GLOFCA PROJECT

«Reducing vulnerabilities of populations in the Central Asia region from glacier lake outburst floods in a changing climate»

Report on task 9B:

Conducting field work at the dam and in the Adygene Lake area. Performing a set of geophysical measurements, drone surveys and GPS measurements of ground reference points

(Geophysical measurements)

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Introduction

For the study of the characteristics of hazardous outburst prone lakes in the moraine-glacier complexes of the Ala-Archa River Valley, fieldwork was conducted at the dams and in the areas of the Bolshoye Adygene and Prilednikovoye Adygene lakes.

The fieldwork involved conducting a set of geophysical measurements, drone surveys, and GPS measurements of ground reference points.

The studies were carried out on the basis of the high-mountain lake-glaciological station Adygene.

Fig. 1 High-altitude lake-glaciological station Adygene.

Geophysical research was conducted on the dams of the high-altitude, outburst prone lakes—Bolshoe Adygene and Prolednikovoe Adygene—to identify their structure and determine potential breach mechanisms.

The comprehensive geophysical studies were carried out using methods such as electrical resistivity tomography (ERT), vertical electrical sounding (VES), magnetometry, and seismometry.

1. Electrical resistivity tomography (ERT)

Electroresistivity tomography was performed on 9 profiles along and 4 across the strike of the Bolshoe Adygene Lake dam, and 4 profiles along and 2 across the strike of the Prilednikovoe Adygene Lake dam. (Figures 2 and 7)

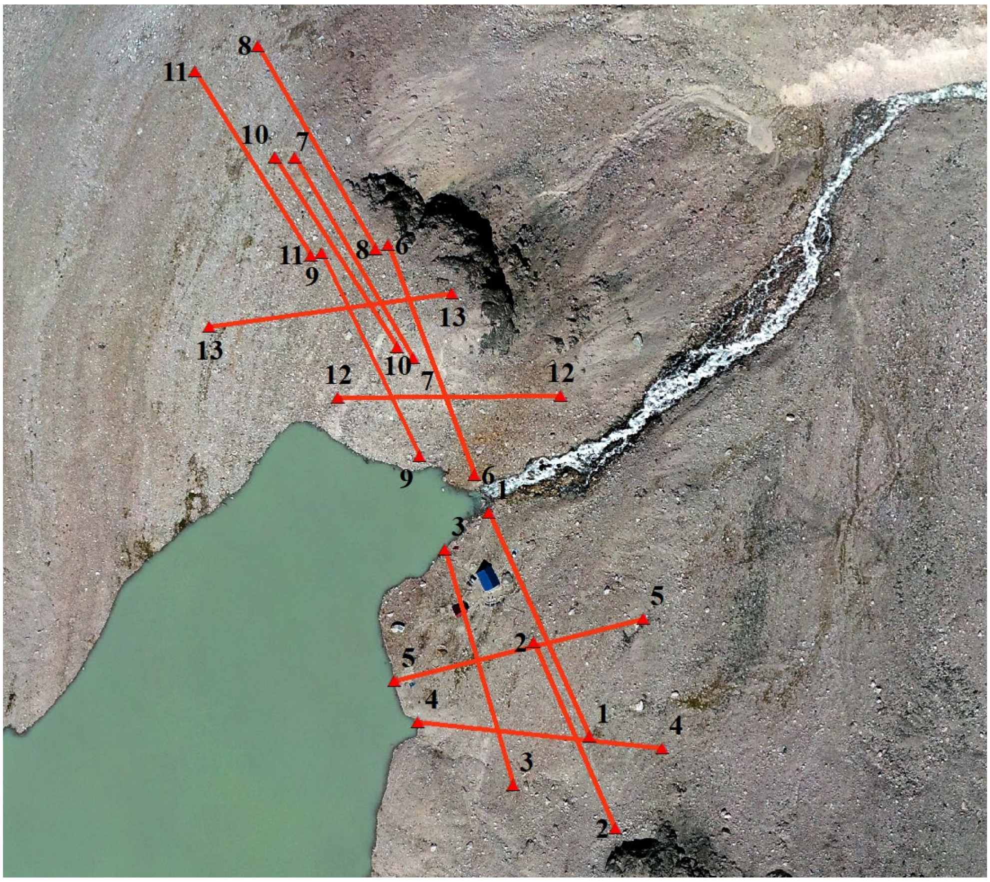


Fig. 2 Plan of the arrangement of profiles for electrical tomographic measurements on the dam of Bolshoe Adygene Lake.

The measurement technique involved multiple repeated measurements of signals in receiving lines at different positions of the power line. This method enables the probing of the geological section from different positions of the source and the transmission of the signal modified by geological objects to the receiving lines.

Lippmann Geophysical Instruments (LGM) - Model 10W - 4 Point Light Earth Resistivity Meter (Germany) was used for electrotomographic measurements.

Hardware characteristic:
Frequency: 0.26 Hz ... 30 Hz
Output current: 1 µA ... 100 mA
Output voltage: up to 380 V
Receiver resolution: 100 nV
Phase resolution: up to 0.05 mrad.
AD converter: 24 bits
Display: 4 x 20 digit LCD display.

In-phase/out-of-phase display
Accuracy: 0.2 %
Speed: 1 sec/measured value
Size: 25 x 12 x 5 cm.
Weight: 750 g


Fig. 3 Conducting electrotomographic measurements.

The measurements were carried out using the dipole-dipole method. The number of electrodes used is 20 pieces. The distance between the electrodes is 5 m.

In order to obtain a more detailed picture of the electrotomographic section of the surveyed areas, the measurements were taken with a 50% overlap.


Fig. 4 Installation and connection of electrodes for electrotomographic measurements.

The processing and interpretation of electrical tomographic measurement data were carried out using IPI2Win and ZondRes2D software programs with visualization on an aerial photography map (UAV).

Results of electrotomographic measurements

(Bolshoe Adygene Lake dam)

As a result of electrotomographic measurements at the dam of Lake Bolshoye Adygene, 13 tomographic sections of electrical resistivity were obtained on 13 profiles: 9 of them along the dam, 4 across the strike. (Fig. 6)

Electrical tomographic sections of elecrical resistivity of the dam of Lake Bolshoye Adygene

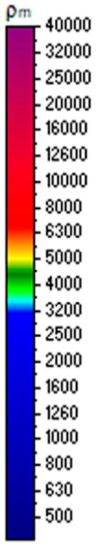
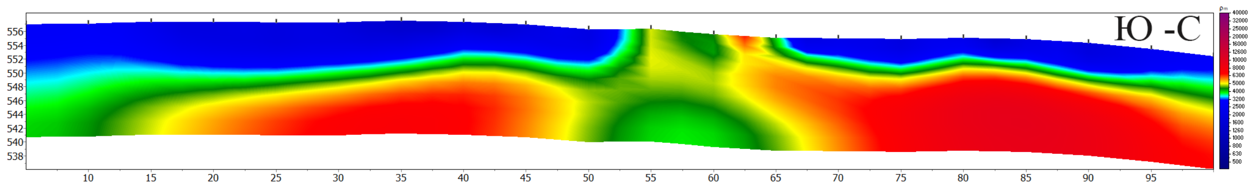
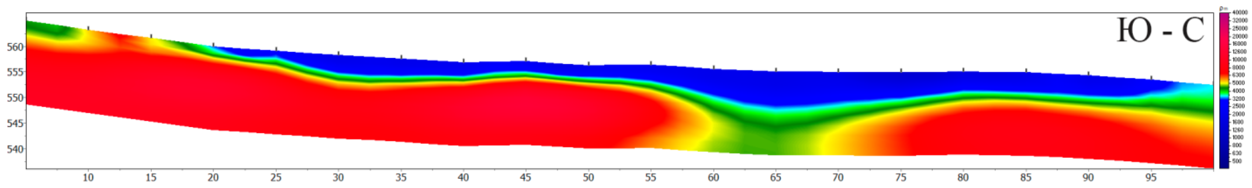


Fig. 5 Scale of electrical resistivity changes at the dam of Lake Bolshoye Adygene.

