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Notes based on:

Evidence for Electromagnetic Emission During Rock Loading and Fracture: A Way Towards an Earthquake Precursor

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NOTES BASED ON:

Evidence for electromagnetic emission during rock loading and fracture: a way towards an earthquake precursor (Submitted for publication).

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Abstract.

We present the results of experiments made on rock samples in the laboratory and in the field which show the very low frequency (ELF, VF (voice frequency), VLF) radio emission associated to mechanical deformation and fracture of the rocks. The interest on this phenomenon is motivated by the possibility to find in this emission, called "radio-seismic", a systematic precursor of fracture and therefore of earthquake occurrence. The same effect could be used in remote monitoring of the state of tension of rocks for possible landslide and in engineering applications on large structures such as dams and bridges.

The method is based on the monitoring of the electromagnetic emission in the acoustic band (20 Hz – 20 kHz) which is possible with the available hardware and software which allows instrumentation at low cost called radio - geophone. The phenomenon at the origin of these emission has not yet been determined with certainty. Here we will refer to two hypotheses both based on the micro - fracturing implied by dilatancy.

The field experiments have been made in a quarry of *Calcare Massiccio* during and after the explosions used to produce the rock material. The laboratory experiments has been made on samples of different rocks (*Calcare Massiccio, Calcare a Rudiste, Scaglia Variegata, Porphyry, Corniola)* subject to uniaxial compression. Besides the radio - geophone we used acoustic sensors and two conventional radio apparatus to monitor the acoustic emission, the pressure wave, and the HF and UHF electromagnetic emissions.

The analog recordings have been converted to digital for filtering and spectral analysis. We observed signals emitted from the rocks which may be associated to the state of stress (compression in the laboratory and extension in the cave) . In the bands ELF-VLF the premonitory signals of the fracture have been systematically observed. These emissions have a maximum intensity in the radio - acoustic band, decreasing with increasing frequency and therefore very low in the radio band of major use. The emission mechanism seems independent from the type of rock and from the type of perturbations used which lead to the fracture. Concerning the type of rock the signals seem more correlated to the structural homogeneity rather than to the mineralogical composition.

1. Introduction. In the figure 8 we may see the final sequences of the precursory signals observed few seconds before the fracture indicated with R. Top and median couples of graphics are obtained with two different samples of Porphyry, the bottom couple is obtained with *Scaglia Variegata.* In each of the 3 couples the top graphic represents the acoustic signal (Mic), the bottom represents the electric signal (E). The abscissa is seconds. The ordinate is in percent of the maximum recorded for the acoustic signal and Volt in percent of the maximum recorder for the electric signal.

If we were allowed to extrapolate linearly from the data of figure 8 we would draw the following implications.

2. Discussion.

In the laboratory experiments the samples were subject to a press which increased almost linearly the pressure until the fracture of the sample was reached.

In the 3 cases under study the times of interest are listed in the following table

Time of first E signal before fracture

22.6 sec

22.4 sec

26.8 sec

If we indicate with x is the stress accumulation rate in the crust, a is the stress accumulation rate in the sample, B_s is the breaking stress in the sample, B_c the breaking stress in the crust, t is the time when the first precursory signal occurs in the sample before failure, and T is the time when the first precursory E signal occurs in the crust before the earthquake.

Let $T_s = B_s/a$, T_c c $= B_c/x$, then

$T_s - t$ is the precursory time in the sample and $T_c - T$ is the corresponding precursory time to the earthquake

$T_c - T = (B_c/x)(1- at/B_s)$

With

$B_c = B_s$

it is

$T_c - T = (B_c - at)/x$

We obtain tghen the following table

Time of first E alarm

$(B_c - a(T_s - 22.6)/x\ )$

$(B_c - a(T_s - 22.4)/x)$

$(B_c - a(T_s - 26.8)/x)$.

In order to interpret the E signal observed and extrapolate the results to practical application we tentatively assume that the breaking strength of the rock samples is about 300 bar and that the corresponding pressure is reached linearly. We observed that in the experiments the breaking pressure was reached in about 300 sec or at a rate of about 1 bar/sec.

With reference to the first experiment with Porphyry we note that the first E precursory signal occurs unmisteakably 22.6 sec before the failure of the sample and try to transfer this results the Earth's crust we tentatively assume that the stress accumulates at a rate of 1 bar/y to reach breaking stress in about 300 years. This would imply that the first E signal emitted by the crust, before the impending earthquake, if the crust had the same elastic properties of this type of porphyry, would occur 22.6 years before the earthquake.

In the case of the second Porphyry sample, with the same hypotheses previously used, since the first E signal emitted by the sample occurred at 22.4 sec before the failure of the sample, then the crust, before the impending earthquake, would emit a signal 22.4 y before the earthquake. But there was also an E signal emitted at 28.3 sec before failure of the sample then we would observe a precursory E signal before the impending earthquake also 28.3 y before it occurs.

Concerning the experiment with the Scaglia Variegata using the assumption previously introduced, if the elastic properties of the crust were the same as those of Scaglia Variegata, since the first E precursory signal occurred 26.8 sec before the failure of the sample, we would see a first precursory signal 26.8 y before the earthquake occurs.

This seems not too encouraging because the alarm time would be too long to be of any practical use; however, fortunately, the fracture causing the earthquake is the ultimate phase of preparation of the event, practically it is the event itself and interests only the barrier broken by the accumulated stress, which concentrates on the barrier, but results from the stress accumulated in the surrounding region which is what we observe on the surface of the crust through the strain measurements. The stress concentration factor of the system (barrier – fault – regional stress) is generally very large and the E signals to be observed would be those emitted by the barrier during the accumulation of elastic energy in the crust at a stress value which is much smaller than that which would cause a fracture of the size of the fault whose dimension is generally much larger than that of the barrier.

In this scenario the time separation between the beginning of the accumulation of the stress in the crust and the time of the earthquake would be much shorter. But this result does not yet solve the problem because the stress concentration factor depends on the geometry of the barrier and is unknown as is the barrier itself then the level of stress in the region could be of help but not solve the problem of the estimate of the time separation between the E signals and the earthquake..

Only in volcanic areas where the strain accumulation may be of the order of 10^-4/yr (Caputo 1978, 1979) the alarm time may be reduced to a reasonable duration.

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Figure Captions

Figure 1. Symbolic representation of the radio - seismic mechanism: a rock is subject to compression (left) and the conductive minerals imbedded in a non conductive background form chaotic circuits which connects the piezoelectric crystals; these in turn create the electric tension. The phenomenon is represented by an electronic circuit (right) in which every cycle of compression and dilatation will invert the polarity of the elements.

Figure 2. Succession of the compression – dilatation cycle in connection with the relation to the direction of the radioloop. Obviously the association of a given tension with a direction is casual.

Figure 3. Hypothetic comparison between the propagation of the electric signals VAN and that of the radio – seismic ones interpreted with the radio – loop theory. The efficiency of the VAN method is limited to the presence of electrically charged masses which are capable to interact with the exceeding charges present in the region of the radio – loop.

Figure 4. Schematic representation of the steps in the *Calcare Massiccio* cave. P are the holes for the explosive. The parallelepiped V is the mass which will be removed by the explosion and S is the location where are instrumentation was placed during the experiment.

Figure 5a.Recording of experiment labelled UC2 04 GP in which a step of Calcare Massiccio is extrated from the cave. Above is the spectrogramme recorded in the pressure microphone (EC), below is that og the E-VLF signal. The explosion an collapse appear in the EC recordning with a continuouus sequence followed by a succession of impulses caused by the fall of ejecta (EJ) from the well. In the E-VLF channel instead one may observe a more complex sequence: A) an impulse at the time of the xplision, B) a brie sequence (not always present) coinciding with the collapse, C) a sequence of clear impulses but so near one another to be almost undistinguishable, D) a cleas sequence of strong inpulses well separated in time, E) random impulses occurring after the previous ones. In this case the event B is more evident than normally, on the contrary the event C is unusually reduced and almost undistinguishable from the sequence D. The abscissa is time in seconds. The ordinate is KHz. The intensity of the grey tone in the spectrum represents its relative amplitude described with 256 different tones. The horizontal lines are monochromatic noise arising from a power line (50 Hz) and from the apparatus near the radio-geophone (7,5 kHz); the impulsive events in the high frequenc are caused by statics of the atmosphere known as *spherics.*

Figure 5b. In this case, contrary to that of figure 8a, in which however results the variabilityof the emitted signals. In this case, contrary to that of figure 8a, the event C is clearly evident, but the sequence D is not well developed. The abscissa is time in seconds. The ordinate is Hz. The intensity of the grey tone in the spectrum represents its relative amplitude.

Figure 6. Dynamic of the collapse of a sped of limestone in the cave and correlation with the associated radio – seismic emission. 1) The explosive charges set in the *Calcare Massiccio* step. 2) Successive explosion of the charges aligned in the step. 3) Detachment of the front of the *Calcare Massiccio* step. 4) Collapse of the step. Fractures in the wall side of the former step.

