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APPLICATION OF THE INTEGRATED GEOPHYSICAL METHODS FOR KARST INVESTIGATIONS

Karst Araştırmalarında Jeofizik Yöntemlerin Birlikte Kullanımı

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ABSTRACT

The development of the karst phenomenon, the types and forms of karst in the limestone rocks, and the pseudokarst in the loose vision deposits which have been encountered during the construction of many hydroenergetic works in Albania have been discussed. The results of the geophysical investigation conducted in the framework of the integrated geological-engineering studies for the detection of the karst zones, the discovery of the caves and the study of the loose deposits which cover the carbonatic rocks have been analyzed and the determination of the physical-mechanical properties have also been included in the above mentioned framework.

ÖZET

Arnavutluk'ta hidroenerji amaçlı yapımlar sırasında karşılaşılan karst oluşumunun gelişimi, kireçtaşlarındaki karst tür ve biçimleri, gevşek tortulların içindeki pseudokarstlar tartışılmıştır. Karst zonlarının bulunması, boşlukların ortaya çıkarılması ve karbonatlı kayaçlar üzerindeki gevşek tortulların araştırılması için jeolojik-mühendislik çalışmalar çerçevesinde gerçekleştirilen jeofizik etüdlerin sonuçları incelenmiş ve mekanik özellikler de çalışmaya eklenmiştir.

INTRODUCTION

The Albanides are parts of the folded Alpine Mediterranean belt and 23% of the surface of this territory of Albania is covered by carbonatic rocks. The major rivers of the country and, even the shortest one has formed a deep valley in the carbonate rocks. There are big hidroenergy dams in these valleys. The projection and construction of these works are preceeded by detailed integrated geological-engineering studies. In this content, geological mapping, various geophysical methods as well as laboratory and field determinations of the physical-mechanical properties of the loose deposits of the surface cover and the bedrocks have been carried out. The results of these studies have been verified by boreholes.

A special attention is given to the study of the karst phenomenon, the detection of the karst zones and understanding of the dynamics of its development from surface to depth.

This special attention is extended to the finding of the caverns and the process of their formation for every concrete case. The focus of this study is concentrated on the loose superimposed deposits.

A BRIEF OUTLOOK OF THE KARST AND ITS DEVELOPMENT IN ALBANIDES

The karstic rocks in Albania are mainly represented by carbonatic and evaporatic rocks. They spread over the southwest, north and northwest parts of Albania (Fig. 1). The age of the karstik rocks is Trias, Jurassic, Cretaceaus and Paleogene. The Permo-Trias evaporides are mainly encountered in the northeast, central and southwest regions of the country.

Geologic, hydrogeologic, geomorphologic and climatic conditions of the country cause the intensive development of the karst phenomenon. The limestone has more than 90% $CaCO_3$, the plateaus of the mountain belts have moderate steepness of they have rough relief, so suitable conditions exist for the development of the karst phenomenon. Karstification is also developed in the western steep slopes of the coastal mountains, because of the humidity due to sea. The average annual tempareture is 12 C in the south of the country and 8 C in the Alps of Albania. The average annual rainfall is more than 1300 mm^3.

The massive upper Trias age limestones and thick-bed

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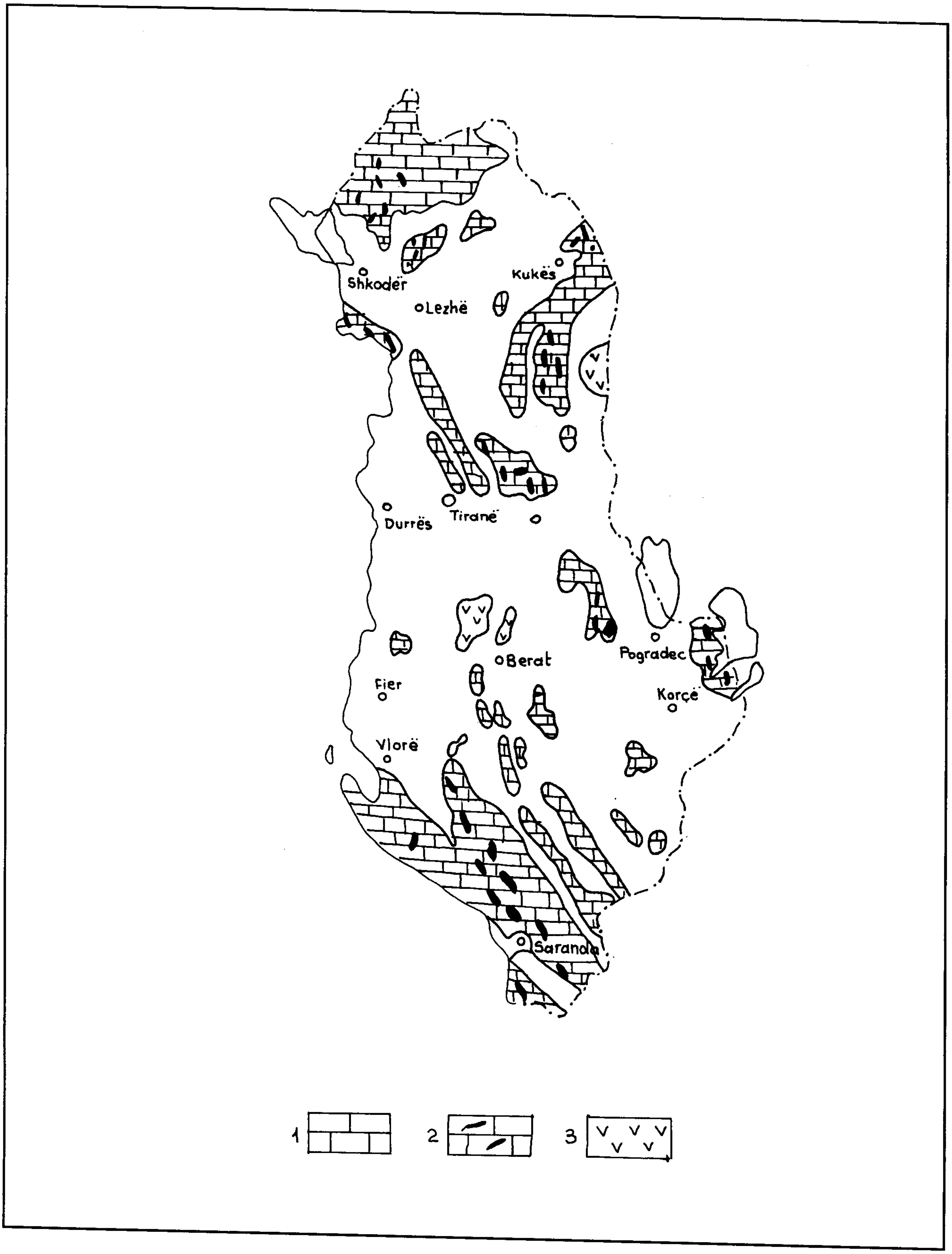