The southern part of the dam of Lake Bolshoye Adygene:

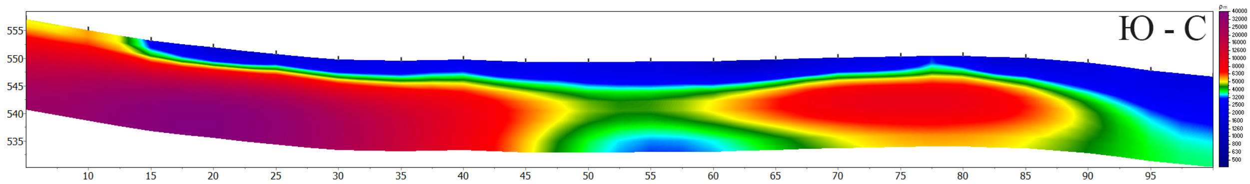


Profile 1-1

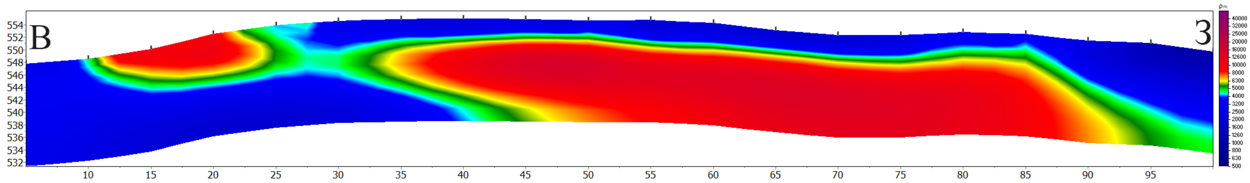


Profile 2-2

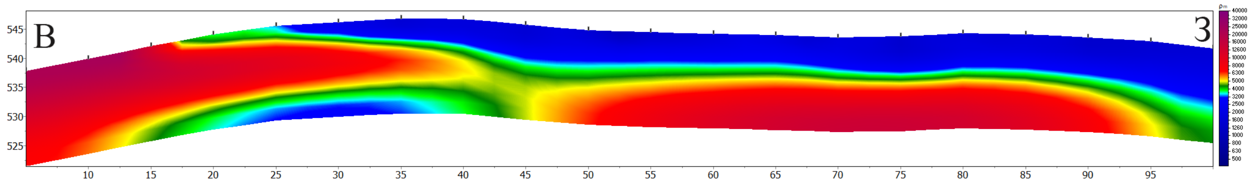
(Profile 2-2 overlaps Profile 1-1 by 50% in a southerly direction)



Profile 3-3

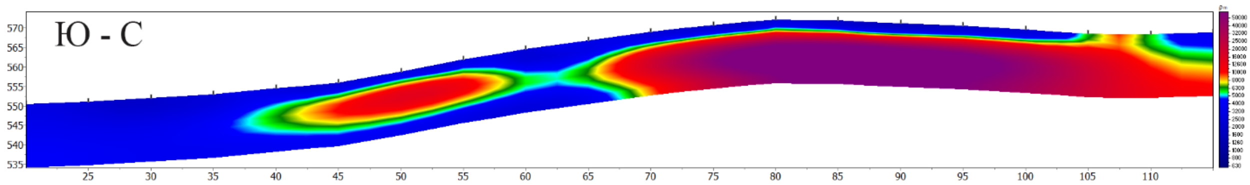


Profile 4-4

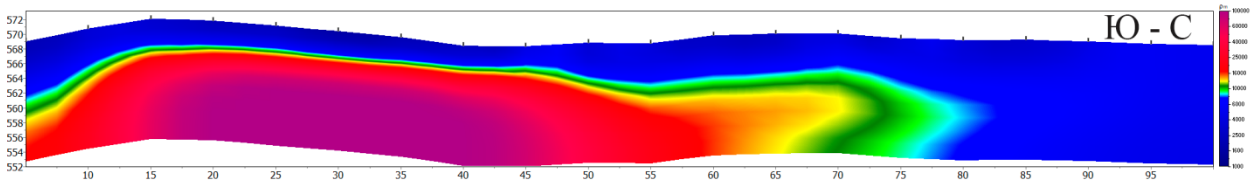


Profile 5-5

The northern part of the dam of Lake Bolshoye Adygene:

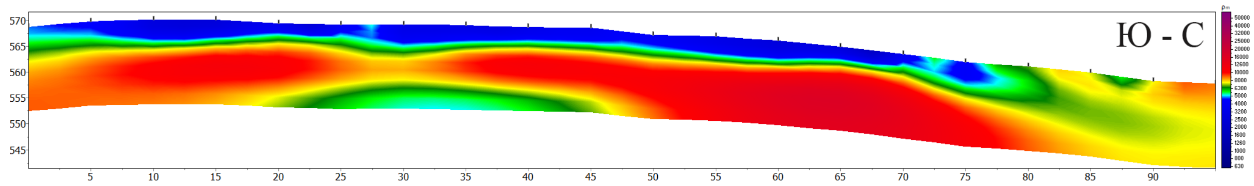


Profile 6-6



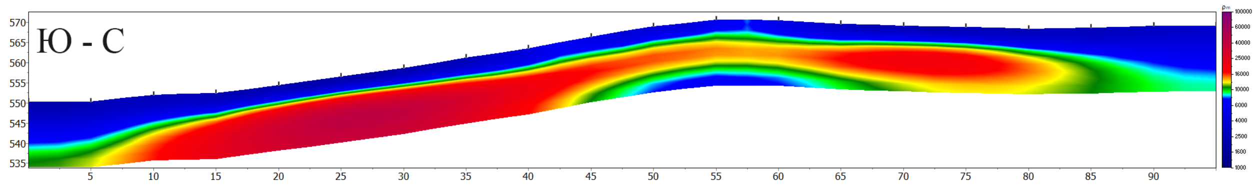
Profile 7-7

(Profile 7-7 overlaps Profile 6-6 by 50% in the north direction)

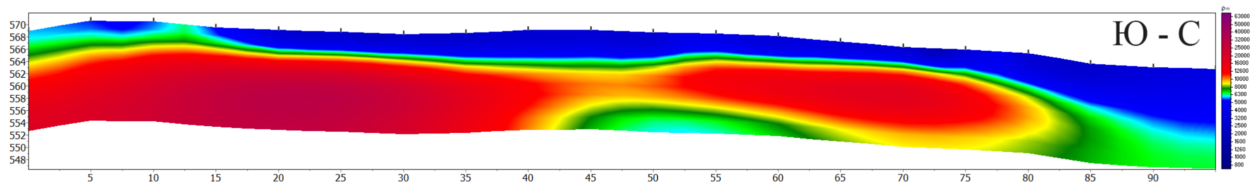


Profile 8-8

(Profile 8-8 overlaps Profile 7-7 by 50% in the northerly direction)

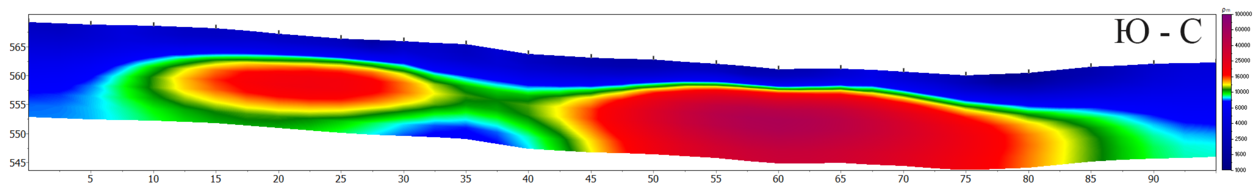


Profile 9-9



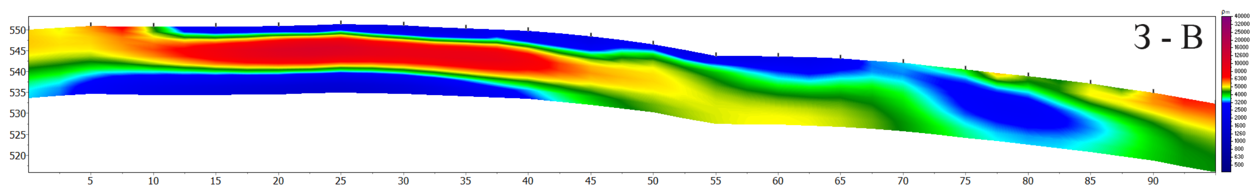
Profile 10-10

(Profile 10-10 overlaps Profile 9-9 by 50% in the southerly direction)

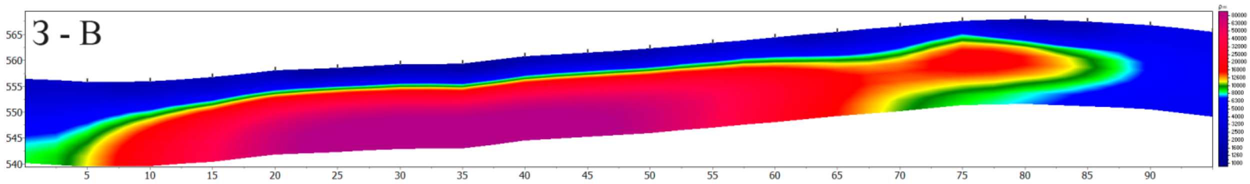


Profile 11-11

(Profile 11-11 overlaps Profile 10-10 by 50% in the southerly direction)



Profile 12-12



Profile 13-13

Fig.6 Electrical tomographic sections of electrical resistivity of the dam of Lake Bolshoye Adygene.