Figure 7. Radio – seismic successions of the type C and D in the band E of the experiment labelled UC 7 in the Calcare Massiccio. In abscissa is time in seconds. In the top figure is the spectrogramme, where the ordinate in kHz, with the intensity in Volt, expressed with 256 different tones of gray in the spectrum, represents the relative amplitude; in the bottom figure is the oscillogramme where the time is in a more detailed scale than in figures 8 and the ordinate is in Volt in percent of the maximum recorded.

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Figura 9 a. Parossistic sequence in the laboratory fracture of a sample of *Calcare a Rudiste*. The abscissa is seconds and the ordinate is in Hz. (Or 1000Hz). The intensity of the grey tone in the spectrum represents its relative amplitude.

Figura 9b. Parossistic sequence in the laboratory fracture of a sample of Porphyry. The abscissa is seconds and the ordinate is in Hz. (Or 1000Hz). The intensity of the grey tone in the spectrum represents its relative amplitude.

Figura 9c. Parossistic sequence in the laboratory fracture of another sample of Porphyry different from that of figure 14b. the two samples of figure 14b and 14c are obtained from the same matrix. The samples are apparently very similar however the microstructures are different as on may note that in the spectrum of this figure where appear the horizontal spectral lines due to scattered splints generated by the fracture. The abscissa is seconds and the ordinate is in kHz. The intensity of the grey tone in the spectrum represents its relative amplitude with 256 different tones.

Figura 10 Examples of parossistic sequences in the laboratory fracture (indicated with F in the figure) of two samples of Porphyry. In each of the 2 couples (Mic) – (E) the top figure represents the acoustic signal, the bottom represents the electric signal. The abscissa is seconds. The ordinate is in percent of the maximum recordede for the acoustic signal and in Volt for the electric signal.

Figure 11 Examples of parossistic sequence and post fracture emission in the laboratory fracture of a sample of Porphyry. The top figure represents the acoustic signal, the bottom represents the electric signal where are evident in Post1 many signals similar for spectral extension and intensity.
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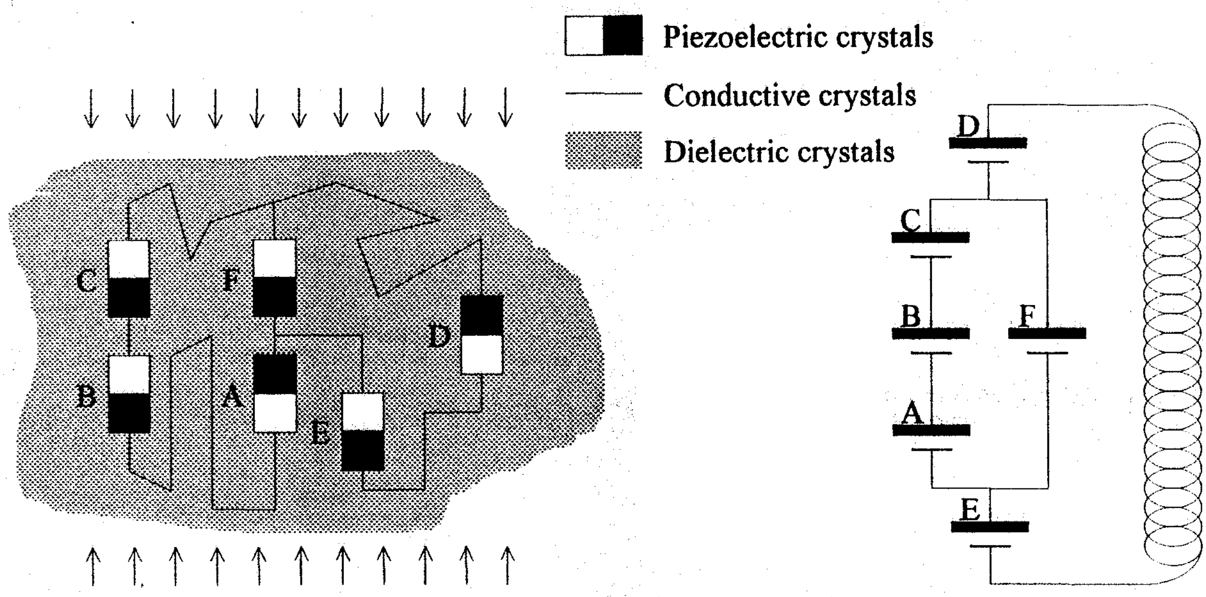
Figure 12 Example of precursory (Pre), parossistic (Par) and post fracture (Post) emissions in the laboratory fracture of a sample of Porphyry. The top figure represents the spectrum and the bottom one represents the oscillogramme of the same sequence where are seen both types of signals recorder in the E-VLF channel. Are evident in Post1 many signals similar for spectral extension and intensity. The abscissa is seconds. The ordinate in the spectrum is kHz for the acoustic signal and the intensity of the grey tone represents its relative amplitude with 256 different tones. The ordinate in the oscillogramme is intensity expressed in percent of the maximum recorded.

Figure 13 Comparison of the acoustic (Mic) and the 3 electric channels emissions in the laboratory fracture of a Porphyry sample. The maximum emission is observed in the Mic and the radio – geophone (E). In the signals at higher frequency , 3.9 MHz and 360 MHZ; the similarity between the latter two channels is due to the amplitude modulation. The abscissa is seconds. The ordinate is in percent of the maximum recorded for the acoustic signal. The ordinate for the three electric signals is Volt.

Figure 14. A typical field experiments. Acoustic channel (Ac) and E channel. The top figure is the continuation in time of the bottom one. Note that the acoustic

signal is present only at the explosion and collapse and later in the fall of the by products of the explosion. The abscissa is time. The ordinate is kHz for the acoustic signal and the intensity of the grey tone in the spectrum represents its relative amplitude with 256 different tones.

Figure 15. A typical laboratory experiments on a Porphyry sample for which we show the acoustic channel (Ac) and E channel. The top figure is the continuation in time of the bottom one. Note that the acoustic signal is well present before and after the fracture. First we have the compression with the formation of isolated micro - fractures which, with increasing time and pressure, increase in number per unit time causing emission of acoustic and electric signals. Then the micro - fractures coalesce and originate the fracture. The abscissa is time. The ordinate is kHz and the intensity of the grey tone in the spectrum represents its relative amplitude with 256 different tones.



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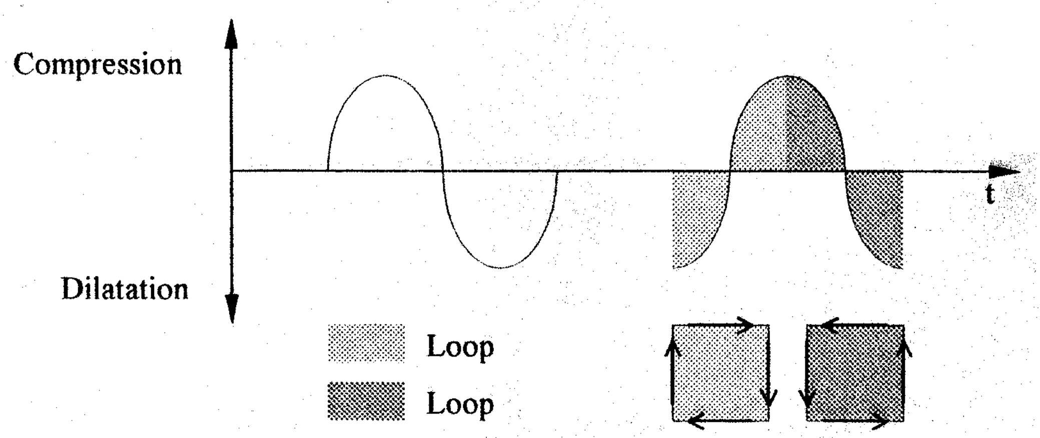

