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AMT SOUNDINGS IN THE DEAD BAND WITHIN THE CHUKOTKA REGION (RUSSIAN FAR EAST)

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The article analyzes the amplitude spectra of audio magnetotelluric sounding (AMTs) data. Particular attention is focused on the frequency range from 1 to 5 kHz, which is called *dead band*. We analyzed the data of base stations used in the fieldwork during the summer and autumn seasons in 2013, 2014, and 2017. The area of work is located in the Chukotka Autonomous Area beyond the Arctic Circle. Previous researchers noted that a reliable signal in the dead band can only be obtained at nighttime. The authors of the article found that in Chukotka region in the daytime against the minimum signal within the *dead band* there is a local maximum at a frequency of 2.4 kHz. When registering a field for more than 3 hours during daytime, in most cases, it is possible to restore the frequencies of 2.2 and 2.6 kHz. These frequencies are reliable benchmarks, allowing in some cases to restore the AMT curve using the correlation between amplitude and phase. We have proposed ways to improve data quality in the dead band when measured during the daytime.

***Keywords*:** audio magnetotelluric sounding (AMT); geomagnetic variation (GM); electromagnetic monitoring; dead band; epithermal gold-bearing quartz veins

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Introduction. The magnetotelluric (MT) [8] and geomagnetic variation (GM) [6, 14-18] methods are implemented by measuring the five components of the Earth's alternating electromagnetic field. This technology is a reliable tool for solving a variety of geological problems. In the study of depths up to 2 km, such high-frequency modification of the magnetotelluric method as audio magnetotelluric sounding – (AMTs) is used. When using this method, studies are performed at frequencies from 1 Hz to 50,000 Hz, depending on the characteristics of the magnetic sensors used. It is believed that the source of the field in the AMT method are thunderstorms in the equatorial part of the Earth. At the same time, there is a minimum amplitude of the signal in the frequency range from 1 to 5 kHz, which is called the *dead band*. When solving a series of shallow depth problems, information on the AMT curve in the range from 1 to 5 kHz is very important. The most complete consideration of the dead band problem can be found in the work of Xavier Garcia and Alan G. Jones [12]. To improve the data quality in the *dead band*, previous researchers have suggested: take measurements at nighttime; increase the sensitivity of magnetic sensors; use when processing more than one base station.

In practice, it is not always possible to implement all of these recommendations. The another approach is to use the dispersion relations in the impedance tensor (the relations between the amplitude phase of the curves of AMT apparent resistance) at the stage of primary processing [13].

The authors performed AMT sounding during the epithermal gold prospecting in the Chukotka region. The geological task required high-quality AMT data, since the objects of prospecting (gold-bearing quartz veins) are small in size (their thickness varies from 1 to 5 m). The veins are overburden by volcanic rocks with a thickness of 80-300 m. The method of AMT data (obtained in 2013) interpretation was described in detail in our previous studies [9]. The geological structure of the area and the results of the AMT data comprehensive interpretation described in more detail by Ermolin et. al [10]. In this article, the authors focus only on AMT data processing.

To identify the features of the signal, the authors analyzed data obtained during the summer and autumn seasons in 2013, 2014, and 2017. Data registration was carried out according to the method with a constant base point [11]. The area is located beyond the Arctic Circle, where the signal in the *dead band* is even weaker. The only way to get high-quality data in the high-frequency

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range was nighttime measurements. This reduced the productivity of field work. To improve daily productivity, measurements were also made during the day. In July and August, it was possible to obtain a curve of acceptable quality during the daytime with a probability of 50-70 %. In September this probability was 40-60 %, in October reduced to 10 %.

The purpose of this study is revealing the features of the amplitude spectra of 5-component measurements (Ex, Ey, Hx, Hy, Hz). It is possible that some features will help to find new ways to improve the AMT and GM data quality in the dead band.

Research methods. The authors had data recorded at base stations during the fieldwork in Chukotka region during the following periods: August-October 2013; July-September 2014; July-August 2017 Five components of the Earth's electromagnetic field were daily recorded for 20 hours from 12 a.m. to 8 a.m. local time. The averaged coordinates of the area are: 170 degrees east longitude, 70 degrees north latitude. In the course of field work, universal recorders MTU-5A, lead non-polarizable electrodes, and magnetic sensors AMTC-30 from Phoenix Geophysics were used. Magnetic sensors were installed in special tripods designed by AGCOS company. All cables and tripods with magnetic sensors were buried at the base station. A feature of the MTU-5A recorders is that at a high sampling rate only part of the time series is recorded. Every 10 seconds in the highest frequency range of 24000 Hz, four measurements were made with a duration of 0.1 seconds. There were 2400 counting per measurement. The results of observations (time series) in the analysis were divided into 30-minute segments. Processing was performed using the SSMT2000 program, which is included in the standard preprocessing package supplied by Phoenix-Geophysic along with the equipment. We used local estimates of the impedance components based on the auto-spectra of the electric field [11] (admittance estimates, Local *E*). In the article, we show data only for 2017 season, because the main conclusions on the AMT signal features for all three seasons do not differ considerably.