The SER (Specific electrical resistance) measurements using the ERT method along the profiles (Fig. 6 and 8) showed that the studied dams have complex and heterogeneous structures.

From the ERT cross-sections, it is evident that the specific electrical resistance of the rocks comprising the dam of Bolshoe Adygene Lake varies from 500 to 40000 Ohm. m.

High values of SER ranging from 5500 to 40000 Ohm. m (red areas of the cross-section) are characteristic of undestroyed bedrock formations constituting the dam, preliminarily interpreted as a riegel (transverse ridge of bedrock) formed by the rocky foundation of the basin.

The SER values ranging from 3200 to 5500 Ohm·m (green areas of the cross-section) likely correspond to the horizon of moraine fragmentary deposits with cemented ice, overlaying the zone of rock fractures with fissure vein ice, due to their location within the permafrost zone.

The SER values ranging from 500 to 3200 Ohm. m (blue areas of the cross-section) likely correspond to the water-saturated horizon of fragmentary moraine deposits, primarily consisting of sandy-silty fill material, transitioning with increasing depth into a frozen state with the formation of cemented ice.

The capabilities of the measurement setup used (20 electrodes, with a profile length of 100 meters) limit the depth of probing to 15 meters. Therefore, the interpretation on the profiles pertains to the upper layer of rocks, down to a depth of 10-15 meters.

On the electrotomographic sections of the dam of the Bolshoye Adygene Lake (Fig.6: (Profiles 1-1; 2-2; 3-3)) 2 zones of rock fracturing of riegel, each 20 and 30 meters wide (green areas of the section) are clearly visible, presumably corresponding to subvertical zones of faults in the basement, where the formation of water filtration zones can be expected, with time and climate warming, these zones may become more pronounced. These zones are also distinguishable in the magnetic field of the dam (marked by arrows in Fig. 13).

(Dam of Prilednikovoe Adygene Lake)

As a result of electrical tomographic measurements on the dam of Prilednikovoe Adygene Lake, 6 tomographic cross-sections of SER were obtained along 6 profiles: 4 along the dam and 2 transversely across it (Fig. 7).

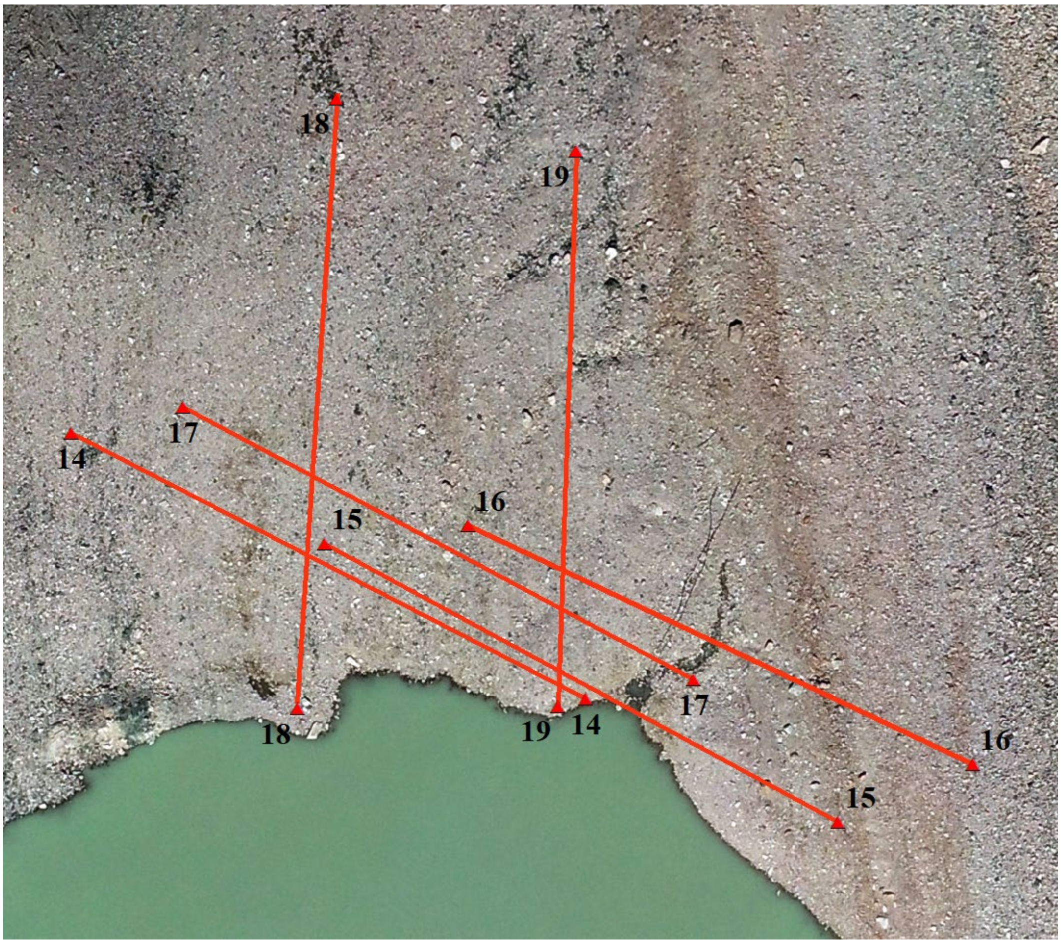


Fig. 7 Plan of the arrangement of profiles for electrical tomographic measurements on the dam of Prilednikovoe Adygene Lake.

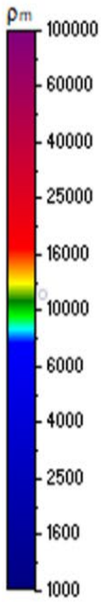
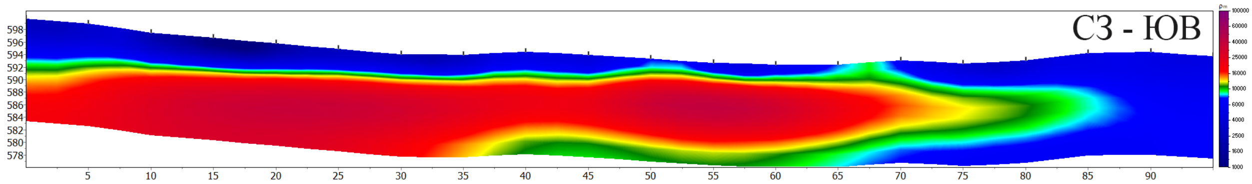
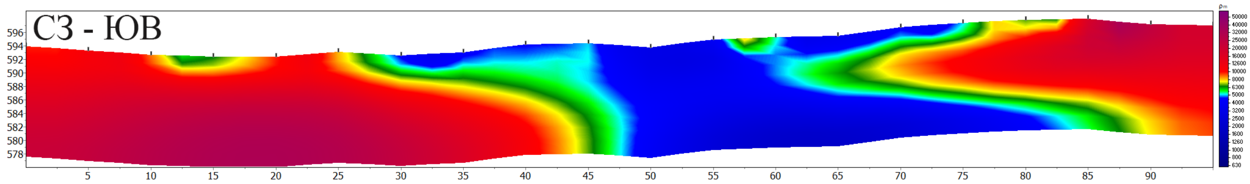


Fig. 8 Scale of variation of SER on the dam of Prilednikovoe Adygene Lake.