Fig. 1. Simplified geological map of karstic regions of Albania. 1) Limestones, dolomites; 2) zone with intensive karst; 3) gypsum and anhydrite.

layered limestones of Cretaceous-Eocene are much karstified. The Eocene age limestones are also karstified. Karst is weakly developed in the lower and middle Trias age limenstones. Jurassic and Cretaceous rocks are altered with siliceous and clay layers in some regions. The studies have shown existence of the open karst or young and the old karst (the buried karst). The open karst is presented by cuspate microrelief in the valleys, caves, funnels and karstic fields with surface of hundreds of square kilometers and with residue of the altered material (Photos 1, 2, 3, 4). This karst has been created channals, grottos, wells and caves in the subsurface (Photo 5). Groundwater is drainaged in the form of huge karstic springs. (A) type of karst is developed (Fig. 2a) when the limenstone is placed over the ophiolides and Creatacous-Eocene age limenstone. This formation occurs at the crest of the anticline and take placed above the impermeable rocks. The occurence of this phenomenon is shown as type B which has been encountered in the massive caused by the flowing surface waters (Fig. 2b). The river valleys in the limenstone are the deepest drainage sectors of the groundwater, therefore the karst phenomenon is developed through both sides of the valleys. Karst is also developed through the river bed, in sectors where the lowering of the erosion base of rivers are accompanied with the corosion and the dissolution of the limenstone. Otherwise, karst is developed only at high levels without necessity of reaching the erosional base of the rivers. These rivers show rapid vertical movement of the territory in the valleys between the massive Upper Trias limestone with steep dips which has a similar characteristic of the karstic nearby valley where the slope of the karst is prominent (Fig. 3). In this hydrodnamic karst type, there is also such a kind of karst participation which is developed near the contact of the limestones with the impermeable rocks (Fig. 4).

The disjunctive tectonic is often encountered in the limenstone structures of the Albanies. Groundwaters circulate through altered zones and that is the reason of the tectonic karst development. It is especially spread at over the intersection points of the longitudinal and transversal faults where many karst springs exist. Due to the structure of limestone in Albania, it is also possible to meet the old karst, which is generally linked with the stratigraphic gap of Trias, Lower Jurassic, Cretaceus and Paleogene, proved by deep boreholes. The karst cavity is filled with clay and bauxite.

The karst phenomenon is also present in the evaporites. Their weak physical-mechanical properties provide the possibility for karstic lattice to be closed by evaporites fall and as a result of this holes, they are formed on the earth's surface. These holes, today, constitute the small lakes, especially in the Belshi zone (Central Albania).

During the construction of the reservoirs, the presence of the pseudokarst in the form of hollows or pipes in the subargillite covers of the karstic rocks has become evident (Fig. 5). The pipe shown in the figure beginning with a karst funnel in the limestone is at a depth of 10-15 m. Its peak is 2.5 m below the earth surface. Its transversal sector is oval with dimension of 1x1.5 m. The pipe is formed by suffacation process which had been filled with the loose earth material with the humidity of 30-35 % and up to 0.5 m under its lintel. Some of these pipes outcrops. Many empty pipes with a diameter of 0.1-1 m exist in the karstic fields. If there is no outcrop, they cause problems for reservoirs water.

