the cave experiments we recorded the electric emission during 8 purposely made explosions to extract rocks which in this case were of massive limestone. The blocks extracted were 30 m (front), by 10 m (height) and by 4 m (depth). Since the electric signal was very strong, the linear antenna of the recording instrument was set perpendicular to the electric field front. The first signal recorded in the observations made in the cave on the occasion of the extraction of rocks is due to the explosive phenomenon and is a very short impulse of difficult analysis, there is a second signal formed by a set of very few impulses with major amplitude around 0.2 kHz (fractures occurred during the collapse of the demolishing front), followed by a set of impulses with maximum spectral amplitude at frequency around 0.8 kHz (due to the relaxation fractures in the remaining mass of rock) finally, we recorded an irregular sequence of impulses with even lower frequency (due to the final relaxation of the rock mass). These signals, which are generally due to a dilatation relaxation, could be assimilated to postseismic phenomena and seem to have different properties from those of the presumed earthquake precursor and from the laboratory compression experiments. A record of the spectrum of a signal recorded is shown in Fig. 3.

A particular experiment was made in the cave with the holes for the explosive set in a semicircular form on the rock bottom of the cave. The rocks fractured by the explosions had no possibility of expansion and were compressed and fractured as in a laboratory compression experiment with confining pressure. A few seconds after recording the usual sequences as in the

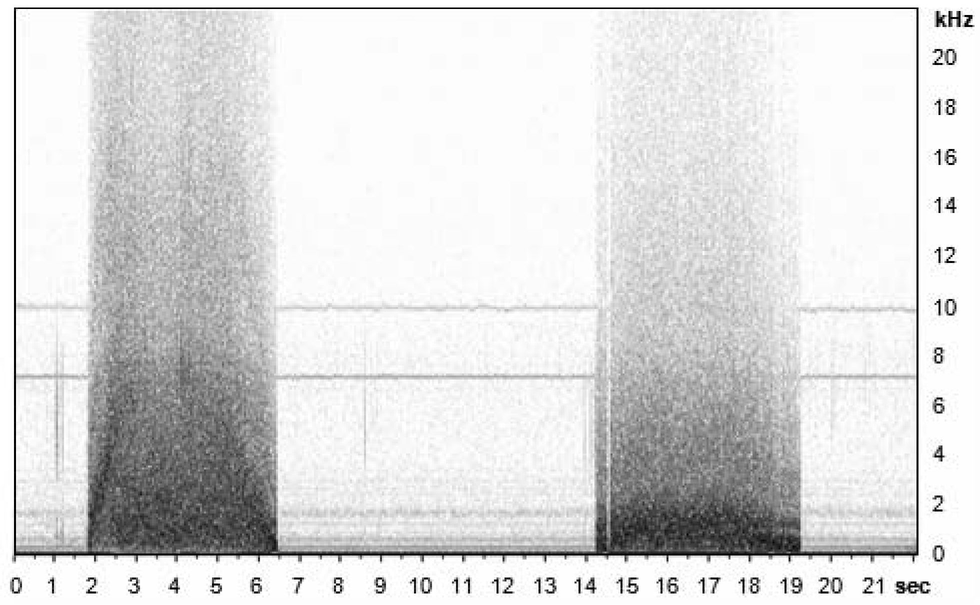

Fig. 3 - The figure shows the spectrogramme of the 2 sets of impulses recorded in the experiment in the cave. The lines parallel to the ordinates represent the spectra whose amplitude is given with 256 tones of grey. Each line is the spectrum of a time window of 0.0116 s at a sampling rate of 44.1 kHz. In the first set we notice the drifting of the 3 kHz frequency band towards the 7 kHz in the time interval from 2 to 2.6 s and then decreasing to the frequency 1 kHz at the time interval from 5 to 6,5 s. In the second set the drifting of the band has a similar drifting to that of the first.

other experiments, we recorded 2 different sets of signals, similar to the presumed earthquake precursor: that is regular successions of almost identical impulses with maximum spectral amplitude in a frequency band width of about 3 kHz initially, drifting towards higher frequency. This experiment delivered an exceptional amount of seismic energy which alarmed villages at a distance of a few kilometres and could possibly be associated to that of an explosive source as in underground nuclear explosions or earthquakes of volcanic origin.

4. The electric precursors in Italy

The observation of electromagnetic emission before, during and after earthquakes begins early in history. The first written Italian report of a possible electric phenomenon associated to earthquakes is in the hand-made copy of a document of an unknown author quoted in the chronicle of Solerti (1889) and described by Caputo (1987, page 103-104). The report describes luminous phenomena occurring during and after the earthquakes of November 17 and December 18, 1570, and also November 23 and 30, 1571. If we extend our attention to the world literature, especially that concerning ancient times, almost certainly we may find older reports.

