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EVALUATION OF THE STATE OF ECOLOGICALLY PROBLEMATIC MINING AND INDUSTRIAL OBJECTS IN KALUSH REGION BY ELECTROMAGNETIC METHODS AND THEIR MONITORING

Environmentally hazardous geological processes in the waste deposits of potash and rock salts pose significant threats to the environment. To detect, to study, and to prevent in time such the processes (karsting, suffosations, landslides) a hardware and software complex for induction sounding of the geological environment in the near zone of field source has been created and tested. The multiprocessor system to control, to acquire, and to transfer the data obtained for analysis and operational geological interpretation to the end users has been developed.

Keywords: geological medium, negative process, ecology, electromagnetic field, soundings, evaluation of geological medium state, and prediction.

Environmentally dangerous geological processes caused by manmade and natural factors on waste deposits of potash and rock salts take place in geological environment mainly up to 100—200 m deep. At the initial stage of adverse processes (formation of caverns, filtration and suffusion, landslides, etc.) when neither the weakening of the structural links nor ground deformations are measurable by direct (piezometric) methods, but in the potentially dangerous areas of geological environment there are recorded material changes in their electrical characteristics. In particular, their electric conductivity grows as a result of intensification of infiltration and saturation of environment with mineralized water. Such electric conductivity anomalies are main objects of search by the electromagnetic (EM) methods while surveying the weak areas in order to assess them, to identify and to study the dangerous geological processes, and to prevent them in due time.

The DC methods have been widely used and constantly improving in order to identify and to monitor environment dangerous processes. They are mainly based on standard equipment and profiling of geological environment by electrode arrays [1, 2] of various size and on periodical measurements of apparent resistivity (ρ_k) and its time dynamics in potentially dangerous areas. The capacity of classic DC methods (vertical electric sounding, dipole electric sounding, electric profiling) are known to be essentially limited with high-resistant insulating horizons lapping the thickness studied and with a low localization of vertical profiling. The latter causes lateral inhomogeneity effects, inasmuch as the underpart of cross sections is the most inhomogeneous. The prospects for the use of constant (quasi-stationary) fields of controlled sources is defined by new approaches to solution of such tasks, including those based on electric resistance tomography [3]. At the same time, DC measurements (as well as natural pulsed electromagnetic fields [5, 6, 7]) can be used successfully in complex with modified EM methods [4] in order to study dynamics of dangerous processes effecting the apparent resistivity and provoking an increase in mechanical stresses, intensity of pulse radiation, and in electric anisotropy.

Georadar systems are notable for high localization and high resolution [8, 9]. They differentiate the geological environment by resistance and permeability on the basis of reflected high-frequency electromagnetic signals. Under favorable conditions of high-resistnat environments (dry soils, permafrost, massive salt rocks, etc), the depth of penetration by best georadars reaches 20—30 m and more, however, in the wet clays and loams, the maximum penetration depth does not exceed 6—10 m, as a result of growing electric conductivity. At a high minerlization of fluid phase, their use is impossible.

As of today, field sounding in the near zone of primary source (TEM) and its numerous modifications, including, high-frequency electromagnetic sounding (HFEMS), is one of the most informative and effective methods for detailed study of the structure and electric properties of geologic environment, i.e. the parameters to evaluate the geo environment status and conditions and to identify dangerous processes and their dynamics. This method was proposed in the 1970s [10, 11]. Later, instrumentation based on HF modifications of this method (*Impulse-Auto* (Siberian R&D Insitute for Geology, Geophysics, and Mineral Raw Materials), *Electrotest-TEM* (*Diogen*), Piers (Karpenko Physico-Mechanical Institute of the NAS of Ukraine), *NanoTEM* (*Zonge*) was designed for sounding small depths. Advanced equipment, including *FastSnap* (by *Sybgeosystems*), has modular design using GPS systems and enables synchronous cluster measurements using a set of autonomous units.

As of today, a material positive experience in using the mentioned developments has been accumulated in the solution of practical, chiefly geological engineering and environmental problems. This experience has confirmed high geological information capacity and effectiveness of electromagnetic sounding method. The available developments are destined mainly for solving a limited range of industrial tasks and incorporated in hardware and softwatre complexes of individual firms. This and other factors (specific format of data records, licensed software programs for processing and control of measurements, high cost of supply and maintenance) essentially complicate their application for creating new technological means suitable for the use in extraordinary cases. Such cases mostly often take place in industrial urban agglomerations and exhausted deposits where electromagnetic radiation from power lines and effects of engineering and communication infrastructure on the measurements are very high.

GEO-ELECTRIC CONDITIONS AND REQUIREMENTS FOR MEASUREMENT SYSTEMS

To address the pressing geotechnical and environmental problems concerning the assessment and monitoring of the geological environment it is important to ensure, in addition to locality and high noise immunity, a wide range of functions of the measurement system and its suitability to electromagnetic monitoring of problem objects in combination with geological and geophysical methods. The software and hardware complex must be capable of diagnostics in a wide range of depths, rapid processing, analysis, and interpretation of the data, their automatic transmission through the communication channel to the server of basic organization, which will significantly raise the productivity and effectiveness of surveys.

The mine fields with karst cavities that may be accompanied with contamination of groundwater and river basin are among the most difficult and potentially dangerous objects of the Kalush mining and industrial region. In addition, all cover horizons and extractive cavities in the depleted horizons can undergo negative (filtration, karstic) processes.

The generalized geo-electric model of the upper part of open-pit mine is simple and corresponds to

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three-layer stratigraphy ($\rho_{1 \geq} \rho_{2 \leq} \rho_3$, where ρ_1—ρ_3 — specific resistivity) represented on the top by pebble clay loam deposits with a thickness of 10—20 m and an electrical resistivity of 30—40 Om·m. Below, there are low-resistivity (0.6—5 Om·m) alluvial formations of the clay and plaster cap having a thickness of 10—50 m and saturated with brines circulating over of high-resistivity (> 200 Om·m) saliferous indigenous deposits represented by potassium and halite rocks and salt breccia.

The situation is complicated by de-compaction of the cover. These areas manifest themselves as local of extended geo-electric inhomogeneity above the depleted and filled with brines cavities. Over time, this leads to instability of cover rocks above the mines, formation of craters, and sudden subsidence of the earth surface. These processes usually are triggered by weakened ceiling and deconsolidated areas of waterproof strata above the cavities. Over time, the collapse of rocks extends to the top, with other previously inactive, local and extensive structural and component inhomogeneity of the clay-plaster caps and aquifer sediments involved into the development of filtration and karst processes that entail large-scale environmental problems and considerable material damage. The surface subsidence and the trough formation above the mine fields with a rate exceeding the planned one is a huge source of aquifer contamination with strongly mineralized waters from the cavities. Today, groundwater pollution is caused mostly by dumps and tailings, with filtration and suffusion processes on the sides of quarries and in the body of tailing dykes posing a material threat.

From the very first meters and down to above mentioned depths, EM sounding of the upper part is associated with specific technical problems caused mainly by a high damp rate of non-stationary process within a wide dynamic range (over 80 dB) of induced field signals $E(t) = \partial B_z/\partial t$ (B_z is vertical component of magnetic flux through the measuring loop (q) of loop-in-loop installation $Q{*}q$). The amplitude of field signals normed by current $E(t)/I_Q$ (I_Q is pulsed current in the generator's loop) at the late stage is about 10^{-5} V/A, while the initial one can exceed 1 V/A. The operating time interval of field signal measurement is determined by required depth of sounding. At the beginning of sounding at relatively small depths (5—10 m), the final time (t_k) of $E(t)$ signal measurement does not exceed 100 μs and grows quadratically as depth increases.