Analysis of the results. In the course of research, the authors visualized the results of processing of a big set of AMT field data obtained at the same point. The analysis is performed for the amplitude of the spectra, as a function of time; amplitude curves as a function of frequency (for more detailed analysis); signal amplitudes for frequencies of 1.5 and 3 kHz; curves of AMT apparent resistance.

1. The spectra amplitudes in time for the five components are shown in Fig.1. In the dead band, there is a clear periodicity of the signal amplitude associated with the time of day. This low-amplitude blue-violet band on all components in the frequency range from 0.9 to 6 kHz get narrow and expands over time. The widest (corresponding to the smallest amplitude) band becomes around 12-3 p.m., and the narrowest (with the maximum amplitude) is observed from 12 to 3 a.m. On the background of a general pattern, it stands out on August 11, 2017, when throughout the day there is an anomalous increase in the signals amplitudes within the entire frequency range.

Figure 2 shows the spectra amplitudes in the dead band for the period from August 8 to 13, with all components having a common signal minimum of the spectrum amplitude in the daytime. Against the background of a general field reduction, a local maximum at a frequency of 2.4 kHz is visible, which is most clearly observed on the vertical component (Hz) of a magnetic field. Here, two local minimums of the *dead band* are clearly manifested: 1.5 and 3 kHz.

In order to analyze in more detail the nature of the spectrum amplitude during the day and night time, the authors constructed the signal amplitude curves as a function of frequency (amplitude spectra).

2. Amplitude spectra for a 4-hour daytime recording on August 8 from 12:30 to 4:30 p.m. and a short 30-minute recording on August 9 from 2:00-2:30 a.m. are shown in Fig.3. The graphs clearly show that the amplitude of the spectra at night is higher than during the daytime. On the daily spectra in the dead band, a local maximum at 2.2 and 2.6 kHz is clearly visible and indicated by a blue semitransparent square in Fig.3.

Since the amplitude spectra of the local maximum in the *dead band* are 85 % higher relative to the values of the two nearest local minima, there is a high probability that the AMT curve can be restored at the local maximum using the daytime recording. Having a local maximum in the dead

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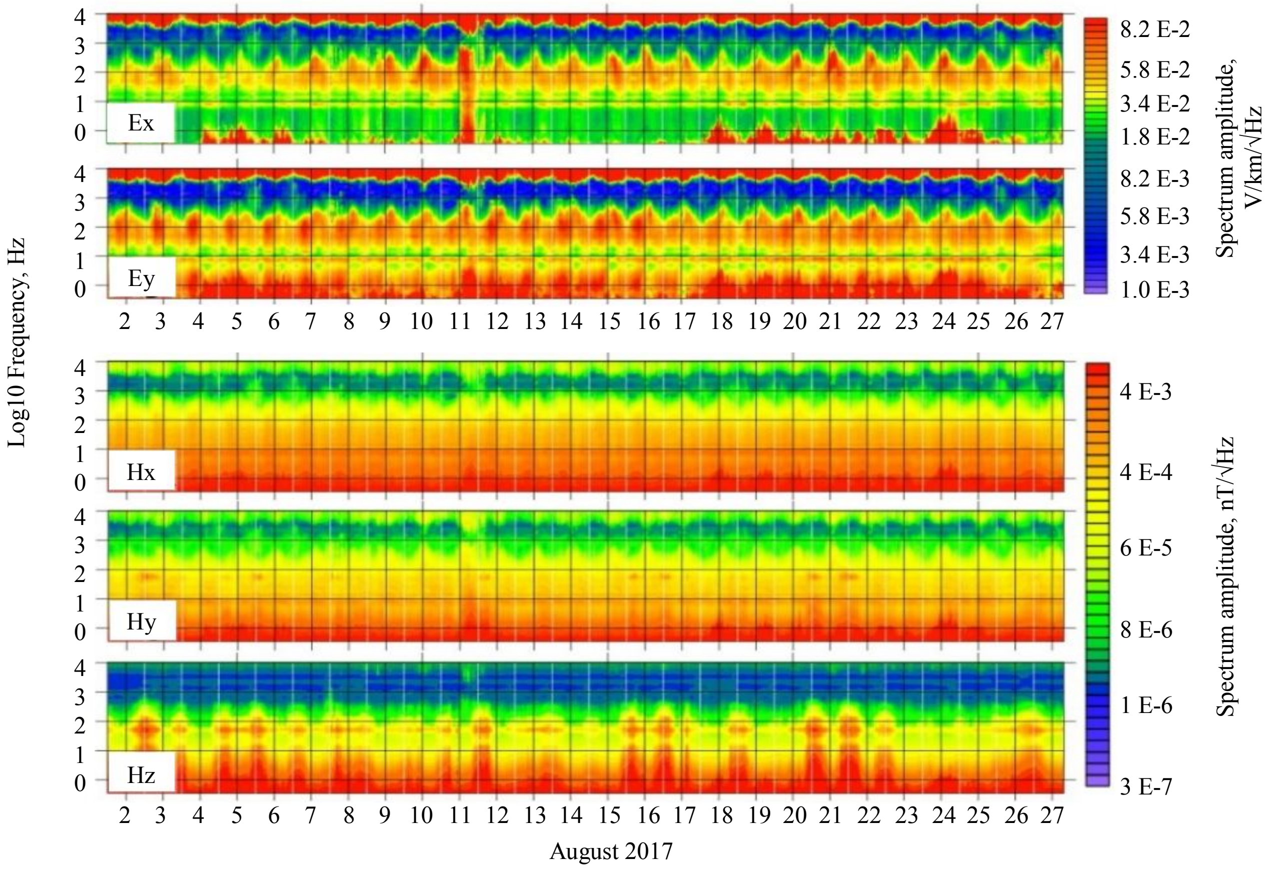

