CRITERIA FOR IDENTIFICATION OF THE FORM AND FUNCTIONAL PROPERTIES OF THE SOIL PROFILE IN STUDIES BY USING GEORADAR "LOZA-B"

A. Ya. Voronin

V.V. Dokuchaev Soil Science Institute, 109117 Moscow, Pyzhevskii 7, bld.2
e-mail: avoron46@gmail.com

The valuable criteria for identification of the soil profile form and its functional properties were determined by interpretation of radarograms obtained in the course of georadiolocated profiling of different territories using the geophysical device "Loza-B". Apart from a standard set of methods for digital processing of radarograms and constructing a temporary profile of changes in the reflected impulse amplitude along the direction of its sounding and transformation with depth it is suggested to use the information on changing the dynamic characteristics of the wave field in homogenous media. It involves the data about splash of the wave field, determination of diffraction points corresponded to horizons and objects, calculation of the frequency characteristics for distribution of reflected signals in the soil profile. The periodical sequence of picks within the amplitude spectrum is characteristic of the simple homogenous layer. Changes in the thickness of the soil horizon are studied by amplitude maximum of reflected impulses in the radarogram. The procedure of soil verification based upon the comparison of real soil profiles with standard within the framework of a definite classifier is conducted by statistic methods for calculating the polynomial functions of trend values of the signal amplitude according to its duration. The statistical processing includes calculation of mean values, standard deviations and the distribution frequency of signal amplitude connected with the layer width and the amount of signal oscillations. The indices of spectral Furie transformation (frequency, period, spectral density) along with trend characteristics of polynomial modulations are considered as the major criteria for the two-staged identification of soils. In spite of attractive pattern of Furie spectral transformation the calculation of trend models and testing the results should be testified by data obtained for soil profiles in field.

Keywords: amplitude of reflected impulse, georadar, identification, soil, radarogram, spectral density, trend.

The principle of georadar action is based upon sounding of the earth surface at different depth by electromagnetic impulses with the view of identifying the differences between the media with varying dielectric permeability by the reflected signal [2, 11, 17, 18]. This approach is considered as one of the trends in gnoseologic knowledge of natural objects including the soil cover and spatial organization of the territory. The mechanism responsible for territorial organization and its vector component are very important for elaborating the models of natural objects. Just the factor of universality, small expenses, the high speed of field studies prove to be priority in the use of the given trend for realizing different economic and ecological projects in the country.

Over the last decades the georadiolocation method has becoming increasingly common in studying the underground media. The great experience has been gained in conducting the field work, in processing and interpreting the data obtained by this method. Georadar is widely adopted now in geology, building, archaeology, ecology, etc. [12].

This method is also applicable in soil studies being associated with the specific functioning of the soil body as a system of interrelated genetic horizons, a system of soil regimes, the fertility and development in the homogeneous geological medium (the parent rock) [1, 3, 6, 7, 15]. But some correctives are required for processing of radarograms and their interpretation.

However, the georadar technologies cannot be applied in soil science on a large scale because there are no methods for soil identification; the verification criteria for diagnostic parameters of soil bodies are absent to construct the models demonstrating the behavior of electromagnetic impulses in the subsurface medium. In some publications an opinion is expressed that it is impossible to elaborate such criteria because the forms of sounded and reflected impulses are created by the proper medium without account of requirements to the determination of typical, objective and comparative criteria [10].

Practically all the available programs for processing of georadar data have a definite set of procedures designed for digital processing of signals – frequency filtration, smoothing, signal rounding, definite visualization parameters, etc. There are also programs, in which the possibility is realized for automated selecting and analyzing the field of reverse dissipation and construction of the profile by using several attributes of the wave field and parameters of the studied medium [10]. However, it is insufficient to determine the valuable criteria for soil identification by analyzing the dynamic characteristics of radarograms (amplitude, frequency, etc.). For instance, it is rather difficult to diagnose the studied soil at a great depth due to the homogeneity of the parent rock, because the synphasic axes[1] are absent.

This study is aimed at elaborating the technology of interpreting the data of georadar profiling to assess the form, properties and status of soils and soil cover.

