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Estimation of Lithospheric Structure Parameters Based on Pulsed Electromagnetic Fields

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Abstract: On the basis of the passive radio wave method, the study of the relationship between the natural pulsed electromagnetic field of the Earth and geophysical processes and environmental conditions is presented. Methodological approaches to the use of the method of registration of the Earth's natural pulse electromagnetic field for monitoring the dynamics of soils are proposed. The technology of real-time monitoring of landslide activity based on a specialized multichannel geophysical recorder is described. The results of in-situ measurements of landslide processes activity by parameters of pulsed electromagnetic fields are presented. It was established that in the measurements of the natural pulse electromagnetic field of the Earth, the temporal structure plays a significant role, as well as spatial differences of measurements on scales of several meters, characterizing, in accordance with the physical model of electromagnetic field formation, the structure of the studied anomaly.

1 INTRODUCTION

The study of the relationship between the signals of the Earth's natural pulsed electromagnetic field (ENPEMF) and the environment has been studied for more than half a century (Vorobyev, 1970; Mastov, Salomatin, Yavorovich, 1983; Boryssenko, Polishchuk, 1999). However, only the use of modern computer technologies and digital analytics allows for the processing of data to yield sufficiently effective solutions for application in the national economy.

Thus, in (Hao, Chen, Zhao et al.) the nonstationary characteristics of the Earth's electromagnetic field are considered using the normalized Fourier transform (NSTFT) and the Wigner-Ville distribution (WVD). The NSTFT-WVD analysis is performed on the frequency-time characteristics of the ENPEMF signal before the Lushan MS 7.0 earthquake. The results obtained by the authors show that the NSTFT-WVD transformation well re-flects the real distribution of the spectrum of time, frequency and energy of the ENPEMF signal (precursors of the impending earthquake) before and after the earthquake.

In (Yong, Wang, Zhang et al., 2021), to study the relationship between electromagnetic phenomena and seismicity in Sichuan Province and Yunnan Province (China), a multi-component high-density seismic monitoring system was deployed to observe electromagnetic and geoacoustic data in the range of 0.1 Hz ÷ 10 kHz. During data collection, it was found that the waveform of the electromagnetic signal, named SRSS wave by the authors, has the characteristics of a diurnal cycle, i.e., the signal changes are synchro-nous with sunrise and sunset. Based on the analysis of the electromagnetic signal wave and seismic events on the example of three real earthquakes, the authors have revealed a strong correlation between the SRSS wave and seismic

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events. More precisely, the SRSS waveform correlates well with the onset of seismic activity.

In (Xie, Liu, Lu, Li, Yao, Wang, Yu, 2018), the authors present a retrospective analysis of electromagnetic anomalies recorded by stationary stations before the 2008 earthquake in Wenchuan (MS8.0). Before the main shock, different types of anomalous changes were observed at 8 stations in the epicentre area. The combined analysis of the sequential data after the shock showed that only the anomalies of the stations located near the rupture zone could be explained by the existing mechanism of geo-resistivity anomalies accompanying the seismogenic process. In general, the parameters derived from the geo-magnetic data of the stations showed anomalous variations including transfer function, harmonic amplitude coefficient, Parkinson vector and vertical polarization intensity, which mainly reflect the subsurface conductivity. The geo-electric field and electromagnetic data near the rupture zone exhibited waveform distortion and energy amplification phenomena. The authors noted that 3 stations in the electromagnetic monitoring network, located at a distance of more than 1300 km from the epicentre, had registered obvious anomalous oscillations several months before the earthquake.

In (Potirakis, Schekotov, Asano, Hayakawa, 2018), the authors analyze the variations of the ultra-low frequency (ULF) magnetic field observed by ground-based methods before earthquakes in Southwest Japan under the city of Kumamoto. The characteristics of the ULF magnetic field were considered from the position of natural time. It was found that they all reached the critical value, but at different time periods for each characteristic, ranging from 2 weeks to 1 month before the earthquakes.

The paper (Gavrilov, Poklad, Rybnov et al., 2021) presents the results of analysis of seismic event signals obtained with seismic, acoustic, electromagnetic and ionosphere instrumental complexes at distances of several thousand kilometers from the earthquake source. The time dependence of formation of spatial atmospheric and geomagnetic effects on the distance to seismic sources has been confirmed. It was experimentally established that the effects of acoustic waves on the ionosphere and seismomagnetic effects differ not only in the time of occurrence, but also in the nature of manifestation.