Fig.1. The amplitudes of the AMT spectra in the frequency range from 0.3 to 10,400 Hz

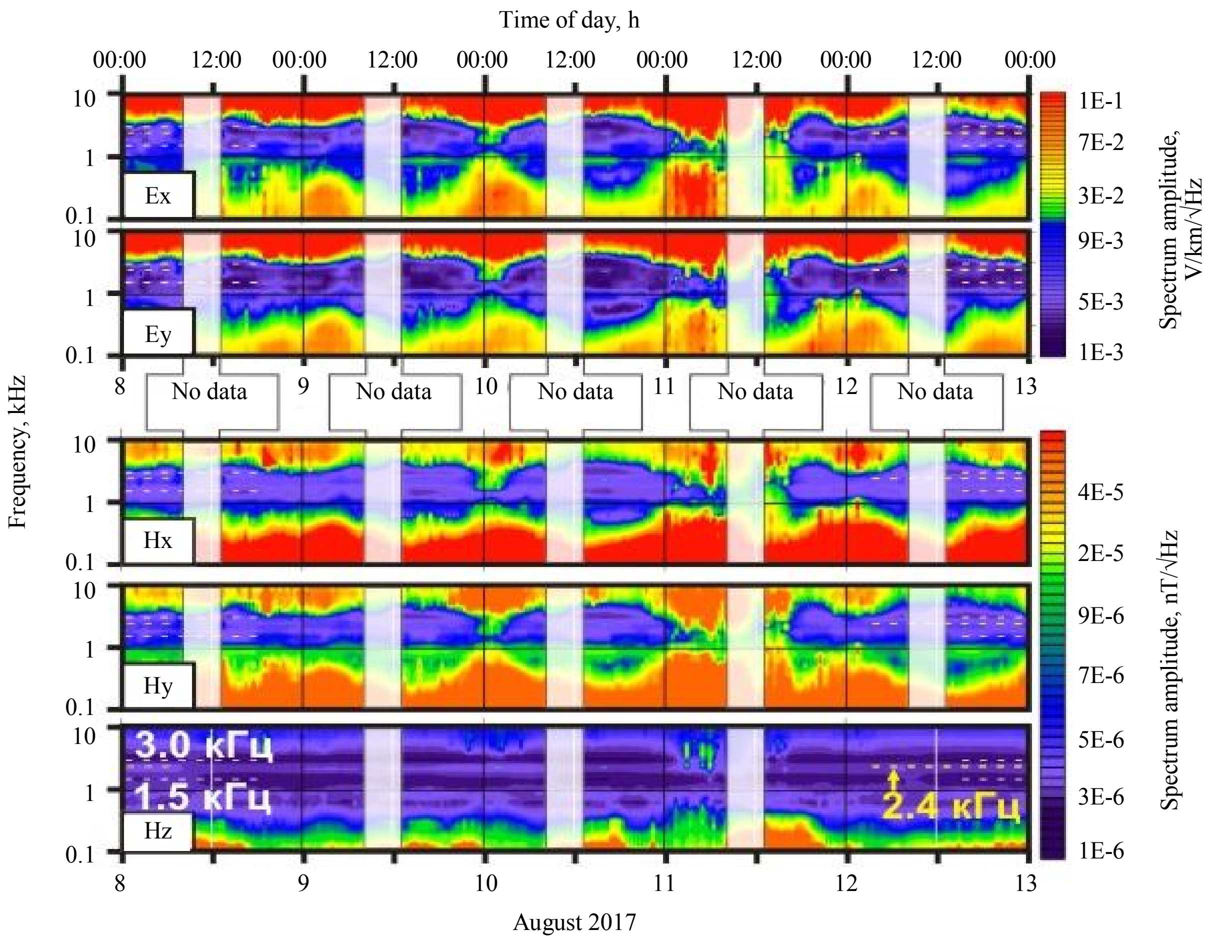

Fig.2. Spectrum amplitudes from August 8 to 13, 2017

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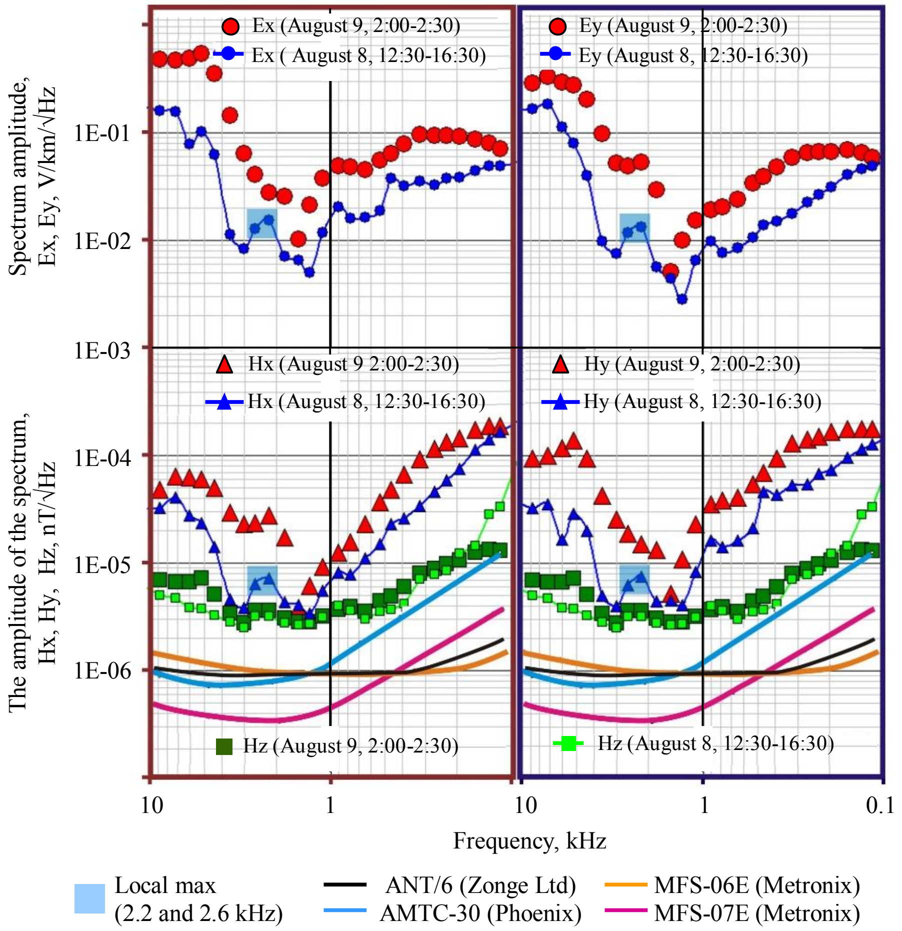

Hx, nT·√Hz			Ex, V/km/√Hz		
3 kHz (min)	2.4 kHz (max)	1.5 kHz (min)	3 kHz (min)	2.4 kHz (max)	1.5 kHz (min)
3.9 E-6	6.8 E-06	4.1 E-06	8.4 E-03	1.4 E-02	6.5 E-03

Fig.3. Comparison of amplitude spectra measured at night and daytime.
Own sensor noise is shown as lines (data from producers' official websites).
The values of the local maximum and two local minima of the amplitude
of the Hx and Ex components in the daytime are shown in the Table

band can be an indicator of daytime data quality. Thus, for daytime measurements, it is advisable to carry out a rapid analysis of the amplitude spectra and other impedance functions immediately after recording in the field. A similar procedure is implemented in the Russian equipment for AMT sounding [5].