GEOLOGICAL INTERPRETATION BASED ON GEOPHYSICAL SURVEYS

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

Electrical Survey

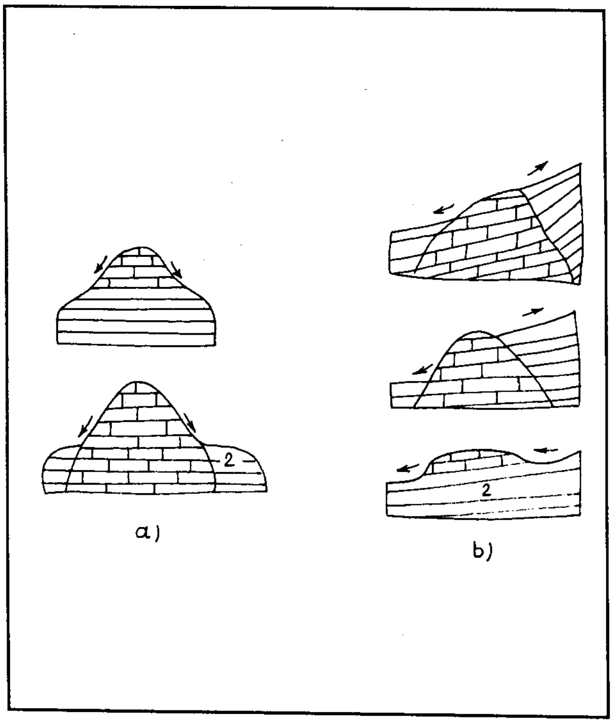
Resistivity of the limestone and the evaporites are high. The range of its variation is wide, depending on the degree of argillization, jointing and the lattice of the karst hollows (Fig. 6). The compact limestone has resistivity values up to 12000 ohm-m. The presence of the clay material lowers the value of resistivity. Jointing and karst lattice make an ifluence only when the cavities are filled with water or clay material and serve as semiconducting channals. In these cases, their resistivity is reduced in some tens of ohm-m. For this reason, the resistivity is not the same for different zones of karst lattice in the vertical direction. It is relatively low in residues solution zones which are characterized by furrows, holes and funnels as they often filled with residues of the altered material. These hollows consist 10-15 % of the rocks volume and reach a depth of almost 5 m. This zone represents the first geoelectrical layer with resistivity of P_1. Below this layer, there is the second layer which can be called as the alteration zone. The pipes, corridors of the underground channals, which reach up to 10 % of the rock volume, are empty when the zone is above the grounwater level. For this reason, the resistivity of top layer is smaller than that of the second layer. The thickness of this zone is different, depending on the joints of the limestone and the shape of the relief. The transition zone is under the second layer. The third geoelectrical layer shows the property of $P_1 => P_2 < P_3$. This is because, the less dense karst lattive is filled with water. The fourth geoelectrical layer is represented by compact limestone, and consequently its resistivity is higher than that of all overlying layers. In this way, in the karstified zones, the geoelectrical section is KH type ($P_1 < P_2 > P_3 < P_4$) (Fig. 2a). Depending on the thicknesses of layers, A type section is also possible ($P_1 > P_2 > P_3$) (Fig. 8, 6).

If karst is not present, the section changes. When the cavities of the transtion zone are filled with clays, the resistivity decreases and induced polarization amplitude increases (Fig. 2b). Induced polarization helps to distinguish them from cavities filled with water (Fig. 2a).

The joint system and empty zones cause electrical anisotropy in the limestone. The anisotropy coefficient is from $\lambda=1.1$ up to 4.85. In the karstified rocks, the rose diagram of apparent resistivity soundings measured in different directions, as a rule, shows main directions which disagree with stratification. The unkarstified limestone does not always have anisotropy and the rise of apparent resistivity values are almost isometric (Fig. 9).

The deposits that cover the limestone in the karst zone, may be cemented (as breccias of the mountain slopes) or loose made up of clays, subargillite, alevrites, sandsilt, sands, and rarely gravels.

All these deposits generally have a smaller resistivity than the limestone (Fig. 2). Their resistivity depends on the content of the siltstone, sandy and even carbonate material. In the case of the high content of the carbonates, the clays have



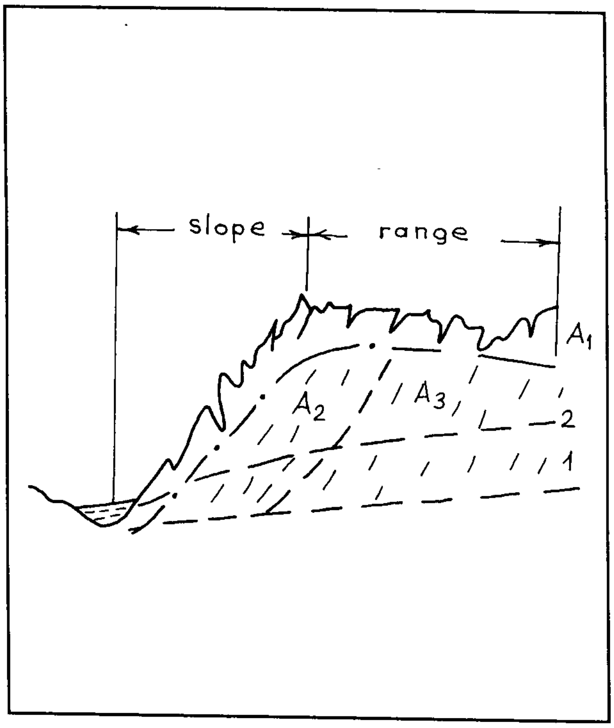


Fig. 2. The karst type A(a) and B(b).

Fig. 3. The sketch of karst development in the zone of Vau i Dejes in Drini river. 1) Basis of karst development, 2) water table.

