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OUTLOOK ON GEOPHYSICAL INVESTIGATION OF KARSTIC ZONES IN ALBANIA.

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ABSTRACT

The paper presents the analysis of the integrated geophysical study results for investigations of the karstic zone in Albania. Electrical profiling and soundings, microgravity and micromagnetic surveys, TURAM and radiowaves methods, refraction seismic of high frequencies, and borehole logging, were included in geophysical complex. Technical construction design and works have been performed according to results of integrated geological-geophysical investigations.

1. INTRODUCTION

Albania is a mountainous Mediterranean country. Geologic, hydrogeologic, geomorphologic and climatic conditions of the country causes the intensive development of karst phenomenon. The karstic formations in Albania are mainly represented by carbonate and evaporite rocks. Triassic, Jurassic, Cretaceous and Paleocene are the ages of karstic carbonate rocks. Groundwater flow through altered and disjunctive tectonic zones of the carbonatic structure causes the tectonic karst development. The presence of the pseudokarstic holes in the subargillite cover in the karstic zones has observed.

There are many rivers streaming from the mountains where seven hydropower plants, with an installed power of 1427 MW have been builds. In Albania, have also been constructed about 250 big water reservoirs for agriculture irrigation purposes. The projection and construction of these works are preceded by detailed integrated geological-geophysical engineering studies. Boreholes have verified the results of these studies. A special attention is given to the study of the karst phenomenon: The detection of the karstic zones, caves, and to evaluated the dynamics of its development from surface to depth. The focus of this study is concentrated also on the loose cover deposits.

The study of the loose cover deposits, the separation of the karstic zone in bedrock and the detection of the cavities have been performed by applied of the electrical soundings and profiling, seismic refraction survey of high frequencies, gravity and magnetic micro-surveys, self potential survey and electromagnetic methods. The zone with unequal development of karst, the karstic lattices in the limestone, and cavities with certain dimension have been isolated. The process of the pseudokarst development in loose deposits has evaluated. The physical-mechanical parameters of the bedrock such as porosity, filtration coefficient, density, modulus of static and dynamic elasticity have been determined. Geophysical surveys have been performed by detailed scale 1:500 and even 1:200, with survey grid (1-2) x (2-5) meters.

The results of the geophysical investigation carry out in the framework of the integrated geological- engineering studies for the detection of the karstic zones, the discovery of the caves and the study of the loose deposits which cover the limestone have been analyzed.

2. GEOLOGICAL SETTING OF THE KARSTIC ZONES AND THEIR PHYSICAL PROPERTIES

Triassic, Jurassic, Cretaceous and Paleocene carbonatic rocks and Permian-Triassic evaporites are represented karstic medium in Albanian Mountains. Average monthly temperature of different areas varies from 2.3-10 up to 17.8-25.9 ^{o}C. The average annual rainfall is more than 1300 mm in Albania. Mediterranean humid climate, rugged relief of the limestone's slope mountains and intensive underground water flowing was created the conditions for development of the karst phenomenon. Are observed open or young karst and old buried karst. Karstic fields, with cuspate microrelief in the valleys, caves, and funnels are extended in the karstic zones. Channels, holes and caves were observed in the subsurface. Karst lattice, micro and macro-fissures are important element of the in karstic zones. Particularly, the karst phenomenon is developed intensively in the riverbed and their slopes. In some cases, the karst cavities are filled with clay or bauxite. The karst phenomenon is also present in the evaporites.

The holes, or pseudo-karst, are observed in the argillite cover mass, over the karstic limestone. Its tops are located at the depth from some centimeter to the some meters. Oval its transversal section has a diameter from some centimeters to 1x1.5 meters.

The petrophysical properties of the rocks in the karstic zones are different from the surrounding environment; therefore the geophysical anomalies can be obtained over karstic zones.

Limestone resistivity varies in wide range, depending by micro and macro fissures, by the lattice of the karst, holes, and the clay content. The compact limestone has resistivity values up to 12 000 Ohm-m. The presence of the clay material decreased the resistivity value. Jointing and karst lattices filled with water or clay material are conducting channels. In these cases, limestone resistivity is decreased up to some tens of Ohm-m Tab.1).