It should be noted that in the *dead band* the amplitude of the magnetic components is lower than the electric ones (relative to the frequency of 100 Hz). Consequently, the noise in the magnetic channels will be greater than in the electric. In this regard, for the range of *dead band* in the study area, the authors used the results of impedance processing using the remote base method with reference electrical channels (*Remote E*) [11]. The intrinsic noise level of the most common magnetic sensors is significantly lower than the amplitude of the natural signal in the *dead band* (Fig.3). Thus, the problem of the *dead band* is not related to the sensitivity of the sensors but is more dependent on external interference. Therefore, it is important to improve the technology of installing magnetic sensors to reduce the level of external noise.

As a result of the increased noise level of magnetic channels, the values of apparent resistances are significantly underestimated. That is what we see in the *dead band*. This is probably the reason why some researchers and AMTs data processors call this frequency range a «telluric pit» – the resistance values seem to «fall into the pit» on the apparent resistance curve.

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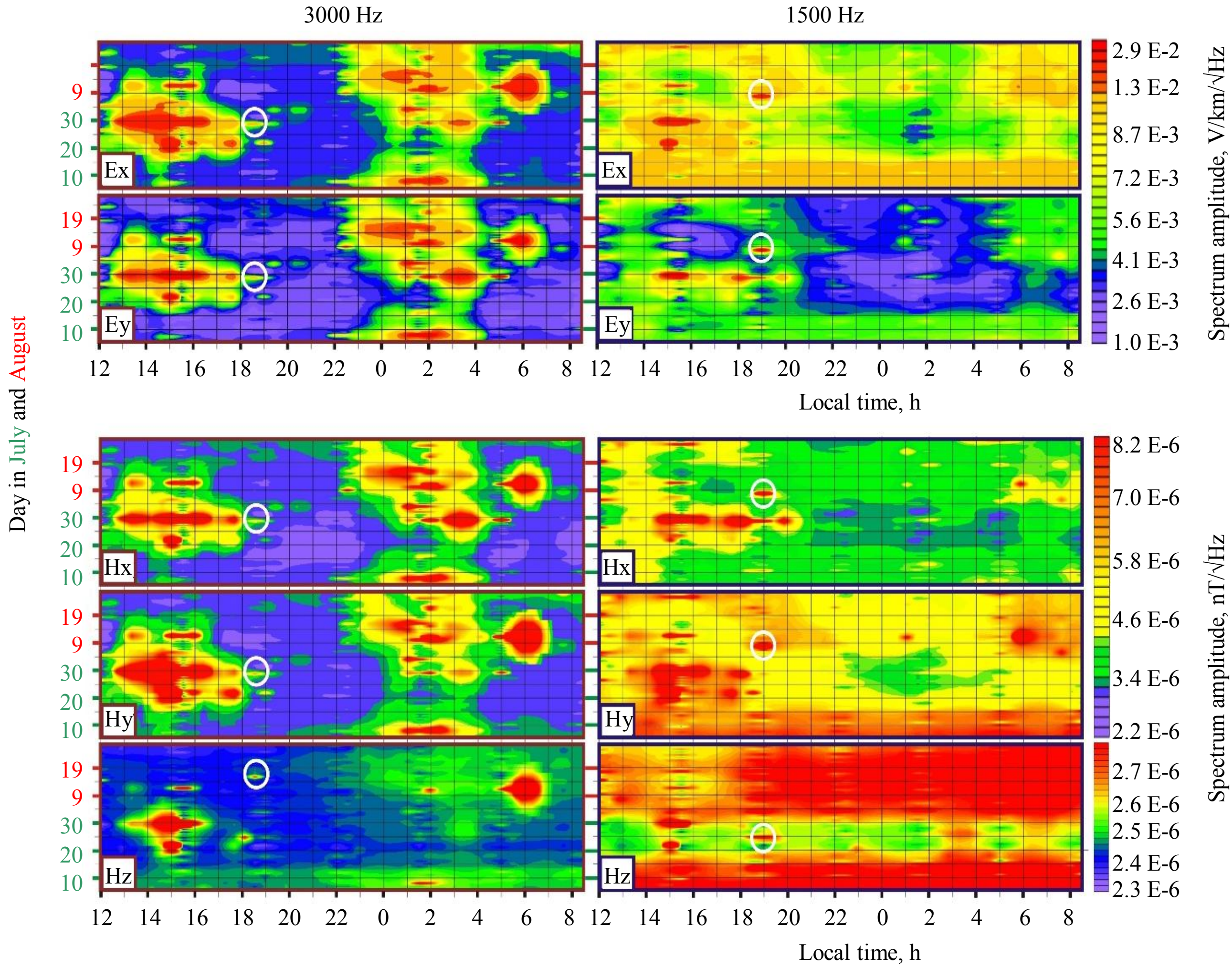

Fig.4. The dependence of the signal amplitude at frequencies of 3 and 1.5 kHz from the local time of day in the period from July 4 to August 26, 2017. White circle shows examples of local maxima

3. The amplitudes of the signals at 1.5 and 3 kHz have minimum values in the *dead band*. The authors performed a detailed analysis of these frequencies. The results are shown in Fig.4.