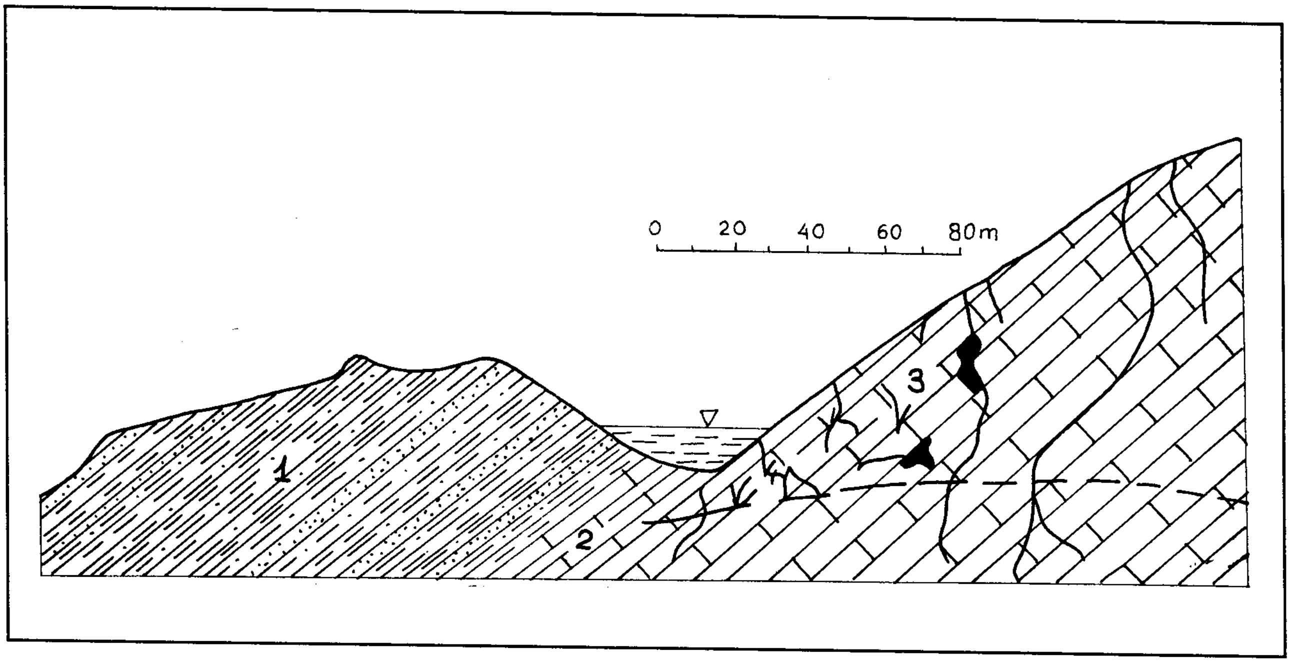


Fig. 4. Cross-section of the reservoir in Cafe Priske near Tirana. 1) Flysch Oligocene, 2) layered marl, 3) karstified Eocene limestone, 4) water table.