Tab. 1

RESISTIVITY OF THE ROCKS IN KARSTFIED ZONES

ROCKS	RESISTIVITY, in Ohmm		
	Minimal	Maximal	Mode
Grey to white subargille	22	50	30
Subargille	25	60	40
Brown subargille	40	80	60
Reddish subargille	60	150	105
Subargille with carbonate material	110	254	180
Karstic limestone; karst lattices filled with clay	155	400	260
Altered limestone	150	1000	600
Compact limestone	1000	15 500	3000

Loose subargille, silt, sand and rarely gravel, or cemented slope clastic breccia represents the cover deposits over the limestone. All these deposits, generally, have a smaller resistivity than the limestone (Tab. 1). Their resistivity depends by the content of the clay, sandy and even carbonate material. In the case of the high content of the carbonate, the subargilles have resistivity values between 110 and 254 Ohmm. There is also a relation between the resistivity of pure subargille without carbonate material and the filtration coefficient.

According to the mathematical and physical modeling, over the karst cavities it is possible to observed increasing of the resistivity and their anomalies (Fig. 1, 2). The empty cavities, with a section of 3 m^2 and located at a depth of 5 m, within compact limestone, cause apparent resistivity anomalies. The underground corridors with 2 meters of square section cause weak anomalies. They may be detected at a depth of 3,5-7 m. There are weak anomalies over the chimneys, which are filled with loose clay over on the subargille deposits. If these holes have a diameter of 2 m and occur at a depth of 2-3 m then they are detectable.

Resistivity is changes in vertical direction, too. The subargilles cover deposits represent first geoelectrical layer (Fig. 3). This layer is characterized by the presence of the furrows; holes and funnels as they often filled with altered material. The altered material content is 10-15 %of the rock volume and reach a depth of almost 5 m. Below this layer, there is the second geoelectrical layer, which can be called as the alteration zone. The caves, corridors of the underground channels, which reach up to 10 % of the rock volume, are empty, where the zone is located above the groundwater level. For this reason, the resistivity of second layer is high. The thickness of this layer varies, depending on the karst forms of the limestone and the shape of the relief. The third geoelectriacal layer shows the signature of $\rho_1<\rho_2>\rho_3$. This is because; the less dense karst lattices are filled with water. Lower geoelectrical layer is represented by compact limestone, with higher resistivity than that of all overlying layers. Fig. 3 presents the sounding resistivity curve KH type ($\rho_1<\rho_2>\rho_3<\rho_4$) of karstic zone. Depending on the thickness of layers, A type geoelectric section is also possible ($\rho_1>\rho_2>\rho_3$).

Subargilles, which are filled karstic cavities and lattices have induced polarization chargeability about 20-30 mV/V.

The lattices system and empty karstic elements are caused electrical anisotropy of the limestone. The anisotropy coefficient varies from λ=1.1 up to 4.85. The rose diagram of apparent resistivity in the karstic rocks, have the main directions with discordance by direction of the stratification.

Limestone are characterized by high density, which varies 2440-2700 kg/m^3, with an average values 2660 kg/m^3. Their density depending from the geological age and presence of the micro and macro fissures. The empty caverns are characterized by a density contrast of about 2600 kg / m^3. The mathematical modeling shows that the gravity anomalies caused by small cavities, with a radius of 0.2 m, can be observed only when the cavity top are at the depth 0.3 m, with a minimum amplitude of the Bouguer anomaly of 0.03 mGal (Fig. 4). The huge cavities with a diameter of 15 m may be detected at a depth of 18 m. The density contrast is smaller for the cavities, which are filled with water or clay. Therefore, is decreased the depth of their investigation. The karstic phenomenon is accompanied with the micro and macro fissures. Consequently is decreased the density of the karstic zones. This supplementary reduction of density occurs in a larger area in comparison with the size of the cavern. This causes an increase on the amplitude of the gravity anomalies. Following, the depth of gravity surveys increases. Their density reduces to 1130 kg / m^3 when they are loose and dry.