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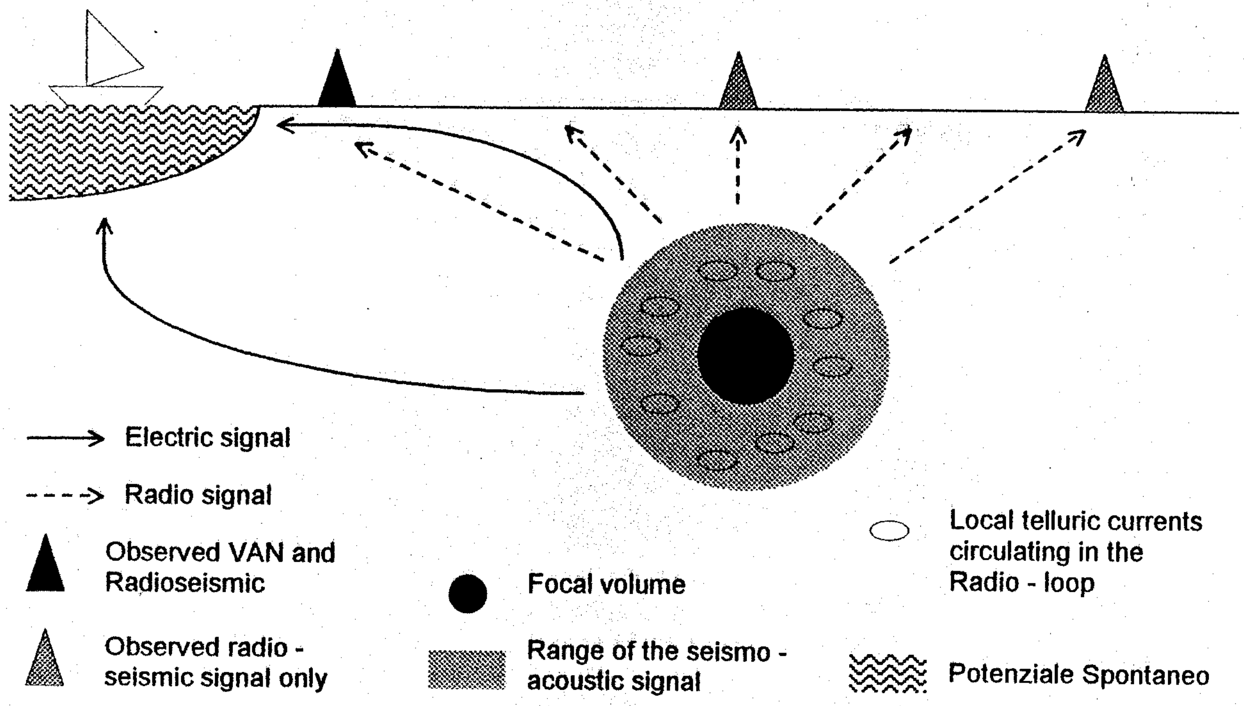

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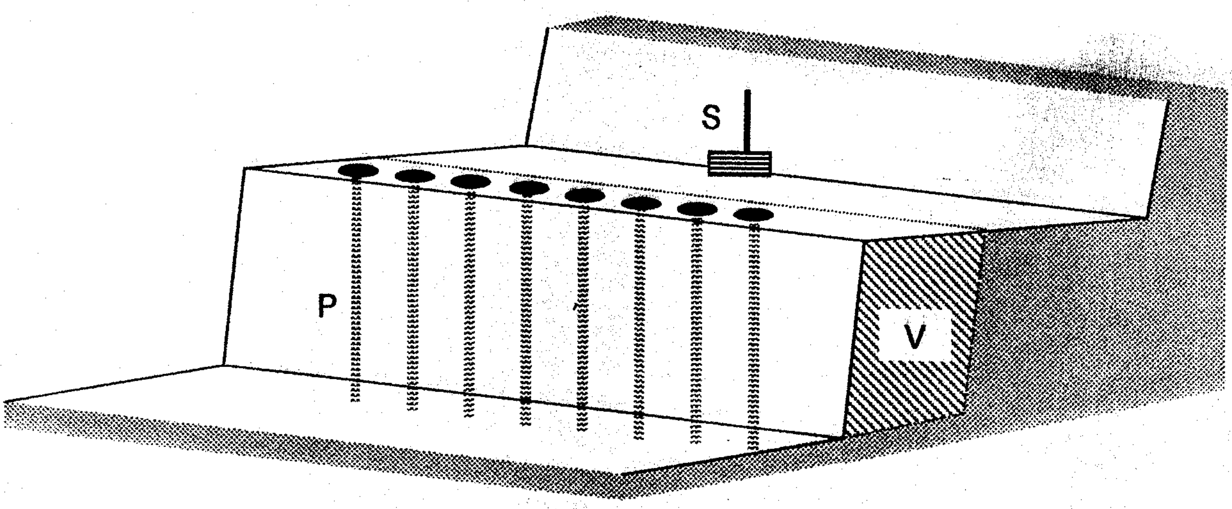

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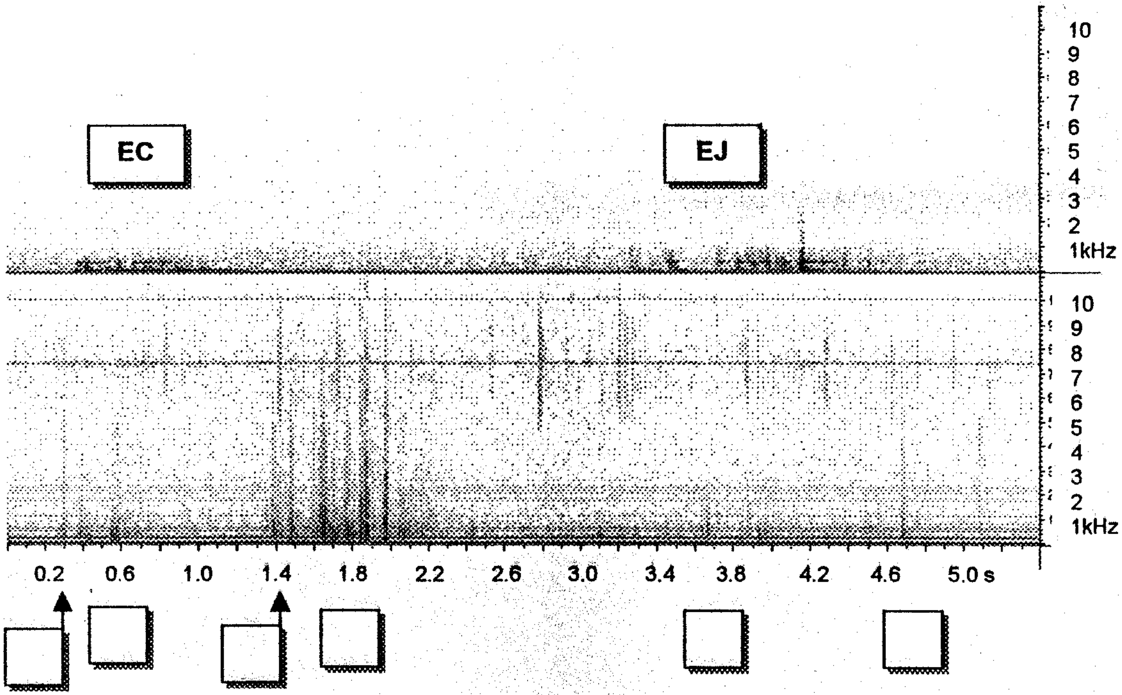

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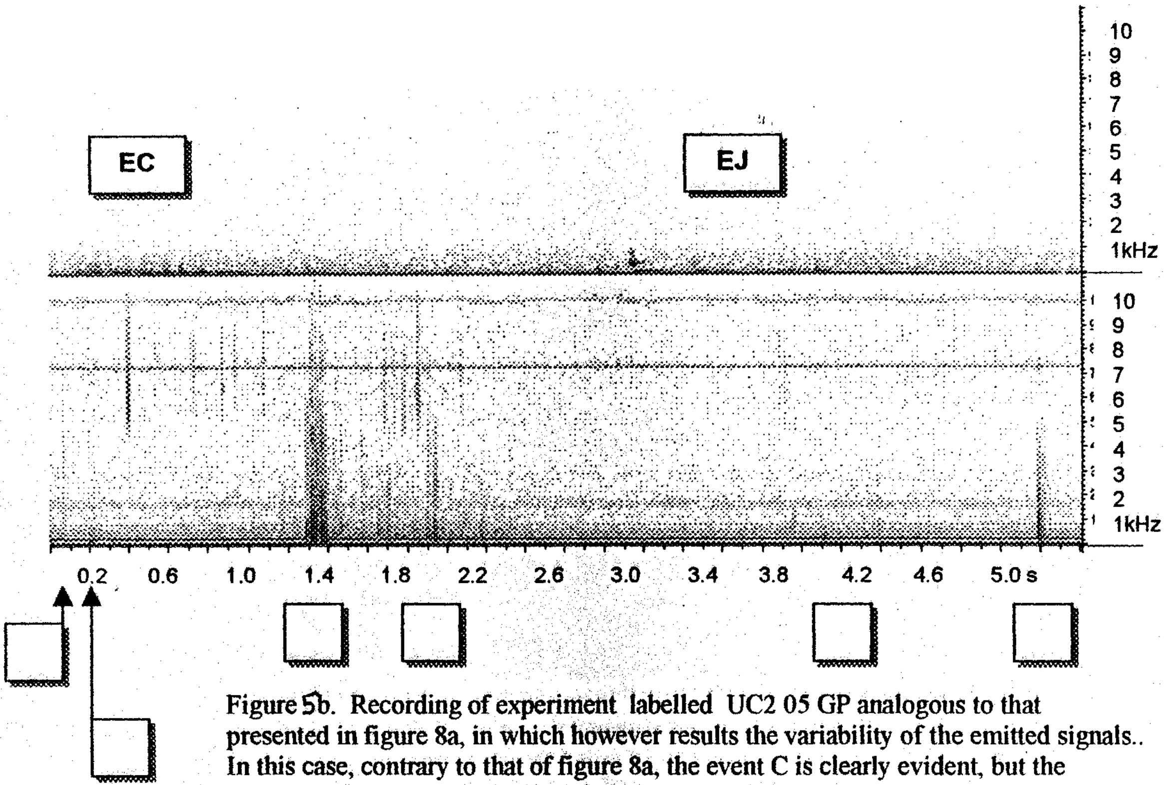