Time interval (t_k—t_n), where t_n is initial time of measurement, that is approximately by two orders of magnitude less than the final time ($t_k/t_n \cong 100$) corresponds to the informative component of $E(t)$ curve not distorted with transition processes. Time interval $10^{-7} \div 10^{-2}$ s and frequency band (100 ÷ ÷ 10 MHz) of measurement channel that is close to that of geo-radar systems correspond to sounding within the whole specified range of depth (100—200 m). This requires a high speed of response and accuracy of synchronization of analog and digital units within a wide range of amplitude of field signal measured.

HARDWARE COMPLEX

The designed electric exploration equipment (Contour-1) has a modular configuration. The structure is showed in Fig. 1, *a*. The complex consists of the generator (generator module, loop Q) and the metering unit (loop q, input module, metering and indication module) controlled by digital circuitry of the system. Required speed of response and noise immunity are provided by proved technical solutions that have been worked out for previously designed equipment for physical modeling of non-stationary electromagnetic processes in electrolytic models [12] which require similar or even higher speed.

The master module has the highest priority in the system. It sets the operating modes of the device in interactive menu, controls the master oscillator that forms all reference and clock signals required for excitation and measurement of unsteady field, and organizes the interaction between the modules and with the system of top-level hierarchy, including personal computer through an appropriate interface. Also, the module provides recording the data obtained to the nonvolatile memory during the field observations. For reliable identification of information received, a file record system is used with each discrete sounding curve (one measurement cycle) recorded to the file with a tag featuring the sounding settings.

The bridge-type generator of pulsed field is controlled via optic elements ensuring the isolation of its electric circuits in the whole frequency band. The structure of metering unit is showed in Fig. 1, *d*. The algorithm of noise immune measurement of wideband signals of the field induced in geological environment is ensured by operations sequentially performed by blocks of the metering module:

- Coding of input signals by levels in discrete time moments counted from the start of formation process;
- Transformation of frequency spectrum of the input signals and narrowing of frequency spectrum of coded signals;
- Synchronous filtration of signals;
- Reduction of commutation noise, DC and slowly variating AC (polarization processes), at the input;
- Coherent detection of signals and removal of byproducts of detection [13].

Basic metrological parameters of the measuring module are given below.

Measured physical value	Descending voltage in receiving coil generated by changing magnetic flux ($\partial B_z/\partial t$)
Time window range	10^{-7} s — 10^{-3} s with a minimum step of 0.1 μs within the whole range and an error of ±0.01 μs
Input signal range	From 10^{-5} to 10 V
Main relative error of exponential voltage	$\delta_0 = \pm[5 + 0{,}1(U_{max} / U_x - 1)]$ %, where U_{max} is upper value of subrange (*B*), U_x is measured value, incl. error caused by duration of sampling
Additional error of temperature fluctuations within –5 до +40 °C	Does not exceed half main error per each 10 °C
Applicable regulations	Statements of test verifications on standard models

The multifunctional digital system of the hardware complex is based on weakly linked functional modules that have no common resources, insofar as they excahge information only. Interaction between all system modules (duplex connections) was ensured using communication port lines. Graph of this multi-controller configuration is showed in Fig. 1, *b*, where the master is marked with 0, while its slaves with 1, 2, 3, 4, and 5. The latter defines required quantity of USART interfaces of master microcontroller and, hence, the type of controller used (ATxmega256A3 by Atmel [14]). The structure of control module based on it is presented in Fig. 1, *c*. An important component of the control module is RAM where data are accumulated and stored. The frames of measurements are formed therein as well, recorded to FLASH-type nonvolatile memory [15], and transferred to data processing center via GSM-operator channels.

To assess the quality of recorded materials and to adjust the configuration and parameters of metering system, preliminary processing and express analysis of data obtained are foreseen. The files generated by the OS and containing data with respective metadata in their internal representation have extension *.log and are stored in the [Log] directory. An example of the output file is showed in Fig. 2, *a* (see color inset), the underlined metadata correspond to parameters used for creation of the input files. *Zond* software developed by Seifullin R.S. and Mamontov V.I. (Ukrainian State Institute for Geological Exploration, Lviv, 1994) was used for transformation and express analysis, with Delphi system as working environment for developing programs for reading and formation of input data packages. It was chosen for power file processor and was a toolkit for designing, developing, and programming a friendly user interface.

To compute the electric parameters of geo-medium *Zond* software needs the input values to be allocated in three different files in [Dat] folder — «names», with filenames of data files to process, «times», with values of time windows used and

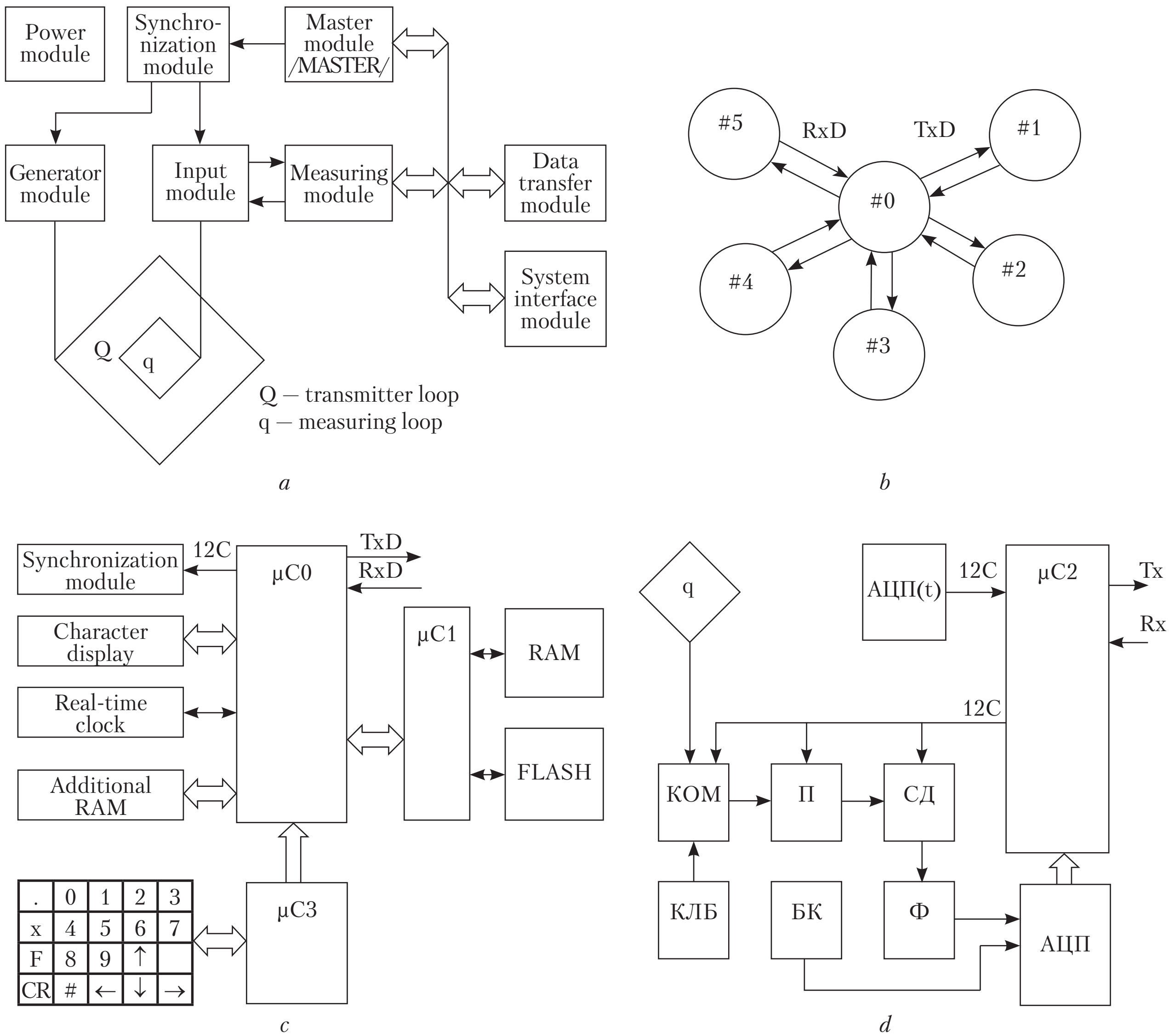

Fig. 1. Scheme of electric exploration hardware: *a* — general structure; *b* — system graph (RxD and TxD are lines of serial interface), *c* — structure of the controlling module, *d* — structure of the metering module (*q* — metering circuit, КОМ — input switch, КЛБ — calibrating unit, П — input signal converter, БК — control unit, АЦП(*t*) — temperature module, СД — synchronous detector, Ф — output filter, μC2 — meter microcontroller, АЦП — ADC of the meter)