INVESTIGATION METHODS

In the course of georadiolocated studies the analysis and processing of data obtained by the geophysical device “Loza-B” were made by using the special program Krot [15–17]. The processing algorithm involves determination of parameters for georadar profiles (block 2), digital processing of data in two options including vertical and horizontal one-dimensional filtration (block 3), the average speed of wave distribution in the ground (block 4), boundaries of layers with varying dielectric permeability drown by hand. The interpretation of results obtained by georadar sounding permits to transform the time scale into the depth one [12]. The results of sounding in the wave field are presented in pictures of colored or gray hue.

The palette of 128 colors permits to obtain a visual picture of amplitude-phase characteristics of georadar profile. This preliminary processing of radarograms is characteristic of all the georadiolocated studies independent on objectives and objects.

To obtain the information on changes in the soil profile, apart from the above processing it is necessary to analyze additionally the dynamic characteristics of its wave field. This analysis is made within the framework of identifying the spatial-temporary perturbations in the field of reflected impulses, restoring the diffraction points as coincided with local horizons and objects, determining the frequency characteristics of electromagnetic irregular and regular reflected waves.

---

[1] Synphasic axe – a line in radarogram, connecting the local maximal values of the reflected impulses amplitude in the same phase in interval of its registration.

If the thickness of the studied object consists of dielectric contrasting rocks, it is possible to observe in radarograms the synphasic axes as coincided with the boundaries of the soil profile differentiation.

In case of changing the rocks the synphasic axes being corresponded to the studied boundaries are hardly observed or absent in radarograms. By this reason, the processing of data cannot be based only on a definite impulse form; the possible variations of parameters are required. To avoid this situation in soil studies the procedure of soil verification based upon the comparison of real soil profiles with standard ones using a definite classifier is conducted by statistical methods for calculating the polynomial functions of trend values of the signal amplitude according to its duration. In this case the statistical processing includes calculation of average values, standard deviations and the distribution frequency of signal amplitude connected with the layer width and the amount of signal oscillations. The obtained parameters are simulated by means of the method of InverseDistance, power-2 in program Voxler 3.

Spectral transformations of data obtained by georadar sounding are promising to elaborate the criteria for soil identification. The indices of spectral Furie transformation (frequency, period, spectral density) along with trend characteristics of polynomial modulations are considered as the major criteria for the two-staged identification of soils.

The heterogeneous pattern of the soil profile is detected by digital data of the oscillatory impulse, the function of which crosses repeatedly the zero- axis. The fractal analysis of the given function is made by using Herst index and fractal dimension. The processing of data allows compiling synthetic maps of spatial allocation of fractal indices at the territory of the studied objects.

These methods and criteria for soil identification make it possible to give a spatial-geometrical assessment of soil contours, the possible application of GIS-technologies in 3D-visualization of georadar data, the use of mathematical and statistical methods with the view of assessing the variation of georadar data about the soil properties and their interaction with crop yield [5, 11].

RESULTS AND DISCUSSION

Criteria for identification of the particle-size distribution of grounds and their moisture. The penetration depth of electromagnetic waves is determined by electrical resistance and dielectrical permeability of grounds. To detect the depth of boundaries between different media and objects it is necessary to know the distribution speed of the wave within the studied medium. The moisture and the content of mineral salts deteriorate the conditions for distribution of electromagnetic waves, thus decreasing the maximal depth of sounding. The dielectrical permeability of the ground is functionally connected with the moisture and texture of rocks [4]. These data permitted to compile a nomogram to show changes in the speed of electromagnetic impulse for different categories of the moisture in texture-differentiated rocks (Fig. 1).