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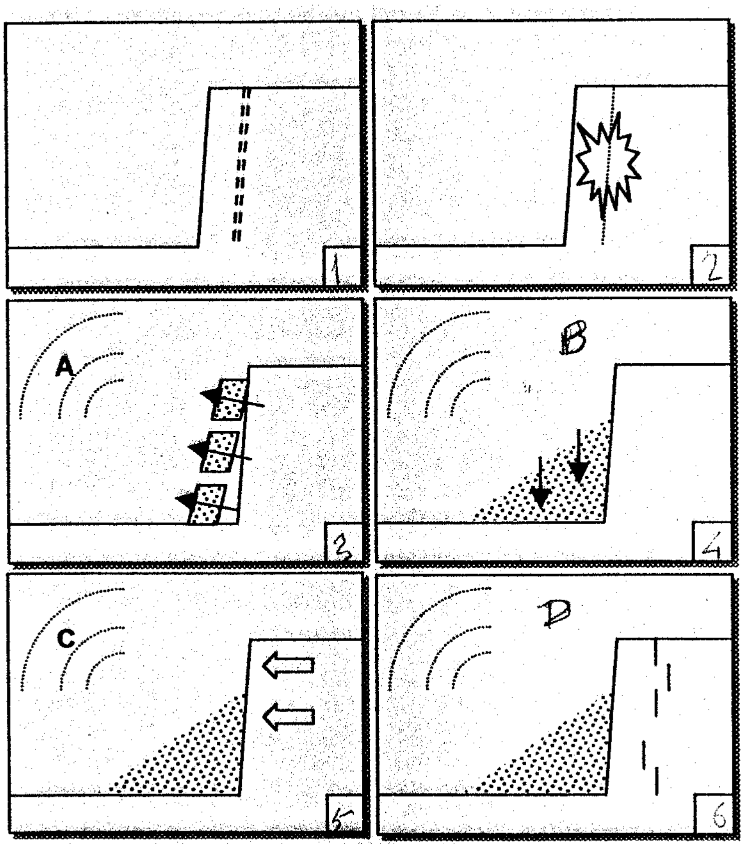

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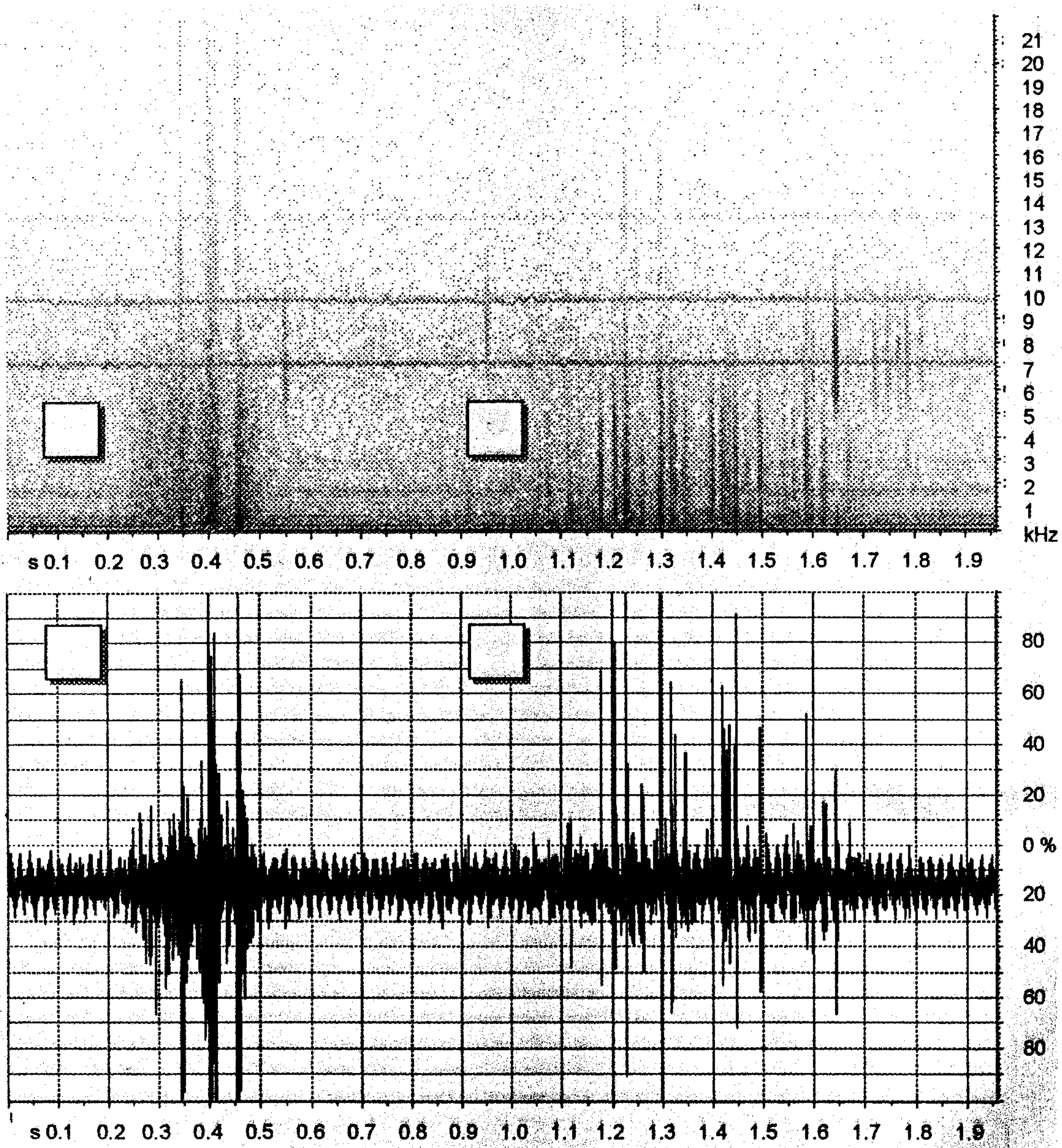

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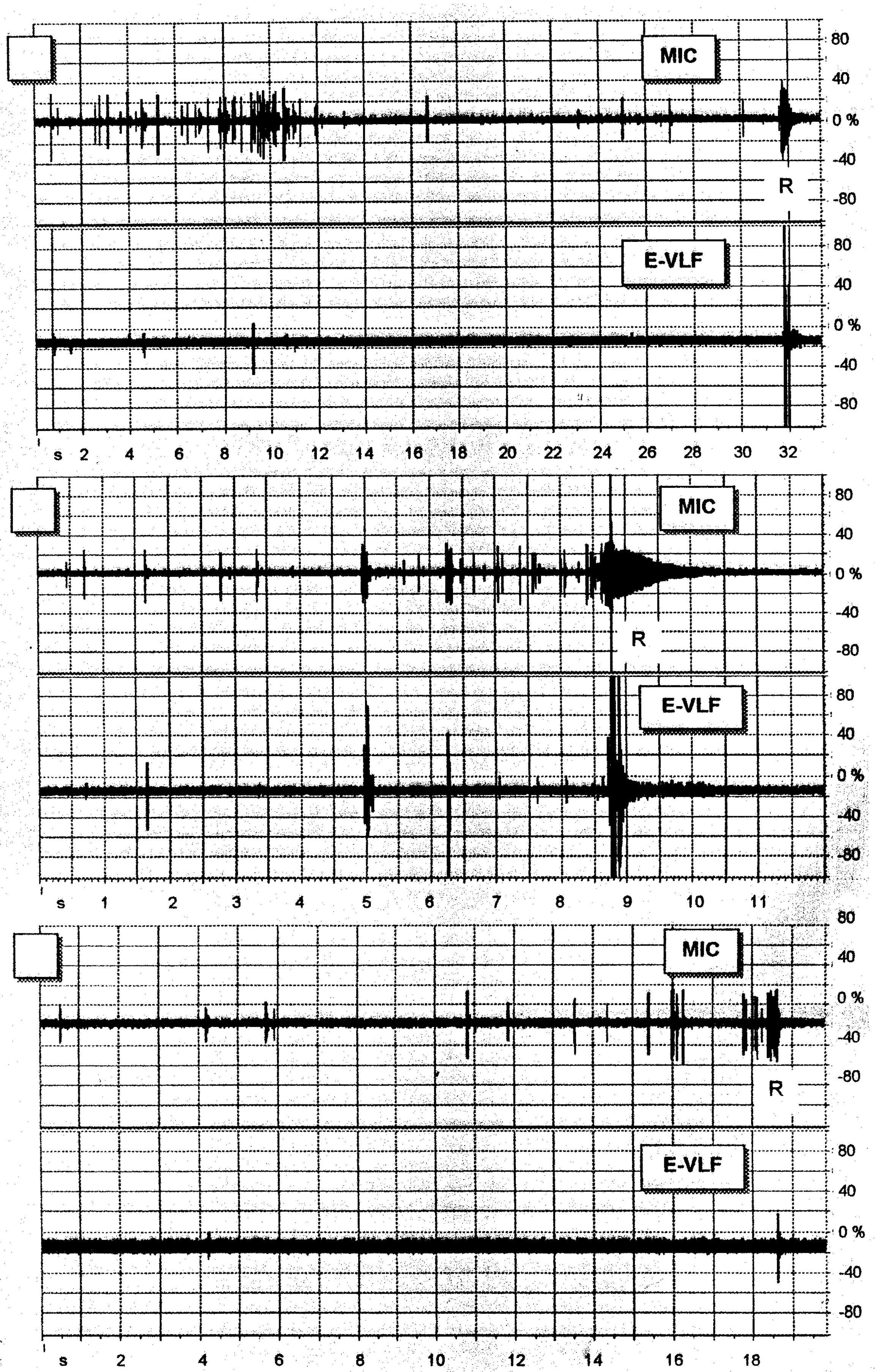