The first systematic list of electric phenomena associated to earthquakes was made by Galli (1910) who reported 148 luminous phenomena that occurred in Italy: 52 before, 37 during and after the associated earthquake. The most frequent phenomena reported are flashes occurring during the earthquake, the luminescent clouds and diffuse lights are reported before during and after the earthquake.

The scientific literature of the second half of the last century on electric precursors (EP) of earthquakes is vast; we list only some of the most important and/or those which are most readily available and pertinent to the matter of this note (Kato *et al*., 1950; Rikitake *et al*., 1967; Varotsos and Alexopulos, 1975; Mizutani *et al*., 1976; Ishido, 1977; Noritomi, 1978; Fitterman, 1979; Bella *et al*., 1995; Mognaschi, 1998).

The first Italian research on this type of precursor is that by Mognaschi and Zezza (2000) who reported the detection of electromagnetic emissions, in a narrow band set between 300 kHz and 3 MHz, from the fracture of rocks and building stones understress.

Bella *et al*. (1995) have also recorded electromagnetic signal of unspecified frequency in the Central Apennines before earthquakes.

A set of experiments on possible EP in the field, began during the last years of the last century, that have shown that rocks emit electric signals, with particular frequency signature, during compression and fracture (Nardi *et al*., 2003; Nardi and Caputo, 2004). The electric signals, recorded in the laboratory and in the field experiments are generally of the same type and particularly in the VLF band.

In the volume of the crust of the Earth, where the preparation of earthquakes occurs, the rocks are subject to stress which makes it reasonable to assume that also in this time period, but mostly in the final stage of the preparation of the earthquake, the same emission recorded in the laboratory and field experiments would occur.

A special instrument, called radio-geophone, operating in a wide band including the acoustic frequencies, was specially designed to record possible EP (Nardi, 2001). The instruments sample the signals at a frequency of 44.1 kHz and consequently with a Nyquist frequency of 22.05 kHz. The instrument, with a dynamical range of 60 dB, has a flat response curve between 80 Hz and 12 kHz which ensures no aliasing. If higher frequencies are received, they are not recorded.

Since the radio-geophone was very successful in recording these signals in the experiments made in the laboratory and in the field, it was then decided to tentatively install the radio-geophone in an experimental station located near Cascia (PG) (lat. 42.8° N; long. 13.1° E; 900 m a.s.l.) in order to record possible EP emission of the earthquakes of the region during August and September 2003. In this station, the spectral analysis of the EM signal was made on hourly samples of the spectra computed every 8 seconds with time marks every 5 minutes. We could thus store data for long time intervals (about 6 months).

On September 10, 2003 at $10^h\ 05^m$ a presumed precursor, in the VLF band, was recorded, possibly associated to the earthquake with magnitude 5.2 that occurred on September 14, 2003 at $22^h\ 42^m\ 50^s$ in the Tosco-Emiliano Apennines (epicentre lat. 44.22° N; long. 11.35° E) at a distance of nearly 270 km from the receiving station. The signal consisted of main inputs with duration of tenths of minutes and separated by a few minutes. Each input consisted of a set of microimpulses.

The filtering of the digital recordings allowed us to eliminate the background noise and to correct for the influence of the response curve of the receiver revealing that both signals are in the band 8 - 10 kHz.

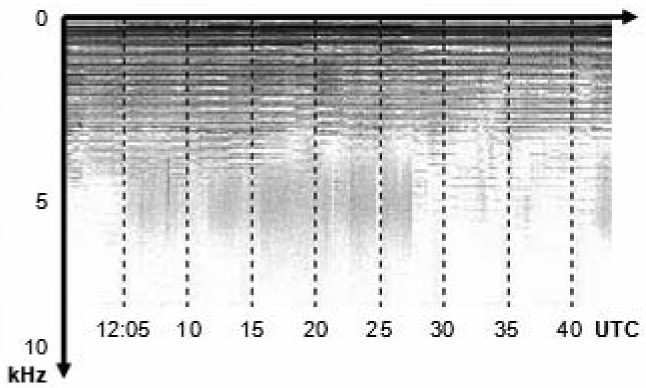

Fig. 4 - Spectrogramme of the signal recorded on September 10, 2003 and concerning the earthquake with magnitude 5.2 that occurred in the Tosco Emiliano Apennines, at a distance of about 270 km from the station, on September 14, 2003. In the figure, the lines parallel to the ordinates represent the spectra whose amplitude is given with 256 tones of grey. Each line is the spectrum of a time window of 8 s at a sampling rate of 44.1 kHz. The time is indicated in the small rectangular windows at the bottom of the figure.

In Fig. 4, we see the spectra of the signals recorded, in Fig. 5, the shaded area represents the spectrum of 20 seconds of recording with a peak of 24 db above the noise level and the pure signal above the background noise is shown in Fig. 6. The presumed precursor was composed of several anomalies of this type each lasting several minutes.