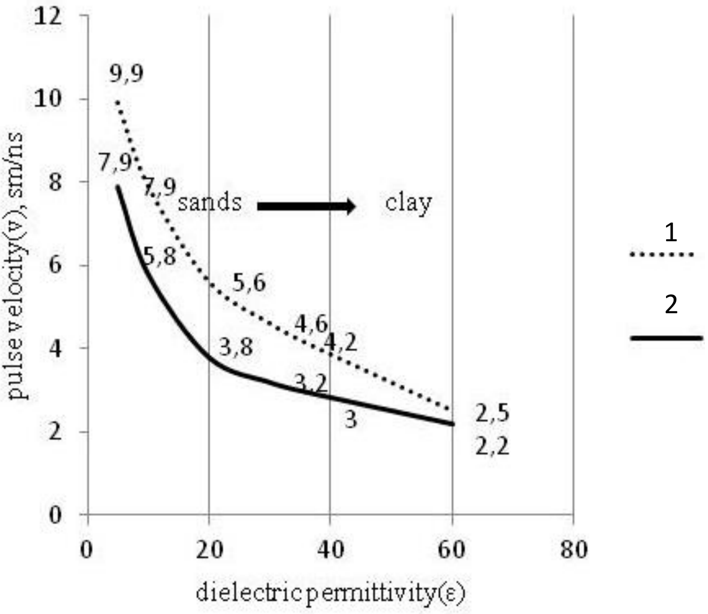


Fig 1. Changes in the impulse speed and dielectrical permeability of grounds with varying particle-size distribution for moisture categories (1 – maximal hygroscopicwater; 2 – minimum field capacity).

The calculated indices of dielectrical permeability of the ground and the distribution speed of impulse in the underground medium are criteria for identification of grounds according to the particle-size distribution and moisture. Their visualization in radarograms is shown by specific pictures (Fig. 2)

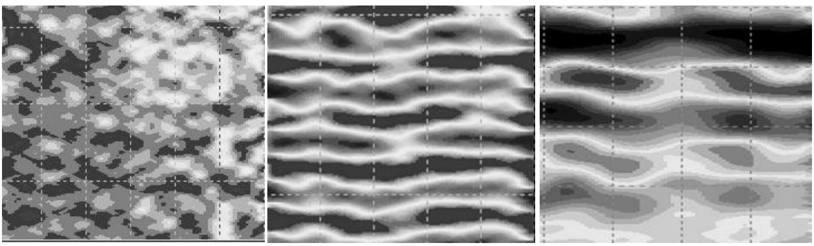
Electromagnetic profiling and identification of local artificially originated objects. Georadar allows identifying the objects according to permeability and conductivity. These properties are inherent to objects of artificial origin in the ground: buried underground constructions and even objects of 5–10 cm in size.

The sounding results are demonstrated on the screen as a reflection profile of boundaries between the media in dependence on signal time. The profile composes of separate reflections obtained in every measuring point. The time of electromagnetic wave depends on the depth of the reflected surface and the distribution speed of wave in the ground.

As an example let us consider the georadar profiling in the cutting steppe at the territory of Central State natural reservation in the Kursk region.

Some radarograms revealed synphasic axes at different depth (Fig. 3). Connecting the points of these axes it seemed possible to identify the surface of local object of 100×20 m at a depth of 2 to 5 m.

Analysis of reflected wave functions along the ways of georadar profiling. The major information on the medium contains the amplitude of the reflected impulse, its polarity, resting time and width of oscillations. The radarogram presents positions of many reflected signals; maximal amplitudes of reflected signals having a local distribution pattern



Sands Loams Clay

Fig. 2. Visualization of parameters for reflected impulses, characterized the grounds with different particle-size distribution.

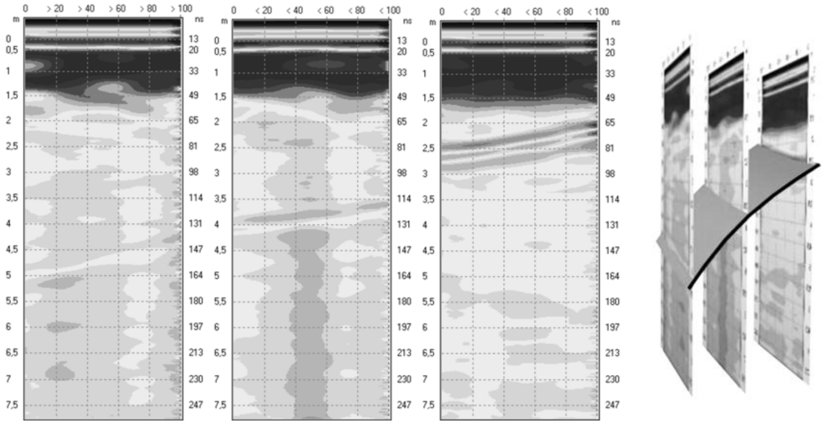
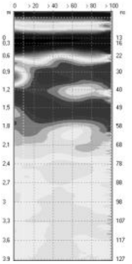
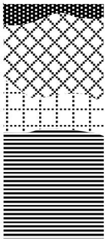
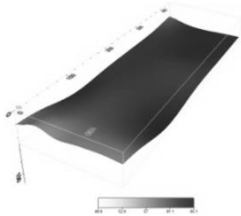
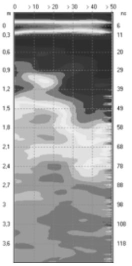
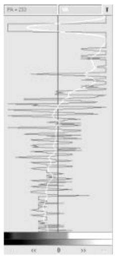
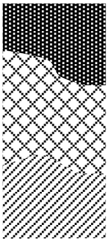
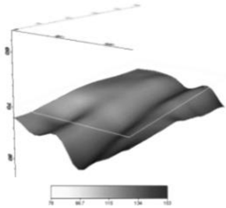