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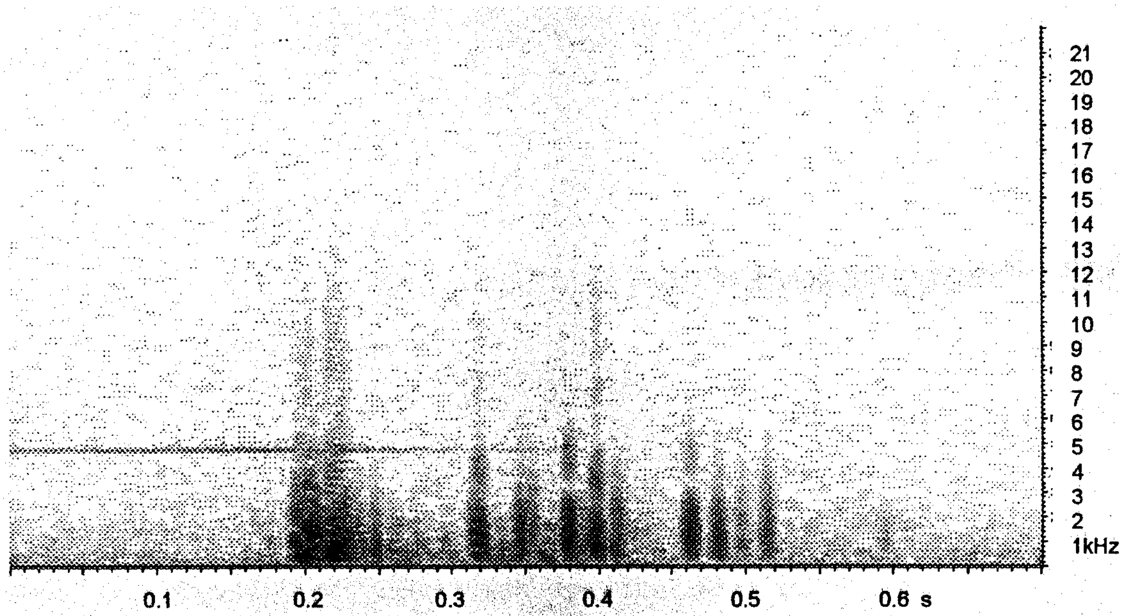
A(MIC)



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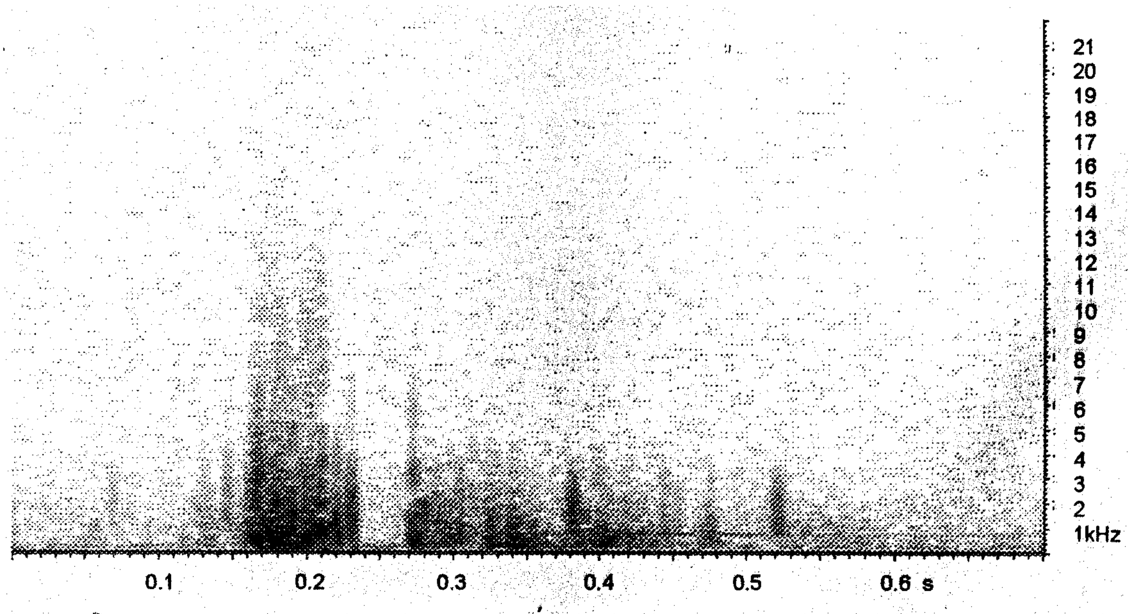

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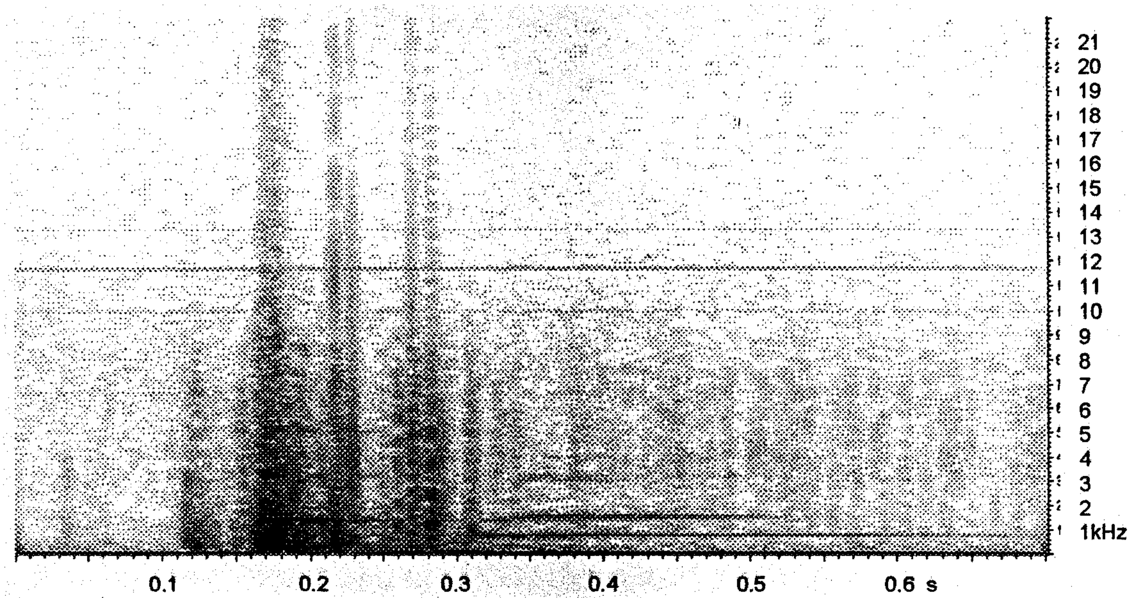