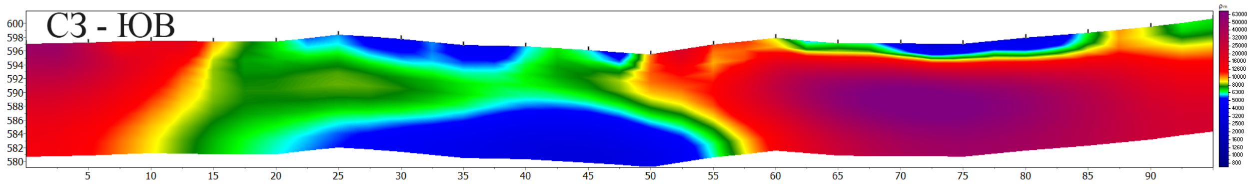


Profile 14-14

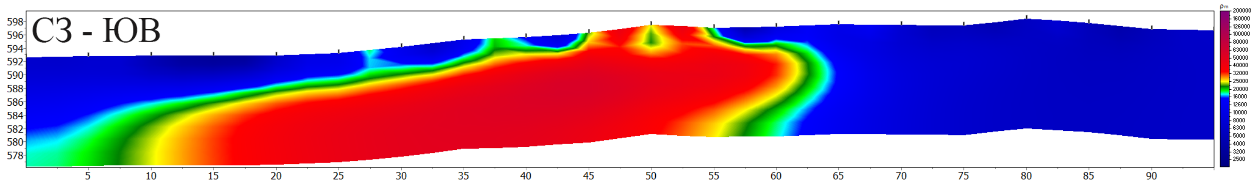


Profile 15-15

(Profile 15-15 overlaps Profile 14-14 by 50% in the southeast direction)

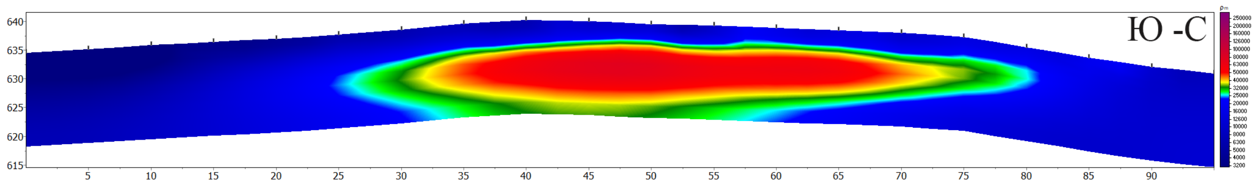


Profile 16-16

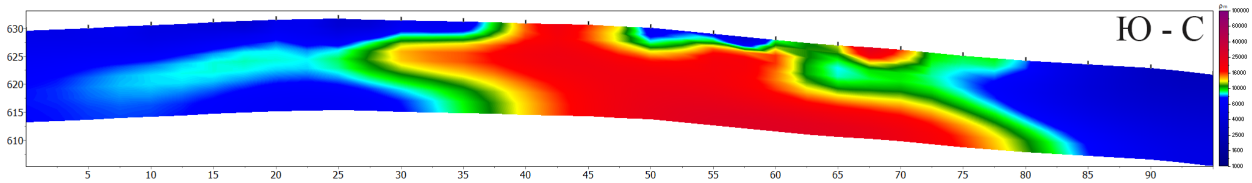


Profile 17-17

(Profile 17-17 overlaps Profile 16-16 by 50% in a northwest direction)



Profile 18-18



Profile 19-19

Fig. 9 Electrical tomographic cross-sections of SER of the dam of Prilednikovoe Adygene Lake.

From the electrical tomographic cross-sections of the dam of Prilednikovoe Adygene Lake, it can be seen that the specific electrical resistance of the rocks constituting the body of the dam varies from 1000 to 100000 Ohm. m.

High values of SER ranging from 10000 to 100000 Ohm. m (red areas of the cross-section) are characteristic of undestroyed bedrock formations constituting the dam, preliminarily interpreted as a riegel.

The SER values ranging from 5000 to 10000 Ohm. m (green areas of the cross-section) are associated with the contact of the planar zone of rock fracturing of the bedrock with frozen moraine deposits containing cemented ice.

The SER values ranging from 1000 to 5000 Ohm. m (blue areas of the cross-section) likely correspond to water-saturated moraine deposits.

In the electrical tomographic cross-section of the dam of Prilednikovoe Adygene Lake (Fig. 9 Profile 15-15), the zone of rock fracturing in the riegel, covered by moraine deposits with signs of water saturation and the possibility of permafrost presence increasing with depth, 20 meters wide in the upper part (blue areas of the cross-section) is of particular interest.

In this zone, with climate warming, the formation of water filtration channels can be expected, which over time may lead to the outburst of Prilednikovoe Adygene Lake.

2. Magnetometric measurements

Magnetometry is one of the geophysical methods based on the differences in the magnetic properties of rock formations.

Magnetometric measurements were conducted along 8 profiles along the bodies of the dams of Bolshoe Adygene Lake and Prilednikovoe Adygene Lake. The distance between profiles was 10-20 meters. The distance between measurement points was 20 meters, and in anomalous zones, it was 5-10 meters.

Magnetometric measurements were conducted using proton magnetometers MMP-203, one of which served as a magnetovariational station (MVS)

Hand-held proton magnetometer MMP-203 is designed for measuring the magnitude of magnetic induction (T). Measurements are based on the principle of proton precession.

Specifications:

Measurement error: ±1 nT;

Measurement range: (20000 - 100000 nT);

Response time: up to 3 s;

Power supply: dry battery with a voltage of 13±3 V;

Power consumption: about 2 W;

Temperature range: from -30 to +50 °C;

Systematic measurement error: ±2 nT;

Root mean square error of one measurement: 1.5 nT;

The measurement result (in nT) is displayed on a five-digit digital indicator.

Fig. 10 Carrying out magnetometric measurements.

Processing and interpretation of magnetometric data was performed using Golden Software Surfer 11 with visualization on the drone survey map.

Results of magnetometer measurements

(Bolshoye Adygene Lake dam)

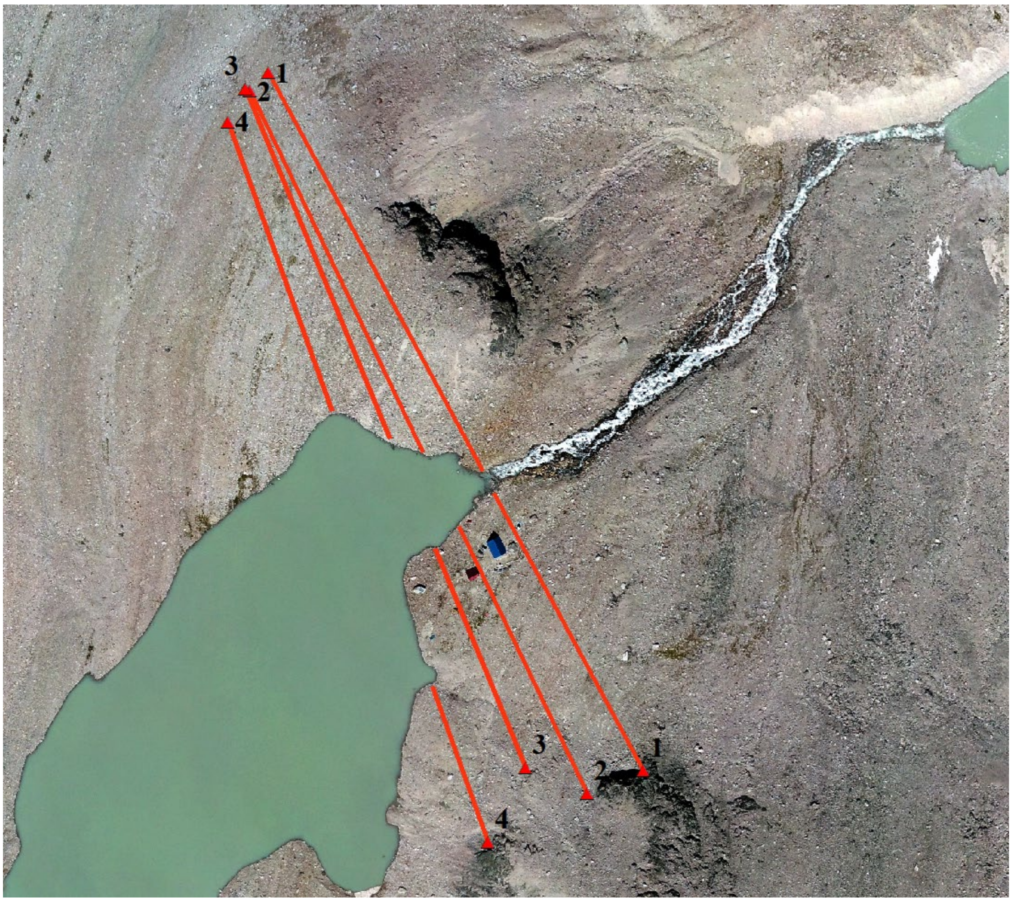
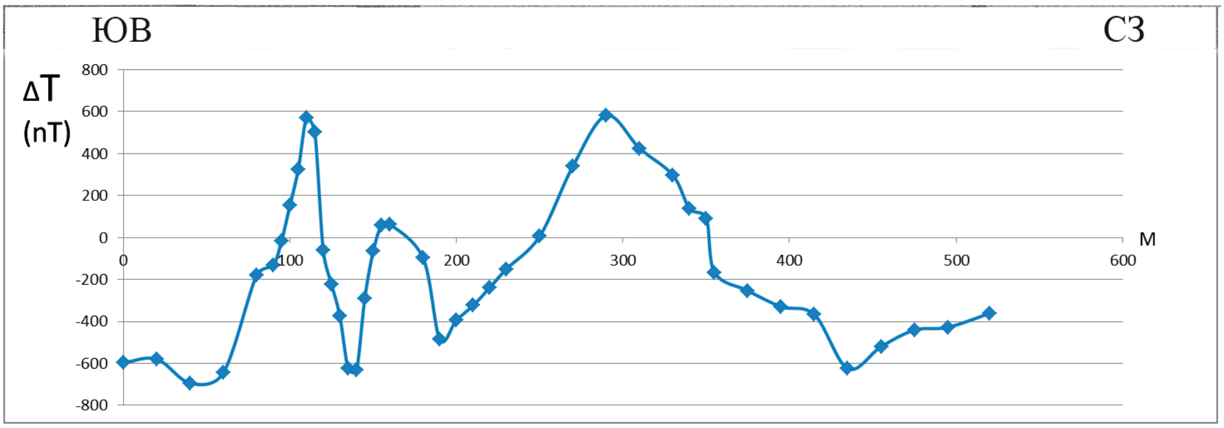
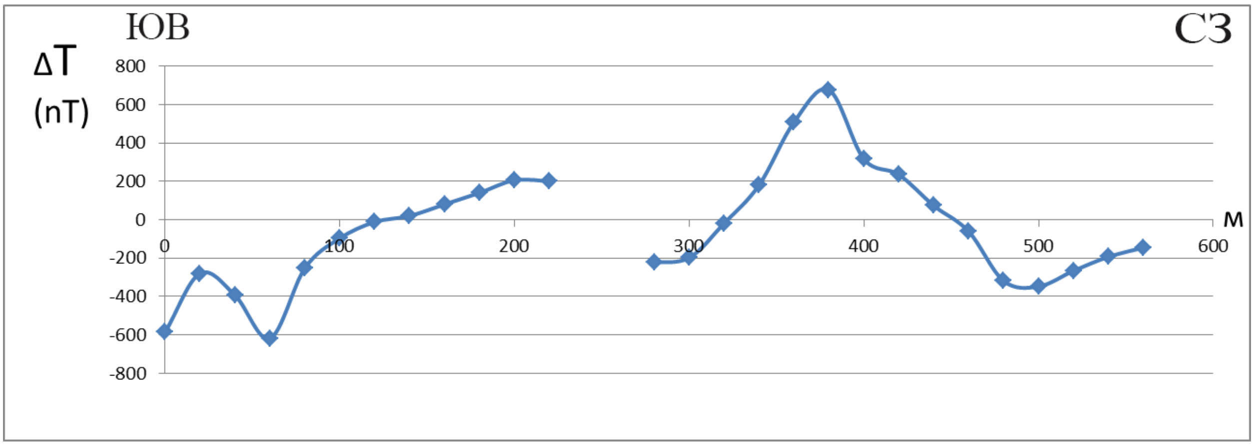