Fig. 3. The surface of local object at the territory of the cutting steppe inCentral biosphere reservation (the Kursk region) identified by synphasic axes of georadar profiling.

on the time axis are criteria for identification the boundaries between soil horizons. The homogeneous soil layer displays the periodical consequence of picks in the amplitude spectrum of reflection from the total thickness of this layer. The boundaries of horizons coincide with local amplitude maxima on time axis of the radarogram (Table 1)

However, this algorithmic function makes it difficult to distinguish the signal reflected by a new horizon from the end of the previous signal. A special technique is required to identify the reflected signals as invariant with respect to different impulse functions [16, 10]. Such a technique takes into account the behavior of electromagnetic wave in the course of attenuation in the homogenous medium to be smooth or irregular. Besides, according to laws of electrodynamics the attenuated signal changes its polarity in case of the wave transition from the medium with low dielectric permeability and conductivity into that characterized by higher values of these parameters. The reflected signal becomes stretched in time. The low conductivity leads to attenuation of signals, whereas the high conductivity – to their dispersed distortion [10].

Table 1. Example of soil identification is presented by using as criteria the data of local amplitude maxima of the reflected signal along the georadar profile

Soil, ground, horizon	Radargram	Pulse radarogram	Profile	3D-visualization of soil humus horizon
Southern chernozemunder crop A–Bk–Cк–D				
Eypical chernozem, virgin, A–AB–Bк–BCk–Ck				

In practice it seemed possible to observe that the change in signal polarity is widely spread in the arable, hay and disturbed lands. The change in the way of georadar profiling with different polarity was also observed in the soil cover with solonetz complexes in the Volgograd region. The georadiolocation survey of gullies revealed changes in the signal polarity on southern eroded slopes.

The attenuation duration is determined by physical properties of the medium. The energetic potential of georadar “Loza-B” is 128 dB, the radiation power – 50 mBt. In dependence on the particle-size distribution the sounding depth can be changed to tens meters (in moist clay grounds – 3–7 m).

The peculiar behavior of the electromagnetic impulse in soil studies served as a basis for statistical processing of values for signal amplitude with duration of 512 ns. The average value of impulse amplitude is used as a criterion for soil identification. There are possibilities to assess variations of this parameter and its dispersion. According to our data the amplitude variation of reflected impulses can reach 40–90% along the ways of georadar profiling. The greatest values for the coefficient of amplitude variation are observed in soddy-podzolic and gray forest soils within the zone of mixed and broad-leaved forests as well as in chestnut soils of the dry steppe zone (Table 2).

It is possible to observe a definite regularity of changes in average values for the amplitude of the reflected impulse in dependence on the natural zone and the land use system. The increased amplitude values are inherent to virgin lands and those occupied by forest shelterbelts.

The calculation of average values for the impulse amplitude along the ways of georadar profiling is not a final procedure of soil identification. The existing signal diffraction along the profile and the noise occurrence leave imprint for the final result. Having analyzed vertical and linear changes in the amplitude of reflected signals the above characteristics of signal serve as a basis for soil verification at the studied territory by using a definite classifier.