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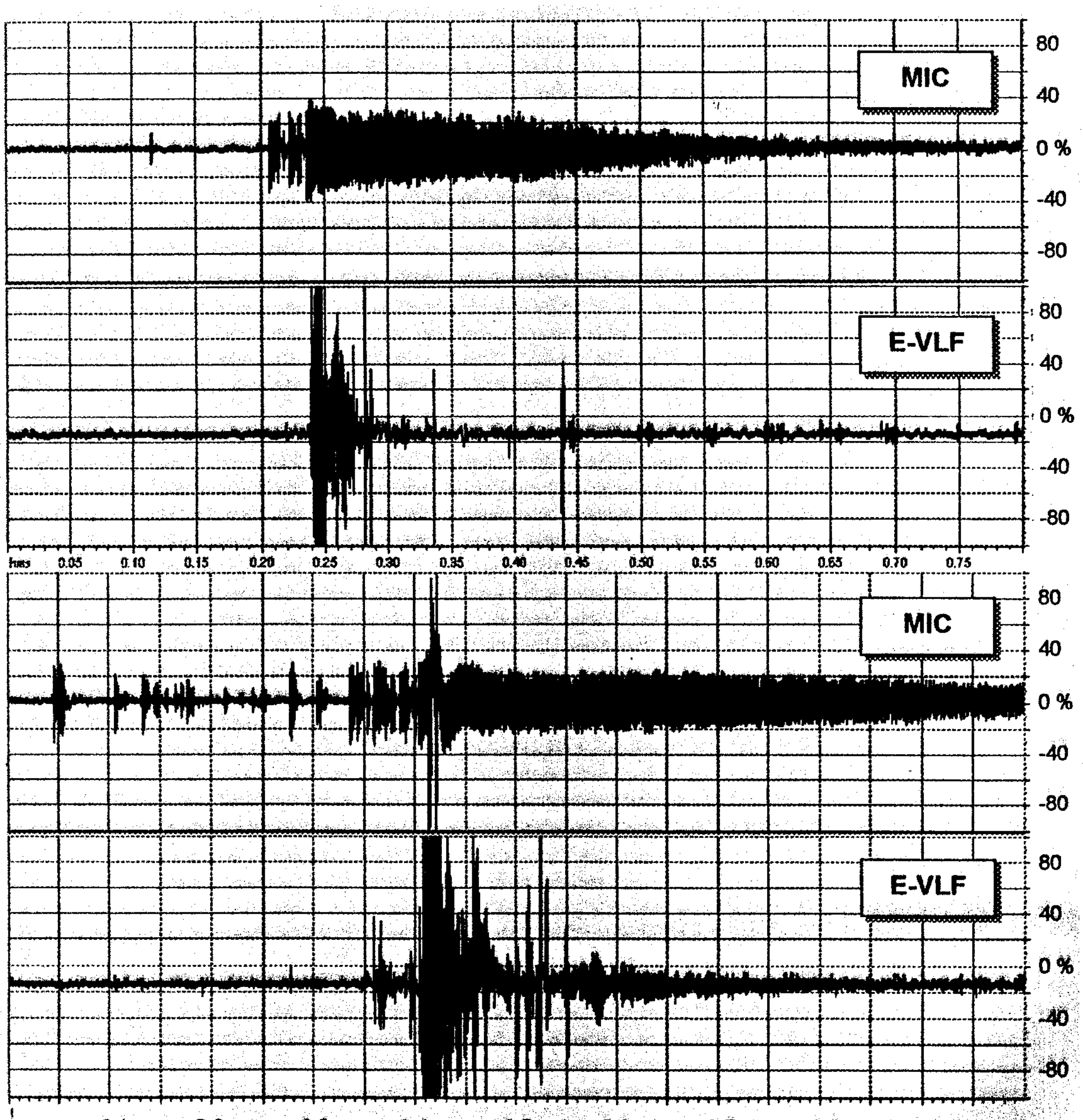

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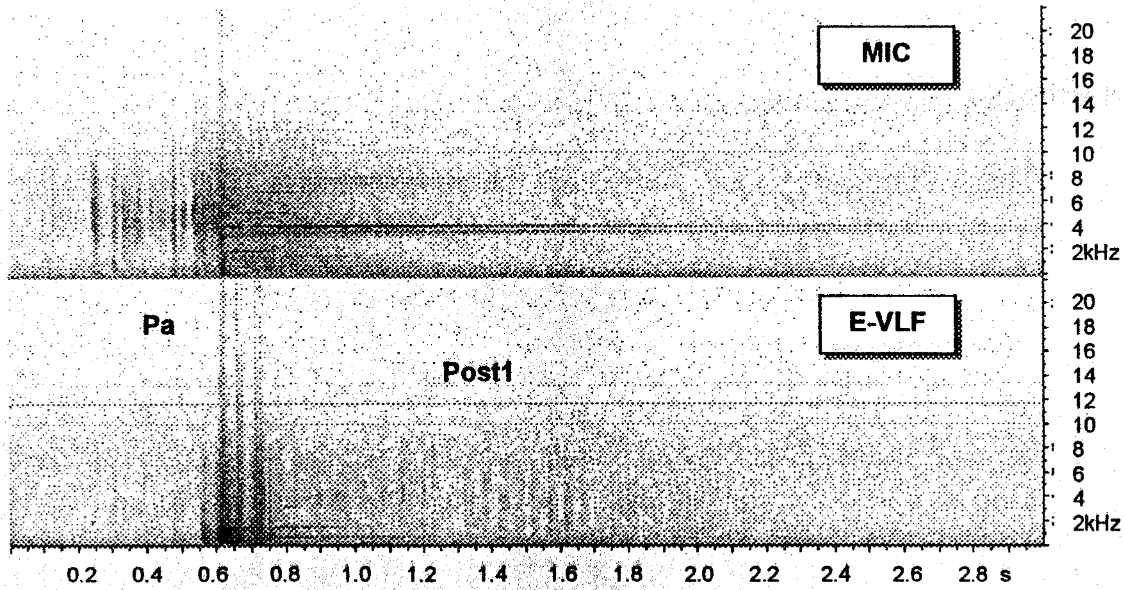

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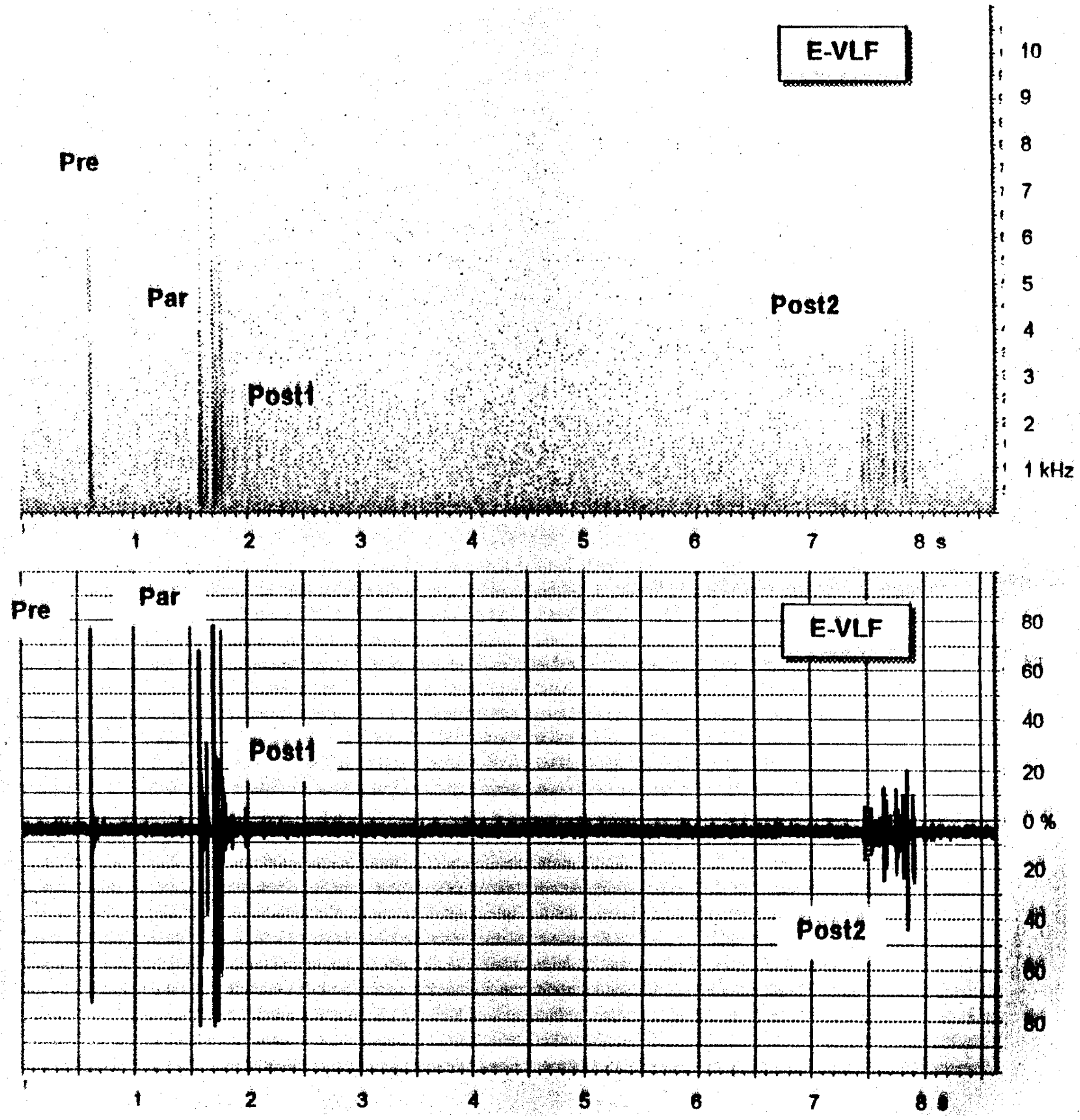