these data files, with extention «*.dat». It corresponds to the values of measured signals at fixed delay instants. For correct formation of the mentioned files (times, names, *.dat) the developed algorithm foresees the following operations:

1) search of files *.log (source files) in the [Log] folder. Metadata are read from the file found, with [Dat] directory created before for their storage;

2) formation of «times» file (time scale is calculated with spacing T_{dsk}) and its record to [Dat] (Fig. 2, *b*);

3) search of all files *.log in [Log] with the further following operations for each file found:

- Reading of *e(t)* signal value and normalization by current $e(t) = e(t)/I$, where I is excitation current (current in transmitter loop (Q);

- Formation of file *.dat and its record to [Dat] folder, with numerical name of 3—4 digits that corresponds to the number of piket from filename *.log(pk.dat), Fig. 2 *c*;

4) search of all *.dat files in [Dat], with all founded names in ascending order constituting their list, the «names» file; the latter is recorded to [Dat], (Fig. 2, *d*).

The output of preliminary data processing program is a package of files (Fig. 2, *b*, *c*, *d*) with input data for calculating the electric parameters of the environment using the *Zond* program.

The source files, i.e. files of measurements on individual picket (Fig. 2, *a*) are transferred into the integration center for input to the database [16] using a GSM module with imbedded TCP/IP stack SIM900 (SimCom). The developed algorithm of data transfer is based on the principle *one measurement — one transfer*. This ensures maximum operativity insofar as for field measurements the data processing center can continuously control and adjust (optimize) the observation mode. The GSM module can be used both as part of the system and autonomously. It enables an operative transfer of data from various services in field conditions, with the data transfer system creating necessary conditions for performing operations with the source data files of the whole set of geophysical methods.

FIELD TESTING

The electromagnetic surveys are aimed at identifying the changes in electro-physical parameters of the geo-environment and establishing the indications and regularities of spatial and time variation of electric resistivity of rocks under the action of natural and manmade factors. These and related tasks may be solved using the developed technology of electromagnetic diagnosis of geomedium and forecasting hazardous processes in it. It is based on TEM soundings and combination of these data with ones of other methods. Within the budget funded and self-financing projects, in previous years, engineering means of detecting and monitoring the dangerous processes, including for mapping the areas of underground waters polluted with liquid wastes of potassium production [20, 21], detecting filtration processes in the body of earth dams, and assessing the condition of cover above salt deposits by EM methods [22, 23], were designed and tested in some areas of designated local test sites (northern band of ore of Dombrovsky quarry and adjacent areas [17], dyke of tailing no. 2, area between the Sivka River and tailing no. 1) [18, 19].

While testing the designed hardware the attention was focused on the mine fields with active subsidence and sinks of surface. In the potentially dangerous zone, there are over thousand residential houses of the town and neighboring villages. With the formation of the trough in the areas of subsidence, the highly mineralized solutions are displaced from filled chambers to the only aquifer in the district. In addition to the existing sources (dumps, tailings, quarry waters) it can eventually become a major factor of contamination, particularly, in the basin of Limnytsya River. The survey using both the methods of sounding by transient field in the near zone (TEM) and natural pulse EM field of the Earth (NPEMFE) has been carried out in the mine fields of Kalush industrial area (Fig. 3, color inset): Northern kainite field (*1*), Khotin sylvinite field (*3*) of the Kalush mine, and Sivka-Kalush mine field (*5*) of Novo-Holyn mine. The chosen objects have materially different geo-electrical conditions, which is important for testing.

NORTHERN KAINITE FIELD

The survey has been made in the chasm area (junction of Witowski, Mostiska, and Hlibov Streets) to assess the conditions of environment using the EM methods in order to detect active zones for taking immediate remedial measures and to stop further development of karst in the chasm. The surveyed site is cluttered up with different objects to be geological obstacles when inversing (cables and 50 Hz lines, concrete and metallic structures) and artificial sources of EM interference (high-voltage lines, power stations, 50 Hz

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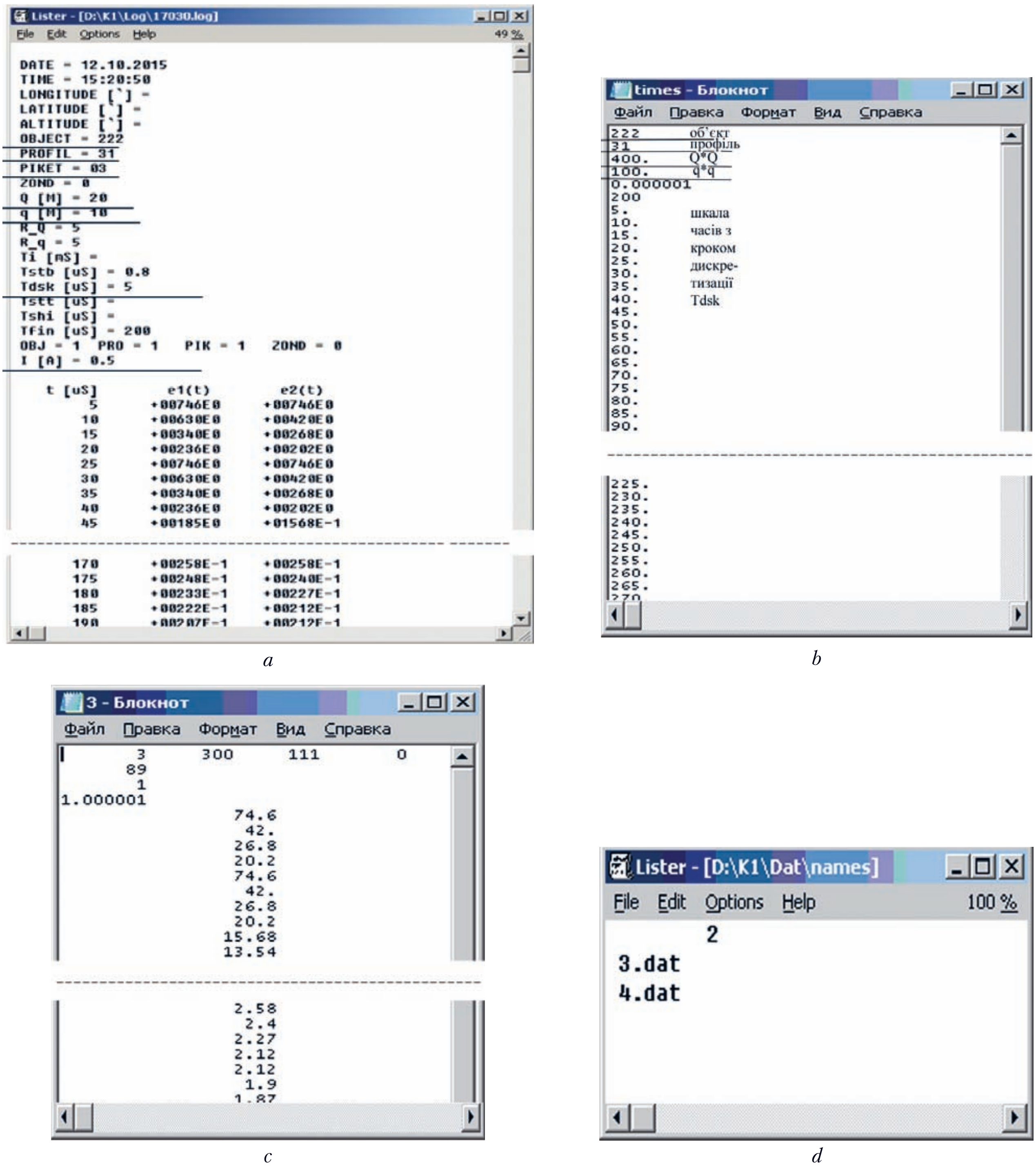


