ISSN 1028-334X, Doklady Earth Sciences, 2007, Vol. 414, No. 4, pp. 638–641. © Pleiades Publishing, Ltd., 2007.
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GEOPHYSICS

Physical Causes of Diurnal Variations in the Geoacoustic Emission Level

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Presented by Academician S.A. Fedotov May 5, 2006

Received June 6, 2006

DOI: 10.1134/S1028334X07040320

The results of geoacoustic (seismoacoustic) observations in seismoactive regions, which reflect variations in the characteristics of acoustic emission of rocks in natural conditions related to tectonic processes, can make a significant contribution to the development of the models of earthquake preparation. The results obtained during measurements in deep boreholes using high sensitivity geophones are very interesting [1], because one can observe in this case the fine effects of the response of geoacoustic emission (GAE) to the variations in the stress–strain state of the rocks. This is usually impossible during measurements at the daytime surface due to the high noise level. In this paper, we discuss the results of the analysis of synchronous measurements of the GAE and natural electromagnetic field (EMF) at frequencies close to 160 Hz. The measurements were carried out in a deep borehole near Petropavlovsk-Kamchatskii to elucidate possible physical causes of diurnal variations in GAE and their relation to the variations in the stress–strain state of the rocks.

Since August 2000, geoacoustic measurements in the Petropavlovsk-Kamchatskii region have been carried out continuously in borehole G-1 (depth 2542 m). Application of a high sensitivity geophone with sensors based on magnetoelastic materials set in the borehole at a depth of 1035 m allowed us to measure the GAE level with a signal amplitude of $\sim 10^{-4}$ m/s^3 in the frequency range up to 1.5 kHz [2]. The equipment complex installed at the borehole bottom additionally amplifies the initial signals of geophone sensors and divides them using band filters into four bands with central frequencies of 30, 160, 560, and 1200 Hz. The averaged values of output filtered and rectified signals of each of the filters are measured. Further analysis is carried out by a microprocessor controller, which performs analog-to-digital conversion of the input signals, calculation of average values over a one-minute interval, and recording of the data. According to the data obtained in the experiment, the installation of the geophone at a sufficiently large depth made it possible to decrease the influence of technogenic noise by more than two orders of value and almost completely eliminate the influence of meteorological conditions on the results of the measurements of the vertical component of the signal. The analysis of the results obtained over almost five years of continuous measurements shows that the time series of the mean GAE level are characterized by a distinct diurnal component (24.0 h) during the time intervals corresponding to a calm seismic situation in the region. The transition times from the minimal values of the mean GAE level to the maximal ones and back correspond to the time of the terminator line passage (times of sunset and sunrise) at the observation point (Fig. 1a). The diurnal GAE cycle is maximal in the channels of the vertical geophone component with central filter frequencies of 30 and 160 Hz. Comparison of the diurnal GAE cycle with the times of previous earthquakes over the 5-yr observation series shows that distortions of the diurnal cycle were observed before all earthquakes with magnitudes $M_{LH} \geqslant 5.0$ in a zone with radius $R \leqslant 300$ km and with magnitudes $M_{LH} \geqslant 5.5$ in a zone with radius $R \leqslant 550$ km from the observation point [2].

Measurements of the natural geomagnetic field carried out at the same point since May 2003 were used to understand the physical causes of diurnal variations in the GAE level. An underground electric antenna of an original design was used for electromagnetic measurements. The channels of electromagnetic and geoacoustic measurements were identical in all other respects. The measurements were carried out in the same frequency ranges.

