ANAS Transactions **Earth Sciences** **2 / 2025**

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ASSESSMENT OF EXOGENIC GEOLOGICAL PROCESS DYNAMICS IN THE YANARDAG AREA OF ABSHERON PENINSULA (AZERBAIJAN) BASED ON VERTICAL ELECTRICAL SOUNDING DATA

Salamov A.M.[1], Safarov R.T.[1*], Zamanova A.H.[1], Ahmadova E.V.[2], Gahramanov M.R.[1]

[1]*Ministry of Science and Education of the Republic of Azerbaijan,*
Institute of Geology and Geophysics, Azerbaijan
119, H.Javid ave., Baku, AZ1073
[2]*Faculty of Geology, Baku State University, Azerbaijan*
33, acad. Z.Khalilov str., Baku, AZ1148
**Corresponding author: rafiqsafarov@gmail.com*

Keywords: *geophysics, mud volcano, electrical prospecting, resistivity, rock, density, faults*

Summary. This paper examines the investigation of exogenic geological processes in the Yanardagh area located in the northern part of the Absheron peninsula at a distance of 27 km from Baku. The peninsula is orographically the southeastern continuation of the Greater Caucasus and occupies an area of approximately 2,000 sq. km. This area was formed as a result of volcanic-tectonic processes and the ignition of natural gas flows that emerged to the surface through cracks. Field geophysical measurements using Vertical Electrical Sounding method were carried out along nine profiles using a symmetrical four-electrode AMNB installation. As a result of the conducted geophysical studies, the following tasks: detailed subdivision of the geological section to a depth of 30 m; identification and tracking of probable faults; determination of some probable physical parameters of the rocks forming the geological section were solved. Three main layers composed of clays with different thickness and electrical resistivity were identified. Based on the plotted maps of the averaged values of the expected physical parameters, it was established that the western part of the area is most susceptible to the impact of exogenic geological processes. Presumably, the main cause of the exogenic geological processes development is an aqueous solution flowing from the mud volcano manifestation located in the southwestern part of the study area. It is proposed the necessity to eliminate the ingress of water flowing from the mud volcano into the geological environment in order to reduce the rate of the exogenic geological processes development in the study area.

Introduction

The Yanardagh geophysical research area, which is one of the rare natural phenomena and also attracts tourists, is located in the northern part of the Absheron Peninsula at a distance of 27 km from Baku. These rare natural phenomena are treated and protected with special care all over the world. Therefore, the study of such phenomena is mandatory and relevant.

The peninsula is orographically the southeastern continuation of the Greater Caucasus, occupies an area of approximately 2,000 square kilometres, and its eastern part extends deep into the Caspian Sea.

According to orographic features, the peninsula is divided into four main parts: northwestern and southwestern – low mountainous, northern (or central) – hilly-ridged plain, and eastern – flat. The study area is located in the north-western part of the peninsula (Fig.1).

The development of exogenic geological processes (EGP) occurs everywhere, both on plains along the banks of rivers, lakes, water reservoirs and seas, and in mountainous areas. Developing in areas of intensive economic exploration, EGPs pose a threat to all open engineering structures without exception (Aliyev, 2002).

Reasonable assessment of the EGPs hazard requires the solution of a number of specific issues related to the structure of the slope, its lithological composition, condition, properties, bedding and thickness of individual rock strata, their water abundance and groundwater regime (Ogilvi, 1990).

Among EGPs, landslides are one of the most widespread and hazardous. Landslides cause significantly greater total damage than volcanic eruptions, floods, hurricanes, and even earthquakes (Goryainov et al., 1987).

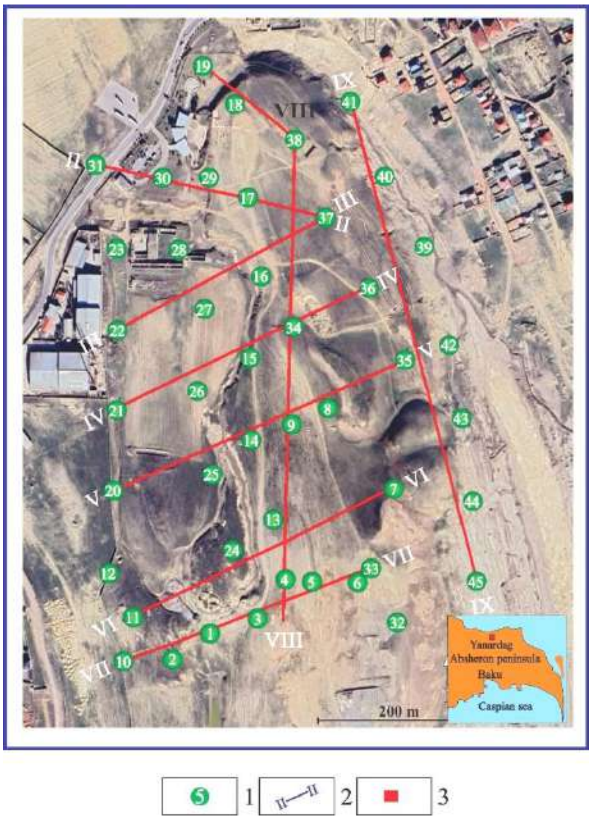

Fig. 1. Location of geophysical profiles in the study area
1 – VES points and their sequence numbers; 2 – geophysical profiles; 3 – location of the geophysical research area – Yanardagh site

