Electromagnetic Method for Exogenetic Geodynamic Elements Mapping in Permafrost Environment

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Abstract. Taking into account the global warming, there is a pressing need to detect thermokarsts and to monitor permafrosts during the design and construction of industry infrastructure in Northern regions. The paper suggests a permafrost probing method based on the Earth’s natural pulsed electromagnetic field parameters recording. Authors describe the architecture and algorithms for the recording hardware. Examples of thermokarst detecting in poleward region are demonstrated. Pulsed electromagnetic fields intensity over thermokarst funnels is 30 times higher than the background levels. Authors substantiate the method’s eligibility to monitor geocryological processes.

1. Introduction

Natural climate dynamics and technogenous changes to surface conditions due to design and maintenance of engineering structures cause a pressing need to estimate a soil bearing capacity and monitor soil conditions. Over 45% of territory in Russia is prone to thermokarst. 72 cities are impacted by it. Thermokarst problem draws considerable attention lately due to global warming and hazardous geocryological processes intensification. Further development of those trends can lead to considerable terrain variations at many industrial sites with rather negative consequences. Rules and regulations for engineering and geological survey for construction at perennially frozen ground determine requirements for spatiotemporal forecast of the surveyed terrain engineering-geocryological conditions to retain constructions stability. Calculated forecast time frame is generally determined by the qualified lifetime of facilities designed, as changes will happen and influence the facilities throughout their whole lifetime. Changes originating from natural causes usually manifest themselves rather slowly, but there are short term unpredictable climate fluctuations and technogenous changes to geocryological conditions which are impossible to account for in a long term forecast, which is confirmed by a large share of deformed permafrost built constructions. Therefore it is necessary to observe ground conditions dynamics, especially at potentially hazardous industrial sites.

2. Results

Earth’s natural pulsed electromagnetic field (ENPEMF) method allows to locate all the fault lines in rock masses in place, including fractures, raptures, sinkholes, taliks, other inconsistencies and to monitor their dynamics to predict potential industrial site hazard. Radio-wave methods applied are based on the phenomenon of electromagnetic emission - dielectric materials emissive ability when...
they are acted on. Electromagnetic emission emerges in the process of charges generation and relaxation on fracture planes during the stress state of the rocks. Pulses emerge both when dielectric uniformity changes and when electrolyte-filled capillaries rift. In rock formations there can be the following sources of natural electromagnetic fields: soil structure inconsistencies, unequally strained structures, fractures and microfractures. All those sources generate pulsed electromagnetic fields as a result of mechanic-to-electric energy conversion, strain waves from the mantle, tides, microseisms, winds, and technological loads thus creating a natural electromagnetic background of lithospheric nature. Observing electromagnetic emission allows to monitor stress-strained state of the rock formation. In a variable field of tectonic stresses (stress-strain) rocks, containing dielectric minerals emit electromagnetic pulses due to mechanical-electric energy conversion. Intensity, frequency and amplitude of those pulses are determined by the structural, strength and deformational parameters of rock masses. In a clay rock, aside from fracturing and deformation of rock matrix, double dielectric layers also take part in electromagnetic fields pulses generation. Intensive fluid filtration in interstices and fractures is also accompanied by the polarization and ENPEMF emergence. Tectonism attributed to block faulted zones, even slowest and low in amplitude are always accompanied by the structural bonds disturbance and the emergence of micro and macro fractures in rock solids, as well as by the diffuse layer ion density change in rock solutions. Those processes lead to electromagnetic emission. Micro and macro fracturing is attended by the charges generation at the fractures shoulders due to electro-adhesion, fracturing electrification. Those charges generate high intensity electric field inside which there’s a possibility of a breakdown in gaseous rock phase, filling microfractures.

Perennial measurement in various regions demonstrated that lithospheric ENPEMF has distinguishable daily and seasonal variations. That can be explained by the fact that stress-related waves in Earth’s crust are related to Earth’s nonuniform rotation around own axis and around Sun [2]. Daily variations depend on calendar date, geolocation, location’s geophysical attributes [3]. Pulsed electromagnetic fields can change both with ground conditions changes and with field sources influence changes. For example, typical daily variations can be disrupted by the changes in the Earth’s crust rhythmic movement as a result of separate crust blocks joining into consolidated mass prior to earthquake or when stress-strained state of rock changes. So, ENPEMF recording can be a multipurpose tool for geophysical survey, Earth’s crust geodynamic activity monitoring and Earth sciences research.