Fig. 2. Files for data express analysis: *a* — structure of *Contour-1* hardware output file; *b, c, d* — file package of «times», «*.dat» and «names» files with input data for the software to transform it into geoelectric parameters of medium

Fig. 3. The Kalush-Holyn deposit. Mines: I — Kalush, II — Nova Holyn, III — Dombrovsky quarry; mine fields: *1* — Northern kainite field, *2* — Central kainite field, *3* — Khotin sylvinite field, *4* — eastern Holyn field, *5* — Sivka-Kalush: A — tailings, B — accumulating basins, C — quarry dumps [24]

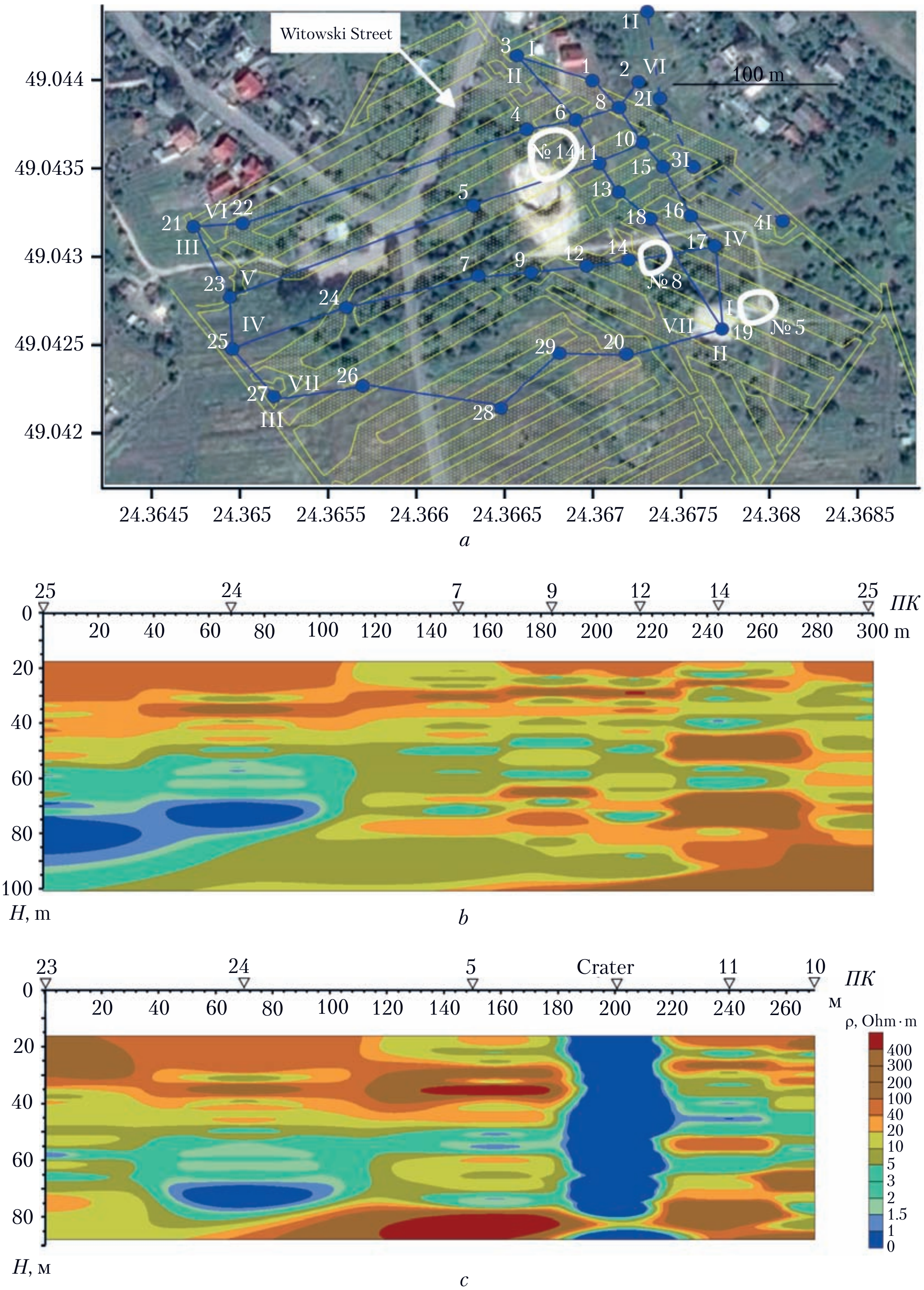


Fig. 4. Results of TEM survey for the site of Northern kainite field in the area of sinkhole (Vitovski Street): *a* — location of profiles I—I — VIII—VIII and underground cavities of the mine field, *b* — geo-electric profile along IV—IV, *c* — geo-electric profile along V—V one crossing the sink crater