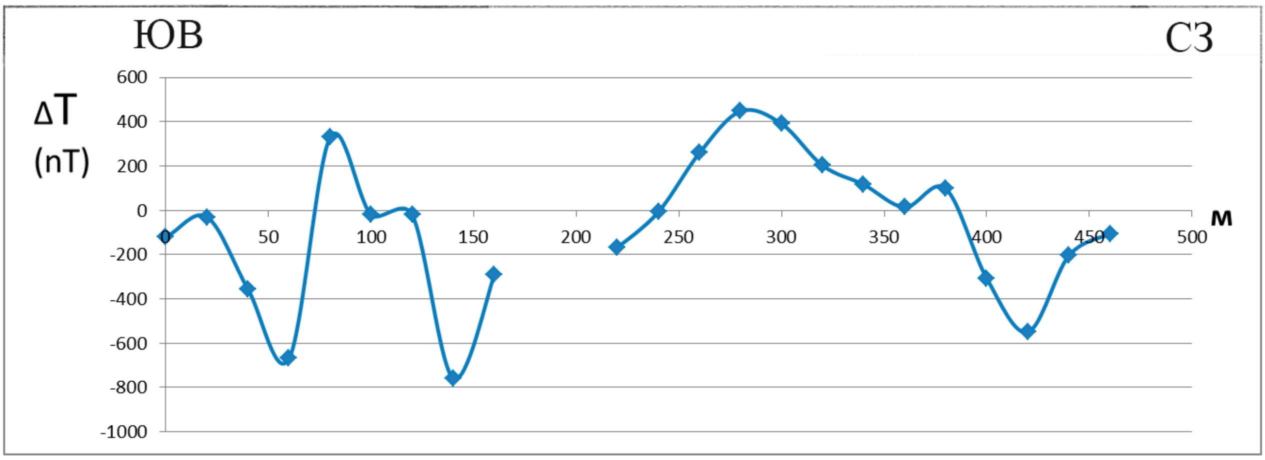
Fig. 11 Plan of profiles of magnetometric measurements at the dam of Lake Bolshoye Adygene



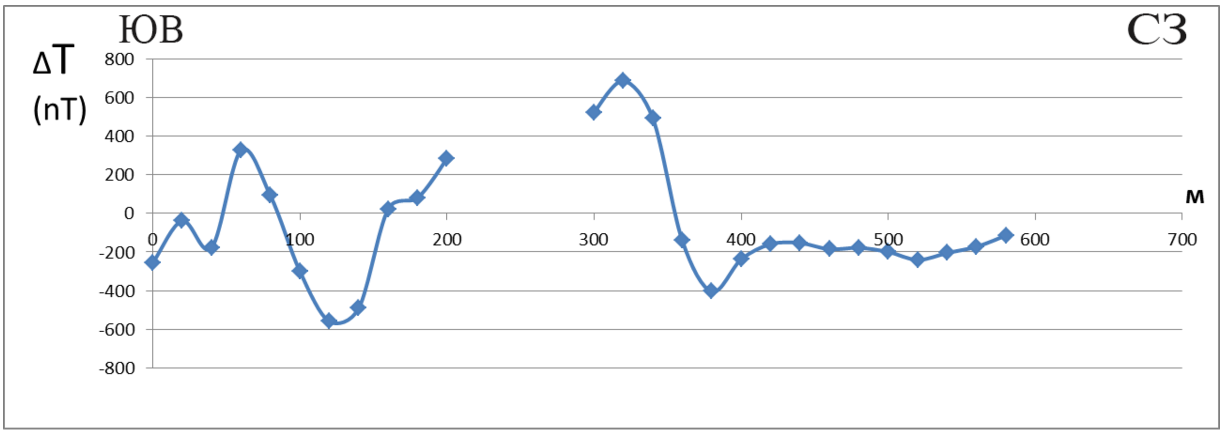
Profile 1-1



Profile 2-2



Profile 3-3



Profile 4-4

Fig. 12 Graphs of anomalous magnetic field ΔTa (nT) of the dam of Bolshoe Adygene Lake.