This is due to the high prevalence of landslide processes and the fact that the mentioned natural disasters often turn out to be the cause of landslides that are more destructive than they themselves, which cause the death of huge numbers of people.

The most spectacular of the known landslide disasters was the 2.2 km^3 landslide that formed in the Pamirs and created Lake Sarez in 1911.

According to R.Shuster, the amount of direct and indirect losses associated with landslides reaches 1 billion dollars per year in the USA (Goryainov et al., 1987). In Japan, this number is much higher. Therefore, study of EGPs, including landslides, is always an actual issue in the world and in Azerbaijan.

Since 1929, the study of landslides in Azerbaijan, including the Absheron Peninsula has been the subject of numerous works by researchers Alizade et al. (1990), Kashkai (1952), Azizbekov (1961), Popov et al. (1990), Shirinov (1965, 1993), Budagov (1982), etc. Various EGPs, including landslides of the Absheron Peninsula were studied by I.A.Israfilbekov, V.A.Listengarten, A.D.Shakhsuvarov (1983), Gul (2003), Konovalov, Gul (1956), Aliyev (2002), Salamov (2015, 2020).

The purpose of the research was to study the geophysical-engineering conditions of the Yanardagh site. In order to achieve this goal, the following tasks were set on geophysical work studies:

- detailed subdivision of the geological section to a depth of 30 m;
- identification and tracing of suspected faults;
- determination of some probable physical parameters of rocks forming the geological section.

To solve the task, the electrical prospecting method – Vertical Electrical Sounding was used.

As it is known, the intensity of EGPs development and landslides depends on numerous geological, natural factors and anthropogenic activities.

Method

Field geophysical measurements were carried out along nine profiles using a symmetrical four-electrode AMNB installation.

As it is known, the modern theory of VES is based on the Schlumberger mathematical model, which allows calculating the specific apparent electrical resistivity ρ_a of a multilayer medium with horizontal interfaces. This method relies on specific electrical resistivity, thickness of individual layers, as well as the dimensions of the VES survey setup (Salamov et al., 2017; Salamov et al., 2023).

The distance between the profiles and between the VES observation points was selected depending on the terrain ruggedness and passability. The survey setup is oriented along the profiles. In order to achieve the detailed subdivision of the geological section and more accurate estimation of sliding plane depth based on the experimental studies results, an additional network with denser AB/2 spacing interval was used: the step was 1 m up to 10 m, then it was 2 m up to 30 m.

Taking into account the above mentioned aim of the detailed subdivision of the geological section and more precise depth determination of the individual lithological varieties, the sizes of the transmitter line AB/2 (AB/2 =1; 2; 3; 4; 5; 6; 7; 8; 9; 10,10; 12,12; 14; 16; 18; 20; 22; 24,24; 26,26; 28; 30) and the receiving line MN/2 (MN/2=0,3; 0,3; 0,3; 0,3; 0,3; 0,3; 0,3; 0,3; 0,3; 0,3;1; 0,3;1; 1; 1; 1; 1; 1; 1;2; 1;2; 2; 2) were adopted based on the results of conducted VES experiments (Salamov et al., 2017).

Following formula was used to calculate the apparent electrical resistivity ρ_a, (Yakubovski, Renard, 1991)

$$\rho_{ai} = \mathrm{K}_{\mathrm{VES}} \frac{\Delta U_{mV}}{I_{mA}} \quad (1)$$

To determine the specific electrical resistivity of individual layers, formula (2) is used, when $\rho_i > \rho_{i-1}$, (Galin, 1989; Popov et al., 1990)

$$\rho_i = [\rho_{ai} \times (AB/2)_i - \rho_{ai-1} \times (AB/2)_{i-1}] / \\ /[(AB/2)_i - (AB/2)_{i-1}] \qquad (2)$$

When $\rho_{i-1} > \rho_i$, formula (3) was used (Salamov et al., 2015)

$$\rho_i = \left\{ \left[\left(\frac{AB}{2}\right)_i - \left(\frac{AB}{2}\right)_{i-1} \right] \times \rho_{ai-1} \times \rho_{ai} \right\} / \\ / \left[\rho_{ai-1} \times (AB/2)_i - \rho_{ai} \times (AB/2)_{i-1}\right] \qquad (3)$$

Expressions (1), (2) and (3) are the main calculation formulas in the proposed method to determine the parameters of a geoelectric section based on VES data for installations where, MN<<AB.