The mechanisms of radiation and regularities of radio noise propagation in the ULF and VLF ranges (30 Hz–30 kHz) have been studied sufficiently well [3, 4]. Remote thunderstorms are the main source of the natural electromagnetic field (NEMF) in these ranges in the northeastern part of Russia [3]. In Kamchatka, the con-

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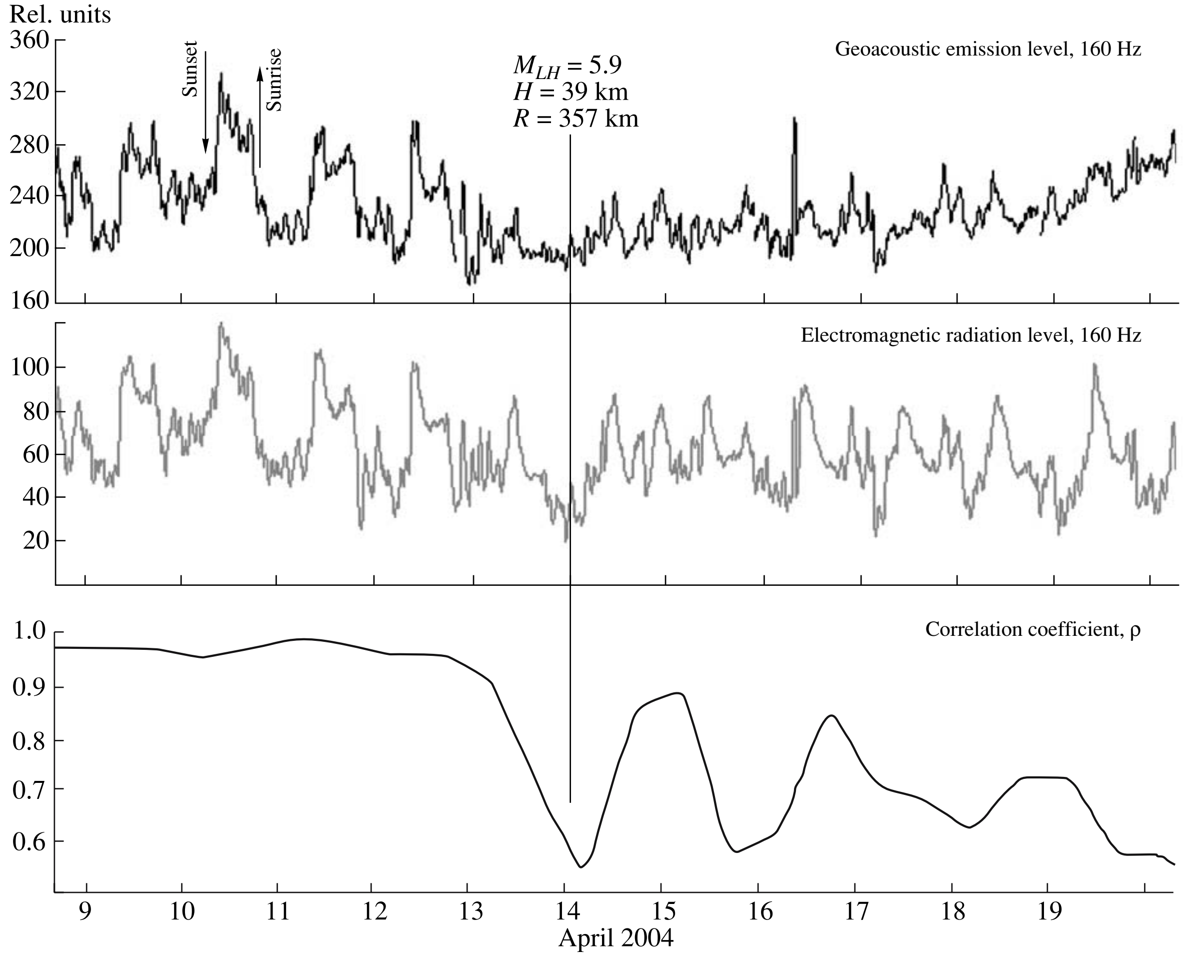

Fig. 1. Example of the results of joint geoacoustic and electromagnetic measurements: GAE level at a filter frequency of 160 Hz (Z component); EMF level at a filter frequency of 160 Hz; correlation coefficient ρ. (M_{LH}) Earthquake magnitude; (H) source depth; (R) epicentral distance.

tinuous fluctuation component gives the greatest contribution to the NEMF in the ULF range. Diurnal variations in the EMF level in the ULF and VLF ranges are related, first of all, to sharp deterioration of the conditions for radiowave propagation in the ionosphere–Earth waveguide during the daytime, which is caused by a decrease in the altitude of the ionosphere in this time of the day owing to the appearance of the D layer at a height of approximately 80 km.