Magnetic susceptibility (40-120) x10-5 SI units characterize the subargilles. This created the condition for creating of the magnetic anomalies over the karstic caves filled with clay material.

According to the mathematical modeling, the cave with a diameter of 4 m, which is located at 2 m depth, below the Earth surface, can be caused an anomaly with amplitude 5 nT.

Seismic waves velocity decreased up to 1 660 m/sec in karstic limestone, which is three time smaller that velocity of the compact limestone (5 000- 6 000 m/sec).

3. THE SURVEY CONFIGURATION

The petrophysical properties of the rocks in the karstic zones are different from the surrounding environment; therefore geophysical anomalies can be obtained over karst zones.

The application of geophysical methods has been necessary, and these methods have been priority over the other classical geological exploration methods, especially for the study of the covered loose deposits over the karstic rocks. The purpose of the geophysical surveys is the discrimination of the zones, which need a special care during the construction of the hydrotechnical works, to avoid filtration and to prevent constructions against the action of the hydrodynamic and hydrostatic pressures. The thickness of the loose covering deposits and their layered structure has been determined. The variations of the top of bedrock and the relation between the loose deposits and bedrock have been investigated. The structure of the bedrock was performed. The zones with unequal development of karst and the karst lattices in the limestone and particular caves have been isolated. The process of the karst development, and the physical-mechanical parameters of the bed-rocks and loose deposits such as porosity, filtration coefficient, density, modulus of static and dynamics elasticity have been evaluated.

Such a broad scope of the problems to be solved by geophysics made necessary the application of surveys by the very detailed scales, 1:500 and even 1:200. Survey grid has been (1-2) x (2-5) m. Have been applied different methods, such as electrical profiling and soundings, gravity and magnetic micro-surveys, self- potential and induced polarization survey, radiowave method, TURAM method, high frequency seismic refraction surveys, and borehole logging.

Electrical profiling were performed with multiple Schlumberger array $A_1A_2A_3MNB_3B_2B_1$. Volumes of the 5-25 % from the electrical soundings were performed with multidirectional array, to electric anisotropy study. Electrical profiling have been carried out by pol-dipol array AMN, $B \rightarrow \infty$, with spacing AO = 10- 300 m. The surveys were performed in two levels:

- In the upper level, at a depth of 10 m, for the search of cavities in the loose cover, and
- In the limestone near the surface, as well as in the lover level, to detect the karst cavities within the limestone.

In some cases have been used the TURAM survey and the method of radio waves with frequencies up to 10 MHz. Induced polarization survey have been applied for the selection of the cavities filled with clay from cavities filled with water. The self- potential surveys have been carried out before and after the raining. The electrical measurements have been conducted with RDC-10 SCINTREX receiver.

The gravity survey has been carried out by a gravimeter with a sensitivity of 0. 01 mGal. Short measured period, than 1 hour, has permitted the observation of anomalies with amplitude of 0.1 mGal. The gravity survey was used prior the other geophysical methods for finding the karst cavities.

The magnetic survey were done with the proton magnetometer of they type MP-2 SCINTREX with sensitivity of 1 nT. Measured values were corrected for diurnal variation. The mean average square error of the surveys was not more than 4-5 nT. Magnetic micro-survey is used for selection of the caves filled with clays from the empty ones.

Seismic refraction surveys were conducted with a 6-trace seismograph. In every channel longitudinal (P) and the transverse (S) waves were recorded, at a distance 0; 2; 3; 5; 10 and 25 m.

For investigation of the underground water infiltration ways have been carried out self-potential surveys. Surveys were performed during the dry period and after the rains. Self-potential anomalies have great amplitude when are observed after the rain. In this case, the water infiltration process is developed intensively and the anomalies are amplified.

Electrical (resistivity and self- polarization-SP) and gamma-ray logs also carried out in boreholes with. The logging plots recording were conducted at scale 1: 50. The correlation between the physical and mechanical properties is made by statistical methods by using the results of in situ and laboratory sample measurements.

