Application of electronic systems of georadical surface sensing

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Abstract. This article discusses the use of a complex of GPR near-surface sounding and the possibility of using GPR in determining the location and spatial parameters of the outbreaks of coal and coal dumps with the aim of quickly making management decisions to minimize the negative impact on the environment.

1. Introduction
The burning of rock mass in the waste dumps leads to the release into the environment of more than two dozen harmful and hazardous substances. In particular, it is carbon dioxide, sulfur dioxide, sulfuric anhydride, nitrous oxide, hydrogen sulfide, sulfuric acid, sulfur, ammonia, cyanide, etc. Given the fact that most of the waste dumps are located in residential areas, their extinguishing is required, and some cases and complete disassembly [1].

In order to comprehensively improve the ecological and geodynamic situation of urban areas, it is rational to make a complete disassembly of extinguished waste heaps with simultaneous hydraulic laying of the worked-out space under the promising areas with empty rocks from the nearest dumps. The results of research conducted in recent years, suggest the possibility of using in coal mines hardening bookmarks on a cementless basis using advanced pumping equipment [2-4].

The results of monitoring the thermal state of extinguished waste dumps show that a recurrence of fire occurs quite often [5]. In this regard, for the operational control and timely localization of sources of ignition of waste dumps, various methods of thermal control of waste dumps are used: remote sensing from unmanned aerial vehicles, thermal imaging of dumps using multi-zone temperature sensors, etc. However such monitoring methods can only give an idea about the start of the ignition process, and as a consequence - to be a signal for making operational decisions to minimize risks from primary or secondary fire of coal mass. To effectively design work for the suppression, reclamation or complete disassembly of dumps of rock mass, it is necessary to have information about the depth of the location of the source of fire, its length and spatial parameters.

This article describes the method of using the electronic complex of geophysical equipment for remote determination of the spatial parameters of the sources of ignition of coal and coal dumps.

2. Materials and methods
When conducting surveys with GPR, the method of vertical traveltime is usually used [6]. In this case, the GPR moves along the profile with a constant separation between the receiving and transmitting antennas, and at each point of the profile a signal is recorded consisting of a probe pulse and
secondary waves (Fig. 1). Any subsurface discontinuities associated with changes in the thickness of the rock mass will give a response in the wave structure of the received signal.

![Figure 1. Scheme of movement of the GPR antennas along the route of the waste dump](image)

The most important parameters characterizing the possibility of using the GPR method in various environments are the specific attenuation and the propagation speed of electromagnetic waves in the medium, which are determined by its electrical properties. Specific attenuation determines the depth of sensing. And knowledge of the propagation velocity of radio waves is necessary to recalculate the time delay of the reflected pulse in the distance to the reflecting boundary. Figure 2 shows the propagation of radio waves in the layers of moldboard mass.

3. **Field surveys of volumetric parameters of the outbreaks of coal and coal dumps**

The most important parameters characterizing the possibility of using the georadiolocation method in various environments are the specific attenuation and propagation velocity of electromagnetic waves in the environment, which are determined by its electrical properties. Specific attenuation determines the depth of sounding. The value of the propagation velocity of radio waves is necessary for recalculating the time delay of the reflected pulse in the distance parameter to the reflecting boundary (Fig. 2).

![Figure 2. Propagation scheme of radio waves in the decompacted layers of dump rocks](image)

The determination of combustion zones using the GPR method is based on studying the effect of temperature on the dielectric constant and conductivity [7].

The dielectric constant $\varepsilon$ shows how many times the field is weakened by the dielectric, quantitatively characterizing the dielectric's property of polarizing in an electric field. The value of the relative dielectric constant of a substance, which characterizes the degree of its polarizability, is determined by the mechanisms of polarization. However, the value largely depends on the state of aggregation of a substance, since during transitions from one state to another, the density of a substance, its viscosity and isotropy significantly change.

The dielectric constant characterizes the speed of passage of a pulse in a medium and in solids can
take on very different numerical values in accordance with the variety of structural features of a solid
dielectric. In solid dielectrics, all types of polarization are possible.

The main parameters necessary to ensure the correct technology for surveying and interpreting
GPR data for most rocks are presented in Table 1 [8].

| Parameter                          | Interpretation                                      |
|------------------------------------|-----------------------------------------------------|
| Dielectric and magnetic permeability | $\mu \approx 1$                                      |
| Phase velocity                     | $V_\phi = \frac{1}{R_e \sqrt{\varepsilon}}$        |
| Medium wavelength                  | $\lambda = \frac{\lambda_0}{R_e \sqrt{\varepsilon}}$ |
| Specific attenuation               | $\Gamma = 8.68\alpha = \frac{54.6}{\lambda \ln \sqrt{\varepsilon}}$ |
|                                    | $\alpha = \frac{c \ln \sqrt{\varepsilon}}{\omega}$ |
|                                    | $L = 20 \log \left[ \frac{E_0}{E_z} \right] = 8.68\alpha z$ |

The inspections of areas of burning sites of coal and rock dumps were conducted near the town of
Shakhty, Rostov Region. The purpose of these studies was to determine the depth parameters of the
source of ignition of coal and coal dumps, as well as zones of decompaction of rocks caused by
burnout of the rock mass [9].