Surfer 25, CorelDRAWX6 and ZOND2 software were used to process and illustrate the field geophysical materials.

ERA-MAX electrical prospecting equipment with an operating frequency of 4.88 Hz was used on field measurements.

The Yanardagh volcano research area belongs to the Caspian seismically active zone, and elevations vary within the range from 80.0 m to 30.0 m.

The VES surveys were conducted along nine (I…IX) profiles with a total length of 3174 running meters. The directions of profiles I-I…VII-VII are northeast-southwest, and of profiles VIII-VIII and IX-IX are north-south.

As a result of the conducted researches on apparent electrical resistivity ($\rho_{a.e.r.}$), vertical sections of apparent electrical resistivity were constructed. Then, based on specific electrical resistivity ($\rho_{s.e.r.}$), geoelectric sections were constructed and then transformed into lithological-geophysical sections. The maps characterising some average physical properties of rocks forming the geological section of the study area were also created.

Geological structure of the study area

The study area is approximately 25 hectares. This area surrounds the Northern local zone of the Gyrmaki mud volcano. In the general background, due to the development of mud volcano structure, a wide and deep gorge (valley) of Gyrmaki is formed (Alizadeh et al., 2016).

In the area of the Gyrmaki mud volcano location, generally, predominant deposits are from the Pliocene. The maximum thickness of such deposits, which have an oval distribution, is 30 m. They are known as grey and brownish-grey sticky clays in the Absheron peninsula. Carbonate-sand deposits are recorded in the eastern foothill zones and on the slopes of both the southern and northern ridges in the direction of the Gyrmaki valley.

Hydrogeology

In the study area, groundwater basins are present in closed synclines and moldstypical for this territory, which explains the sporadic distribution of groundwater. In the molds, groundwater confined to all stratigraphic levels forms a single radial flow directed from the sides of the mold towards the Caspian Sea (Alizadeh et al., 2016).

Discussion

It should be noted that analogical geophysical studies were not carried out in this area before.

As a result of the conducted field geophysical studies, the apparent electrical resistivity of rocks was calculated. These data were subjected to interpretation, and the specific electrical resistivity of rocks was determined.

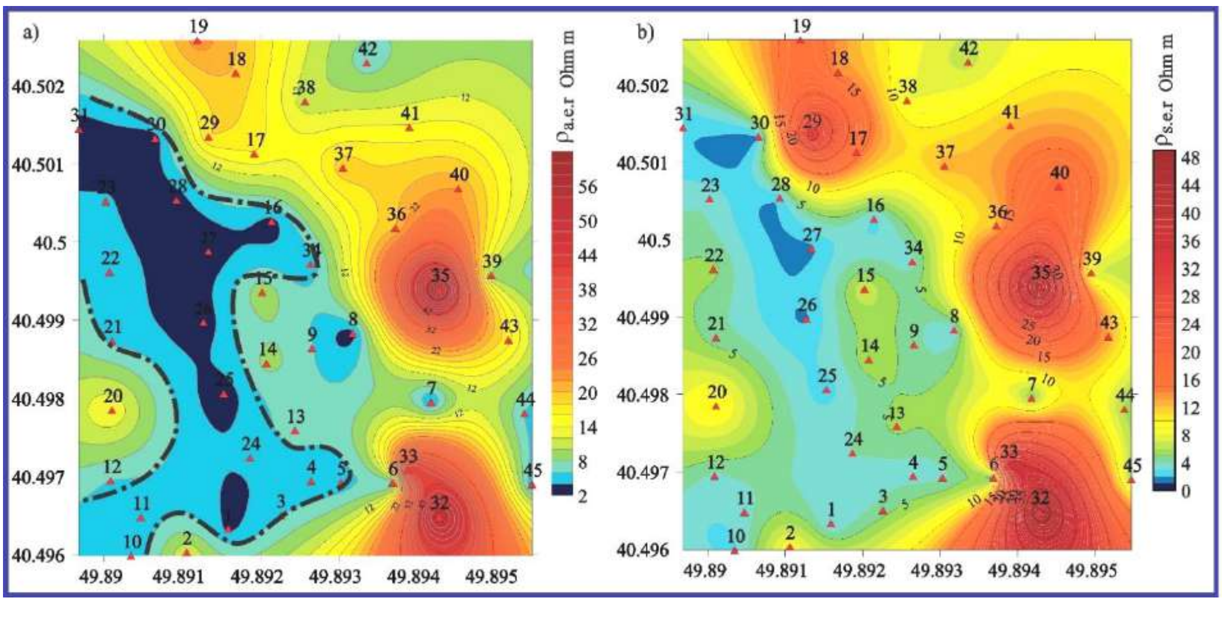

Fig. 2. Maps of the averaged electrical parameters of rocks (a- $\rho_{a.e.r.}$ and b – $\rho_{s.e.r.}$) in the geological section of the Yanardagh study area

As it can be seen from the constructed maps based on the averaged values (particularly – $\rho_{a.e.r.}$, Fig.2a) on rocks in the geological section, the study area conditionally can be divided into two parts. According to the constructed maps, from west to east, an increase in the averaged values of $\rho_{a.e.r.}$, and $\rho_{s.e.r.}$ in rocks in the geological section is observed (Fig. 2 a, b). This indicator may be associated with both the lithological composition of rocks and a decrease in their moisture (water) content.

