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Hot Springs and Underwater Crater EM Sounding and DC Tomography

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ABSTRACT

Results of geophysical investigation of shallow depth volcanic formations are presented.

The work discusses the method and 3D data inversion results of multinode resistivity tomography at the Karymskoe Lake above Tokarev crater, Academii Nauk volcano, Kamchatka. Results of exploration are presented as isosurfaces, accompanied by a discussion of the correlating scuba diving study. The usefulness of this type of electric tomography for the aquatic works and shallow volcanic structures study assessed.

Electromagnetic induction frequency soundings of shallow depth volcanic structures including exploration of mud pots channels, maar structure, hot springs water paths, ore-forming thermal field and petroleum traps were performed. The mud pot structure in 3D is visually presented.

1. INTRODUCTION

Difficult access for direct study of volcanic structures covered with fresh water, such as craters, hot springs, fumaroles, is a problem that often has no solution, or at least no cost effective one. Electrical tomography – the geophysical technique, essentially developed over last decades – could give much more information about the topography of the bottom, water mineralization gradient and bottom forming rock structure, than the conventional scuba diving missions.

Resistivity measurement is one of the most common methods for shallow depth exploration. The vertical electric sounding (VES) has traditionally been the most widely used technique for horizontally layered media study. Conventional VES is based on 1D sounding curves. Their measurement net is spread out and not overlapping. That is why they are referred to as independent. The need to make more detailed studies with only 10-20 m between measurement stations requires a new approach to the VES data acquisition. To satisfy this need, 2D electrical tomography, also known as Resistivity Imaging or Electrical Resistivity Tomography has been developed. The main feature of this approach is short distance between electrodes and measurement stations, linear increment of the electrode spacing and data processing approach, where the data from different stations is evaluated in connection with each other, taking into consideration their spatial distribution. Further method development includes 3D tomography.

2. METHODS OF EXPLORATION

2.1 Electrical Resistivity Tomography

Resistivity measurement is one of the most wide spread methods for shallow depth exploration. Conventional VES is based on 1D sounding curves. Physically it is measurement of voltage and current in the 4-electrodes system as it is shown at Figure 1. Then, having information about geometry of the electrodes array, voltage and current, it is possible to calculate the resistivity of the media. The depth of such measurement depends on the distance between potential electrodes (L). Increasing L, one can make deeper measurement, building sounding curve. The devices for Resistivity Imaging include an automatic switch board that is able to connect to transmitter and receiver any of the electrodes, connected to the board by the string (multinode cable).

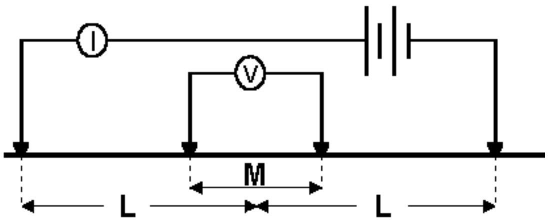

Figure 1: Conventional 1D VES array.

For the work presented here, the 48-electrodes system was used (see Figure 2).

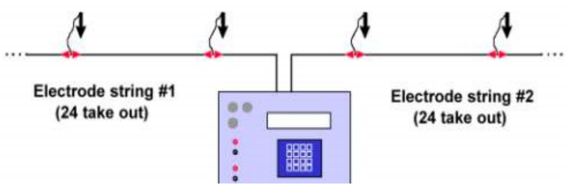

Figure 2: Resistivity imaging device.

2.2 Near Surface Electromagnetic Frequency Induction Soundings (NEMFIS)

The second method used for the presented studies is a special, version of FD-I (frequency domain induction) soundings. The transmitter and receiver of the FD-I sensors consist of coils that do not need any contact with the ground. The sounding parameter here is the frequency: lower frequency is able to induce currents in deeper structures. It makes the soundings quick and easy to operate. The NEMFIS device is able to sound up to 7 m of subsurface media. The results of soundings can be presented as geoelectric maps, cross-sections and 3D visualization.

3. OBJECTS

During the 2007-2009 expeditions, numerous volcanic structures were studied by both Electrical Resistivity Tomography and NEMFIS technique. In this paper only two of them are presented.

3.1 Tokarev Crater

In the beginning of 1996 a unique event happened; namely the simultaneous eruption of Karymsky volcano and underwater eruption at the North part of Akademii Nauk caldera (aka Karymskoe Lake). The increase of seismic activity in the area was recorded since the spring of 1995. Right before eruptions an earthquake of M = 5.6 (Dec, 31, 1995) with epicenter at Kronozky bay (60 km far in North-East direction) and, one hour later – another earthquake of M = 6.9 with epicenter 25 km far in the South direction took place. Then, a series of earthquakes of M > 5.0 have occured. The Karymsky volcano exploded on January 2, 1996. Fifteen hours later the underwater eruption in Karymskoe Lake began [2]. Within a few weeks of the eruption the new peninsula (New Year peninsula) and underwater crater, (Tokarev crater) appeared. Then, as the result of few minor explosions, 4 maars were formed at the surface of the New Year peninsula. The peninsula and crater can be seen in the satellite image (see Figure 3).