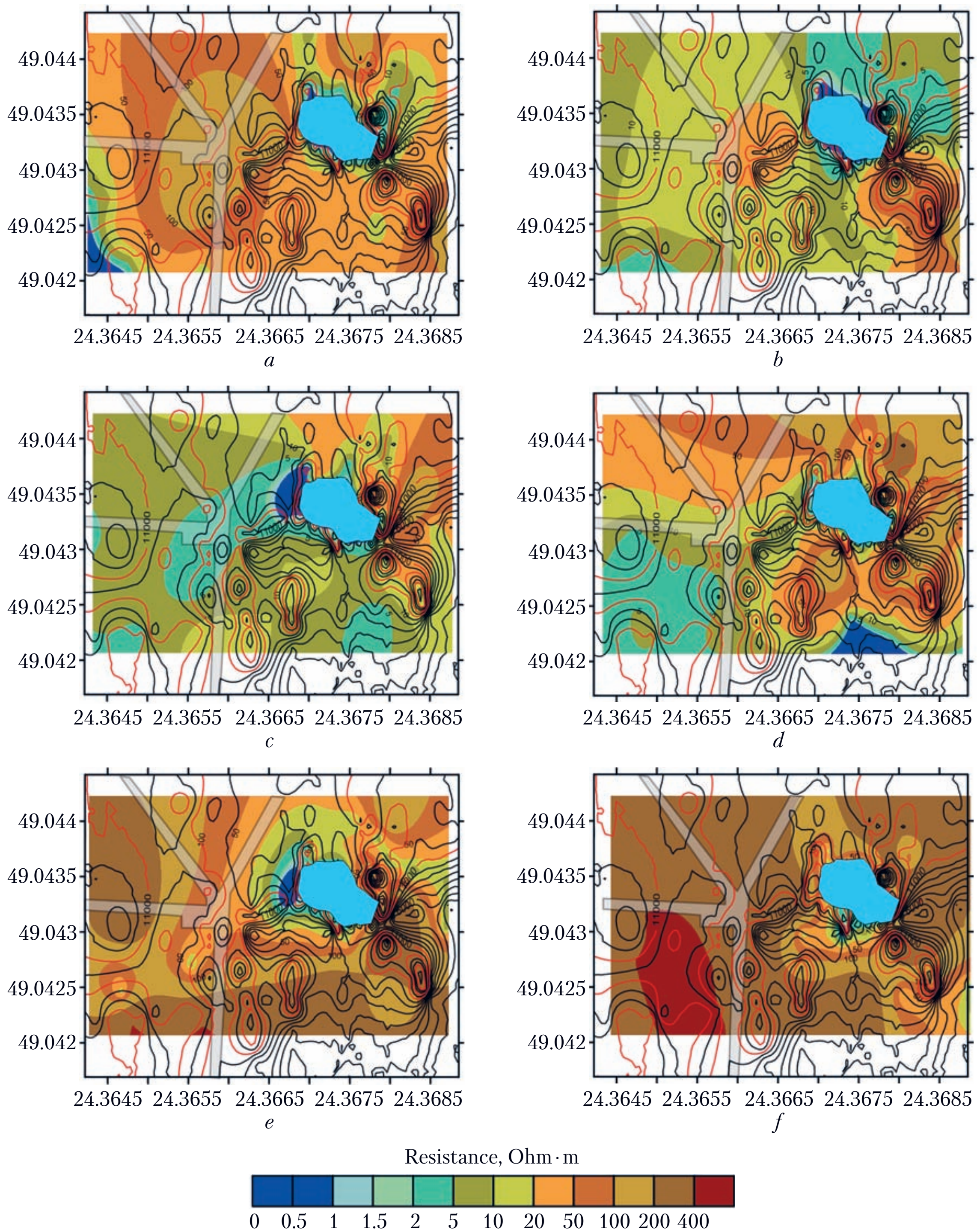


Fig. 5. 2D distribution of apparent resistivity at different depth according to the TEM data and intensity iso-lines (N/c) of NPEMFE signals on the daylight surface, red iso-lines correspond to values over 10000

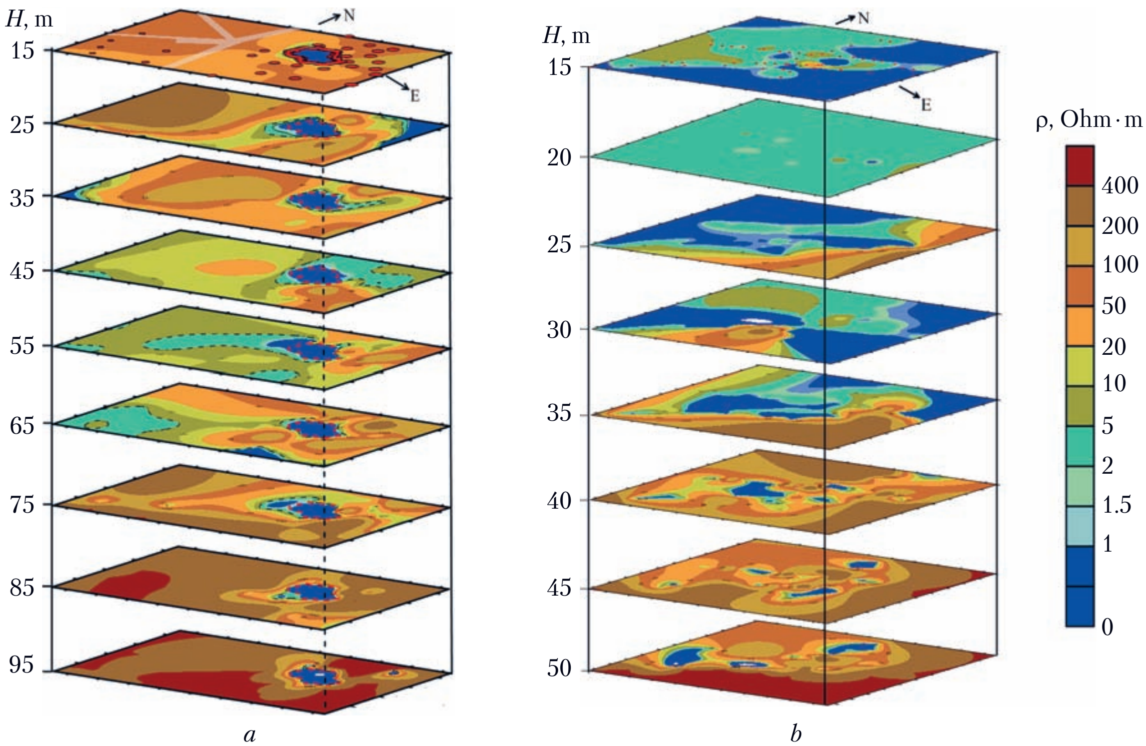


Fig. 6. Geo-electric models of 2D distribution of apparent resistivity ρ (Ohm·m) on the surveyed sites: *a* — Northern kainite field, *b* — Khotin sylvinite field; *H* is depth, meter