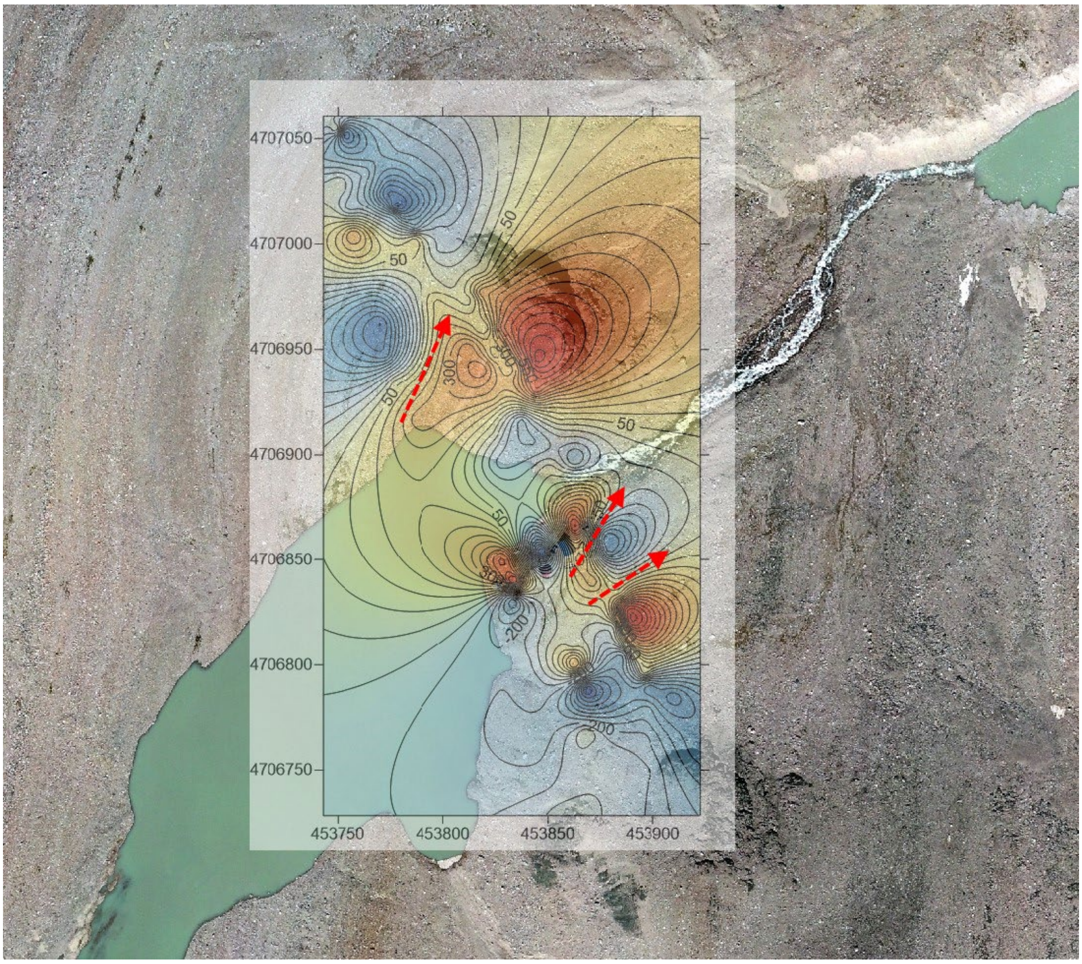


Fig. 13 Map of anomalous magnetic field ΔTa (nT) of the dam of Bolshoe Adygene Lake.
(red dashed lines indicate potential water outburst locations from the lake)

As a result of magnetometric works, a map of the anomalous magnetic field (ΔTa) of the dam of Lake Bolshoye Adygene was built.

The angular parts of the map of the anomalous magnetic field were interpolated by the Golden Software Surfer 11 program and inaccurately reflect the actual field values.

Analysis of the graphs and map of the anomalous magnetic field allows us to identify, in the southeastern part of the dam, 2 anomalous zones with intensities from + 600 to - 600 nT, which are confined to subvertical zones of fracturing in the riegel. Such alternating anomalies are characteristic of fault zones.

In the northwestern part of the dam, an anomalous zone with intensities ranging from +300 to -300 nT has also been identified, which is likely caused by a sub-vertical zone of fracturing in the riegel.

In these three presumed fault zones of fracturing (highlighted by red dashed lines), warming climate may lead to the formation of channels, through which an outburst of the lake could occur (Fig.13)

(Dam of Prilednikovoe Adygene Lake)

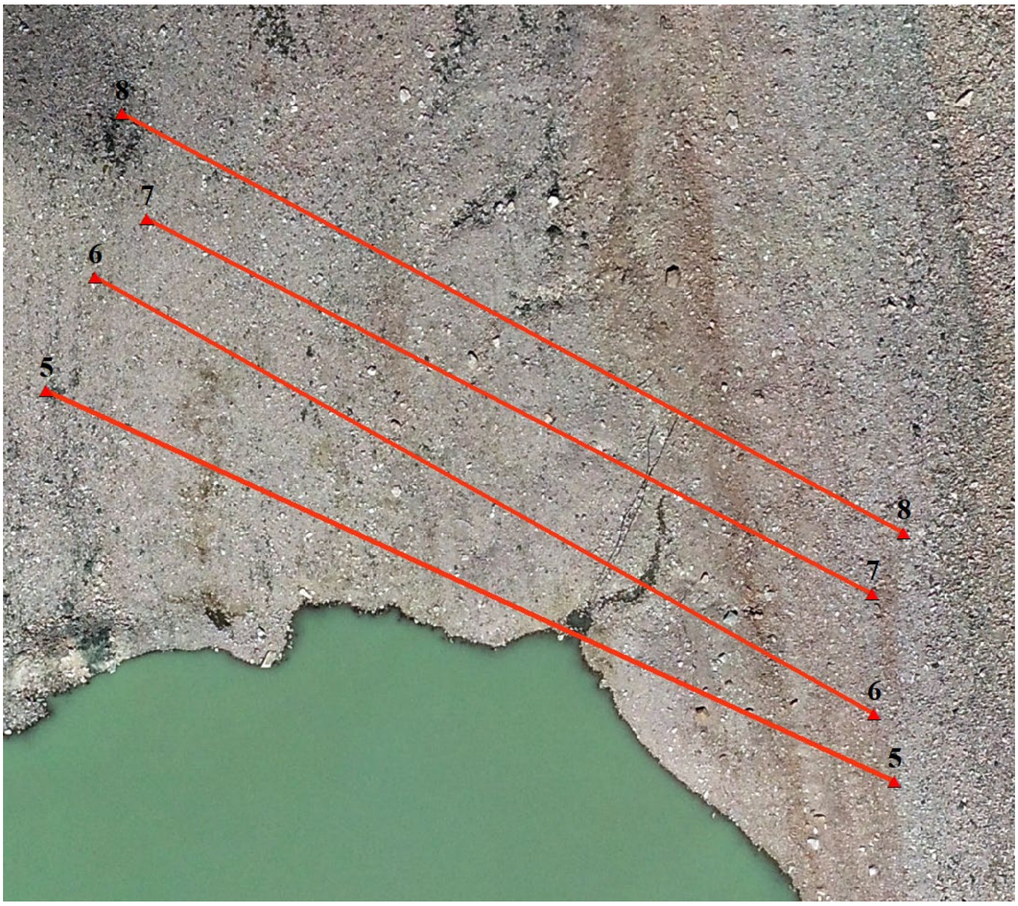
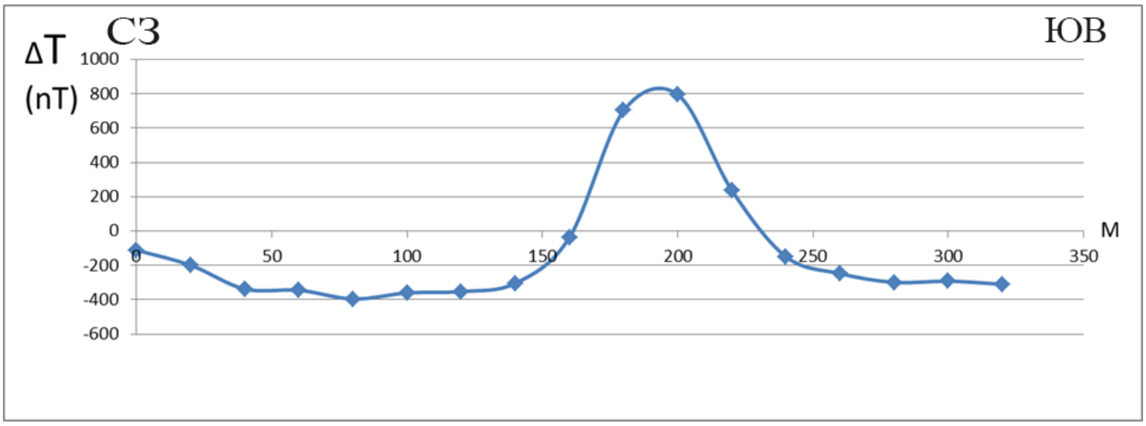
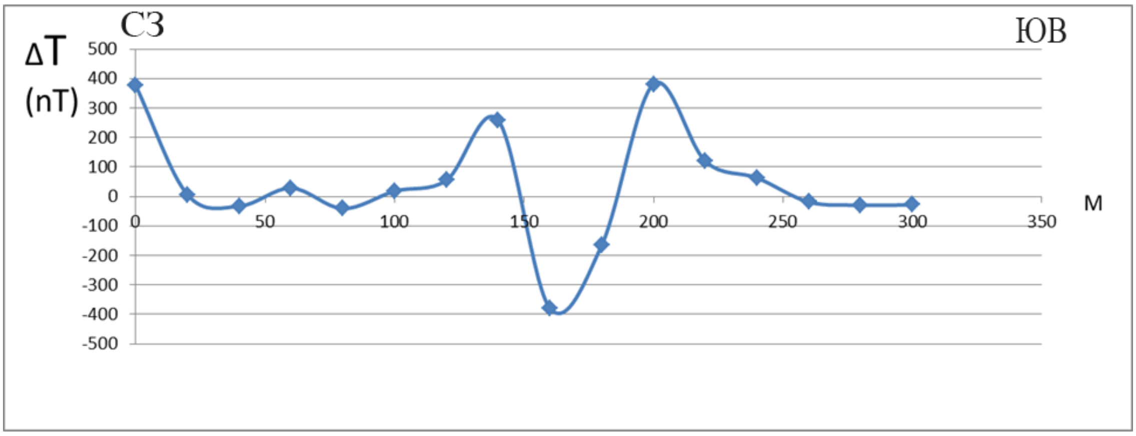