For a frequency of 3 kHz on all components, the signal is higher at night from 12 a.m. to 4 a.m. At the same time, from July 15 to August 15, increased values are observed from 1 p.m. to 5 p.m. local time.

For a frequency of 1.5 kHz, the signal level is higher in the daytime. At nighttime from 10 p.m. to 5 a.m. the values are minimal. Thus, the frequency of 1.5 kHz is the most problematic in the *dead band* in the area under study.

Single local anomalies of increased amplitudes (white circles in Fig. 4) are randomly present throughout the day. The authors used the MTU-5A equipment, where at the sampling frequency of 24 kHz in practice only 2 to 5 % of the recording time is really recorded. Probably, the recording of a continuous time series and an increase in the sampling rate will help to fix rarer signal pulses. Perhaps this will help to partially solve the problem with the quality of AMTs curves in the *dead band*.

4. The curves of apparent resistivity and impedance phases for short daytime recording, 4-hour daytime recording, and 15-hour recording, obtained at the same point, are shown in Fig.5. All curves are edited in frequency.

The curve calculated from the 30-minute daytime record (Fig.5, *a*) is rejected since the amplitude and phase values at 11 consecutive frequencies in the *dead band* deviated significantly from the real curve.

The curve calculated from the 4-hour daytime record (Fig.5, *b*) is of significantly better quality. The main feature of this curve is that the local maximum frequency (2.2 and 2.6 kHz) can be

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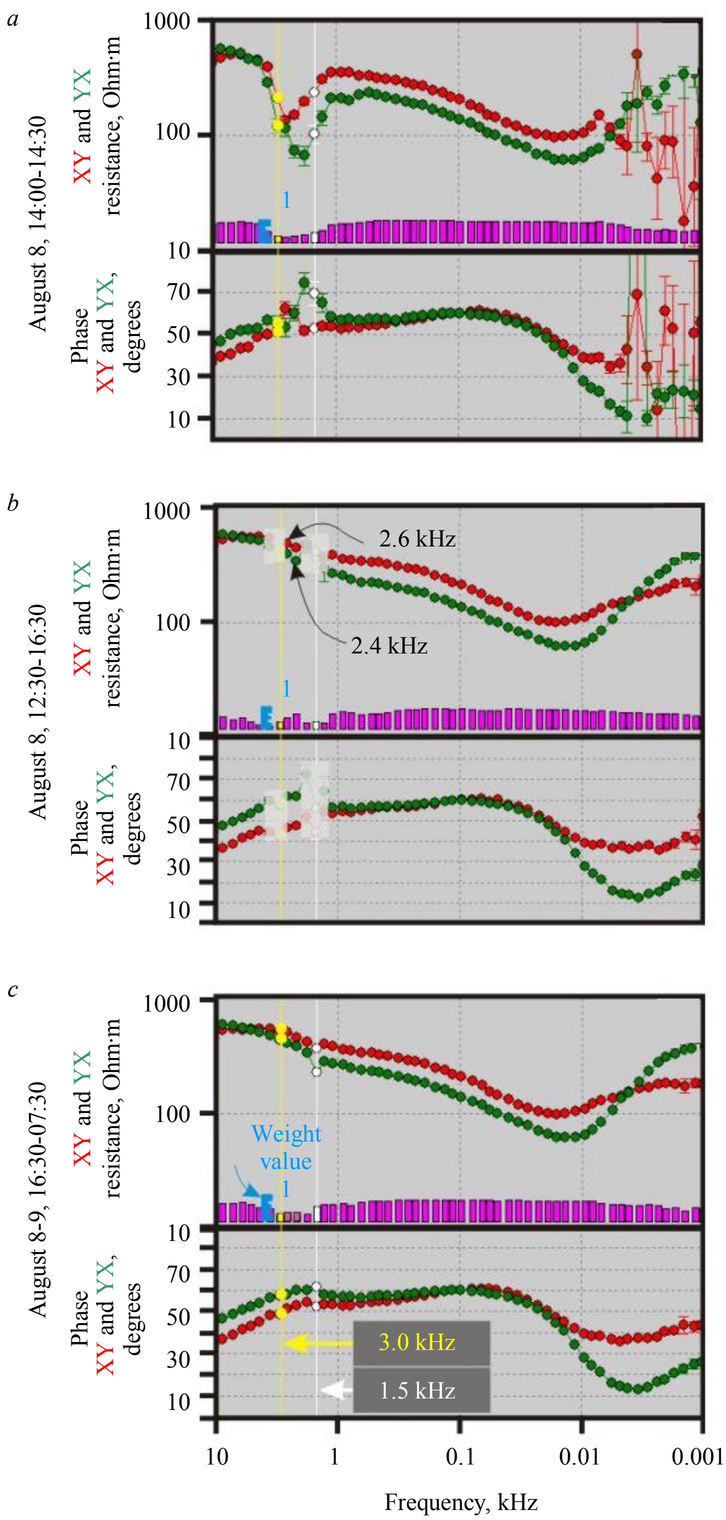