Analytical method of soil identification according to parameters of spectral density of reflected signals along the ways of georadar profiling. The wave diffraction is caused by the medium heterogeneity. In such a medium the signal becomes dissipated in different directions and a part of impulse energy is lost. The visual picture on the screen gets unclear. The values of reflected signal amplitudes become higher, different frequencies appear in the spectrum, the noise is increased.

Contrary to this process the decrease in values of the amplitude to be close to harmonic fluctuations makes the system more simple and leads to its organization. The spectral analysis permits to evaluate this situation and to divide any electromagnetic signal into simple components. The process of complicated aperiodic and periodic division of signals into simple components is known as Furie analysis. Among attributes of spectral transformation the parameter of signal spectral density is of great importance.

Table 2. Statistical processing of reflected signals amplitude along the ways of georadar profiling in different agricultural areas of the European Chernozem zone

Soils, agricultural area, location	Amount of ways, n*	Average value of amplitude $\overline{x}$	Standard deviation s	Error, m	Variation coefficient, v, %
Chestnut soils, virgin, Volgograd region	5	128	118	5	93
Southern chernozems, arable land, Saratov region	5	149	58	3	39
Typical chernozems, cutting steppe, Kursk region	6	112	59	3	53
Typicl chernozems, forest shelter, Kursk region	6	120	65	3	54
Typical chernozems, arable land, Kursk region	9	132	60	3	46
Ordinary chernozems, cutting steppe, Voronezh region	6	111	66	3	60
Ordinary chernozems, arable land, Voronezh region	6	128	54	2	42
Ordinary chrnozems, forest shelter, Voronezh region	6	114	77	4	68
Gray forest soils, arable land, Tula region	5	119	62	3	52
Soddy-podzolic soils, arable land, Moscow region	5	137	61	3	45

* 512 in track amplitude values.

Below are given some examples of reflected impulses transformation in several objects occupied by chernozem soils (Fig. 4). Calculations were performed in program Statistica.

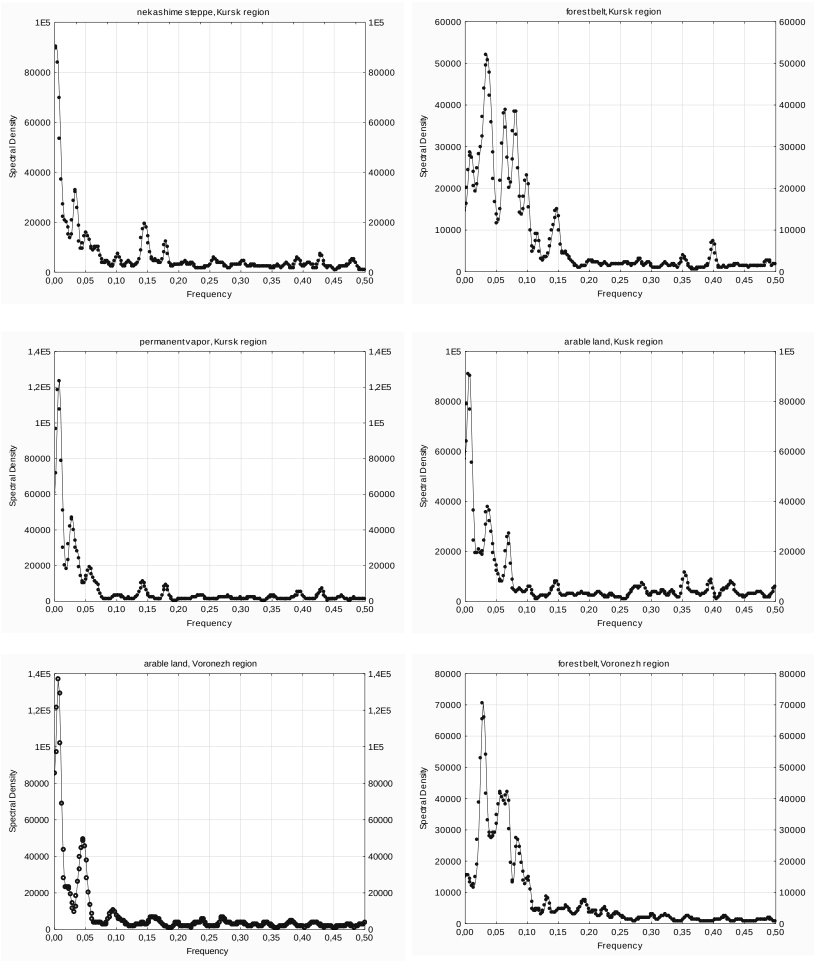


Fig. 4. Changes in spectral density of reflected signals amplitude along the ways of georadar profiling of chernozems in different agricultural lands.