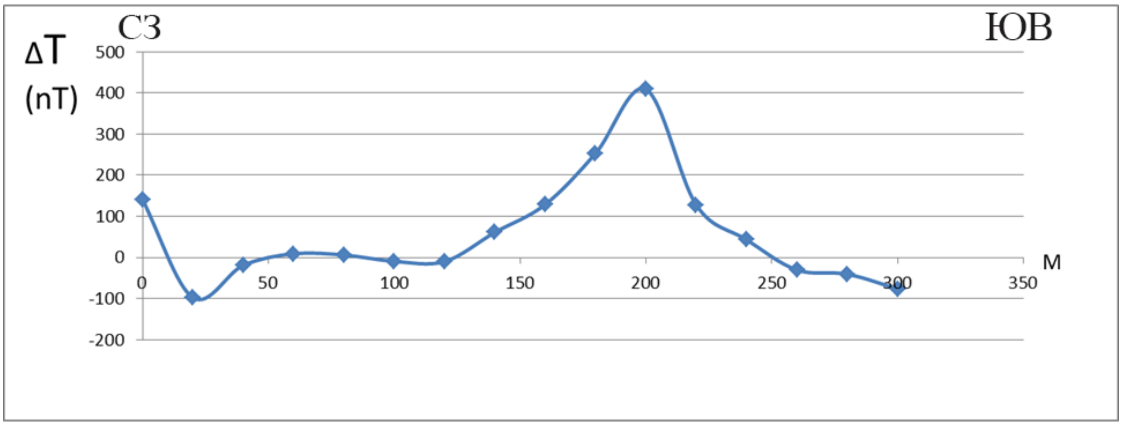
Fig.14 Plan of profiles of magnetometric measurements at the dam of Lake Prilodnikovoye Adygene.



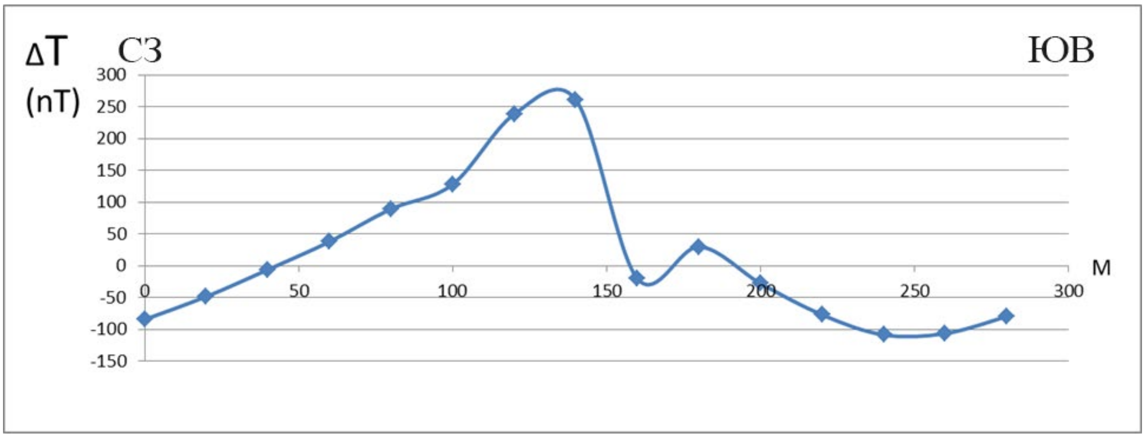
Profile 5-5



Profile 6-6



Profile 7-7



Profile 8-8

Fig. 15 Graphs of anomalous magnetic field ΔTa (nT) of the dam of Prilednikovoe Adygene Lake.

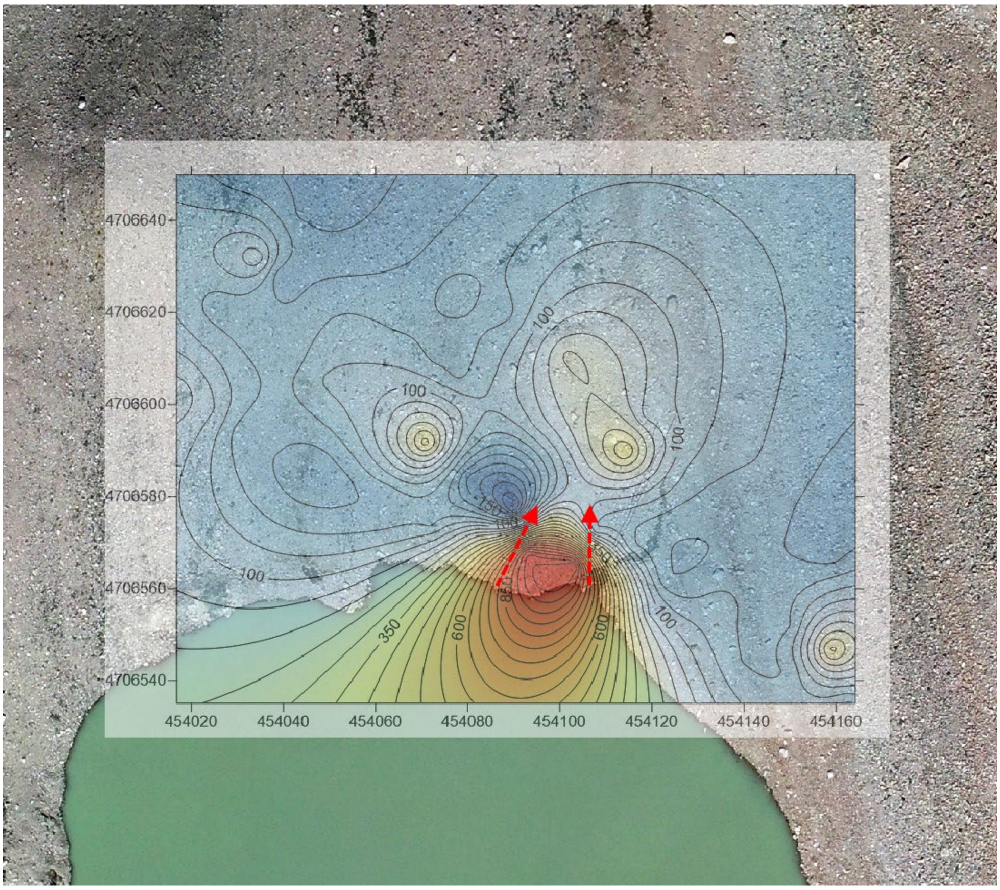


Fig. 16 Map of anomalous magnetic field ΔTa (nT) of the dam of Prilednikovoe Adygene Lake.

As a result of magnetometric surveys, a map of the anomalous magnetic field of the dam of Prilednikovoe Adygene Lake was built.

The zone of fracturing in the riegel of the dam is clearly distinguished in the magnetic field by a double alternating anomaly ranging from -400 to +800 nT. The width of the fracturing zone is 30 meters.

In this zone, with a warming climate, we can also expect the formation of water seepage channels, which may eventually cause the outburst of Prilednikovoe Adygene Lake.

Conclusions

В результате предварительной обработки и интерпретации полученных геофизических данных внутри тел плотин озер Большое Адыгене и Приледниковое Адыгене удалось выявить слоистость моренных отложений, представленную водонасыщенным слоем обломочных моренных отложений в верхней части разреза и мерзлыми моренными отложениями, содержащими цементационный лед, в более глубоких частях разреза, структуры в виде ригелей - выступов скальных пород фундамента, а так же обводненные зоны трещиноватости, разломов скального фундамента. Мерзлые моренные отложения, содержащие цементационный лед и зоны трещиноватости разломов в ригелях являются потенциальными источниками опасностей, которые при потеплении климата могут спровоцировать развитие прорыва озер.

As a result of preliminary processing and interpretation of the obtained geophysical data within the dam bodies of the Bolshoye Adygene and Prilednikovoye Adygene lakes, it was possible to reveal the layering of moraine sediments represented by a water-saturated layer of clastic moraine sediments in the upper part of the section and frozen moraine sediments containing cementation ice in deeper parts of the section, structures in the form of riegels- protrusions of rocky foundation, as well as waterlogged zones in fractures, faults in the bedrock. Frozen moraine sediments containing cementation ice and fracture zones in the riegels are potential sources of hazards, which, with climate warming, may provoke the development of lake outbursts.

The results of ERT and magnetometry are preliminary and require further analysis. This report does not include the results of VES and seismic works, which are currently being processed and interpreted.

Installation of ground reference points, GPS measurements and aerial photography

Executor: Konokov T.