Proof of feasibility test for exogenetic geodynamic elements mapping in permafrost environment was performed at Chayandinskoe oil and gas condensate deposit in Yakutia. Permafrost area at the research location is over 60%. Maximum frozen zone depth on flat and table land is 100-250 m. Maximum depth of seasonal thawing is 3.0-4.6 m for sands and 2.0-2.7 m for clay loam. Thermokarstic formations predominantly develop in very icy alluvial and boggy deposits. Thermokarst processes develop in paragenesis with heaving. The reasons for thermokarst development are increase in yearly average rocks temperature and changes in a terrain rate of water-encroachment. Currently thermokarst processes are developed on table lands of watershed, formed as eluvial deposits on terrigenous-carbonate rocks formations and manifest at small basins of up to 0.5 m in depth. Thermokarst processes are connected to segregated ice thawing. Their development intensified strongly since oil and gas deposit exploration and development.

During the office studies ENPEMF anomalies were compared against engineering-geocryological drilling, snow survey, field and laboratory research of water-physical property of ground and remote morphotectonic analysis library materials. All the date mentioned above was provided by “MSU-Geophysics” Ltd.

ENPEMF recording was performed by the multichannel geophysical recorders “MGR-01” [4]. In basic configuration MGR-01 has two channels measuring magnetic components and on channel measuring electric component of electromagnetic field. Antennas to receive ENPEMF magnetic component in north-south direction and west-east direction are magnetic ferrite antennas, receiving a signal in a very low frequency (VLF) band. Mutually orthogonal position of those antennas allows to obtain system directional pattern close to radial. Differential capacity transmitter, working in near-
field reception zone in a frequency band of 500 Hz – 100 kHz was used as an antenna for ENPEMF electric component reception. Amplification path parameters of recorders and settings are changed by software. Recorders allow to measure pulsed flow intensity with a preset sampling interval from 1 second up to 4 minutes and an amplitude of the first pulse exceeding preset threshold for each sampling interval.

Before the start of the work all recorders were set up for the same sensitivity, amplification paths parameters were picked based on geological and tectonic particular properties at the operating region according to calibration charts [3]. Technically ENPEMF spatial anomalies detection was performed by comparing pulsed flow intensity data recorded at each survey station against the reference station data using authentic patented technique. That way background noises are excluded from EMPEMF spatiotemporal variations and anomalies related to Earth’s crust structure at measurement site are isolated.

![Figure 1](image1.png)

**Figure 1.** Spatial variations of electromagnetic noises at the locations without rock discontinuity.

Figure 1 represents ENPEMF spatial variations at a location without tectonic disturbance and Earth’s crust exogenous geodynamics. At that and other charts thin line with dots shows actual measurement and thick curve shows 3 points running average. Although in general the territory surveyed has a complicated tectonic structure, electromagnetic noise anomalies at this plot do not exceed 40% over the background noises.

![Figure 2a](image2a.png) ![Figure 2b](image2b.png)

**Figure 2.** Spatial variations of electromagnetic noises at the locations nearby exogenous geodynamic elements.

a) thermokarst funnel; b) sinkhole.
Figure 2 represents ENPEMF spatial variations when crossing thermokarst funnels. On those charts anomalous noise values are 30–40 times higher than background values. Based on the integrated geophysical research of the location nearby to specified Earth’s crust disturbance is assigned to very dangerous category by engineering-geocryological conditions. Complexity of development conditions category is very complex. Perennially frozen grounds have sporadic distribution.

ENPEMF method applicability for stress-strained state of rocks dynamic monitoring is confirmed by successfully operating systems for geohazard prediction at main gas pipelines [3-5]. ENPEMF parameters based algorithm for geodynamic processed monitoring is based on two criteria. First one shows difference in reading intensity between the recorders located at stress-strained state of rocks observing points and the reference recorder. Reference recorder is located not farther than 25m (VLF band wavelength) from observing ones at a site safe from geodynamic activity. Another criterion assesses similarity in different recorders data. Excess intensity of ENPEMF pulse flow at each observation point comparing to reference station is calculated based on specific formulas.

As a second parameter of stress-strained state of rocks, estimation is used for correlation between ENPEMF daily variation of reference station and i-th observation station. Spearman’s formula [6] is used to calculate the correlation coefficient.

Pulse flow intensity surplus of over 150% over three days and more is considered a potential hazard for industrial site operation.

3. Summary

Suggested method for ENPEMF signal analysis and a network of spatially distributed stations provides accurate reproducible results, robustly reflecting geodynamic activity. System application allows to detect tension and compression zones, stress directions in real time for rock structures with landslide activities. A system equivalent to the one described above could be used to monitor perennial frozen ground state [7].

In summary, Earth natural pulsed electromagnetic fields method can be applied for both preliminary surveys at permafrost engineering sites and monitoring of permafrost under technogenous influence.

References

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