The paper (Dovbnya, 2022) also analyses the results of remote observation at different polygons of pulsed electromagnetic VLF signals registered at remote earthquakes within a few minutes after the seismic event. Daily and seasonal dependences of the frequency of earthquake precursors and the character of spatial distribution of their generation zones on the Earth's surface are investigated. The author noted that the dynamic spectra of signals from earthquakes occurring in different regions of the Earth's sur-face were similar. They were repeated at different magnitudes and depths of the origin and were observed in the same time interval related to the moment of the earthquake.

In conclusion, we note (Nardi, Pignatelli, Spagnuolo, 2022), in which the authors propose to use other geophysical signals for probing the state of crustal deformation, in addition to those directly related to the measurement of ENPEMF signals when travelling along faults. The authors correlate electromagnetic signals in the very low frequency region of moderate earth-quakes with paroxysmal rupture of rock specimens in uniaxial laboratory tests. This similarity, according to the authors, provides another channel for estimating rock deformation. For example, to extend the measurements with laboratory data and use neural network-based machine learning to classify the precursors of rock ruptures and, consequently, to predict real seismic events.

The practice of using the ENPEMF method has shown its reliability. Natural electromagnetic emission, which due to physical reasons (relaxation of charges) occurs when the stress state of the rock massif changes (change in the continuity of dielectric materials), allows to apply radio wave methods for its registration. And, consequently, to localise changes in the state of rocks (cracks, microcracks, discontinuities, taliks, karsts and other inhomogeneities) and to control their dynamics.

It is worth noting that, despite the fact that ENPEMFs are widely used for engineering and geophysical surveys, forecasting of geodynamic events, and geocryological studies, the scientific community continues to debate about the sources and nature of these fields. A large group of researchers believes that the lion's share of impulses in the structure of the ENPEMF arises as a result of thunderstorm discharges in the atmosphere. The proven efficiency of methods based on the registration of these fields is due to the “fact that in the VLF range electromagnetic waves propagate in the Earth-Ionosphere waveguide and depending on the geological structure and stress-strain state of the Earth's crust, the conditions of wave propagation and the depth of their penetration into the underlying surface change”.

Another group of researchers, which includes the authors of this paper, without denying the presence of the atmospheric component of ENPEMF, proves that

their lithospheric component takes a significant place in the general structure of these fields. It is the deformation waves from the Earth's lower mantle, including tidal forces, various types of natural and anthropogenic load that create the natural electromagnetic background of lithospheric origin.

Thus, lithospheric electromagnetic characteristics directly reflect geosphere processes and, in particular, provide operational assessment, control and prediction of the structure of lithological heterogeneities and evaluation of the geodynamic regime in seismically active regions of the Earth. Large territories in Russia are located in seismically active zones, a large number of industrial and social facilities are under the threat of destruction by earthquakes and landslides. Therefore, the solution of problems of research of the possibility of scientifically based forecast of the environment, forecast of geodynamic processes is very relevant, and the possibilities of the ENPEMF-based VLF recorder toolkit for solving these problems are limitless.

2 RESULTS AND DISCUSSION

A programmable multi-channel geophysical recorder was used to identify geophysical structures and monitor geodynamic processes based on the recording of signals from the Earth's natural pulsed electromagnetic field. The device was developed at the Institute for Monitoring Climate and Environmental Systems of the Siberian Branch of the Russian Academy of Sciences.

Electric and magnetic radio noise in the VLF range of the electromagnetic field is measured by perpendicularly oriented ferrite antennas on two independent channels. west-east. For the control device of all measuring channels of the recorder are developed their own programs, which are loaded into the built-in electrically reprogrammable ROM of microcontrollers. This allows rapid change of algorithms for data acquisition and preprocessing.

The device is highly sensitive not only to the presence of various discontinuities in the Earth's crust, but also to the boundaries between different types of rock. Most of the ENPEMF measurements presented below are made on the magnetic component of the field at the resonance frequency of 14.5 kHz at the field strength discrimination threshold of the order of (0.01÷0.02) A/m. Experimental observations have shown that it is at this frequency that the maximum magnetic induction is recorded when rock samples are destroyed.

2.1 Experiment 1

We will demonstrate the anomalies of pulsed electromagnetic fields on the results of field studies of an active landslide slope. Note that for the Tomsk region landslide processes are the most dangerous among a wide range of geological processes. Therefore, it is very important to verify the algorithms for forecasting the probability of occurrence of extreme events in full-scale conditions on different landslide slopes with different levels of study.

