ISSN 0145-8752, Moscow University Geology Bulletin, 2016, Vol. 71, No. 4, pp. 300–303.

Radiowave and Gas-Emanation Control of Objects in the Fuel and Energy Sector in the Zones of Natural and Anthropogenic Risks

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Received May 15, 2015

Abstract—Radiowave and gas-emanation geophysical methods have long been used to study the upper segment of a geological section, i.e., at the depths of the first tens of meters. This work deals with the improvement of these methods and the accuracy of the results of works due to the use of the new techniques and technology of other electrical prospecting methods. A complex of geophysical and geochemical methods based on studying the Earth's radio fields (the ERF method) and the emanation fields of radon or other gases in the soil (EM) has been developed and widely tested. The proposed methods were tested during the study of the zones of natural and anthropogenic risks (landslides, karsts, etc.) at fuel and energy-sector objects (pipelines, their construction sites, etc.). They can be used to solve other engineering and hydrogeological tasks related to the upper segment of a geological section .

Keywords: radiowave fields of the Earth, gas and emanation surveys, zones of natural and anthropogenic risks, fuel and energy sector, study of the upper segment of the section

DOI: 10.3103/S0145875216040049

INTRODUCTION

The shallow-depth electrical prospecting and geochemical methods have long been used to reveal geophysical inhomogeneities and to monitor geodynamic zones and processes in the upper segment of a geological section with a thickness of up to few tens of meters (Electrical Prospecting. 1978, 1989; Geophysical... 1983).

This works deal with the integration of a new method for studying the Earth's radio field (ERF) and a gas-emanation method (EM). These methods can be used to study the structure and the zones of natural and anthropogenic risks in the upper segment of a geological section and the underlying rocks and to perform monitoring of hazardous geodynamic processes.

The ERF method is based on the use of radio fields of low-frequency and very-low frequency broadcast and special radiostations (with a frequency ranging from 10 to 200 kHz) and the natural fields of space, the Sun, and the Earth within the same frequency range. In electrical prospecting, the predecessors of this method were (1) radio-interferometry for measuring the intensity of magnetic components in radio fields of radiostations (the vertical component (H_z) and the full vector of the horizontal component (H_p); this method has been used since the 1950s (Tarkhov, 1961), and (2) the method of the Earth's natural pulse electromagnetic fields of solar-space and terrestrial origins (Electrical Prospecting ..., 1989). In addition to these methods, we introduced a technology for works and techniques of data processing from the other electrical prospecting methods into the ERF-EM method: magnetotelluric sounding (MTS) and magnetovariation sounding (MVS), i.e., the methods of electrical prospecting that have long been used in the deep investigation of the Earth and during prospecting for different minerals and energy commodities (Berdichevskii, Dmitriev, 1999, 2009; Electrical Prospecting..., 1989; Khmelevskoy, 1999). The different variants of magnetotellurics (MTS, MVS, etc.) use electromagnetic fields (EMFs) of lower frequencies (less than 1 Hz and greater than 1 kHz).

Equipment and technology of ERF works. Using methods of the Earth's radio field in works requires receivers with antennas for measuring different components of the electromagnetic field: electric (E_x, E_y) and magnetic (H_x, H_y, H_z) ones, the x- and y-axes are horizontal, the z-axis is vertical. Several such receivers have been developed and used by one of the authors of this work, M.M. Zaderigolova, for the different variants of the ERF method (Zaderigolova, 1998, 2009; RF patents: nos. 2363965, 2009; no.123546, 2012). Together with the base station that synchronously records the same components of the ERF as at ordinary points, they provide an increase in the information on the medium, an improvement of measurement accuracy, and independence on selected radiostations.