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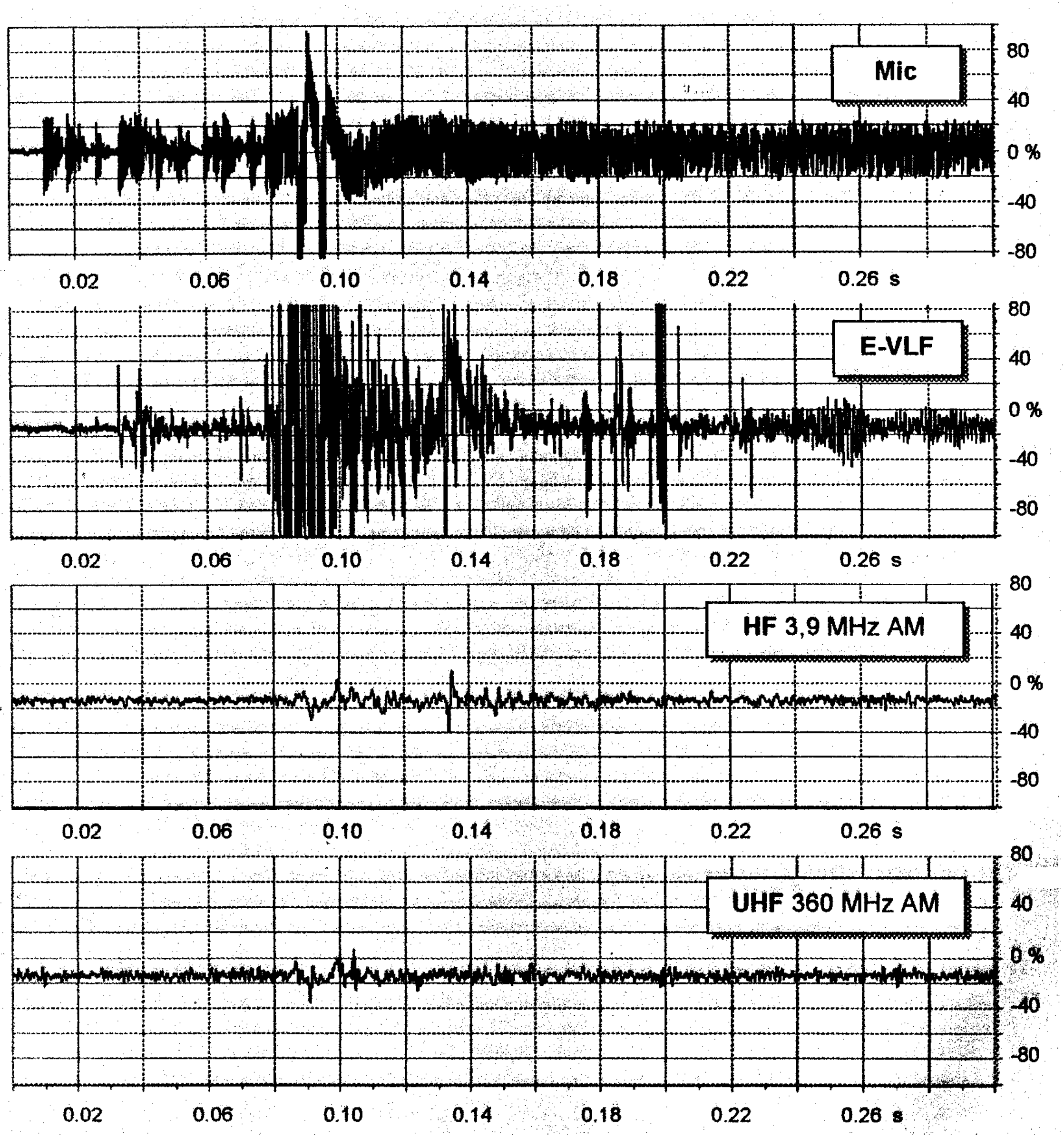

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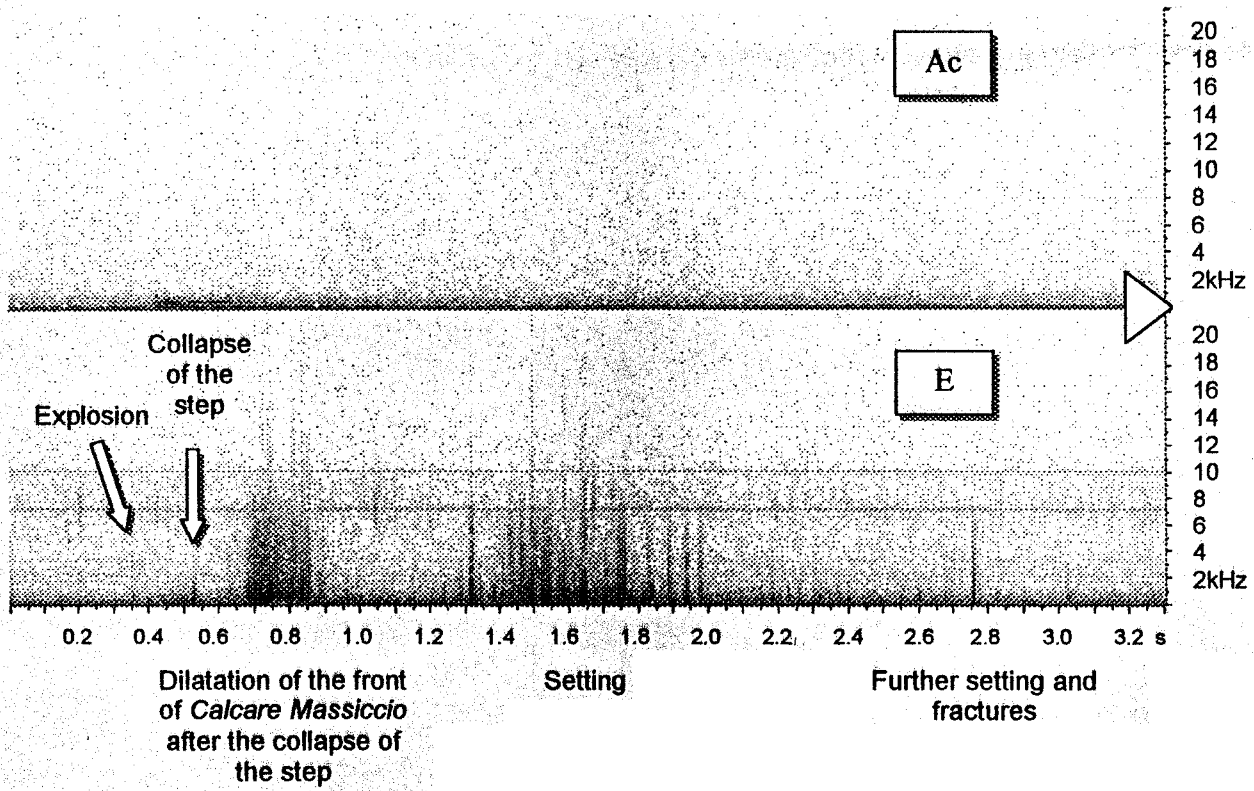
Figure 14. A typical field experiments. Acoustic channel (Ac) and E channel. The top figure is the continuation in time of the bottom one. Note that the acoustic signal is present only at the explosion and collapse and later in the fall of the by products of the explosion. The abscissa seconds. The ordinate is kHz and the intensity of the grey tone in the spectrum represents its relative amplitude.