The results of joint geoacoustic and electromagnetic measurements showed that the variations in the GAE and EMF levels were practically identical during the period of the stable diurnal GAE cycle. The correlation coefficient ρ over such an interval is approximately ρ = 0.80–0.99. For example, ρ = 0.91–0.99 in the interval April 9–12, 2004 (Fig. 1) and ρ = 0.92–0.93 in the interval June 15–17, 2003 (Fig. 2). At the same time, before strong earthquakes (one day before or earlier), as well as during the relaxation periods, the character of variations in the GAE and EMF levels differed strongly: ρ = 0.53–0.89 in the interval April 13–19, 2004 (Fig. 1) and ρ = 0.001–0.34 in the interval May 28–June 9, 2003 (Fig. 2).

A comparison of our data and the results of laboratory experiments with samples of rocks influenced by the EMF under compression [5] demonstrates the similarity of the observed effects. The results of such experiments show that the impact of the EMF upon samples of rocks in a strained state usually triggers a significant increase in the acoustic emission level. The sensitivity to electromagnetic impact (response of the acoustic emission) depends on the shear stress [5]. Such an effect is similar to the effect of an increase in the GAE level during nighttime due to an increase in the NEMF level. Within the framework of this model of diurnal variations in the GAE level, we can consider qualitatively modulation of the GAE level (microcrack formation) by the NEMF. The disappearance of the diurnal GAE cycle before sufficiently strong earthquakes and its later restoration are explained in this case by the variation in the sensitivity of rocks to the