The surveys were carried out according to the scheme shown in Figure 3 in compliance with safety
requirements when working in the immediate vicinity of fire sources.

![Figure 3. Propagation scheme of radio waves in the decompacted layers of dump rocks](image)

4. Results
The difference in phase velocity for different frequencies determines the variance. The probe pulse in
a medium with dispersion changes its shape due to phase distortion of the shape.

The approximate values of the electrical characteristics of some soils and rocks at a field frequency
of 100 MHz used to operate in the study area are given in Tables 2 and 3 [10].
Table 2. Dielectric values of materials in the frequency range recommended for measurements

| Material        | Dielectric constant | Conduction | Specific attenuation | Phase velocity |
|-----------------|---------------------|------------|----------------------|----------------|
| Air             | 1                   | 0          | 0                    | 300            |
| Fresh water     | 81                  | 10^{-3}    | 0,18                 | 33             |
| Sea water       | 81                  | 4          | 330                  | 15             |
| Sandy soil is dry | 2,6                | 1,4*10^{-4}| 0,14                 | 190            |
| Sandy soil moist | 25                | 6,9*10^{-3} | 2,3                  | 60             |
| Dry loam        | 2,5                | 1,1*10^{-4}| 0,11                 | 190            |
| Wet loam        | 19                 | 2,1*10^{-2}| 7,9                  | 69             |
| Clay soil is dry | 2,4                | 2,7*10^{-4}| 0,28                 | 190            |
| Clay soil moist | 15                 | 5*10^{-2}  | 20                    | 74             |
| Basalt wet      | 8                  | 10^{-2}    | 5,6                  | 110            |
| Granite wet     | 7                  | 10^{-3}    | 0,62                 | 110            |
| Clay slate moist | 7                 | 10^{-1}    | 45                    | 83             |
| Sandstone wet   | 6                  | 4*10^{-2}  | 24                    | 110            |
| Limestone moist | 8                  | 2,5*10^{-2}| 14                    | 110            |
| Iron            | 1                  | 10^{6}     | 1,7*10^{7}           | -              |

As the moisture content of the soil increases, the specific dielectric constant also increases. The electrical conductivity of the soil increases.

Table 3. Dependence of the basic electromagnetic parameters of soils on humidity

| Material         | Dielectric constant | Conduction |
|------------------|---------------------|------------|
| Road construction| 5…10               | 0,0002…0,000002 |
| Rock             | 4…10               | 0,01…0,000 |
| Clay             | 4…16               | 0,05…0,0002 |
| Loam             | 2,5…19             | 0,021…0,00011 |
| Sand             | 3…25               | 0,007…0,00002 |
| Peat wet         | 50…78              | 0,002…0,001 |
| Moraine          | 9…25               | 0,01…0,0001 |
| Il               | 9…23               | 0,001…0,0001 |
| Metal            | 1…2                | 10000000   |
| Ice              | 3…4                | 0,001     |
| Water            | 80…81              | 0,002…0,001 |
| Air              | 1                   | 0         |
| Road construction| 5…10               | 0,0002…0,000002 |
| Rock             | 4…10               | 0,01…0,00000 |

The minimum values of the dielectric constant correspond to the dry state of the material, the maximum - to the wet [11].

With an increase in the water content in the examined layers, the parameters of the specific dielectric constant also increase, and the electrical conductivity also increases.

When examining the zones of dumps intended for thermal imaging, the values of the dielectric constant of the corresponding rocks in the non-wetted state are taken, since in the field of examination the surface is exposed to heating and drying under the thermal influence of the combustion centers.
Figures 4-6 show the results of the traversing of the profiles of tracks 1-3 by the GROT 12E receiver and the 9 kV transmitter using antennas - 1 m.

The results obtained from the survey of route 2 are presented in Figure 6 and largely repeat the results obtained from route 1. There is a clear change in the dielectric constant parameter of rocks as the source of combustion approaches the outer surface of the blade, as well as the difference in the areas of decompaction of rocks caused by the burning out of rock volumes [12-13].

When examining the territory along the route section 3 (Figure 6), a zone of burning of maximum intensity was identified. In this area, the temperature of the surface rocks was higher than the ambient temperature, which was clearly determined without the use of special devices. On the radarogram this zone is highlighted as a separate section.
To confirm the obtained results, the passage on route 3 using antennas 2 m, GROT 12E receiver, 9 kV transmitter was repeated. The results of the site survey are presented in Figure 7.

5. Conclusion
Burnout zones of rocks in coal dumps are clearly visible on radarograms due to the appearance of softening and voids in the dump mass, formed as a result of the combustion process. In addition, this method allowed tracing the trajectory of the spread of combustion along the length of the survey routes.

The obtained results allow concluding about the consistency of this method to obtain additional information used in planning activities for the suppression and recultivation of coal dumps located in residential areas.

Further study of the temperature dependence of the dielectric constant, as well as the application of the above-described method of remote sensing of zones of softening and burnt voids in combination with the use of additional thermal control methods will allow building three-dimensional models of high accuracy before starting the work of extinguishing and reclamation. This will reduce labor costs and the cost of work, making their planning more accessible and taking measures to improve the environmental situation of mining towns and settlements more accessible.
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