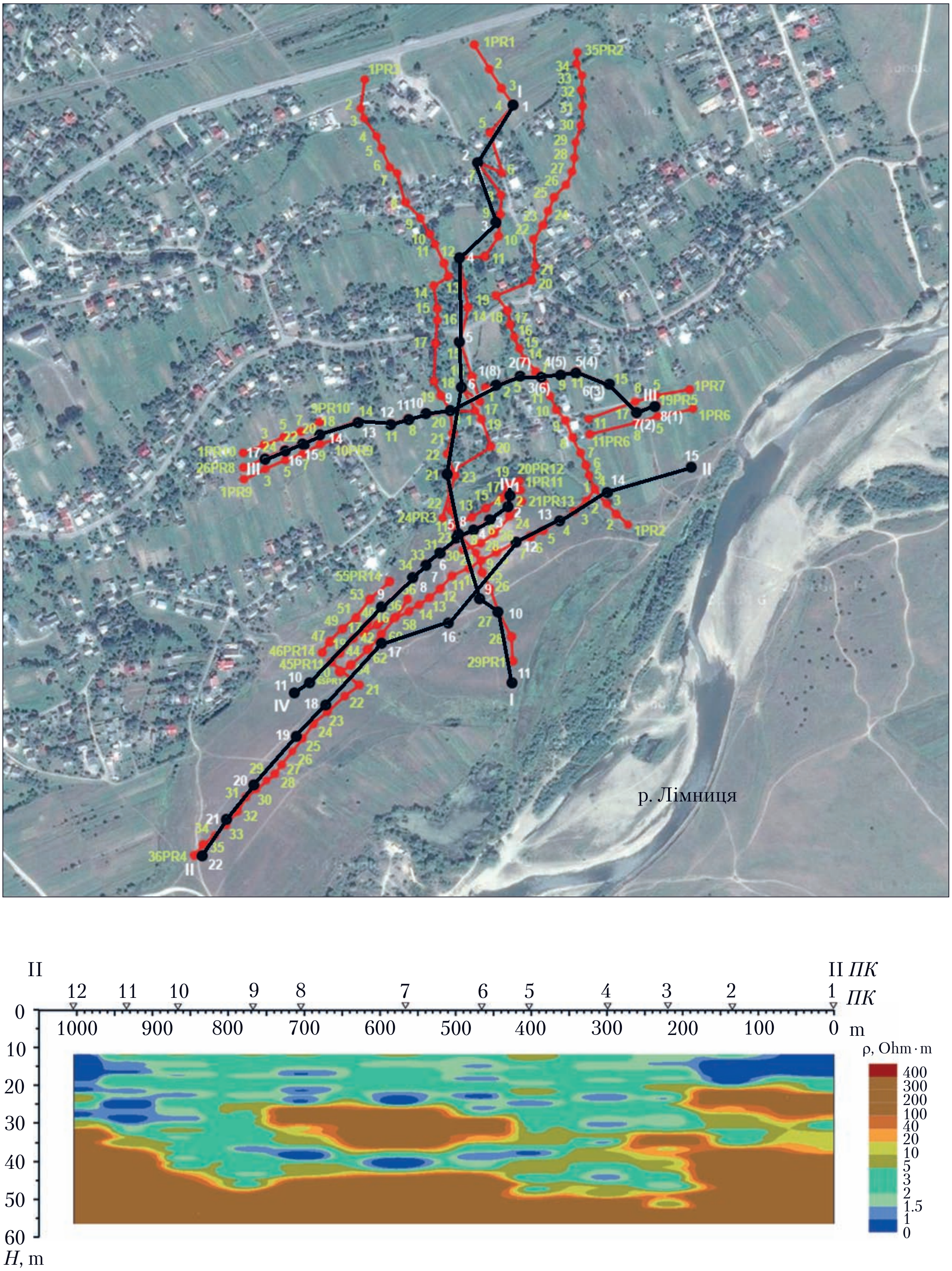


Fig. 7. TEM and NPEMFE profile grid (I—I — IV—IV) on the Khotin sylvinite field. Below, there is geoelectric profile along transversal profile II—II

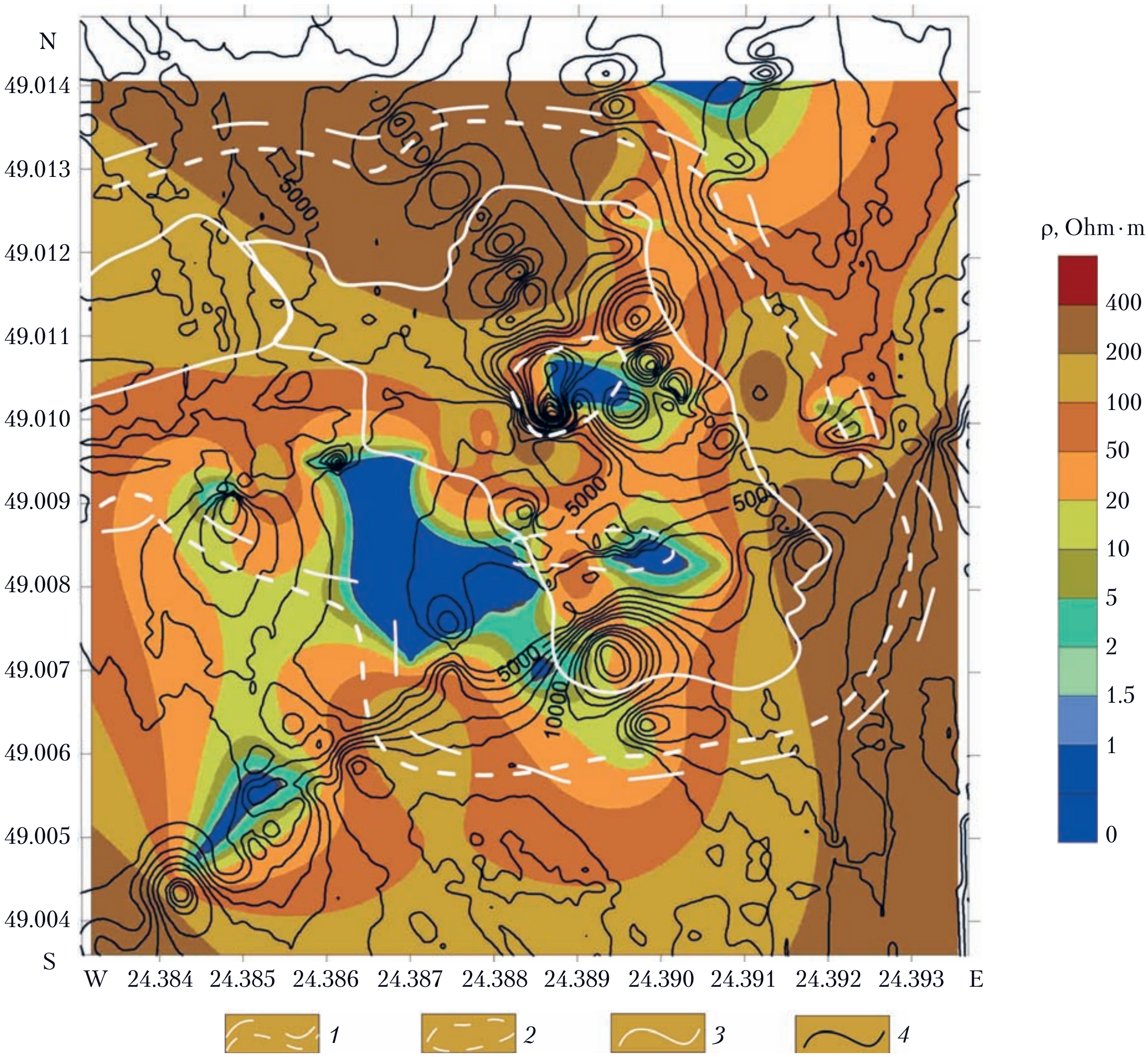
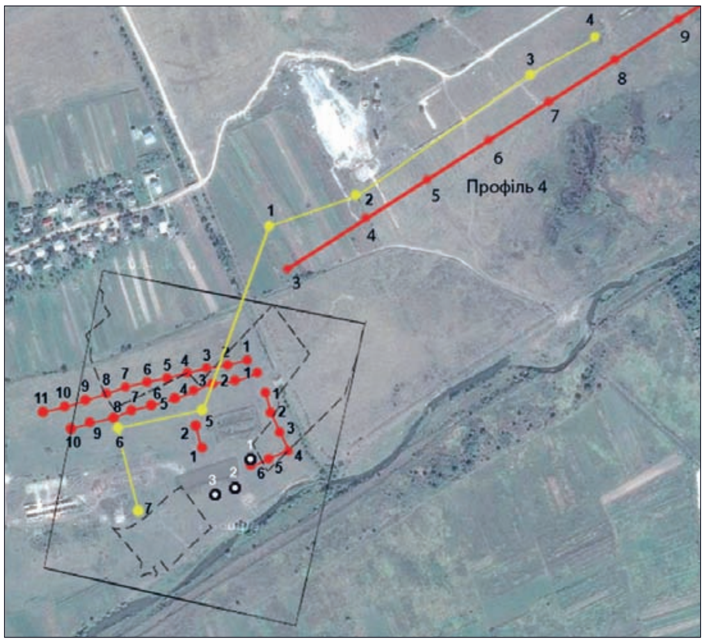
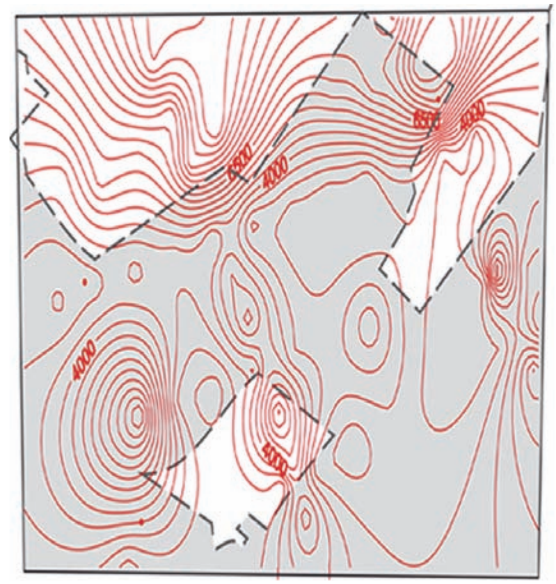