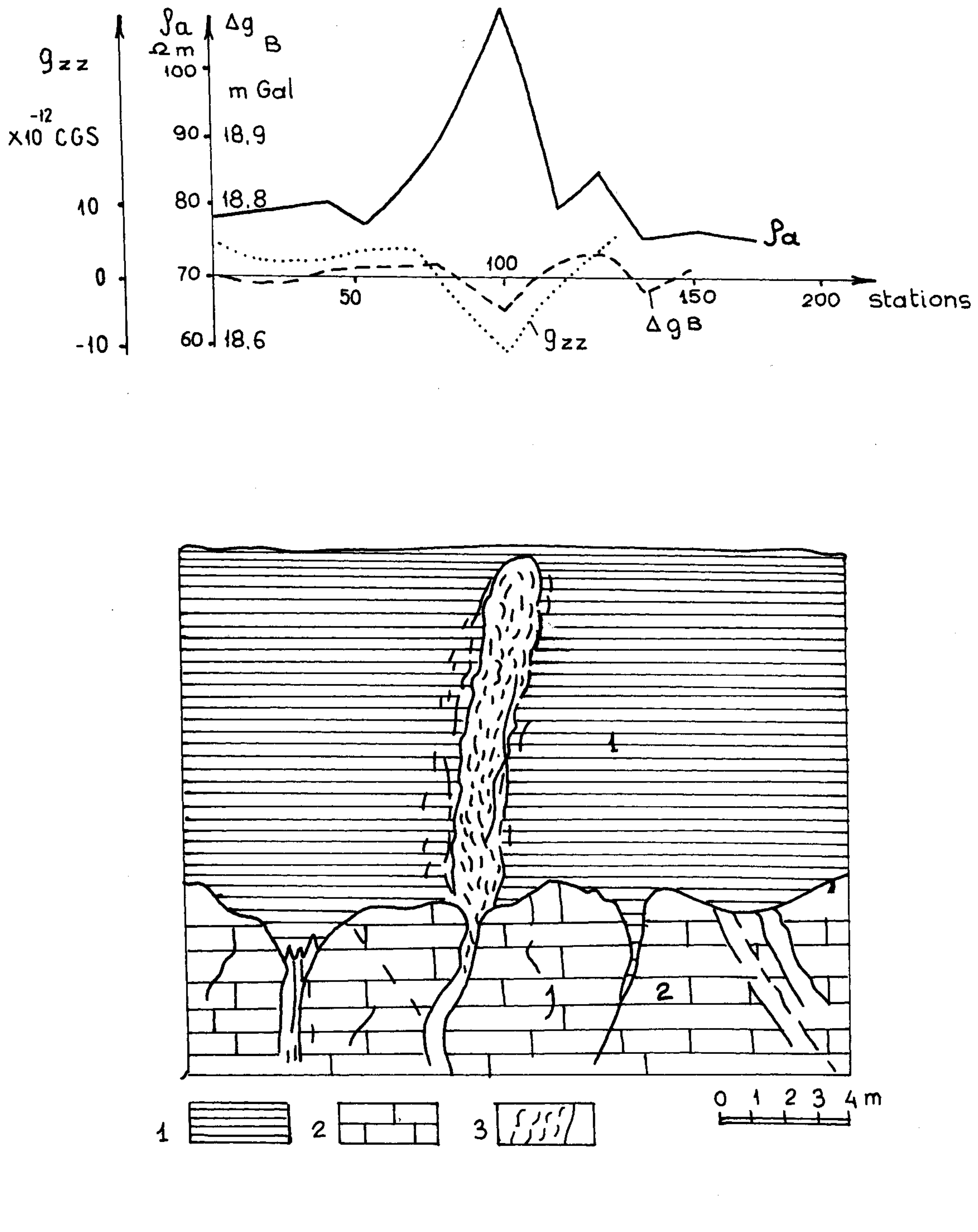


Fig. 5. Cross-section of a suffocation pipe (pseudokarst) in the subargillite cover and the corresponding geophysical anomalies. 1) Limestone, 2) plastic subargillites, 3) loose clay material.

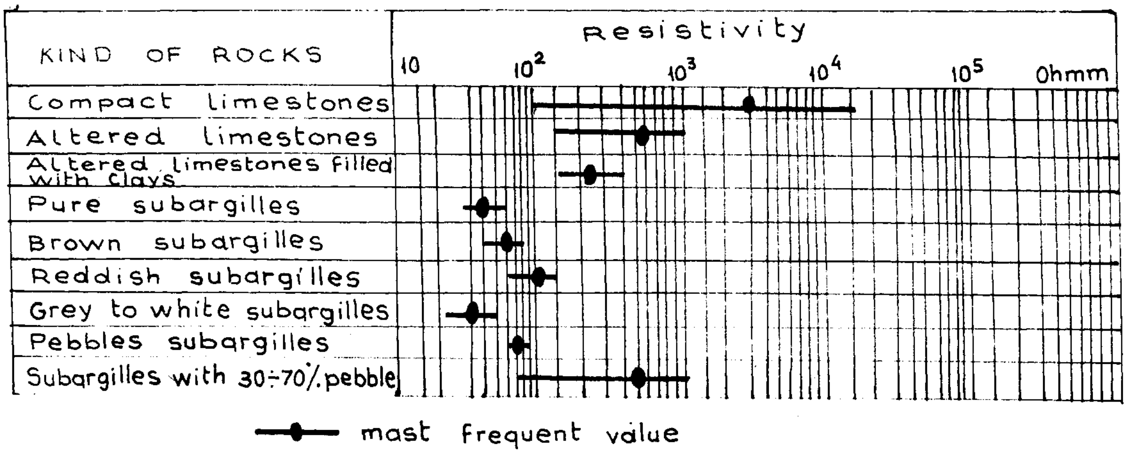


Fig. 6. Variation of the resistivity of the limestone and the overlaying deposits of subargillite in the karst zones.

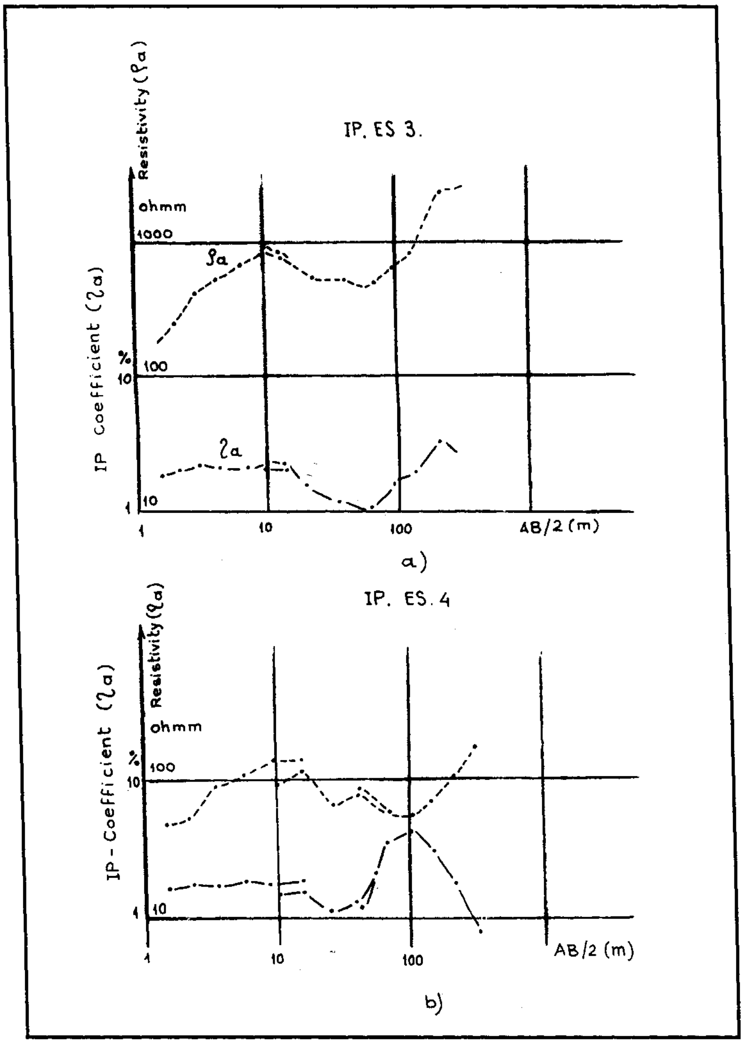


Fig. 7. Apparent resistivity curve of KH type obtained with electrical sounding over the karst zone, and the coefficient of induced polarization over karst zones with cavities filled with water (a) and clay (b).