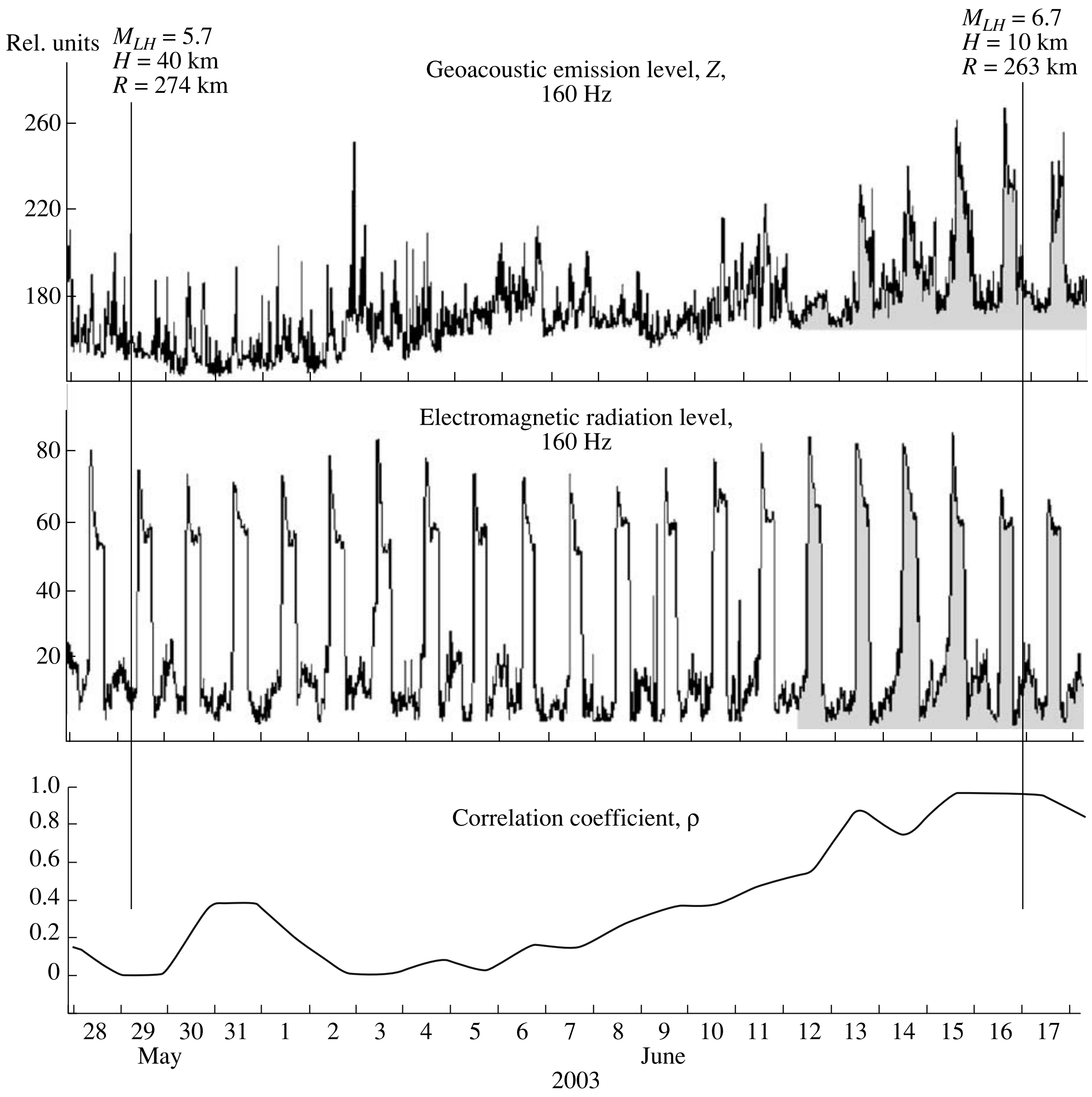

Fig. 2. Example of restoration of the daily GAE cycle compared to the results of electromagnetic measurements.

modulating electromagnetic impact due to the variations in its stress–strain state.

Quantitative estimates of the observed modulation effect of the GAE level by the Earth's NEMF are as follows. According to the literature data, the greatest values of the electric component of the NEMF in the entire ULF range at the Earth's surface are ~0.45–1.0 mV/m [4]. According to [6], attenuation of the electric component calculated for a frequency of 160 Hz and a depth of 1000 m under conditions of medium humidity ($\sigma = 10^{-2}$) is ~9 dB. Thus, the electric component of the NEMF at a depth of 1000 m cannot exceed 0.16–0.36 mV/m. At the same time, according to the data on experiments devoted to the influence of EMF on the activity of acoustic emission [5], the values of electric field strength reached 800–1600 V/m. Thus, the level of electric field stress upon rocks in natural conditions at a depth of approximately 1000 m is lower than the experimental value by at least six orders of value.

At the same time, it is necessary to take into account the following. During measurements in a borehole, the effective radius R_{ef} of a spherical region around the observation point, where 90% of the energy of microoscillations is provided by the sources of geoacoustic noise concentrated in this region, can approximately be estimated using a relation from [7]: $R_{\text{ef}} \approx Q\lambda$, where Q is the quality factor of the medium and λ is the wavelength.

The most conservative estimates of geoacoustic noises with frequency f = 160 Hz yield R_{ef} values not less than a few hundred meters. It is also necessary to take the following fact into account during the measurement of the GAE level in a deep borehole: the displacement-adjusted minimal amplitudes of the measured signals at a frequency of 160 Hz are ~10^{-9} m [2]. The realization of such sensitivity allows us to record acoustic noises from signal sources located at a distance of at least a few tens of meters, i.e., in the volume of rocks not less than 100 m^3, which is approximately six orders of value greater than the volumes of samples used in the experiments. Assuming that the number of microcracks subjected to the influence of the electric field is proportional to the volume of the rocks, it is possible to explain the observed effects of GAE level modulation by the Earth's weak EMF.

ACKNOWLEDGMENTS

This work was supported by the Far East Division of the Russian Academy of Sciences (project no. 06-III-A-08-327) and by the Russian Foundation for Basic Research (project no. 06-05-96071).

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