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Fracto-emissions as seismic precursors

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Three different forms of energy might be used as earthquake precursors for environmental protection against seismicity. At the tectonic scale, Acoustic Emission (AE) prevails, as well as Electro-Magnetic Emission (EME) at the intermediate scales, and Neutron Emission (NE) at the nano-scale. TeraHertz pressure waves are in fact produced at the last extremely small scale, and fracture experiments on natural rocks have recently demonstrated that these high-frequency waves are able to induce nuclear fission reactions with neutron and/or alpha particle emissions. Very important applications to earthquake precursors can be proposed. The authors present the results they are obtaining at a gypsum mine located in Northern Italy. In this mine, to avoid interference with human activities, the instrumental control units have been located at one hundred metres underground. The experimental results obtained from July 1st, 2013 to December 31, 2015 (five semesters) are analysed by means of a suitable multi-modal statistics. The experimental observations reveal a strong correlation between the three fracto-emission peaks (acoustic, electromagnetic, and neutron emissions) and the major earthquakes occurred in the surrounding areas.

1. Introduction

Solids that break in a brittle way are subjected to a rapid emission of energy involving the generation of pressure waves that travel at a characteristic speed with an order of magnitude of 10^3 m/s. Considering the very important case of earthquakes, it is possible to observe that, as fracture at the nanoscale (10^{-9} m) emits pressure waves at the frequency scale of TeraHertz (10^{12} Hz), so fracture at the microscale (10^{-6} m) emits pressure waves at the frequency scale of GigaHertz (10^9 Hz), at the scale of millimetre emits pressure waves at the scale of MegaHertz (10^6 Hz), at the scale of metre emits pressure waves at the scale of kiloHertz (10^3 Hz), and eventually faults at the kilometre scale emit pressure waves at the scale of the simple Hertz, which is the typical and most likely frequency of seismic oscillations (Fig. 1) [1].

The animals with sensitive hearing in the ultrasonic field (frequency > 20 kHz) "feel" the earthquake up to one day in advance, when the active cracks are still below the metre scale. Ultrasounds are in fact a well-known seismic precursor [2,3]. With frequencies between Mega- and GigaHertz, and therefore cracks between the micron and the millimetre scale, pressure waves can generate electromagnetic waves of the same frequency, which turn out to be even a more advanced seismic precursor (up to a few days before) [4,5]. When pressure waves show frequencies between Giga- and TeraHertz, and then with cracks below the micron scale, we are witnessing a phenomenon partially unexpected: pressure waves resonate with the crystal lattices and, through a complex cascade of events (acceleration of electrons, bremsstrahlung gamma radi-

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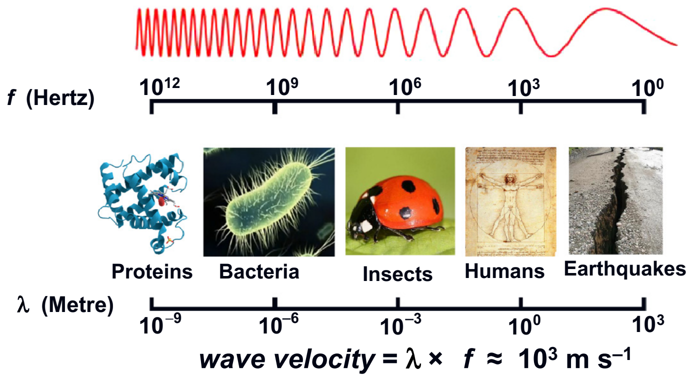

Fig. 1. Correlation between wavelength (forming crack) scale and frequency scale by assuming a constant pressure wave velocity.

ation, photo-fission, etc.), may produce nuclear fission reactions [6–16]. It can be shown experimentally how such fission reactions can emit neutrons [17–19] like in the well-known case of uranium-235 but without gamma radiation and radioactive wastes. Note that the Debye frequency, i.e., the fundamental frequency of free vibration of crystal lattices, is around the TeraHertz, and this is not a coincidence, since it is simply due to the fact that the inter-atomic distance is just around the nanometre, as indeed the minimum size of the lattice defects. As the chain reactions are sustained by thermal neutrons in a nuclear power plant, so the piezonuclear reactions are triggered by pressure waves that have a frequency close to the resonance frequency of the crystal lattice and an energy close to that of thermal neutrons [8]. Neutrons therefore appear to be as the most advanced earthquake precursor (up to three weeks before) [20–27].

In the present work, after summarizing the results obtained during two different experimental investigations at "Testa Grigia" laboratory (Plateau Rosa, Cervinia, Italy) and at the seismic district of "Val Trebbia" (Bettola, Piacenza, Italy) [28,29], the authors describe the preliminary results acquired at a gypsum mine situated in Northern Italy (Murisengo, Alessandria) and related to the evaluation of acoustic, electromagnetic, and nuclear phenomena. The monitoring system, based on the simultaneous acquisition of the various physical quantities, controls the structural stability of the mine carrying out, at the same time, the environment monitoring for the seismic risk evaluation. The preliminary results obtained during the in-situ monitoring revealed a strong correlation between AE/EME/NE emissions and the major earthquakes occurring in the surrounding areas.

2. Seismic precursors: acoustic, electromagnetic, neutron emissions

Seismic precursors are phenomena that take place well in advance than the occurrence of an earthquake. These parameters are of various kind, such as ground deformation, changes in tilt and strain and in Earth tidal strain, changes in the geoacoustic and geomagnetic field, in radon and carbon dioxide content, in environmental radioactivity and so on.

The monitoring and the correct interpretation of these phenomena provide the basis for the assessment of the three main parameters of an earthquake: place and time of occurrence, as well as magnitude of the quake.

Moreover, the prediction strategy has to take into account an integral approach that includes the evaluation of several physical quantities and that discriminates true signals from the environmental background or noise.

In addition, it is very important to consider that, in the period before the earthquake occurrence, a very wide area of cracking rocks is active and in a critical condition around the future earthquake focal zone under the influence of tectonic stresses. In particular, Dobrovolsky et al. [30] tried to calculate the dimension of this earthquake preparation area as a function of the magnitude of the incoming earthquake considering an arbitrary heterogeneity and anisotropy of the Earth's surface. Assuming that the zone of effective manifestation of the precursor deformations is a circle with the centre in the epicentre of the next earthquake, the radius R of this 'strain zone' may be up to hundreds kilometres for earthquakes with a magnitude M equal to 5 degrees in the Richter scale and can tend to the whole Earth surface for a M = 9 seismic event (for example, Sumatra 2004, Chile 2010, Japan 2011). Comparison between theoretical and field results showed a satisfactory agreement [30]. In addition, it was also observed that all the precursors tend to fall into this circle.

In the last decades a great number of laboratory tests and experimental observations evidenced that mechanical, electromagnetic, and neutron emissions, together with radon levels, carbon dioxide emanations and temperature variations, are the most reliable natural phenomena that can be linked to earthquake preparation.

In particular, the experimental tests carried out since 2008 at the Politecnico di Torino have demonstrated how the monitoring of the different forms of energy (Acoustic Emission AE, Electro-Magnetic Emission EME, and Neutron Emission NE), emitted during the failure of natural and artificial brittle materials, enables an accurate interpretation of mechanical damage and fracture, not only at the scale of the laboratory, but also at the Earth's crust scale [31–38].