Fig. 8. 2D distribution of apparent resistivity at a depth of 45 m superimposed with NPEMFE distribution on the daylight surface and engineering geological data on the Khotin sylvinite field: *1* — trough subsidence boundaries according to engineering geological data, *2* — the most sunk areas, *3* — mine field boundaries, *4* — iso-lines of NPEMFE vertical component



a



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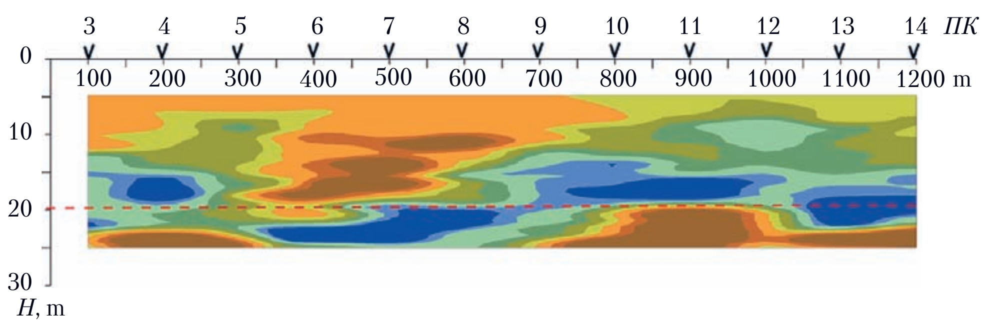

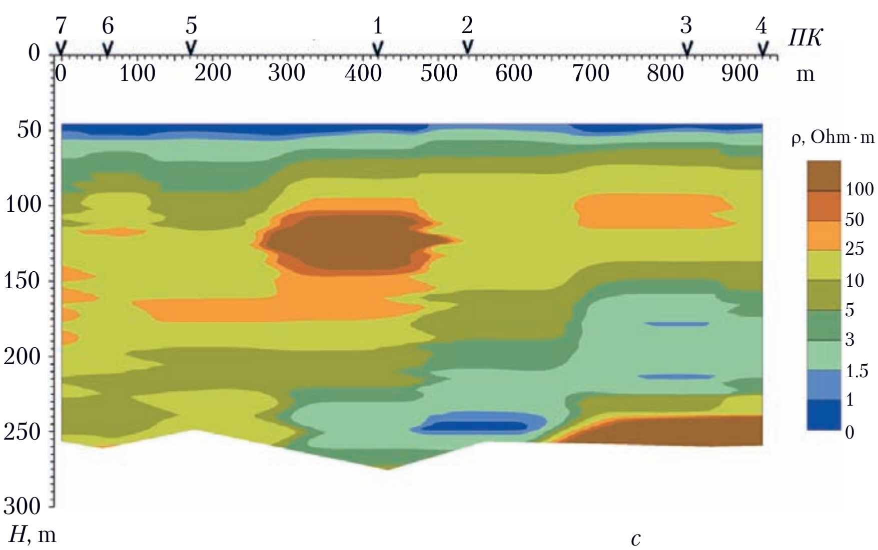

c

Fig. 9. Results of survey at the site of Sivka-Kalush mine field (mark as rectangular!): *a* — depth and repeated (cycle of 2015) profiles (dash lines in the rectangular mark location of mine field the measurements were done above), *b* — intensities of NPEMFE vertical component, *c* — repeated (shallow) geo-electric profile and depth geo-electric profile

pickups). The optimal dimensions of measurement installations (in terms of minimum effect of lateral inclusions on the sounding results) and points of sounding have been determined taking into account the geo-electric conditions of the site. Hence, firstly, the pickets suitable for survey were identified to make sounding, with geo-electric profiles formed thereafter.

Eight basic profiles in the area of chasm were defined in accordance with 2D EM sounding grid (Fig. 4, *a*, see color inset); soundings 1—29 were carried out by installation with $Q = (30 \times 30)$ m^2 and $q = (20 \times 20)$ m^2, the soundings 11, 21, 31, 41, 51, 61 were made by means of installation with $Q = (125 \times 125)$ m^2 and $q = (60 \times 60)$ m^2. The results of profile measurements by TEM and NPEMFE methods are showed as geo-electric profiles (Fig. 4, *b*, *c*, see color inset), as depth profiles of plane distribution of apparent resistivity, starting with a depth of 15 m and down to 95 m (made each 10 m), with superimposed contours of intensity distribution (N_x/c, N_z/c) of NPEMFE signals (Fig. 5, *a*—*e*, color inset), and as 3D geo-electric model of the site based on the profiles (Fig. 6, *a*, color inset). The profiles *a*—*f* (Fig. 5) of 2D distribution of specific resistance correspond to the following depths: *a* — 35, *b* — 45, *c* — 55, *d* — 65, *e* — 75, and *f* — 85 m.

The given dependences based on data of EM-sounding have been obtained as a result of preliminary processing and transformation of time dependences of unsteady filed measured on each picket into apparent resistivity (electric conductivity) of the environment at different depths. The spatial distribution of apparent resistivity ρ reflects in an objective way a complex structure and material composition of oversalt rocks.

Three components (N_x, N_y, N_z) of NPEMFE on this plane were measured and recorded by automated device (RKhINDS-PM-05) using much denser grid as compared with TEM-soundings. Intensities of signals (N/c is number of pulses per second) of horizontal (N_x, N_y) and vertical (N_z) components were measured within maximally wide frequency band 2—50 kHz according to specifications of the device. The values of component are laid as contour lines on the depth profiles of 2D apparent resistivity distribution (Fig. 5, *a*—*f*)

From the data presented one can see that laterally elongated abnormally high values of electric conductivity are reported near the chasm, starting with a depth of 35 m. At a larger depth (45 m), abnormal increased conductivity appears on north-eastern part of the chasm and disappears at further depths; in south-western part, at a depth of more than 55 m, there is recorded an elongated area of increased electric conductivity spreading deeper but not reaching the maximum depth. Hence, according to TEM data, the decompacted area has an elongated shape of limited capacity, which covers relatively small depths in northern east (probably, aquifer), passes through the area of chasm and spreads in southern west direction shifting to lower hypsometric levels. Having analyzed the TEM data and NPEMFE anomalies in complex with geological structure and processes occurring in this area under the influence of natural and man-made factors, one could conclude as follows:

- In the eastern part of the site, the cavities of mine field mapped (Fig. 4, *a*), with sinks no. 14, no. 8, no. 5 located along a straight line show that in the past the karstic processes intensively developed along the cavities, with the sinks reflected by anomalies of TEM and NPEMFE;
- In the western part, the underground cavities are oriented to other (south-western) direction that coincides with extension of low-resistant (decompacted) zone detected by TEM, with no local anomalies typical for karst manifestation reported (the selected zone location deepens correspondingly with the depth of waste deposit).

The most dangerous in terms of activation of karstic processes are the limited areas located close to the sink on north and southwest and having typical features of karst, according to the results obtained. The decompaction of cover in these areas at low depths is likely explained by favorable properties of its material and facial composition. These conditions are kept at a larger depth, in southwest part in the direction of anomalous zone detected by TEM.