The spectral density is quite different. There are objects of forest shelters, where the data about the average signal density exceed by 1.5 times the identical data about the virgin soils and display a specific dispersed picture on the screen.

Statistical processing made it possible to use the indices of spectral density as a criterion for soil identification (Fig. 5).

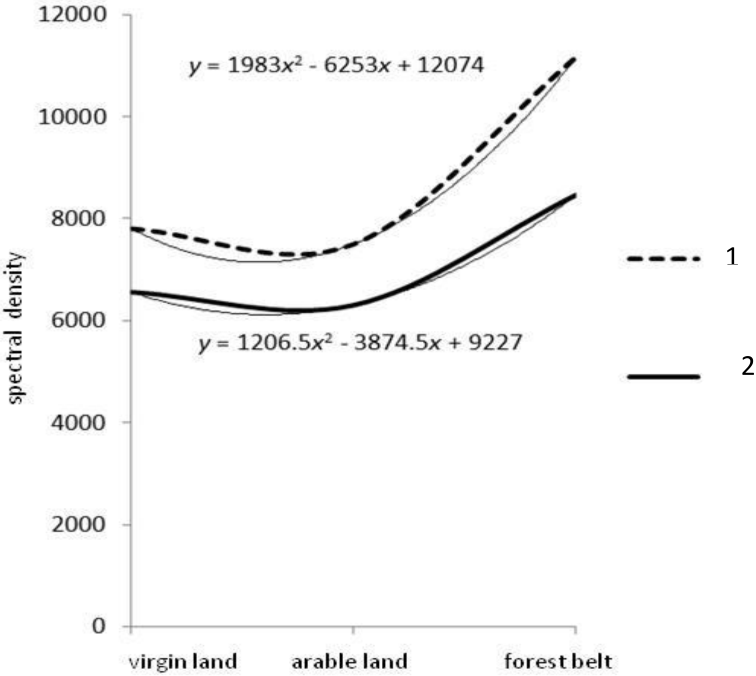


Fig. 5. Changes in average values of spectral density of reflected impulses along the ways of georadar profiling of chernozems (1 – ordinary chernozem, Voronezh region; 2 – typical chernozem, Kursk region)

There are linear regressions, in which the data about the spectral density of impulses are used as factorial features and the parameters of soil indices – as final results. Besides, the relative parameters of spectral density of the reflected impulse are used as a criterion for soil identification, the values of which seem approximated to maximal ones in the given georadar profile. Such parameters are used as coefficients of correction for real or calculated values of the amplitude, for leveling the impulse diffraction effect. The coefficients of correction are changed in the 0.1-1.0 range.

Values approximation of the reflected signal amplitude by the method of polimial functions. The proposed method of interpretation permits to identify statistically the soil structures in one point of georadar profiling. It is rather efficient for identification of dynamic objects including the soils under conditions of the increased signal noises. The method of polynomial functions is intended to calculate trend in the amplitude changes. The trend or tendency $f(t)$ is a possible stable regularity observed during the definite period of time. In georadar profiling the signal duration makes up 512 ns.

Usually the trend is described by a function $f(t)$, as a rule, it is monotonous and the time is its argument. The trends can be described by using different equations including linear, logarithmic, etc. In our case under consideration are polynomial functions of the first and second order. The factual trend type is determined as based upon the selection of its functional model by means of statistical methods or smoothing of initial temporary row, the latter being replaced by calculated data is a simple method to identify the development tendency. This transformation is known as filtration. Calculation is performed in programs Krot, Excel, Statistica.

Ascending and descending types of trends are distinguished to reflect changes in the amplitude polarity of reflected impulses in the subsurface medium along the separate georadar ways of profiling. Usually in the georadar profile there are trends characterized by one signal polarity but it is possible to observe the profiles, in which the trends reveal the alteration, for instance, in the flat-bottom valley where the chestnut soils are widely spread. The humus soil horizon on the southern slope has been washed away, carbonate clayey deposits are exposed. There are deluvial deposits on the bottom of this valley. The gypsum accumulation is found at a depth of 3 m.