4. DISCUSSIONS OF THE RESULTS

The results of geophysical surveys carried out in some karstic zones in Albania will be analyzed.

The water reservoir, near of the Shkodra city in Northwest part of Albania, is located over the Triassic-Jurassic karstic limestone. Clays, subargilles, silt and sand of deluvial- provulial loose deposits are covered the karstic limestone. According to the electrical sounding results, loose cover deposits have a thickness, which varies from 1-2 m to 26 m. In some sectors of the reservoir area were observed the KH and HA types sounding curves are of (Fig. 5). The karst phenomenon is developed in these sectors. There are observed also an electrical anisotropy of the limestone. In the deepest sectors of the valley, the karstic limestone are eroded. Consequently, were observed two-layers sounding.

Resistivity and gravity anomalies have been observed also over the limestone blocks or deepening of the limestone top. Fig. 6 presents the Bouguer anomaly map in irrigation reservoir in Vlora district in southwestern coastal zones of Albania. Reservoir is located over a Jurassic-Cretaceous karstic carbonate and carbonate-clay breccia formation. There are observed five Bouguer anomalies (Fig. 6). Anomalies G-1, G-2, and G-3, according to the complex interpretation of the gravity survey data and electrical profiling and soundings, have been concluded that these anomalies are located over the sectors where is increased the thickness of the loose cover deposits. Anomalies G-3 and G-4 are coincided with the Self-Potential anomalies. This fact is an argument for the kartic origin of the gravity anomalies G-3 and G-4.

The karst cavities and lattices which are filled with clay, have been selected by magnetic and the induced polarization data. Over these sectors, magnetic and induced polarization anomalies are observed (Fig. 5). These sectors are also clearly seen in the borehole logging plots, by increasing of the intensity of natural gamma radiation.

The karstic zones were also observed by refraction seismic surveys. In the time sections have been indicated that there is a three layered section in the right one. The upper layer has a wave propagation velocity of V_1= 3100 m/sec, the second one V_2 = 1660 m/sec and the third one V_3 =

5000 m/sec. The second layer, with low seismic wave velocity, shows the presence of the karstic limestone.

Fig. 6 presents the field-potential anomalies in the irrigation reservoir. The self-potential anomalies have been well contoured the water infiltration ways.

The loose clay and subargilles deposits, that cover the limestone in the studied karst zones, have relatively higher resistivity values, varying between 20 and 80 Ohm-m. This reveals that they are carbonatic or permeable. In different reservoirs, some holes were found in the loose deposits, that covers the karstic limestone. Over these holes, a maximum of the apparent resistivity and minimum of the gravity force were observed (Fig. 7). Both are weak anomalies. Resistivity anomalies have the amplitude about 20-50 Ohmm. These anomalies are also similar to the anomalies are observed also in buried limestone block. The density of the clays and subargillites varies between 1800 kg / m^3 and 2000 kg / m^3. The amplitude of the gravity anomalies is increased for the second derivative of the vertical component of the gravity g_{zz}. But, such minimum are found also in cases where the thickness of the loose deposits increases. Consequently, the resistivity method and gravity survey is necessary to use in complex.

5.CONCLUSIONS

1) Karstic zones and the underground cavity detection have been performed effectively by the integrated geophysical methods.

2) The karstic zones can be separated from the compact limestone by the KH and HA or A type of the resistivity sounding curves and by the electrical anisotropy. In addition to the resistivity method, have been used the high frequency seismic refraction surveys. The caverns that have a radius about 1 m and are located close to Earth surface have been detected by using conventional gravimeter with sensitivity of 0. 01 mgal.

3) Selection of the caverns filled with clay was performed by application of the induced polarization soundings and magnetic micro-survey, in complex with the resistivity soundings. Good results are also obtained by the method of high frequency radio-waves method, with a frequency up to 10 MHz, during the salt mine investigation.

4) Detection of the holes in the loose subargille cover deposits is possible to be performed by the electrical profiling and the gravity surveys.

5) The boreholes logging, electrical, radioactive and acoustic logs, have been permit to evaluated physical properties of the rocks and loose deposits, and verify results of the geophysical surveys. The evaluation of the physical properties is necessary to base also in the laboratory determination of the samples.