During the summer and autumn periods (June and September), surveys were conducted along identical routes. A complex methodology was used in the measurement process: a stationary reference station located outside the landslide zone recorded ENPEMF background fluctuations, while mobile recorders took measurements at each checkpoint along the route. The pickets were placed at a distance of 20÷25 meters from each other, their exact coordinates were determined using a GPS-navigator and taken into account in the subsequent data processing. The results were analyzed by comparing the background ENPEMF values with the data recorded at the control points. Negative ENPEMF anomalies indicated the presence of compressive stresses in the rocks, while positive anomalies indicated tension. The results of data processing for the four routes are presented in Figure 1 and Figure 2.

Figure 1: Graphs (1, 3) of landslide slope studies.

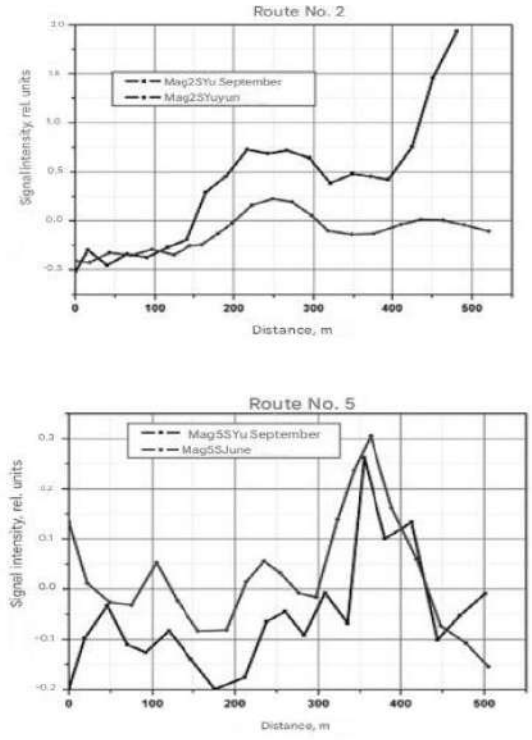

Figure 2: Graphs (2, 5) of landslide slope studies.

The comparative analysis showed a significant coincidence of the measurement results for both periods. It is noteworthy that almost twofold increase of compression stresses in the soil was recorded at the section 50÷180 meters of route No.1. The autumn observations revealed a more complex picture of the stress-strain state of the soil compared to the summer data. Route 2 also showed a doubling of tensile stresses from 170 meters to the terminus. Increased activity of land-slide processes is probably related to increased soil moisture.

2.2 Experiment 2

Another direction of expedition research was to develop a methodology for map-ping active tectonic disturbances. This is an urgent task in risk assessment and development of algorithms for making management decisions when the state of the natural environment changes. Seismic oscillations during earthquakes, in addition to direct vibration impact on infrastructure objects and host soils, lead to activation of slope seismogenic landslide and landslide phenomena, provoke mudslides and avalanches. At the same time, the greatest danger is posed by areas confined to active faults. It is known that such zones are accompanied by increased fracturing of rocks. In addition, an active tectonic fault can amplify seismic effects of distant earthquakes and lead to displacement of rock masses. Aggressive gases of lithospheric origin escaping to the day surface in tectonic fault zones can accelerate corrosion of infrastructure metal.

A series of expeditionary studies on ENPEMF registration in en-route measurements of lithospheric parameters in the areas of tectonic disturbances was carried out on the profile passing through the Urbina thrust. This is a large known tectonic disturbance of the internal structure of the Earth's crust near Khaldeyevo settlement, Tomsk region. The route, about two kilometers long, was repeated twice in different seasons and under different meteorological conditions. This palaeofault is currently inactive. It is characterized by an anomaly relative to background values of about 20% (see Fig. 3, Fig. 4).

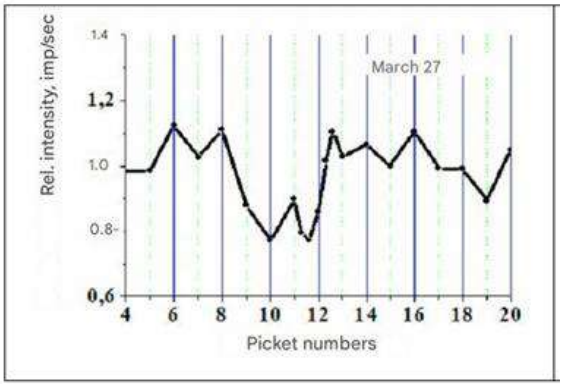

Figure 3: Graphs anomalies 1.