In the eastern part of the study area, where the averaged values ($\rho_{a.e.r.}$) varies approximately in the range of 12-38 Ohm-m, and in the western part, this indicator is 2-8 Ohm-m.

A similar picture is observed on the map compiled with the averaged values of the specific electrical resistivity ($\rho_{s.e.r.}$) of rocks that make up the geological section of the study area under water (here, rocks are considered to be under the influence of water). In the western part of the area, rock $\rho_{s.e.r.}$ values decrease and vary in the range of 2-5 Ohm-m. This indicator of rocks varies in the range of 10-16 Ohm-m in the eastern and northern parts.

In the western part of the study area, a strip of very low $\rho_{a.e.r.}$values in northwest-southeast direction was identified, which is of certain geological interest.

In the southwestern (VES No. 10, 11, 12) part of the study area there is a manifestation of the mud volcano apophysis and an outlet of an aqueous solution from it, which flows to the north and some part of the water disappears in the geological environment around VES No. 30, 31, 23, 28, 27, 25, 26, and the rest flows to the east. Part of the water, which flows in the north direction penetrates the geological environment and moistens it to the middle of the area approximately. Therefore, in the eastern part of the area, there is a decrease in all, except for natural humidity, the probable physical parameters of rocks forming the geological section.

In order to get the detailed subdivision of the geological section, field measurements were carried out using the VES method and vertical sections of the apparent electrical resistivity of rocks and probable lithological and geophysical sections were constructed (Fig. 3).

As can be seen from the constructed sections of profiles VI-VI and VIII-VIII, three rock layers of different thickness were identified. The top of the first layer was identified at a depth of approximately 7-8 m and the lithology is presumably composed of clays with a thickness of 12-14 m and with $\rho_{s.e.r.}$ of 2-4 Ohm-m. This layer is traced in the VES No.11-13 of profile VI-VI and VES No.3-16 of profile VIII-VIII.

On the top of this layer, a layer with a thickness of 3-7 m and $\rho_{s.e.r.}$ of 0.5-1 Ohm-m is traced. It is assumed that this layer is the sliding plane of a potential landslide and the main factor of EGPs development. In our opinion, this is true for the eastern part of the study area, since the dip of relief increases towards the east.

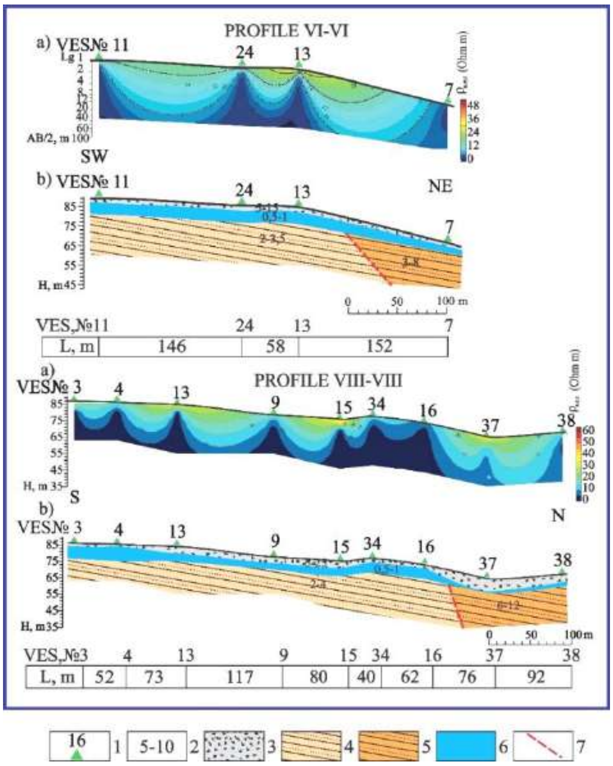

Fig. 3. Vertical sections of apparent electrical resistivity of rocks (a) and probable lithological-geophysical sections (b) along profiles VI-VI, VIII-VIII in Yanardagh area

1 – VES survey points and their sequence numbers; 2 – specific electrical resistivity of rocks forming the geological section; 3 – deposits composed of different rock fragments; 4 – clayey rocks; 5 – clays with alternating thin layers of sand; 6 – heavily watered layer; 7 – probable fault

The uppermost layer with a thickness of 3-7 m and $\rho_{s.e.r.}$ of 5-30 Ohm-m can be traced along the entire extent of the profiles. This layer is composed of different rock fragments and it is possible that these deposits are a potential landslide mass.