Initial data of georadar profiling were filtered; under calculation were trends in the amplitude changes according to polynomes of the second degree for 11 profiling ways. The coefficients of correction for the signal diffraction were used being changed in the 0.1–1.0 range (Table 3).

Table 3. Calculated values of the impulse amplitude obtained by approximation method of polymial functions along the ways of georadar profiling in the flat-bottom valley of chestnut soils in the Volgograd region

Time, ns	Distance between ways, m											
	0		30		50		70		80		100	
	Y	0.86*y**	*y*	0.40*y*	*y*	0.66*y*	*y*	1.00*y*	*y*	0.82*y*	*y*	0.88*y*
1	129	111	164	66	158	104	92	92	150	123	102	90
40	115	99	149	60	132	87	118	118	120	98	107	94
80	100	86	132	53	115	76	131	131	95	78	105	92
120	86	74	118	47	100	66	136	136	75	62	96	84
160	72	62	102	41	95	63	130	130	60	49	84	74
200	60	52	90	36	95	63	112	112	50	41	65	57
240	45	39	78	31	100	66	85	85	45	37	40	35
256	40	34	72	29	104	69	72	72	42	34	30	26

* With coefficient of correction for the diffraction of the reflected impulse.

Verification of new calculated values for the amplitude by using the coefficient of correction showed a higher correlation of their changes in dependence on relief elements and slope exposition conditioned by different moisture amount and eroded upper soil horizons.

In spite of attractive Furie transformation and calculation of trend models they can serve only as additional options to diagnose the soil horizons. The field data of bores and soil pits are required to test their similarity with standard ones.

As a result of data processing was the database included the information on the reflected signal in every meter of the subsurface medium.

To visualize it in program Voxler, the model of amplitude values was elaborated. The program permits to present the data in 3D measurement.

The 3D imagination of the sounding data is a volume model of the real studied object. It is impossible to construct such a model for the test polygonby using traditional methods due to consumption of great expenses, labor and time.

CONCLUSION

Every identified soil horizon represents a simple homogeneous layer with the specific periodical consequence of picks in the amplitude spectrum of the total impulse reflection within the thickness of this layer.

Changes in its thickness are calculated by amplitude maxima. The maximal values of the reflected signals amplitude are criteria for identifying the boundaries of soil horizons. Transformation of the time axis into the depth one is implemented by calculation of the distribution speed of electromagnetic waves in every layer. The data generalized according to dielectric permeability of grounds, their functional links with the moisture and the particle-size distribution of rocks permitted to compile a nomogram to show changes in the speed of the electromagnetic impulse for different categories of the ground moisture. The calculated indices of dielectric permeability in grounds and the distribution speed of the impulse in the underground medium are criteria of ground identification according to their particle-size distribution and moisture.

The assessment of the electromagnetic impulse behavior in the underground medium allowed using the statistical processing of values for the signal amplitude as a verification method. Under use is the average value of the impulse amplitude as a criterion for soil identification. There is a possibility for assessing the variations of this parameter and its dispersion.

To assess the diffraction of electromagnetic waves in the studied medium, the heterogeneity of which leads to increasing the noise and smoothing the boundaries of soil horizons identified in radarograms, the statistical method of spectral transformation of the reflected impulse amplitude is applicable. The statistical processing permits to use the spectral density as a criterion for identification of boundaries between sol horizons, calculating the correction coefficients for the signal diffraction.

The soil formation conditions and the land use system can have influence on possible changes in the trend vector of the reflected impulses amplitude in separate ways of georadar profiling of the soil cover, Polynomial trend models of these indices make it possible to compare the results and forecast the behavior of the given soil structures in the future.