6. REFERENCES

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Fig. 1. Amplitude of the anomalies of the apparent resistivity over a cubic cave, according to the 2D physical modeling. Top of the cave is located at depth 7 m. Cubic side 5 and 15 m (a/h=0.71 and 2.14).

Fig. 2. Amplitude of the anomalies of the apparent resistivity over a vertical prismatic cave, according to the 2D physical modeling. Top of the cave is located cave at depth 15 m. Prism has a base 2 m and height 10 meters.

Fig. 3. Resistivity and Induced Polarization sounding curves over a vide karstic cave and filled with water cave.

Fig. 4. Dependence of the radius of sphere cave by depth of their top. Cave is caused gravity anomaly with an amplitude 0.03 mGal. Filled with water cave has a density contrast -1600 kg/m^3 and empty cave –2600 kg/m^3.

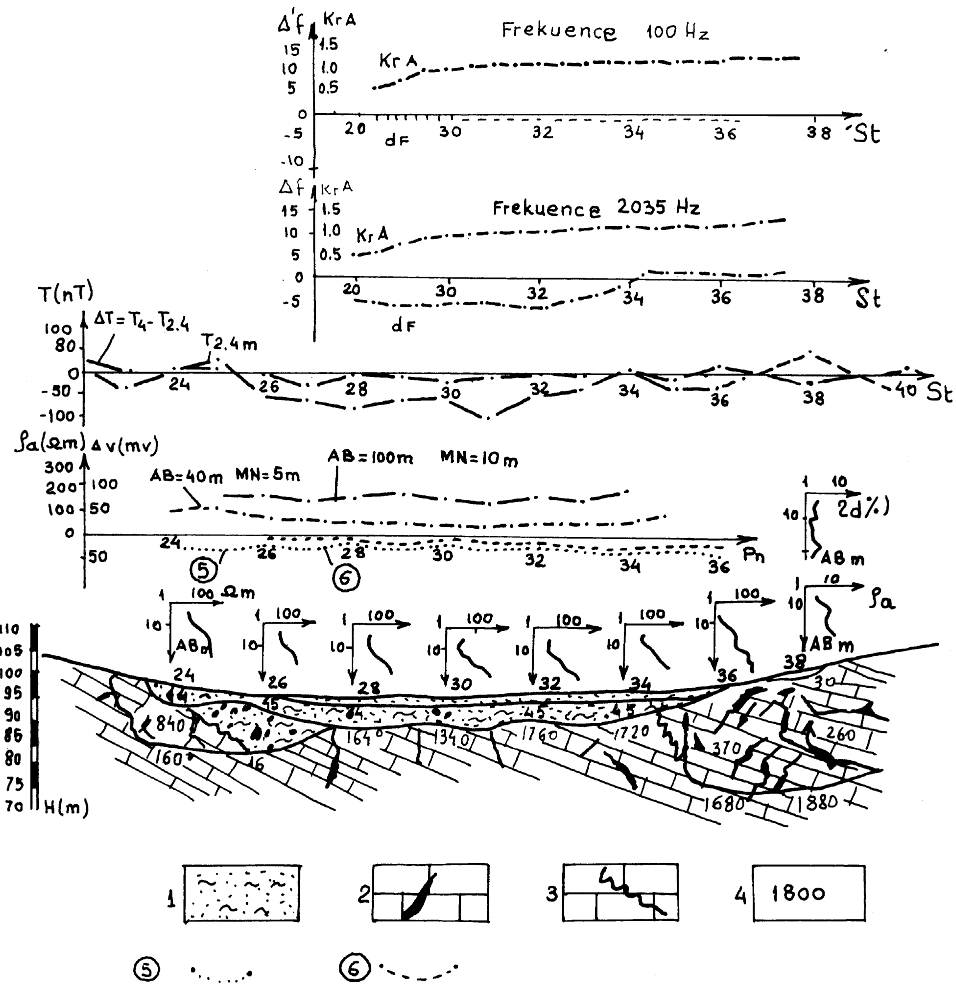

Fig. 5. Integrated geologic-geophysical section of the observed line in the reservoir near of the Shkodra city.