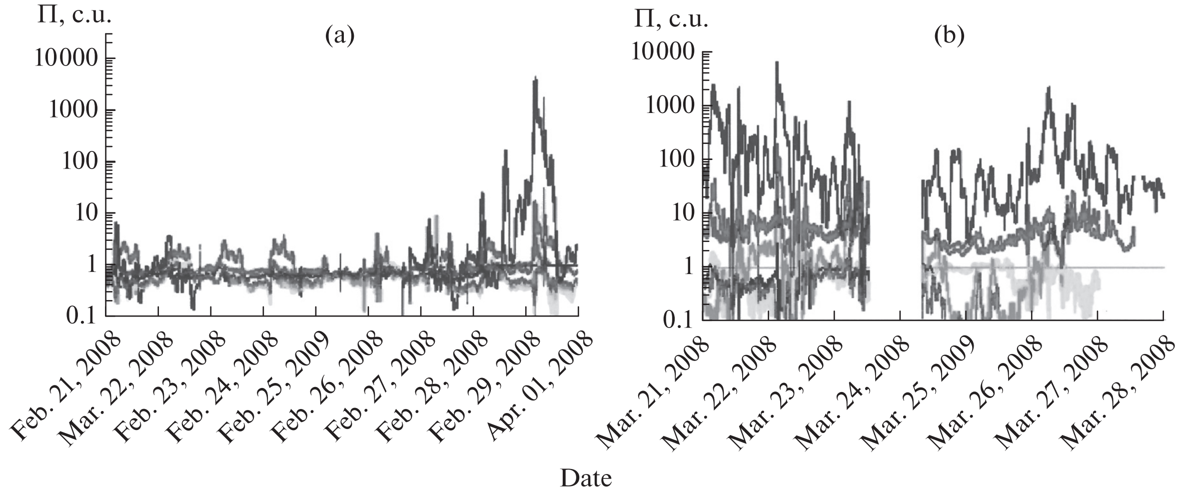

Fig. 1. Fragments of the ERF data in the form of records of different parameters of a radio field (P) on the monitor of a dispatcher for a North Caucasian gas pipeline segment on different days of measurements from February 21 until March 28, 2008: *a* and *b* are quiet and hazardous days for the activation of a landslide on the gas pipeline route, respectively.

Due to the attenuation of the radio waves of such frequencies (the skin effect), the depth of the electromagnetic fields is sufficient for studying the upper segment of a geological section .

The ERF method is advantageous, because it does not require radiation sources (its own transmitters are the EMF sources), since EMFs exist almost everywhere in different low-frequency radiostations (10–200 kHz); moreover, the natural EMF of the Earth exists everywhere with the same frequencies. Another advantage is that we can also use the MTS and MVS theory, which was developed for planar electromagnetic waves, in the distant zone from the EMF sources (Berdichevskii, Dmitriev, 1999, 2009; Khmelevskoy, 1989, 1999). One more advantage is that the EMF parameters in the ERF method depend not only on the specific electrical resistivity of rocks and geological strata as in MTS and MVS, but also on the dielectric and magnetic permeability, as well as on the other properties (seismometric, piezoeletric, electroelastic, etc.) that are at least statistically related to mountain-mechanical, hydrogeological, strength, and other properties of rock massifs (Aksenov, 2006; Bobyleva, 2010, 2015; Zaderigolova, 1998, 2009).

To improve the accuracy and the statistical reliability of the method, the parameters that are measured (observed) during the course of computer processing can be transformed to the interpretation parameters of the geoelectric section. To do this, we calculate the impedances ($Z_{xy} = E_x/H_y$, $Z_{yx}=E_y/H_x$), as is done in MTS, or for magnetic components ($W_{xz} = H_x/H_z$, $W_{yz} = H_y/H_z$), as in MVS, which are sometimes called tippers.

As a result of measuring the different components of the field and the additional calculations of Z, W, however, it is better to standardize them all with the similar parameters at the extra-anomalous reference point in the segment under study; an increase occurs in interference resistance and the reliability of revealing anomalies on the graphs and the maps of the distribution of these parameters. Additional information can be obtained using integral characteristics of observed or interpretation parameters. The meaning of such transformations is to evaluate the intensity of the objects that create anomalies. All of the calculations are performed on a computer, which makes the geophysical information reliable along with the determination of the coordinates for the observation points using GPS or GLONASS.

The technology for working with the ERF method may include three variants:

1. The primary study of the entire object can be performed using radioprofiling (RFS) followed by measuring the EMF at the same frequency and with a step of several meters.

2. The placement of stations at the revealed anomalies of sounding at ~1 m and the calculation of several of the above interpretation parameters on different frequencies at each point. At the largest anomalies, it is expedient to establish automated stations (systems) for regular repeated observations, i.e., for automatic monitoring at the largest anomalies.

3. If devices for gas-emanation methods are available, the concentration of radioactive gases (radon, thoron), methane or carbon dioxide (or at least one of these) is monitored. The measurements in drill holes ~1 m deep take up to 30 minutes.

The rules for carrying out geophysical studies during engineering-geological surveys, including the Earth's natural pulse electromagnetic field method, which is the closest predecessor of the ERF method, are stated as the Federal normative documents in the