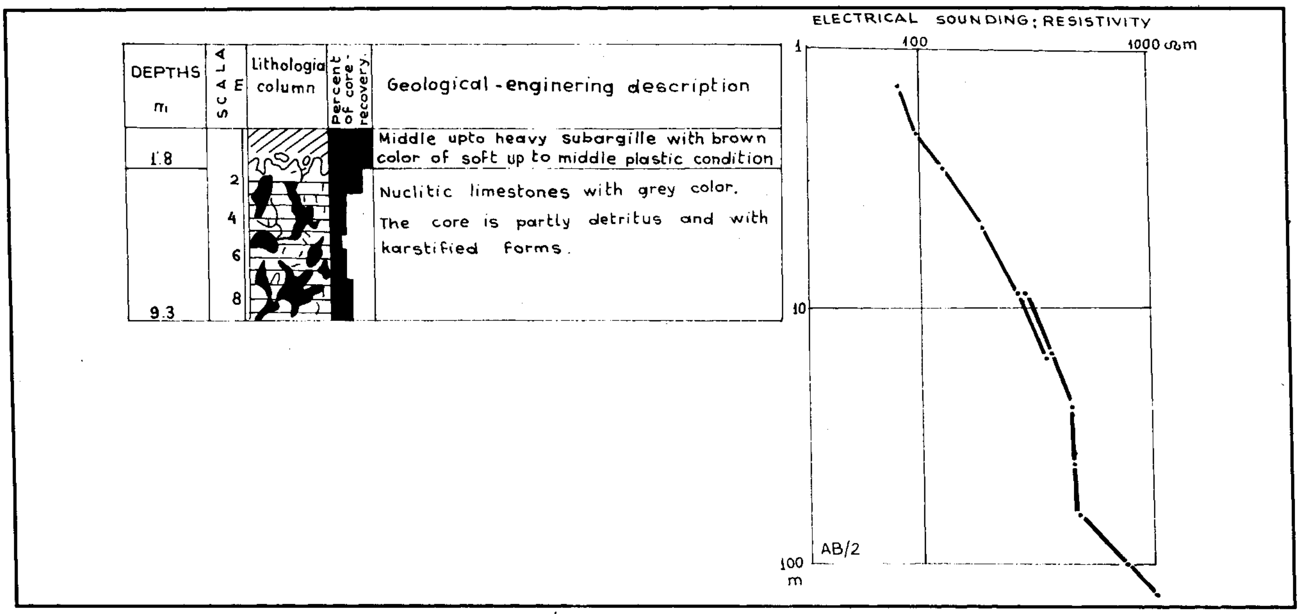


Fig. 8. Apparent resistivity curve of type A over the karst zones.