1. Subargille cover; 2. Intensive karstified limestone; 3. Karstified limestone; 4. The values of the resistivity, in Ohmm; 5. Self-Potential observed after the rain; 6. Self-Potential observed in dry weather.

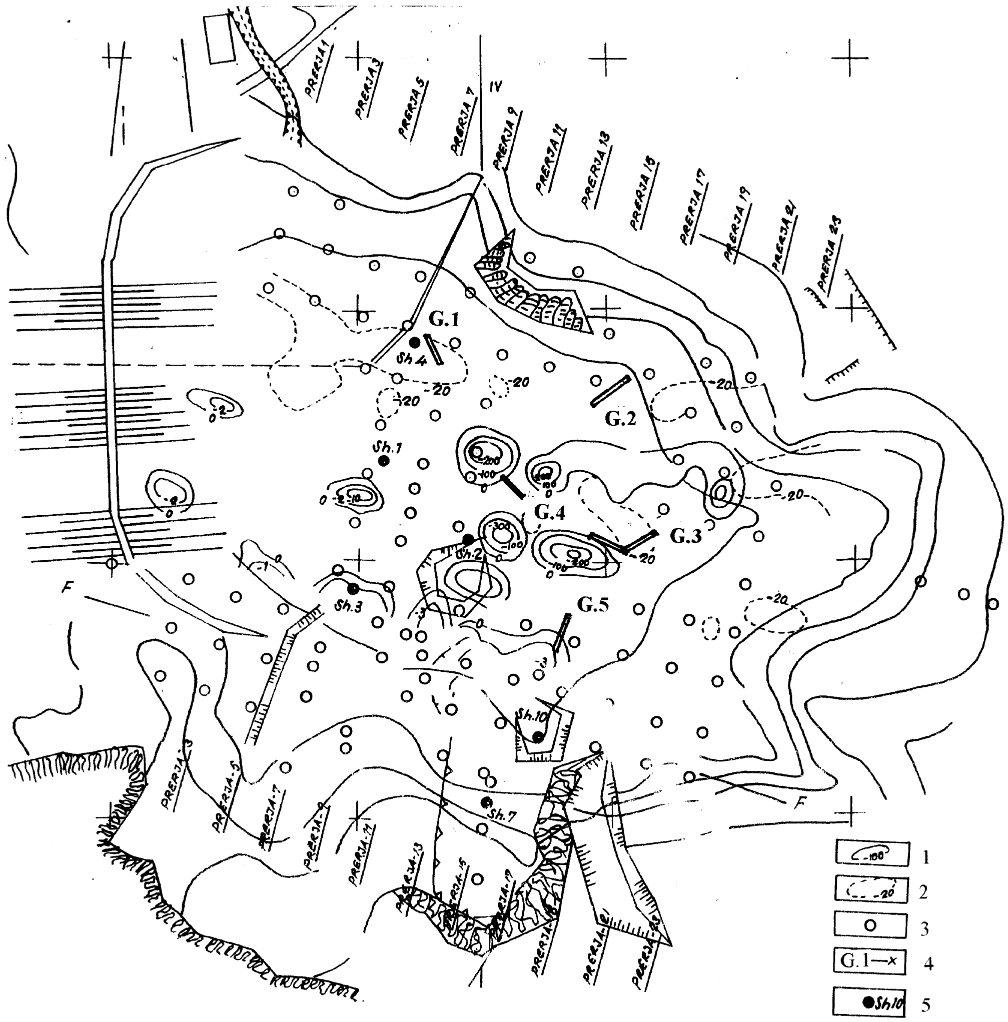

Fig. 6. Bouguer anomalies and Self-potential anomalies in the reservoir near in the Vlora district.

1. Self-potential contours observed in dry period; 2- Self-potential contours observed after the rain; 3- G.1- G.5- Bouguer anomaly axis; 4- Electric sounding center; 5- Borehole.

Fig. 7.