Figure 3: Tokarev crater at North part of Karymskoe Lake.

3.2 Uzon Volcano Mud Pots

A square sized 50 x 12 m with approximately 10 mud pots and mud volcanoes is situated in the Uzon volcano caldera (see Figure 4). The pots temperatures vary between 40 and 70^{o}C at the surface. The rocks accommodating the pots are soft, and consist of gravel, sand and clay. No direct method of study (drilling, sampling) can give information about this structure. An electromagnetic sounding is a good possibility of non-disturbing shallow depth exploration of the unique formation.

Figure 4: Uzon volcano caldera, mud pots.

4. METHODOLOGY

To work on the water, a floating device was created. The resistivity meter IRIS SYSCAL Pro and the operator seat were installed on the inflatable catamaran. Floats were attached to the each 2 m of multinode cables. To drive the catamaran, the cord was attached to the catamaran in parallel with the cables (see Figure 5). The catamaran was driven by a motor; a cable was managed by two crew members, pulling the ends of cord at the sides of the “C” shaped peninsula. The cord end positions were recorded using GPS receivers. Thus, a floating measurement line of 235 m length was created. Measurements were made every 20 m, moving the line from North to South. 18 cross-sections were made within 8 hours. The measured area covered the peninsula “C” almost fully.

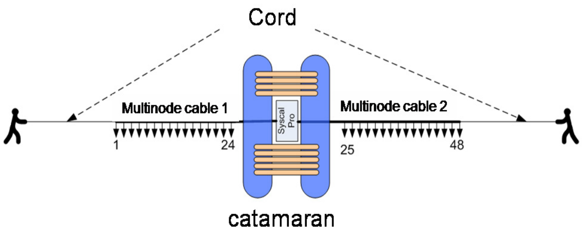

Figure 5: Resistivity imaging floating device.

NEMFIS exploration of the mud pots was performed by snake line, 6 parallel lines, and 50 stations each. The station step was 1 m, and spacing between the lines was 2 m. NEMFIS in operation is shown in Figure 9.

5. RESULTS

Taking into consideration the well strongly pronounced 3D feature of the object, the 2D data were used to create the 3D inversion by RES3DINV software. All 18 of the 2D geoelectric cross-sections are shown in the Figure 6. The 3D visualization is of the isosurfaces of 55 (top), 80 (center) and 98 (bottom) Ohm·m shown in Figure 7. It can be seen that the crater bottom consists of two “channels”. It corresponds with the data of the bottom material transport in two directions to the surface of the New Year peninsula and to the topographical survey made in 1999 by scuba divers. Small changes of electric resistivity of water can be clearly seen (Figure 6). The very top of the water is slightly more resistive because of the rain water. It can be seen that the typical cross-section of the Tokarev crater consists of three geoelectric elements: water with resistivity up to 30 Ohm·m, various destructed rocks (gravel, some clay etc) with resistivity up to 70 Ohm·m and basalt, not completely destroyed by the eruption, with resistivity more than 70 Ohm·m. Field operation time was 8 hours, data processing took 10 hours.

The isosurface of 6.5 Ohm·m is shown in Figure 8. The vertical pipe-like structures can be seen. Obviously, the pipes indicate thermal spring paths, transporting hot waters to the mud pots. However, some or the pots are not connected to such “roots”. It means that these pots are filled with the rain waters only. The contrast in geochemical features of the mud pots proves this assumption. The measurement took less than 2 hours, data processing took 20 minutes.

6. CONCLUSION

The upper part of volcanic structures covered with fresh water can be effectively studied using properly customized Resistivity Imaging techniques. Not only the structure of underwater surface, but the composition of the water and below the bottom structures can be studied quite detailed at the depth up to 90 m using 5-m spacing multinode cables. Authors suppose, that the exploration depth can be increased, using one “infinite” cable.