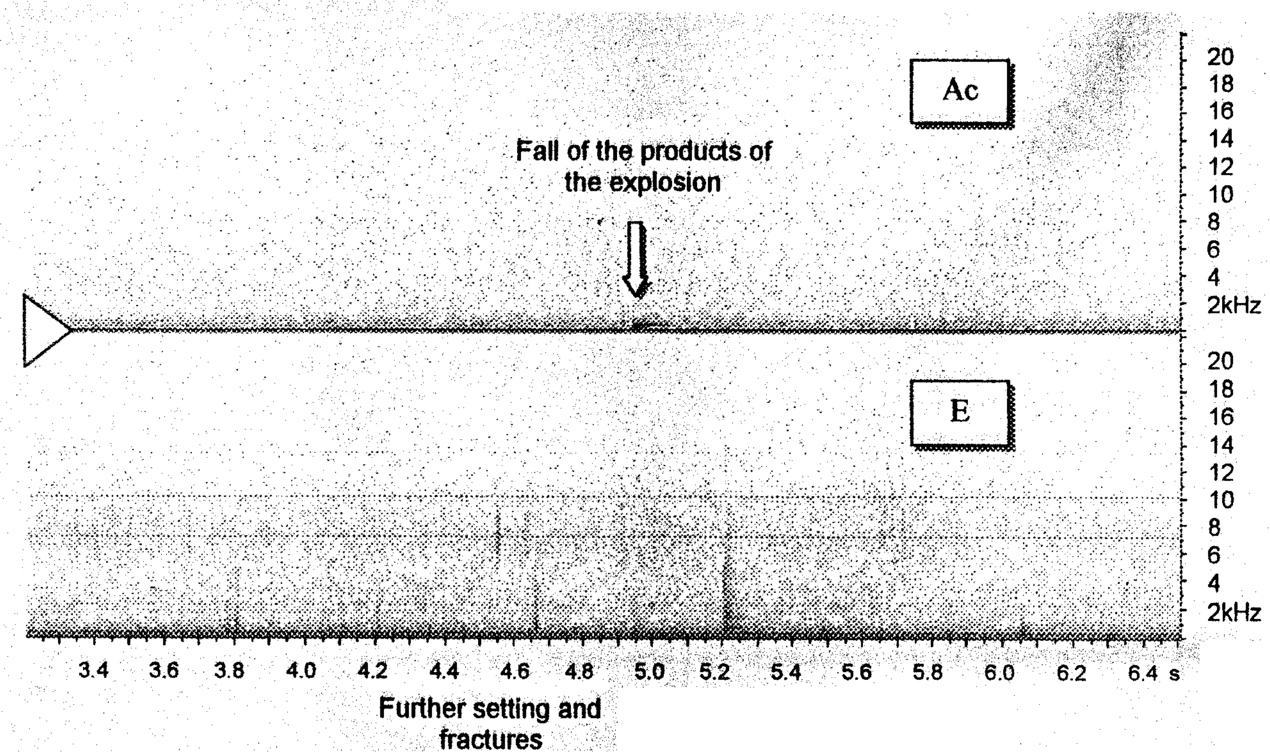
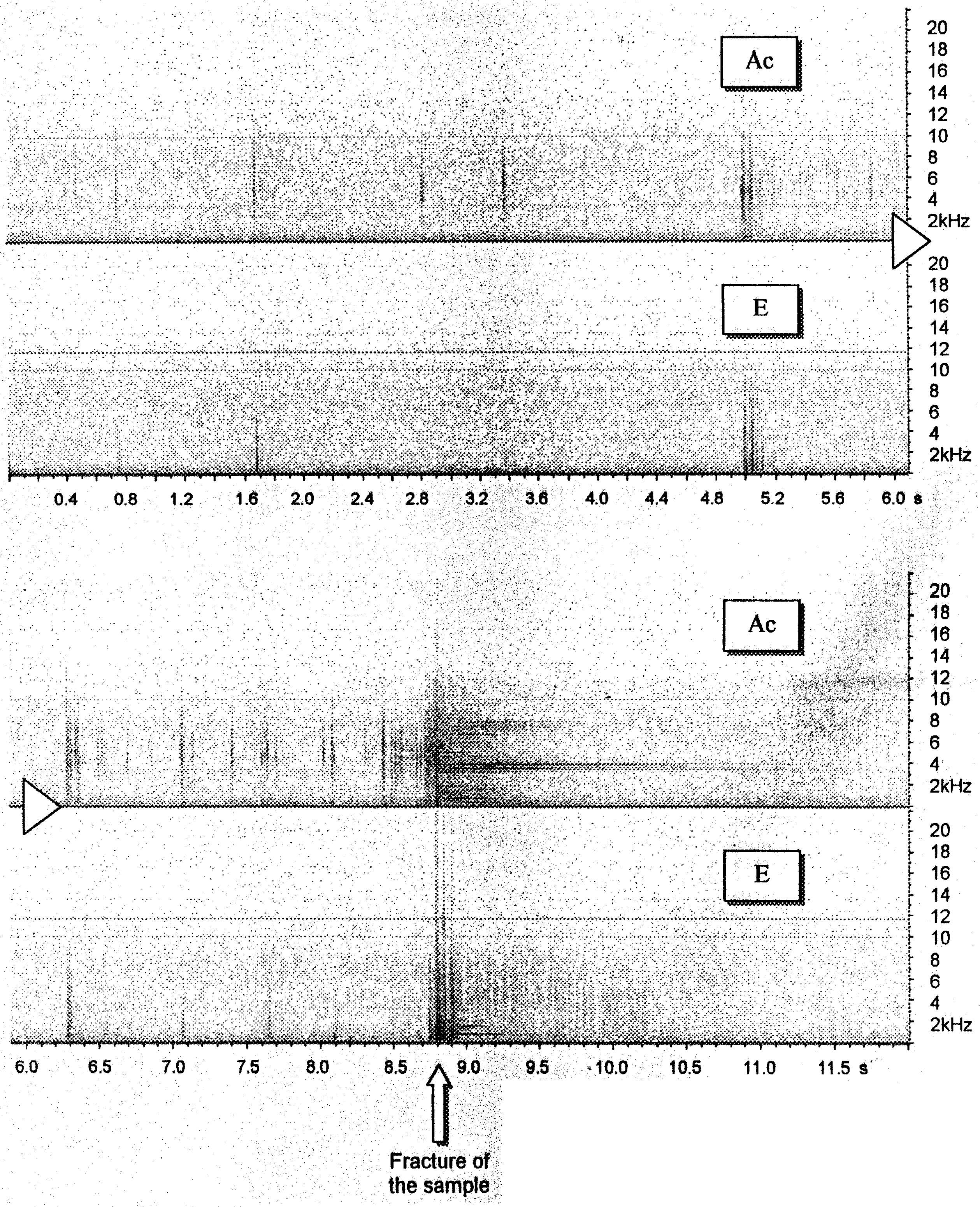


Figure 15- A typical laboratory experiments on a Porphyry sample for which we show the acoustic channel (Ac) and E channel. The top figure is the continuation in time of the bottom one. Note that the acoustic signal is well present before and after the fracture. First we have the compression with the formation of isolated micro - fractures which, with increasing time and pressure, increase in number per unit time causing emission of acoustic and electric signals. Then the micro - fractures coalesce and originate the fracture. The abscissa is seconds. The ordinate is kHz and the intensity of the grey tone in the spectrum represents its relative amplitude.



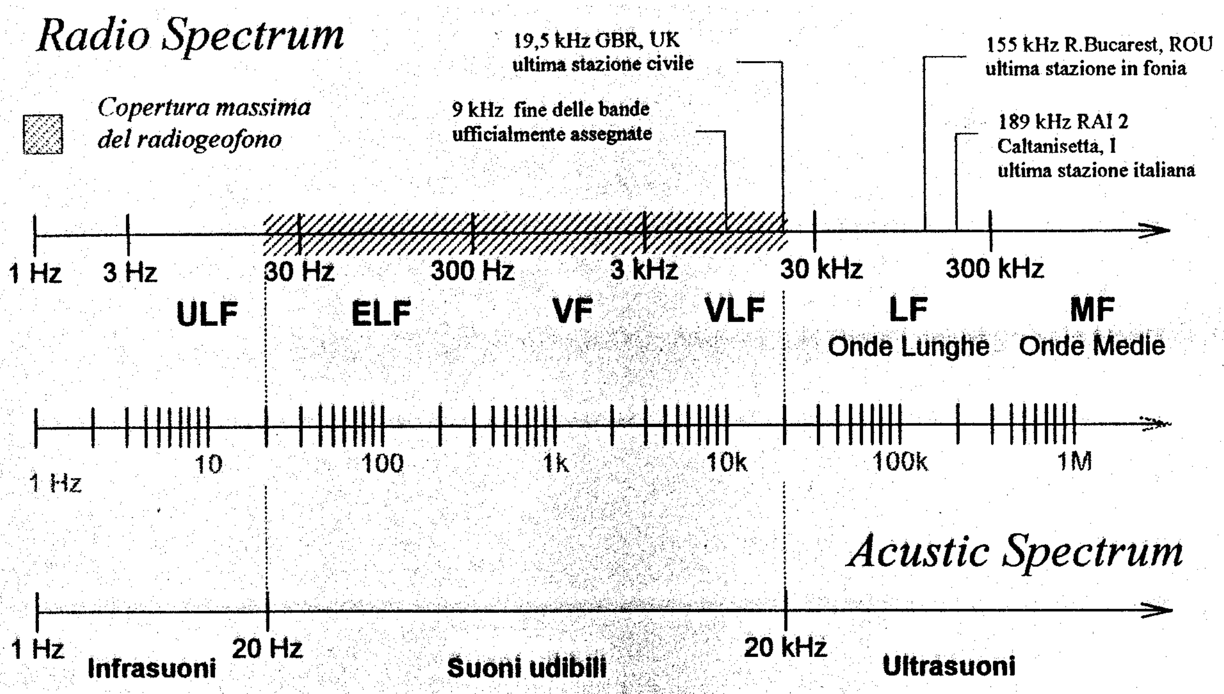


Fig. 16 - Corrispondenza dello spettro radio a bassissima frequenza con lo spettro delle frequenze acustiche. Le oscillazioni sono di natura diversa ma interessano la medesima gamma di frequenze. Nello schema è indicata anche la banda operativa del radiogeofono.