Profile VI-VI in the interval of VES No. 13-17 and profile VIII-VIII of VES No. 16-37 revealed probable faults in the north-south direction with a dip towards south-east (Fig. 3.).

To the northeast of the identified fault line, an increase in the $\rho_{s.e.r.}$ values of the rocks can be traced and presumably composed of clays with thin layers of sand.

In our opinion, the identified fault and the second layer of the section, which has very low electrical resistivity will provoke the movement of the landslide mass to the east.

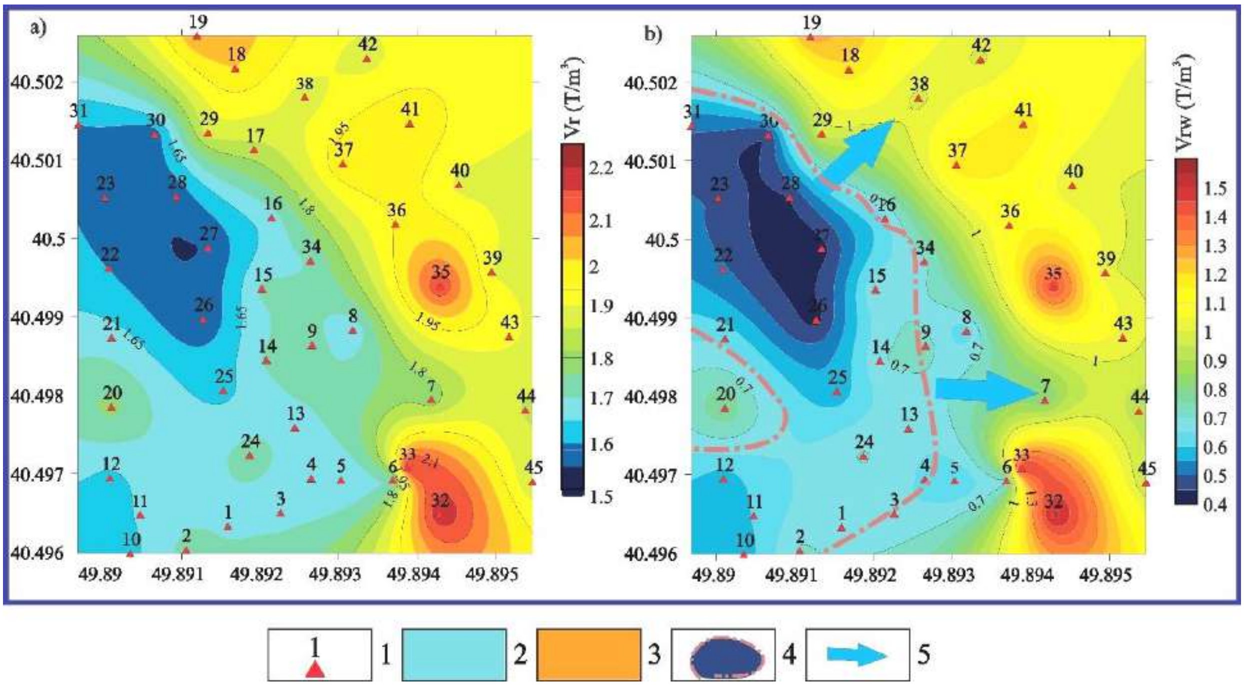

Fig. 4. Maps of expected averaged density values on rocks in the geological section (a) and rocks of the geological section under influence of water (b)
1 – VES points and their sequence numbers; 2 – area with an estimated density of 0.5-1.7 t/m^3; 3 – area with an estimated density of 1.7-2.1 t/m^3; 4 – area with an abnormally lower estimated density of 0.4-0.6 t/m^3; 5 – estimated direction of landslide mass movement

In order to more accurately identify the area most susceptible to the influence of EGP, maps of the probable average density of rocks forming the geological section (a) and the density of rocks under water (Fig. 4, b) were constructed.

According to the constructed maps, the probable density of rocks varies in the range of 1.5-2.1 t/m^3 (a) in the study area and in the range of 0.5-1.4 t/m^3 (b) under water respectively.

As can be seen from the maps compiled using the averaged values of rock densities (a) and (b), the study area is divided into two parts – the western part with low rock densities and the eastern part with relatively high rock densities.

On the map of the average rock density of under water, an area with density of 0.4-1.0 t/m^3 is distinguished, which is presumably an area subject to the intensive influence of EGPs. This area coincides with disappearance of part of the aqueous solution that flows out from the mud volcano mentioned above.