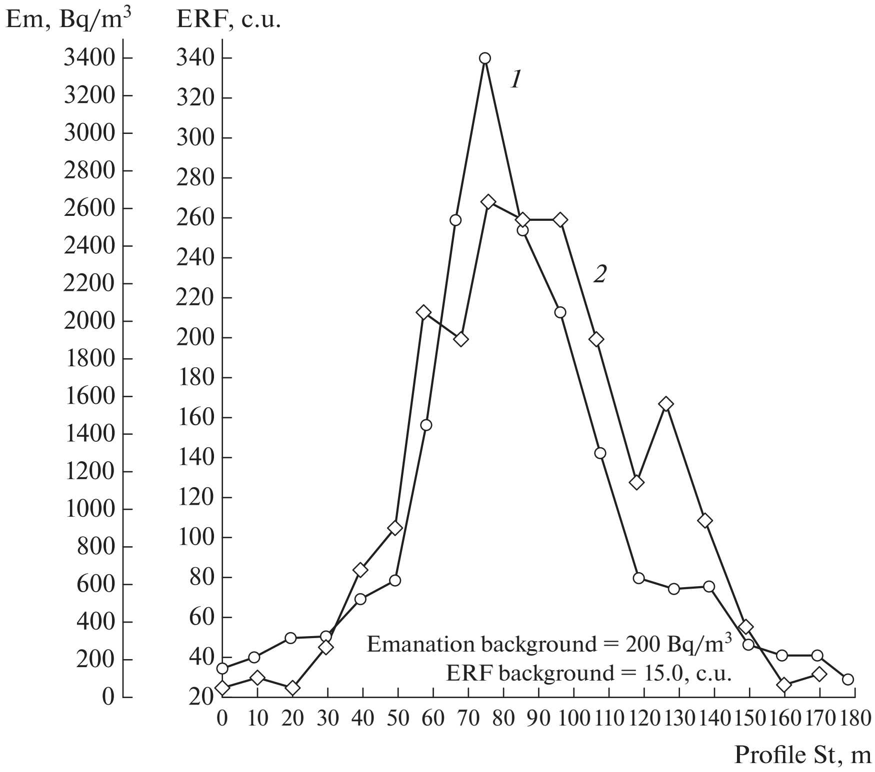

Fig. 2. An example of integrated monitoring of hazardous geodynamic processes (landslide motion) along the profile on a gas pipeline near the city of Tskhinvali in the North Caucasus in June–July 2014 with the sudden activation of the landslide geodynamic processes at the profile center: *1* is the ERF data and *2* is the data obtained by the emanation method (EM).

Code of Rules and Regulations on Engineering Surveys during Construction Works SP-11-105-97 (Code..., 2004), which, in addition to the rules and the range of surveying methods, describes different methods in shallow depth geophysics, features of work procedures, and solvable problems.

The theory and practice of the ERF method. A rigorous physicomathematical theory that could provide deterministic relationships between the observed geophysical parameters and the geoelectrical section has not yet been developed in the ERF method. This is explained by the complex and multifaceted character of the physicogeological models of hazardous geodynamic processes and the zones of natural and anthropogenic risks, various geometrical and physical properties of exploration objects, and their variation in space and time. In mechanics, a few electromechanical relationships have been established for simple models of objects (Aksenov, 2006; Bobyleva, 2010, 2015).

The ERF method intensively employs probabilistic-statistical approaches to processing (quality, visual interpretation). These are quite sufficient, since the main result of the ERF method is to locate anomalous field segments and to estimate their dynamics in time (monitoring). The criterion for the engineering-geological interpretation of the ERF method and the verification is the study of hazardous geodynamic processes and zones of natural and anthropogenic risks using aerospace, geodetic, engineering-geological, hydrogeological, seismic, mountain-technical, and other information.

After developing the radio-equipment for ERF and acquiring devices for measuring the concentrations of radioactive gases (radon and thoron) or hydrocarbon gases (methane) to carry out works in drilled holes at a depth of ~1 m, M.M. Zaderigolova conducted experimental works in several regions in Russia and abroad (Zaderigolova, 1998, 2009; Zaderigolova, 2013). Figure 1 gives an example of a fragment of a record of a North Caucasian gas-pipeline segment on different days on the monitor of a dispatcher. In Fig. 1a, according to the radio-wave control method, a landslide on the pipeline route is inactive; in Fig. 1b all of the recorded and estimated parameters of ERF increase. Here, the signal increase occurs gradually. In Fig. 1b, there are anomalous disturbances of ERF signals at the onset of the landslide process, as well as their maximum during its activation and the accident; the ERF parameters then return to the normal state (Fig. 2). We note that many geophysical anomalous damaging processes (earthquakes, magnetic storms, rock avalanches, and landslides) occur according to the same law: an increase, a maximum, a decrease. The time of the increase in an anomalous signal can be used to make a geophysical prediction of the place and time of catastrophes. Studying the first precursors is a complex problem; it should be developed in the future. Figure 2 shows an example of integrated monitoring (ERF-EM).

CONCLUSIONS

A new complex approach to studying hazardous geodynamic processes and zones of natural and anthropogenic risks using the radio wave and gas-emanation methods has been characterized. The modern method of studying natural and anthropogenic Earth's radio fields was developed based on the technologies that are used in several other methods of electrical prospecting, which made it possible to obtain not only the observed parameters, but also the estimated characteristics of the field. The techniques of statistical computer data processing are used. The estimated parameters are physically more suitable for geological-geophysical interpretation.

The domestic instrumentation developed by M.M. Zaderigolova that is used in high-quality technical and computer-assisted equipment for the ERF method increases the accuracy, informativeness, and reliability of results, although it increases their cost. The anomalies obtained by the ERF method are confirmed by the gas-emanation measurements in the drill holes, which characterizes the reliability and objectivity of information (Aksyutin, Zaderigolova et al., 2015). The method should be put into practice so that gas pipeline operators can make decisions to prevent accidents.

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Translated by L. Mukhortova

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