REFERENCES

1. Belobrov V.P., Aidiev A.Ya., Voronin A.Ya., Kulenkamp A.Yu. Otsenkaneodnorodnostipochvennogopokrovapripolevomopytepominimi-zatsiiobrabotok, *Agri-environmental problems of soil science and agriculture is, Leah,* Kursk, 2013, pp. 14–18.
2. Vladov M.L., Starovoitov A.V. Interpretatsiyadannykhgeoradiolo-katsionnykhnablyudenii, *Exploration and protection of mineral resources,* 2001, No.3, pp.11–14.
3. Voronin A.Ya., Pyagai E.T., Belobrov V.P., AidievA.Ya., Kulenkamp A.Yu. Georadarnyimetodizucheniyapochvennogopokrova (na primere tipich-nykhchernozemov), *Agri-environmental problems of soil science and agriculture, Kursk,* 2013, pp.33–38.
4. Denisov R.R., Kapustin V.V. Obrabotkageoradarnykhdannykh v avto-maticheskomrezhime, *Geophysics,* 2010, No.4, pp.76–80.
5. Dmitriev E.A., Samsonova V.P., Rozhkov V.A. Ob ispol'zovaniiteoriislu-chainykhfunktsiipriizucheniipochvennogopokrova, *Vestnik Mosk. Univ. Ser. Biology, Soil Science,* 1974, No.3, pp.43–53.
6. Zolotaya L.A., Kalishcheva M.V., KhmelevskoiV.K. Vozmozhnostigeofi-zicheskikhmetodovpriizucheniisostava i strukturypochvennogopokrova, *Exploration and protection of mineral resources,* 2004, No. 5, pp. 47–50.
7. Kalinkevich A.A., Krylova M.S., Masyuk V.M, Marchuk V.N. Ispol'zo-vaniegeoradaradlyaissledovaniyaneodnorodnosteiverkhnegosloya-pochvykhvoinogolesa, *Radioengineering*, 2009, No. 3.
8. Kalinkevich A.A., Kutuza B.G., Krylova M.S. i dr. Ob opyteispol'zo-vani-yageoradarnykhdannykhdlyainterpretatsiiRLI, poluchaemykh s po-moshch'yuIMARK, *Tr. 2nd Intern. Conf. "Akustooptichekie and radio-locating methods of measurement and processing of information."* Suzdal', 2007, pp.9–16.
9. *Classification and diagnostics of soils of the USSR,* Moscow, 1977, 223 p.
10. Kopeikin, V.V. The propagation of electromagnetic pulses in the subterrestrial environment, (http://www.geo-radar.ru/articles/articles.php), 2012.
11. Lyubushkin A.A. *Geophysical data analysis systems and ecological-ray monitoring*, Moscow, 2007, 228 p.
12. *Guidelines on the use of ground penetrating radar at obsl-ment of road constructions. The Ministry of Transport of the Russian Federation,* Moscow, 2003.
13. *Subsurface sensing using geophysical comple* “LOZA”, “LOZA-M” (poiskprotyazhennykhpodzemnykhsooruzhe-nii) (metodicheskierek-omendatsii), Moscow, 2012, 16 p.

14.Pyagai E.T., Belobrov V.P., Molchanov E.N., SeoMungChul, Son Ion Kui. Ispol'zovaniegeoradara v pochvennykhissledovaniyakh, *ByulletenPochvennogoinstitutaim. V.V. Dokuchaeva*,2009, Vol. 64, pp. Vyp. 64, pp.34–40.
15.Pyagai E.T., Il'inL. I., Morozov P.A. *Monitoring and forecast agroeko logical state lands*, Moscow, 2013, 297 p.
16.Reznikov A.E., Kopeikin V.V., Morozov P.A., Shchekotov A.Yu. Razrabotkaapparatury, metodovobrabotkidannykhdlyaelektromagnitnogo pod-poverkhnostnogozondirovaniya i opytikhprimeneniya, *Successes INDIVIDUALS-ray science*, 2000, No 5, pp.565-568
17.Starovoitov A.V. *The interpretation of GPR data*, Moscow, 2008, 192 p.
18.Yankovskii K.P. Otsenkadiagnosticheskikhvozmozhnosteisistemgeora-darnogozondirovaniyaprirodnykh i prirodno-antropogennykhob"ektov. Avtoref. … dis. kand. tech.nauk, Moscow, 2005.
19.Fisher M. Ground-penetrating radar used to uncover misteries beneath our feet, Soil Horizons, 2013, Vol. 54, No. 6, P. 54.