We note that further filtering indicates that the frequency band is centred around 9 kHz.

We note also that signals with the same signature had already been recorded with a more rudimental instrument, at the station near Cascia beginning at least 50 days before the earthquake of Colfiorito (epicentre lat. 43.0° N, long. 12.9° E, about 30 km from Cascia) that occurred on

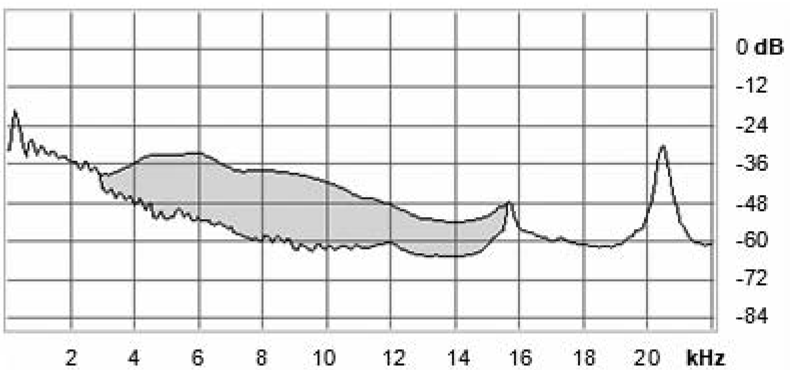

Fig. 5 - Presumed precursor recorded in the field on September 10, 2003 and concerning the earthquake with magnitude 5.2 that occurred in the Tosco Emiliano Apennines at a distance of about 270 km on September 14, 2003. The bottom solid line is the spectrum of the noise, the top one is that of the signal recorded. The shaded area represents the difference of the spectra of 20 seconds of recording with a sampling rate of 44.1 kHz, it has a peak of 24 db above the noise level. The presumed precursor was composed of several anomalies each lasting several minutes. The amplitude scale in the ordinate is decreasing towards the bottom.

Fig. 6 - Residual spectrum of the 20 seconds of recording with a peak of 24 db above the noise level after subtracting the background noise. This figure represents the difference of the recorded signal after subtracting that of the noise.

September 26, 1997 with magnitude 5.3 and followed by a set of aftershocks. The signals, in the form of a sound, were recorded during the whole of the month of August. We estimated that the corresponding electromagnetic emission band was in the range between 3 and 5 kHz. The distance from Colfiorito is about 30 km. The signal was repeated at intervals of 15 - 20 minutes with interruptions of 10 minutes at most. Each episode could have interruptions of a few seconds. This type of emission, was never recorded in years, of though not continuous, of monitoring.

The EP of the Colfiorito (of September 19, 1997) and of the Tosco Emiliano Apennines (of September 14, 2003) consists of sets of impulses practically identical in duration, separation and spectral band; sometimes the band is slowly drifting keeping its width and intensity. The sets have a duration of many minutes (around 10) and are separated by about the same time for both earthquakes. The frequencies in the impulses recorded are the same as in the laboratory experiments in the band 3-12 kHz.

The distance between the recorded EP signal and the epicentre of the earthquake tentatively associated to it is too large for being of practical use in forecasting earthquakes, at least one should use a large number of stations equipped with instruments of the radio-geophone type. Probably stations with improved instrumentation equipped with directional antennas are needed.

The signals recorded at the station near Cascia have not been recorded in other circumstances during the months when the radio-geophone was installed at Cascia nor at any other stations located at Frascati and Norcia for a few months.

5. Conclusions

The findings reported in this brief note are very preliminary and intended to catch the attention of the scientific community to the phenomenology reported and the possibility it offers for the forecasting of earthquakes. The studies on the emission during compression of rocks in the laboratory may possibly be associated to preseismic phenomena while those made for the normal extraction of rocks in the cave could be associated to post seismic phenomena.

The similarities between the signals recorded before the earthquakes of Colfiorito (of September 19, 1997) and the Tosco Emiliano Apennines (of September 14, 2003) and those observed in the laboratory during the uniaxial compression and fracture of rock samples seem positive and it is encouraging to pursue the studies in this field. Their are only 2 stations with radio-geophone now installed and operating in Italy, an increase in the number of these stations would be necessary to establish the distance from where the signals may be observed.

We note that an EP of the September 14, 2003 earthquake was observed also by Mognaschi (2004) at the Department of Physics of the University of Pavia, in a frequency band (0.01 Hz - 5 Hz), as amplitude signal integrated over the entire band as a function of time.

For more information on earthquake's precursors see for instance the texts of Asada (1982), Mizutani (1982) and Mogi (1985) which contain a vast literature on electric precursors of earthquakes and of precursors of many other types.

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