When shooting with a drone, key elements for effective operation are ground control points (GCP). GCPs or GCPs help to define the boundaries of an area and correctly scale everything in between. This tool is important in surveying because it improves the accuracy of maps.

However, in order to obtain accurate data from ground control points, it is necessary to ensure that they are properly placed as shown in Figure 1. This resulted in +- 3 cm per pixel, providing a reliable basis for generating accurate geospatial data.

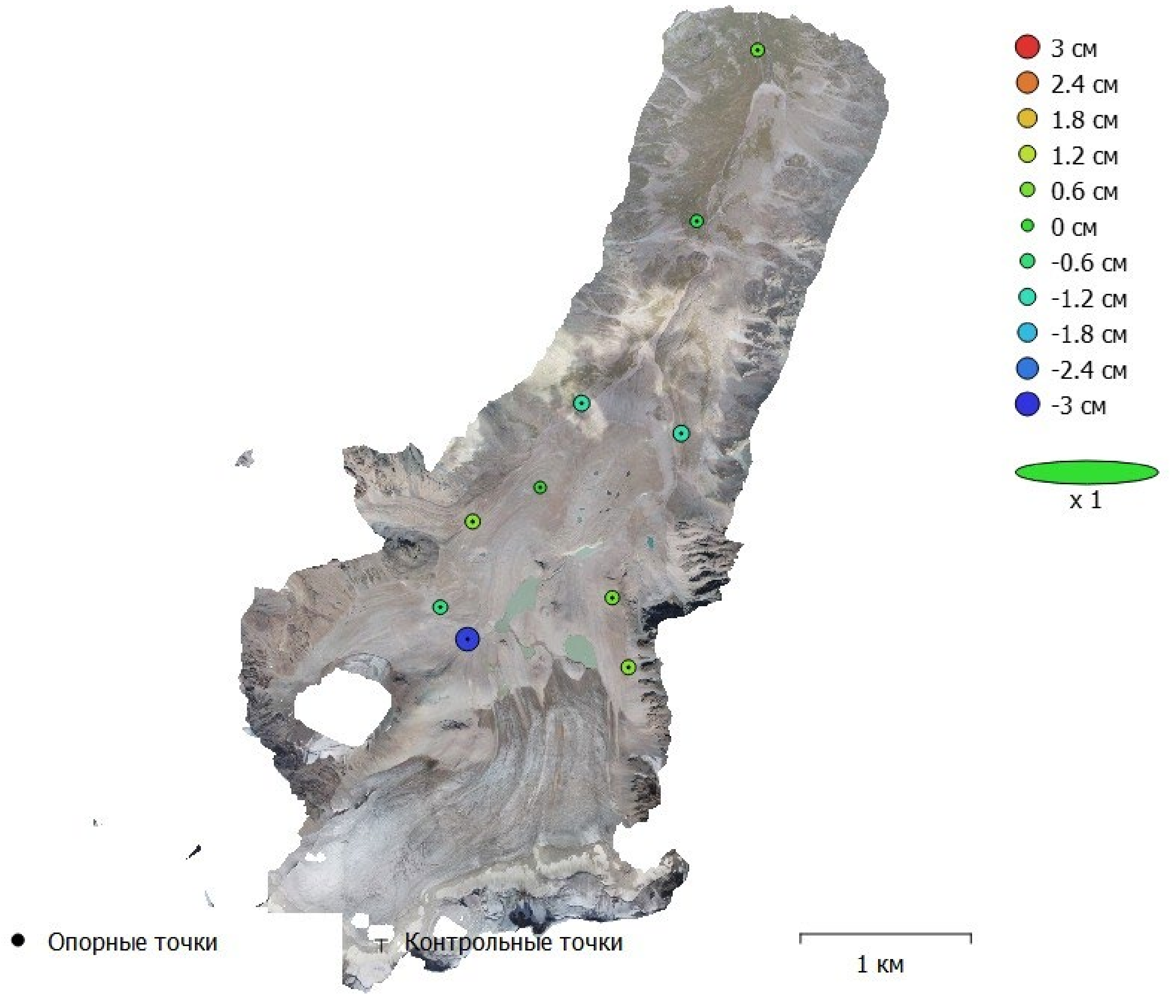


Fig 1. Positions of reference and control points and error estimation. Error in Z is displayed by ellipse color. Errors in plan are shown by the ellipse shape. The calculated positions of the reference points are marked with a black dot, and those of the control points with a cross

1) Establishment of ground control points, GPS measurements and aerial photography:

During the field survey, ground control points were established for subsequent geodetic measurements and aerial photography. The coordinates of these points were determined using a dual-frequency GNSS receiver ASHTECH PROMARK 800 with a high accuracy not exceeding 30 cm at a distance from one reference point to the next, ranging from 200 meters to one kilometer. This ensured uniform coverage of the surveyed area.

Fig.2 Dual frequency GNSS receiver ASHTECH PROMARK 800

The ground control points were specially made of 0.6 mm thick galvanized sheets coated with an anti-corrosion layer and painted with white paint to ensure good visibility at their installation sites (Fig.4). Their shape in the form of a cross (cruciform shape) with the size of 120x120 cm provided effective recognition and georeferencing in further processing of aerial photography. The total number of installed ground points amounted to 11.

Fig.3 Measurement of ground point coordinates.

Fig.4 Ground reference with coordinates, for georeferencing of aerial survey results

Aerial photography was conducted using a DJI Phantom 4 Pro V2.0 quadcopter. The survey was carried out at an altitude of 500 meters from the launch site, taking into account the complexity of the relief and scale of the glacier. These data became an important element of preliminary processing and further analysis of geoinformation data obtained from studies of permafrost-ice dams of high-mountain lakes Bolshoye Adygene and Priledniokovoe Adygene in the upper reaches of the Ala-Archa River basin in Alamudun district of Chui oblast of Kyrgyzstan.

Fig. 5 **DJI Phantom 4 Pro V2.0** quadcopter

The survey size covered 700 hectares and the survey area extended from the glacier to the moraine tongue, which provided a more complete overview and a basis for a detailed analysis of the geological and geophysical characteristics of the area.

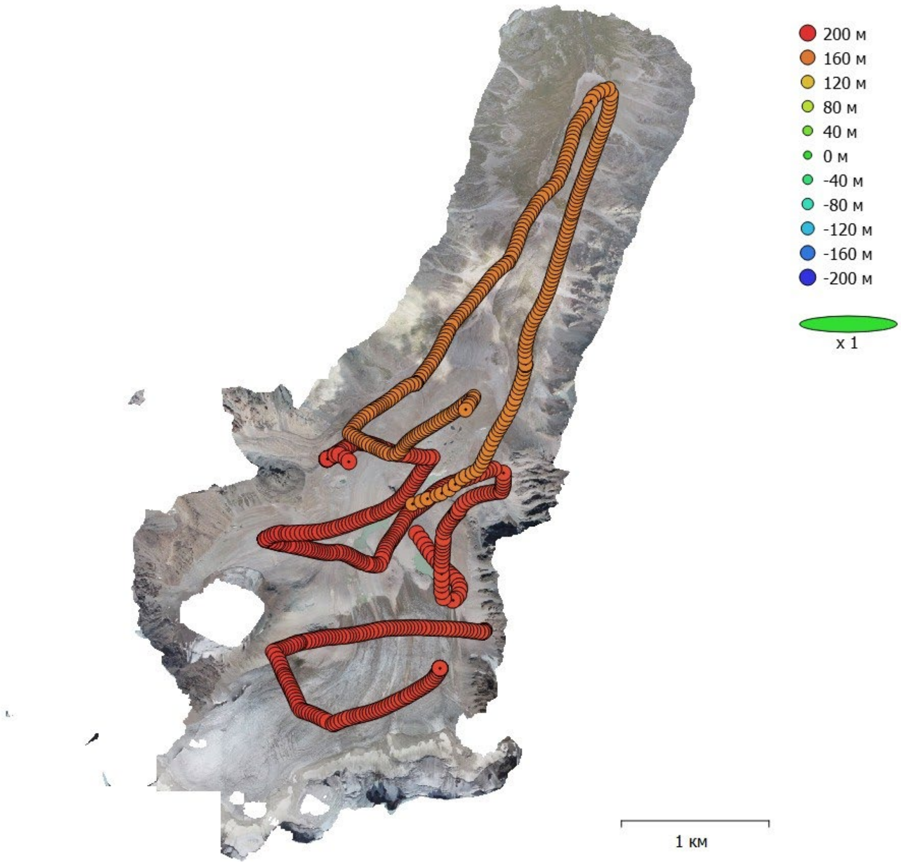


Fig. 6 Calculated positions of photo centers and error estimation. Error in Z is displayed by ellipse color. Errors in plan are displayed by ellipse shape. Calculated positions of the photo centers are marked with a black dot