Fig.5. Curves of apparent resistivity and impedance phase: for the daytime 30-minute (*a*) and 4-hour (*b*) recording (August 8); for the nighttime 15-hour recording August 8-9 (*c*)

restored after the online rejection of solutions with low weight. The presence of these benchmarks allows restoring the curve in the *dead band*. As a rule, in practice, the values that deviate significantly from the average level of the curve (1-2 frequencies above and 2-3 frequencies below the local maximum) are removed. Remote frequencies are indicated by white transparent rectangles in Figure 5, *b*. After that, the dispersion relations between the amplitude and the phase of the magnetotelluric impedance (dispersion relations of the first kind) are used. This procedure is called amplitude-phase correction [7]. Some authors implement this procedure at the stage of primary data processing [13]. The main idea of an amplitude-phase correction is that the same frequency ranges of amplitude and phase carry information about different depths (the phase is responsible for the deeper part of the section). In addition, phase curves are less susceptible to interference [2, 3].

Unfortunately, the amplitude-phase correction of the apparent resistance AMTs curves is the only way to use daytime records in the northern latitudes at present. It should be remembered that this procedure is correct only for areas where there are no clear dispersion ratios imbalances in the impedance tensor. Imbalances in amplitude and phase ratios are found both in theory and in practice [1, 4].

The curve calculated by recording from 4:30 p.m. to 7:30 a.m. (15 hours of recording) is of good quality (Fig.5, *c*). By removing the 1.5 kHz frequency, you can use this curve for analysis and interpretation.

The solution to the prospecting problem. After the data processing and the amplitude-phase correction, the analysis of the magnitotelluric impedance parameters and the solution of the inverse problem are performed. The result of the interpretation is geoelectric models. To demonstrate the effectiveness of the proposed method of daytime records processing, we give an example of detecting the continuation of a known epithermal gold-bearing quartz vein. The methodology for analyzing and interpreting AMT data is presented in authors' early works [9, 10].

Figure 6 shows the geoelectric sections (solutions of the inverse 2D problem), drown in 2013 according to AMT data. Initially (prior to the AMTs planning), the position of the epithermal gold-