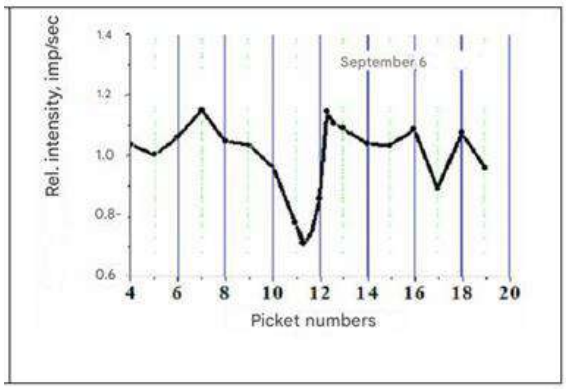

Figure 4: Graphs anomalies 2.

In general, as expected, the fault is characterized by a positive anomaly in the ENPEMF structure and a negative anomaly along its axis, which is clogged with low-emitting friction clay and swamped. It is

important that studies of the tectonic palaeofracture conducted in different seasons showed good reproducibility of geophysical measurements, which indicates weak dissolution of its fill by wastewater and stability of the inactive state.

2.3 Experiment 3

To confirm the presence of the lithospheric component in ENPEMF, a number of experiments were conducted in locations protected from atmospheric influences. Both natural elements in their natural state and concrete structures were used as shielding materials, including a drainage rock excavation on the bank of the Tom River designed to intercept groundwater from various aquifers.

During the period of operation of the drainage mine, there were several accidents associated with waterlogged rock outbursts. All accidents occurred at the nodal inter-section of tectonic disturbance zones. In the last recorded accident, through the de-formed and in some places destroyed concrete support in the roof of the excavation there was an outburst of watered rocks, represented by gravel, crushed sandstone, sand with the presence of crushed rock of strong vein quartz-calcite composition. The volume of rock dumping was about 60 cubic meters. The danger of destruction of the industrial facility is still present, therefore, along with the assessment of the lithospheric component in the structure of the ENPEMF, the experiment was aimed at evaluating the possibility of creating methods and equipment for monitoring the condition of concrete support.

When performing profile measurements in the drainage mine, it turned out that the support was made with closed reinforcement, which does not allow receiving the electromagnetic signal emitted by the rocks outside the excavation. The recording equipment was reconfigured to a high sensitivity to measure the electromagnetic emission from the concrete of the support. It was assumed that since the electromagnetic emission of a material depends on its physical properties and the strength of its influence in areas with concrete weakened by dangerous geological processes, there would be an increased signal of natural pulse electromagnetic emission in areas with anomalous pressure on the support. On different days, 4 emission measurements were made in the drainage mine adit with the most complicated geological structure. Each of the four routes included measurements at 57 pickets for 20 seconds. The results of electromagnetic emission measurements are shown in Figure 5.

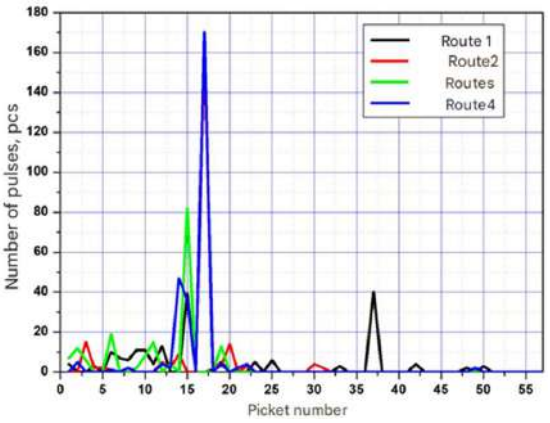

Figure 5: Electromagnetic emission of concrete bracing of a drainage mine adit.

The data are well reproduced, the maximum emission values were obtained at pickets 1÷20 and territorially coincide with the zone of rock crushing detected during tunnelling. Thus, as a result of the field experiment it was confirmed that even in insignificant in volume materials with physical properties close to rocks, in conditions of their natural occurrence it is possible to reliably register electromagnetic signals characterising the state of the material.

3 CONCLUSIONS

Studies of potentially hazardous natural objects in the region have demonstrated a high rate of development of exogenous slope processes. The results obtained indicate the need for regular monitoring to ensure the safety of infrastructure facilities, as episodic observations are insufficient to effectively control the situation. In Tomsk and many settlements of the Tomsk region there is still a significant risk of destruction of socially important objects due to landslide activation, which actualizes the need for continuous monitoring of stress-strain state of soils. In terms of costs, the most effective monitoring can be carried out by means of means of registration of natural pulse electromagnetic field of the Earth. Crustal faults are less dangerous in our region, as most of them are healed. But landslide processes are usually confined to tectonic faults. The expedition studies have shown that fault zones are confidently mapped by ENPEMF registration method and further studies of their nature and mechanisms of their realization in the regional geosystem are of scientific and practical interest.

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