KHOTIN SYLVINITE FIELD

The Khotin field is located to the southward of Kalush mine. The area is characterized by relatively small amount of geological (metallic structures, pipelines) and EM industrial obstacles. Unlike the Northern kainite and other fields its shutdown was not accompanied with filling the cavities with concentrated solution. The surface of this field has significantly sunk; recently, flooding of areas adjacent to the Limnytsia River has been reported, since the mine field is partly located under the river.

The condition of geological environment in the area of the trough subsidence has been assessed by comprehensive survey of geo-electric characteristics by TEM and 2D distribution of NPEMFE. The arrangement of profiles and pickets of TEM (black dots) and pickets of NPEMFE (yellow dots) is given in Fig. 7 (color inset). Below, this figure shows a geo-electric profiles oriented across the long axis of the trough subsidence, which (along with other profiles) features all high- and low-resistant elements and testifies to the correctness of field transformations made.

On the basis of geo-electric profiles, cross sections of 2D distribution of apparent resistivity and 3D geo-electric model of the geological environment have been built for the site (Fig. 6, *b*, color inset). The depth profile (45 m) of 2D distribution of apparent resistivity with NPEMFE iso-lines is amended with *a priori* data of boundaries of the trough subsidence, the mine field, and formations caused by degradation of geological environment (Fig. 8, color inset). These formations exist in the central part of the trough subsidence and are unambiguously recorded by the two techniques as anomalies caused by depth factors inasmuch as they manifest themselves on all profiles of 3D geo-electric model and 2D surface distribution of NPEMFE.

SIVKA-KALUSH MINE FIELD

A part of area between tailing no. 1 and the Sivka River was chosen as local test field for elaborating the method for detection and study of dynamics of aureole of underground waters contamination with fluid wastes of potassium production. The contamination is mainly caused by manmade factors (the excessive wastes from the tailing are known to be thrown to the Sivka River). Also, during the formation of holes (sinking of surface), concentrated solutions of immersed cavities can adversely affect the aquifer. Probable relations of aquifer and cavities of the mine field partly located within the local test site have been studied by the works performed.

Fig. 9 (color inset) shows the arrangement of profiles of EM sounding by loop-in-loop installation of the following sizes: $Q = (125 \times 125)$ m^2 and $q = (60 \times 60)$ m^2 (yellow) and $Q = (30 \times 30)$ m^2 and $q = (20 \times 20)$ m^2 (red). The results of sounding by the larger device have been compared with previous cycle (4th profile of local test site, 2015) of observations and given in Fig. 9, *c*. The positions of these profiles showed in Fig. 9, *a* coincide with the real ones, i.e. with those given in the scheme. One can see that in the common interval, the profiles are matched. In particular, in the depth profile, between pickets 2 and 3, in the upper part of geo-electric profile, there is an area with increased apparent resistivity, which has been confirmed also by the results of shallow sounding, but no relation between aquifer and solutions of underground cavities was detected. The data obtained will be used for further monitoring of contamination aureoles.

The 2D distribution of NPEMFE was measured on the part of the test site partially located above the mine field (Fig. 9, *a*) and marked with a rectangle. The area of the mine field is colored grey (Fig. 9, *b*). The results of measurements of the vertical component (N_z) show that maximum changes and an increase in its intensity are reported on the boundaries of mine field and outside it. Lesser radiation levels above the mine field are likely explained by a shunt effect of highly mineralized solution filling the cavities. At the same time, on the boundaries, growing mechanical stresses and, consequently, larger anomalies of NPEMFE and manifestations of anisotropy of electric properties can be expected. This should

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be taken into consideration while organizing monitoring of such objects.

The results of comprehensive survey of the selected objects have showed that in all cases the EM sounding definitely detects areas affected by karstic processes and determines their geometric and geo-electric characteristics. The correlation of TEM data with surface anomalies of NPEMFE intensity has certain specific features to be taken into consideration while interpreting the data. The clearest correlation is reported for the data obtained above near-surface formations (the chasms of Northern kainite field). Correlation in relatively high-resistant profiles in the absence of obstacles is observed significantly deeper (Khotin sylvinite field). However, the above mentioned (Sivka-Kalush field) changes in intensity of NPEMFE radiation above the boundaries of the mine field with cavities filled with saturated solution create conditions for additional tracking of dynamic processes in its boundary part along with EM soundings.

CONCLUSIONS

The obtained results of survey of mine fields having different geo-electric conditions have showed that the designed equipment for sounding of the upper part of geological medium by unsteady EM fields in the near zone of source of primary field enables to detect and to quantitatively determine the geo-electric and structural specific features of anomalous areas, as well as their dynamics to assess the geo-medium condition and to predict the development of unfavorable processes.

The comprehensive monitoring is provided by the hardware and software complex designed using the advanced engineering developments (GPS and GSM technologies) and by systems for measurement, control, data acquiring and transferring to the data processing center. Algorithms and software packages for rapid evaluation of field data and interpretation of materials obtained in complicated geophysical conditions have been developed. In addition to the classic application of AC and DC methods, the equipment foresees the use of untypical modifications of electric prospecting, depending on the problems to be solved (study of the environment structure or monitoring of its dynamics).

Detailed 2D soundings (TEM method) of problematic objects have been done in combination with measurements of natural pulsed EM field of the Earth, which has enabled to improve geological information capacity and reliability of observations. Upon results of tests of designed equipment on the problematic objects of Kalush-Holyn deposit, geo-electric profiles have been obtained, geo-electric models of surveyed areas have been built, and strain-stressed areas in the zones of intensively developing karstic processes have been identified. The data obtained confirm a high informative capacity of the complex and feasibility of its incorporation into the system of geological and geophysical monitoring of industrial agglomeration territories.

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ОЦІНКА СТАНУ ЕКОЛОГІЧНО ПРОБЛЕМНИХ ОБ'ЄКТІВ КАЛУСЬКОГО ГІРНИЧО-ПРОМИСЛОВОГО РАЙОНУ ЕЛЕКТРОМАГНІТНИМИ МЕТОДАМИ ТА ЇХ МОНІТОРИНГ

Екологічно небезпечні геологічні процеси, що виникають на відпрацьованих родовищах калійної та кам'яної солі, створюють суттєві реальні загрози для навколишнього середовища. Для виявлення, вивчення та своєчасного попередження таких процесів (карст, суфозія, зсуви) створено і апробовано апаратурно-програмний комплекс індукційних малоглибинних зондувань геологічного середовища у ближній зоні джерела поля. Розроблено мультипроцесорну систему керування, збору та передачі користувачам отриманих даних для аналізу та оперативної геологічної інтерпретації.

Ключові слова: геосередовище, негативний процес, екологія, електромагнітне поле, зондування, оцінка стану, прогнозування.

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ОЦЕНКА СОСТОЯНИЯ ЭКОЛОГИЧЕСКИ ПРОБЛЕМНЫХ ОБЪЕКТОВ КАЛУШСКОГО ГОРНО-ПРОМЫШЛЕННОГО РАЙОНА ЭЛЕКТРОМАГНИТНЫМИ МЕТОДАМИ И ИХ МОНИТОРИНГ

Экологически опасные геологические процессы, возникающие на отработанных месторождениях калийной и каменной солей, создают существенные реальные угрозы для окружающей среды. Для выявления, изучения и своевременного предупреждения таких процессов (карст, суффозия, оползни) создан и апробирован аппаратурно-программный комплекс индукционных малоглубинных зондирований геологической среды в ближней зоне источника поля. Разработанана система управления, сбора и передачи пользователям полученных данных для анализа и оперативной геологической интерпретации.

Ключевые слова: геосреда, негативный процесс, экология, электромагнитное поле, зондирование, оценка состояния, прогнозирование.

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