According to the map of the probable under water rock density, the allocated anomalous area seems to tend to connect with the apophysis of the mud volcano, which is located at the southwestern end of the study area.

As a result of acquired data analysis, it can be assumed with some confidence that in the event of activation of geodynamic and EGPs, the potential landslide mass will move to the south and south-east directions, approximately, towards VES No. 38-42, and 7-44 (Fig. 4, b).

As a result of the field data interpretation, maps of the potential landslide mass thickness (Fig.5a) and thickness of the probable sliding plane (Fig.5b) were constructed.

The potential landslide mass thickness (a) varies in the range of 1.5-8.5 m, and increases to the east. The thickness of the supposed sliding plane varies in the range of 1.5-6.5 m.

The map shows a pattern in which the probable sliding plane thickness decreases relatively from the west to east.

In order to obtain additional data on the rock water content degree, a map of the probable natural water content of the study area was constructed.

According to the probable natural water content distribution, the study area is approximately divided into two parts, i.e. the west is over-moistened and the east is relatively less moistened (Fig.6a).

It is confirmed that the water solution from the mud volcano manifestation penetrates into the geological environment and moistens it. It can be said that the main reason for the EGPs development is the soil subsidence formation, as well as the potential landslide massif formation in the study area is the water solution that flows from the mud volcano manifestation.

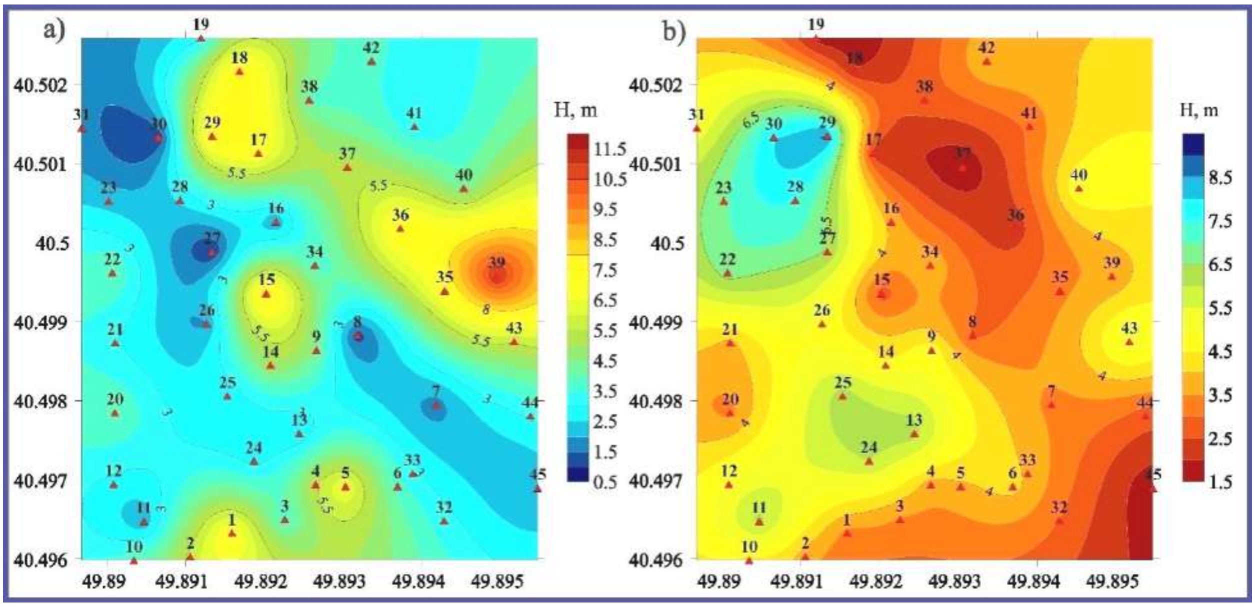

Fig. 5. Maps of the potential landslide mass thickness (a) and the probable sliding plane of the landslide (b) of the Yanardagh study area