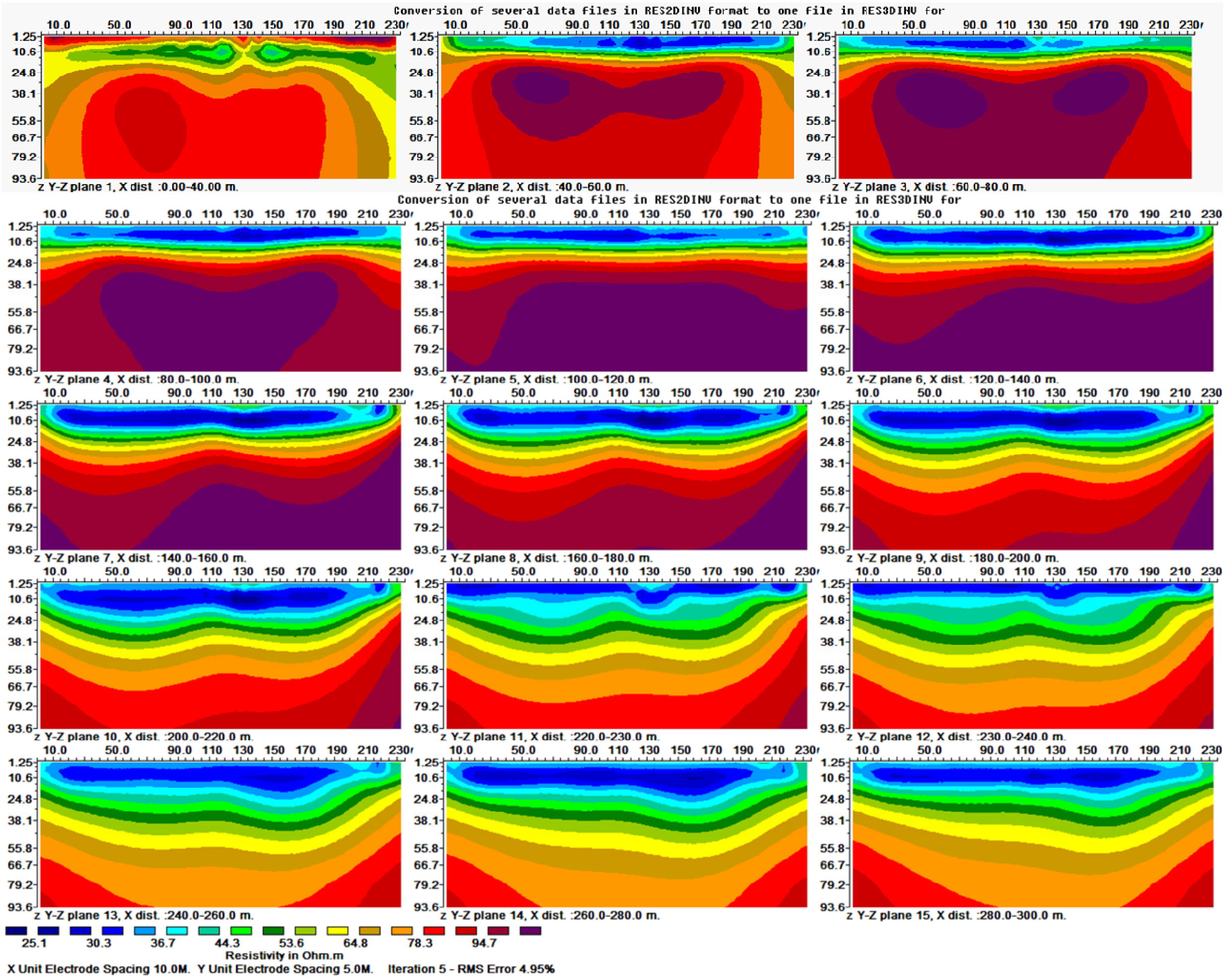

Figure 6: Resistivity imaging cross-sections.

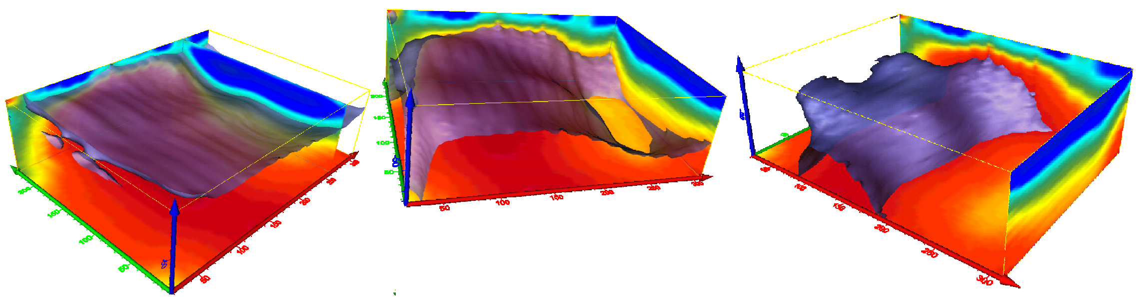

Figure 7: Resistivity imaging 3D isosurfaces.

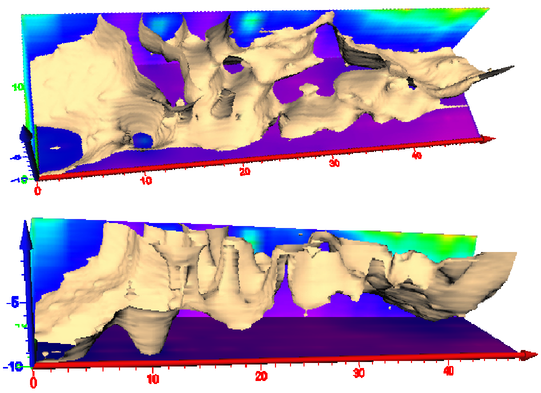

Figure 8: Mud pot "roots".

Figure 9: NEMFIS operation.

Sometimes it is not possible to get the galvanic contact with the surface. For such cases electromagnetic sounding with NEMFIS device is very informative technique for study of shallow volcanic structures. Getting information about upper 7 meters of subsurface media can be very fast and economically effective: NEMFIS can be handled a single operator.

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