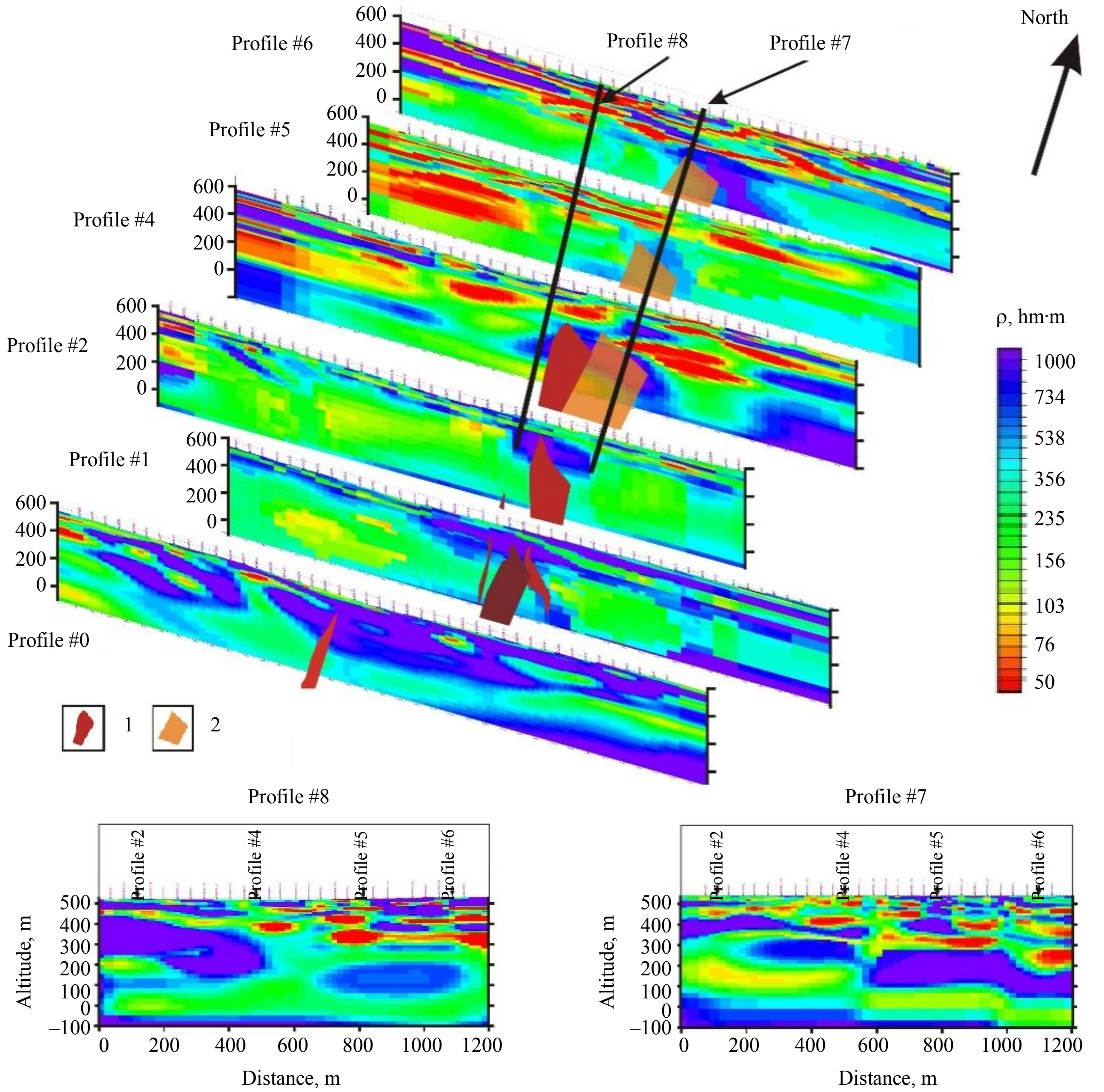

Fig.6. 3D visualization of geoelectric sections (solutions of inverse 2D AMT problem)
1 – position of the epithermal gold-bearing quartz vein, known prior to the application of AMTs;
2 – position of the northern part of the gold-bearing quartz vein, revealed by drilling six months after the AMT forecast

bearing quartz vein, with a thickness of 3 m, was known (1 in Fig.6). The vein is overlapped by basaltic lava flows and their tuffs. The thickness of the overlapping interlaid rocks ranges from 80 m (in the South) to 300 m (in the North). As a result of comparing the geoelectric sections along profiles 1 and 2 with the drilling data, it was determined that the position of the known vein corresponds to the increased values of specific resistance. The zone has a deep narrow channel. It can be seen that in the south the insulator zone expands considerably, and in the north, it descends and shifts towards the east. Six months later, the northern continuation of the increased resistance zone was drilled and a new vein was discovered.

It should be noted that if the authors did not use two daytime (3-hour) AMT records every day, but only one nighttime one, then the operation performance would decrease three times. Considering the fact that the field work was assigned to a short period and a limited number of MTU-5A stations, it would be impossible to solve the problem using only one nighttime recording per day using one station.

Summary. We have performed the amplitude analysis of AMT spectra in the dead band obtained during fieldwork in Chukotka in the summer and autumn seasons in 2013, 2014, and 2017. To obtain high-quality AMT data beyond the Arctic Circle, the *dead band* requires measurements at nighttime (as recommended by previous researchers). The authors have described a local maximum in the *dead band* in the daytime (frequencies of 2.2 and 2.6 kHz), bordering two local minima (frequencies of 1.5 and 3 kHz). The most problematic is the frequency of 1.5 kHz.

Daytime measurements can be used when it is possible to restore the curve at a local maximum (2.6-2.2 kHz). As a rule, for the MTU-5A equipment (Phoenix Geophysics), measurements during the day should be carried out for 3 hours at least. At the same time, it is necessary that on both sides of the local maximum no more than 2-3 frequencies should be defective.

To improve the data quality in the *dead band*, you should use equipment with a permanent record of the time series at a high sampling rate. It is also necessary to improve the installation methods of magnetic sensors and electrodes. For recording equipment, online visualization of the signals spectra amplitude and other functions of magnetotelluric impedance immediately after the field measurement is relevant.

The use of daytime records with a duration of more than 3 hours allows to receive AMT data, suitable (after the amplitude-phase correction) for further analysis and interpretation. The effectiveness of the proposed methodology for AMT data processing is shown on the example of the forecast of the northern continuation of the known epithermal gold-bearing quartz vein. The forecast was confirmed by drilling six months after the AMT sounding.

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