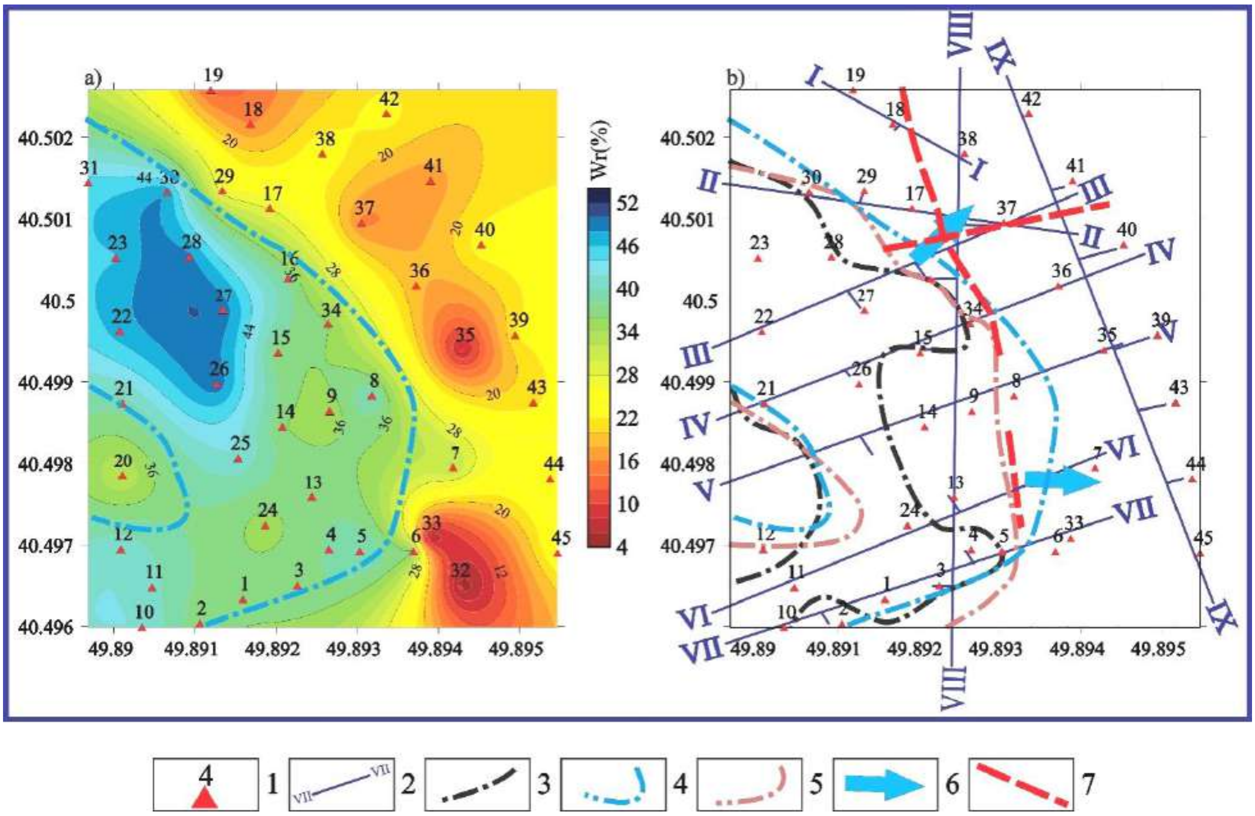

Fig. 6. Maps of natural rock moisture in the geological section (a) and the results of the Yanardagh geophysical research (b) area
1 – VES points and their sequence numbers; 2 – geophysical profiles; 3 – contour of low apparent electrical resistivity; 4 – contour of the abnormally moistened sediments; 5 – contour of the abnormal under water rock density; 6 – probable movement direction of potential landslide mass; 7 – probable fault identified based on VES data

Conclusion

As a result of the interpretation, we obtained:

– Three main layers were identified and subdivided to a depth of 30 m in the geological section of the study area;

– Three layers mainly composed of clays with different thickness and electrical resistivity were identified;

– Faults in the north-south and west-east directions were identified (Fig.6b);

– It was presumably established that in the western part of the study area the rock apparent and specific resistivity and their probable density decreases relative to the eastern part, and the rock natural water content increases;

– Water solution from the mud volcano manifestation flows to the north and along its way is absorbed to the east moistening the eastern part of the study area;

– As a result of moistening the eastern part, a potential landslide area is formed;

– The main reasons of EGPs development are flowing water solution (atmospheric precipitation) and revealed faults.

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ИССЛЕДОВАНИЕ РАЗВИТИЯ ЭКЗОГЕННЫХ ГЕОЛОГИЧЕСКИХ ПРОЦЕССОВ ВЕРТИКАЛЬНЫМ ЭЛЕКТРИЧЕСКИМ ЗОНДИРОВАНИЕМ НА ПЛОЩАДИ ЯНАРДАГ АБШЕРОНСКОГО ПОЛУОСТРОВА (АЗЕРБАЙДЖАН)

Саламов А.М.[1], Сафаров Р.Т.[1], Заманова А.Г.[1], Ахмедова Э.В.[2], Кахраманов М.Р.[1]

[1]*Министерство науки и образования Азербайджанской Республики, Институт геологии и геофизики, Азербайджан AZ1073, Баку, просп. Г.Джавида, 119*

[2]*Геологический факультет, Бакинский государственный университет, Азербайджан AZ1148, Баку, ул. акад. З. Халилова, 33*