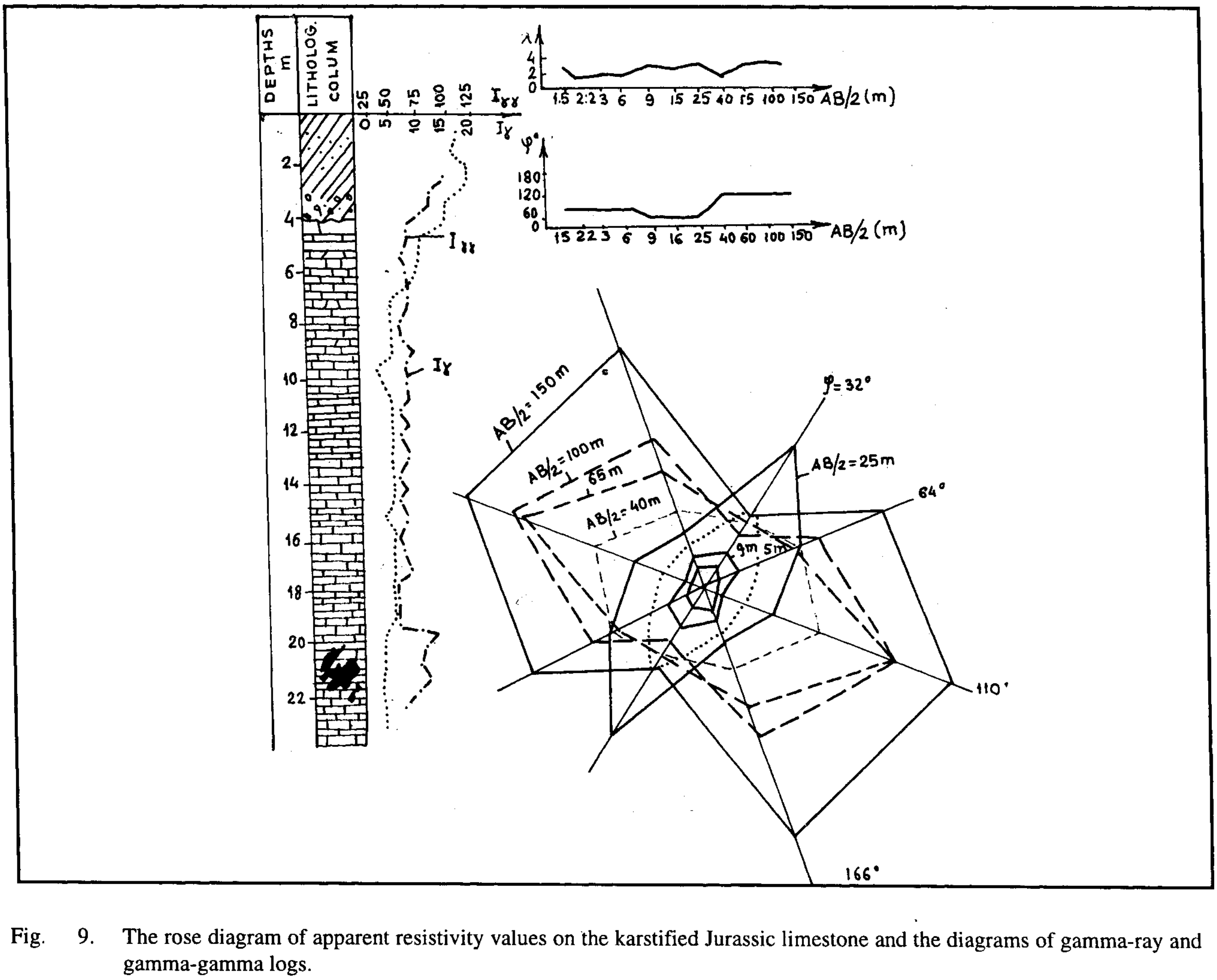


Fig. 9. The rose diagram of apparent resistivity values on the karstified Jurassic limestone and the diagrams of gamma-ray and gamma-gamma logs.

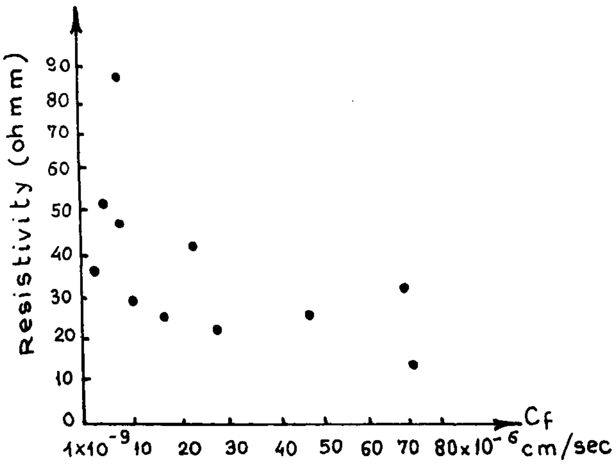


Fig. 10. Resistivity versus the filtration coefficient of subargillite.

resistivity values between 110 and 254 ohm-m. There is also a relation between the resistivity of pure subargillite without carbonate material and the filtration coefficient (Fig. 10). But, we should keep in mind that the resistivity of the loose deposits may change greatly depending on the content of the granules even for the same coefficient of filtration.

The resistivity of the loose clay and subargillite deposits change in vertical direction as a result of jointing (Konomi and Kapllani 1987). Generally, resistivity is reduced 3-4 times in comparision of the resistivity of the top 100 cm.

The above idea helps make a decision about resistivities of the rocks and the deposits in some karst zones.

Firstly, zones of the limestone and the evaporites with unequally degrees of karstification may be separated by using the resistivity method and the low frequency electromagnetic method (TURAM).

Secondly, there are well mapped loose deposits and their physical-mechanical properties are determined through these methods.

Thirdly, finding empty caverns in the limestone is possible by the help of joints, but the increase of the apparent resistivity on these caverns cannot be discerned from the anomaly on sectors of the compact limestone. The caverns filled with water can be more easily detected by using resistivity and the electromagnetic methods, especially with high frequency.

Fourtly, apparent resistivity method can detect empty caverns in the loose subargille deposits. Finally, using time variations of the resistivity, it can be judged upon the development of the jointing of the loose subargillite and clay deposits.

The possibilities of the geoelectric methods for the solution of these tasks, especially in finding caverns, have been proved by the observed anomalies and by mathematical and physical models. These studies shows that the empty caverns with a section of 3 m^2 and burried at a depth of 5 m, within compact limestone cause apparent resistivity anomalies. The underground corridors with 2 m of square section cause weak anomalies, but they may be discerred at a depth of 3, 5-7 m. If we want to discern them in great depths, for example at 10 m, they must have a dimension side of 2 m (Konomi et.al. 1985). There are weak anomalies over the chimneys, which are filled with loose clay over on the subargillite deposits. If these pipes have a diameter of 2 m and occur at a depth of 2-3 m then they are discernible (Konomi et.al. 1985).

Gravity Survey

The possibility of the use of microgravity surveys for the exploration of the karst zones and detection of the caverns are discussed by examining both the observed and the theoretical Bouguer anomalies.

The empty caverns are characterized by a density contrast of about 2600 kg/m^3. The calculations show that the anomalies caused by small cavities with a radius of 0.2 m can be selected only when the depth of their roofs are 0.3 m in view of the minimum amplitude of the Bouguer anomaly of 0.03 mgal.

The huge cavities with a diameter of 15 m may be detected at a depth of 18 m (Konomi et. al. 1985). When the cavities are filled with water or clay, the reminant density reduced, therefore the depth of their prospect decreases.

The gravity exploration was used prior the other geophysical methods for finding the karst cavities. In most cases, the presence of the underground caverns is accompanied with falls and joints, consequently the compactness of the top of the limestone or their density decrease. 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 anomaly, and as a result of this, the depth of prospecting increases.

Magnetic Survey

Magnetic survey is used for discerning the caverns filled with clays from the empty caverns or caverns filled with water which are found by means of other geophysical methods. This can be realized as a clay deposit has a little magnetic effect since it is placed embedded in nonmagnetic limestone. In the field studies subargillite with magnetic susceptibility (40-120) $x10^{-5}$ SI units has been encountered, consequently cavern with a diameter of 4 m and 2 m below the earth surface can produce an anomaly of the order of 5 nT. In a depth of 2 m, the anomaly caused by this cavern is insignificant.