**Автор, отвечающий за переписку: rafiqsafarov@gmail.com*

Резюме. В данной работе приводятся результаты изучения экзогенных геологических процессов на площади Янардаг, расположенной в северной части Абшеронского полуострова на расстоянии 27 км от Баку. В орографическом отношении полуостров является юго-восточным продолжением Большого Кавказа и занимает площадь около 2000 кв. км. Район геофизических исследований относится к числу редких памятников природы и образовался в результате вулкано-тектонических процессов и возгорания природных газовых потоков, вышедших на поверхность по трещинам. Эта территория окружает северную локальную зону грязевого вулкана Гырмаки. Полевые геофизические измерения методом вертикального электрического зондирования проводились по девяти профилям с использованием симметричной четырехэлектродной установки AMNB. В результате проведенных геофизических исследований были решены следующие задачи: детальное расчленение геологического разреза до глубины 30 м; выявление и трассирование вероятных разломов; определение некоторых вероятных физических параметров пород, слагающих геологический разрез. Были выделены три основных сложенных глинами слоя, имеющих различную толщину и электрическое сопротивление. На основе построенных карт усредненных значений предполагаемых физических параметров установлено, что западная часть площади наиболее подвержена воздействию экзогенных геологических процессов. Предположительно, основной причиной развития экзогенных геологических процессов является водный раствор, вытекающий из грязевулканического проявления, расположенного в юго-западной части исследуемой территории. В целях снижения скорости развития экзогенных геологических процессов, на исследуемой территории предлагается исключить попадание в геологическую среду вод, стекающих с грязевого вулкана.

Ключевые слова: *геофизика, грязевой вулкан, электроразведка, сопротивления, порода, плотность, разрывные нарушения*

ABŞERON YARIMADASININ YANARDAĞ SAHƏSİNDƏ EKZOGEN GEOLOJİ PROSESLƏRİN İNKİŞAFININ ŞAQULİ ELEKTRİK ZONDLAMA ÜSULU İLƏ TƏDQİQİ (AZƏRBAYCAN)

Salamov Ə.M.[1], Səfərov R.T.[1], Zamanova A.H.[1], Əhmədova E.V.[2], Qəhrəmanov M.R.[1]

[1]*Azərbaycan Respublikasının Elm və Təhsil Nazirliyi, Geologiya və Geofizika Institutu, Azərbaycan*
AZ1073, Bakı, H.Cavid prosp., 119
[2]*Geologiya fakültəsi, Bakı Dövlət Universiteti, Azərbaycan*
AZ1148, Bakı, akad. Z.Xəlilov küç., 33
**Yazışmalara məsul: rafiqsafarov@gmail.com*

Xülasə. Bu tədqiqat işində Abşeron yarımadasının şimal hissəsində, Bakıdan 27 km məsafədə yerləşən Yanardağ ərazisində ekzogen geoloji proseslər araşdırılır. Oroqrafik cəhətdən yarımada Böyük Qafqazın cənub-şərq davamıdır və təxminən 2000 km^2 ərazini əhatə edir. Geofiziki tədqiqat sahəsi nadir təbii abidələrdən biridir və vulkanik-tektonik proseslər və çatlardan səthə çıxan təbii qaz axınlarının alovlanması nəticəsində əmələ gəlmişdir. Bu ərazi Qırməki palçıq vulkanının şimal hissəsini əhatə edir. Şaquli Elektrik Zondlama metodundan istifadə edərək çöl geofiziki ölçmələri simmetrik dörd elektrodlu AMNB qurğusundan istifadə edərək doqquz profil boyunca aparılmışdır. Yerinə yetirilmiş geofiziki tədqiqatlar nəticəsində aşağıdakı məsələlər həll edilmişdir: geoloji kəsilişin 30 m dərinliyə qədər müfəssəl bölünməsi; ehtimal olunan qırılmaların müəyyən edilməsi və izlənilməsi; geoloji kəsilişi təşkil edən süxurların bəzi ehtimal olunan fiziki parametrlərinin müəyyən edilməsi. Müxtəlif qalınlığa və elektrik müqavimətinə malik gillərdən ibarət üç əsas lay müəyyən edilmişdir. Ehtimal olunan fiziki parametrlərin tərtib edilmiş orta qiymətlərinin paylanma xəritələri əsasında müəyyən edilmişdir ki, ərazinin qərb hissəsi ekzogen geoloji proseslərin təsirinə daha çox həssasdır. Güman edilir ki, ekzogen geoloji proseslərin inkişafının əsas səbəbi tədqiqat sahəsinin cənub-qərb hissəsində yerləşən palçıq vulkanı təzahüründən axan sulu məhluldur. Təklif olunur ki, tədqiq olunan ərazidə ekzogen geoloji proseslərin inkişaf sürətini azaltmaq üçün palçıq vulkanından axan suyun geoloji mühitə daxil olmasını aradan qaldırmaq lazımdır.

Açar sözlər: *geofizika, palçıq vulkanı, elektrik kəşfiyyatı, müqavimət, süxur, sıxlıq, qırılmalar*