FIELD APPLICATIONS OF GEOPHYSICAL METHODS

The application of geophysical methods is necessary and it has priority over the other classical geological xploration methods especially for the study of the covered parts of the rocks containing karst phenomena.

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.

Geophysics made contributions to the solution of the problems in different hydroenergetic and hydrotechnique constructions in Albania.

The thickness of the loose covering deposits and their layered structure has been determined. The variation of the top of bedrocks and the relation between the loose deposits and bedrocks have been studied. The structure of the bed-rocks were mapped and the disjunctive tectonics determining their dip elements have also been studied.

The zones with unequal development of karst and the karst lattices in the limestone and particular caverns with certain dimensions have been isolated. The loose deposits have been found in the limestone. The process of the karst development and its mechanical properties have also been studied and evaluated.

The slopes of the rivers have been studied in order to know their stability and to predict the most dangerous sliding sectors and to evaluate their dynamics.

The physical-mechanical parameters of the bedrocks and loose deposits such as porosity, filtration coefficient, density, modulus of static and dynamics elasticity have been determined.

Such a broad scope of the problems to be solved by geophysics made neccessary the application of surveys from the small scales to the very detailed scales 1/500 and even 1/200 with survey grid (1-2) x (2-5) m using various methods such as gravity and magnetic microsurvey, self-potential method, electrical profilings and soundings, induced polarization, radiowave method, TURAM method, high frequency seismic refraction surveys.

Intensive investigations are also carried out in boreholes with electrical (normal), self polarization (PS) and gamma-ray methods.

The investigation is conducted 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 lower level to detect the karst cavities within the limestone. For this reason, the electrical profilings were conducted with multiple Schlumberger array $A_1A_2A_3MNB_3B_2B_1$. For the detailed purposes, Sclumberger electrical soundings have been carried out. There electrode arrays have been used in case of rough topography instead of Sclumberger profilings and soundings. Current experience shows that 5-25 % of the electrical soundings must be conducted in a multidirectional array spreading. We have used the TURAM method and the method of radiowaves with frequences up to 10 MHz. The self potential surveys have been carried out before and after the raining. The electrical measurements have been conducted with RDC-10 recevier and with autocompensator instrument. The gravity measurements have been carried out in sensitivity of 0.01 mgal depending to particular field procedure and data processing. Surveys with shorter peridos than 1 hour made possible, the isolation of anomalies with an amplitude of 0.1 mGal. In the future, microgravimeter with a sensitivity of the order 0.001 mgal will be used.

The magnetic survey were done with the proton magnetometer of they type MP-2 with sensitivity of 1 nT. measured values were corrected for diurnal variation. The mean square error of the surveys was not more than 4-5 nT.

Seismic refraction surveys were conducted with a 6 channels recording system. In every channel longitudinal (P) and the tranverse (S) waves are measured at a distance 2; 3; 5; 10 and 25 m.

The automatic recording of the well logging diagrams were conducted in the 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.

ANALYSIS OF THE RESULTS OF SOME GEOPHYSICAL SURVEYS

In this section, the results of geophysical surveys carried out over some karstic zones in Albania will be analised.

The zone of Gruemira water reservoirs near the city of Shkodra is placed over the karstified Jurassic-Trias in Albania Alps. The loose sediments consisting of clays, subargillite and sandysilt delovial-proluvial deposits overlay the limestones. The Vertical Electrical Sounting method (VES) was used to determine to the thickness of these deposits varies from 1-2 m to 26 m (Fig. 11). In some sectors, the VES was conducted with detailed grid of 5x5 m. The results shows that the top of limestone is not flat, but is is cuspated and contains holes (Fig. 11). This proves the existence of karstic phenomenon.

The geoelectrical section is generally two-layer medium. The upper layer is clay and has low resistivity values. The second layer is represented by the limestone with a high resistivity. So, the apperent resistivity curves have two layers. But, in a particular sector, the curves are of the KH and HA types (Fig. 12 and 13). The karst phenomenon is much developed in these sectors. These zones have also an accentuated electrical anisotropy (Fig. 9). These sectors lie in the left border of the reservoir, especially near the dam, the middle part of the reservoir and to extention of the right border. In the deepest sectors of the valley, the karstified limestone is eroded and less altered. Judging from microrelief, fissures and karst cavities exits.

Over these above mentioned three intensive karst zones, self potential anomalies have been also observed, especially for the surveys after the rain (Fig. 14). The survey of the self-potential before the rain revealed that weak anomalies are localized and only over the karstified zones near the dam. After the rain the process of water filtration is intensified and the anomalies are amplified. They are extended and occupy almost the whole surface of the reservoir would be built.

In the right slope of the hill, nearly where the dam is supported by lattices of karst caverns with an outcrop. These caverns have the form of the underground pits, with a section of about 4 m^2, the top of the which is 5 m deep (Fig. 15). At the stations 2-9 and 19, there were apparent resistivity anomalies over caverns C1 and C2. This broad anomaly coincides with the karst lattice. It is found by the measurements carried out with pol-dipol arrays with separations AO=10, 30, 50, 90 and 100 m. Anomalies are also found in the stations 13, 24 and 29 which may be caused by other caverns or by compact limestone layers. Gravity studies and boreholes are necessary to make alternative interpretations. The influence of the cavern in station 6 is also clearly presented in the apperent resistivity sounding curves of K type. The highest values of the apperent resistivity, measured with electrode distances of AB/2=15 and 25 m express the influence of the cavity C2. In the uncarstified sectors, for example in the station 10, the electrical sounding curve shows different behavior such as the apparent resistivity decreases by increasing the array spread, as a

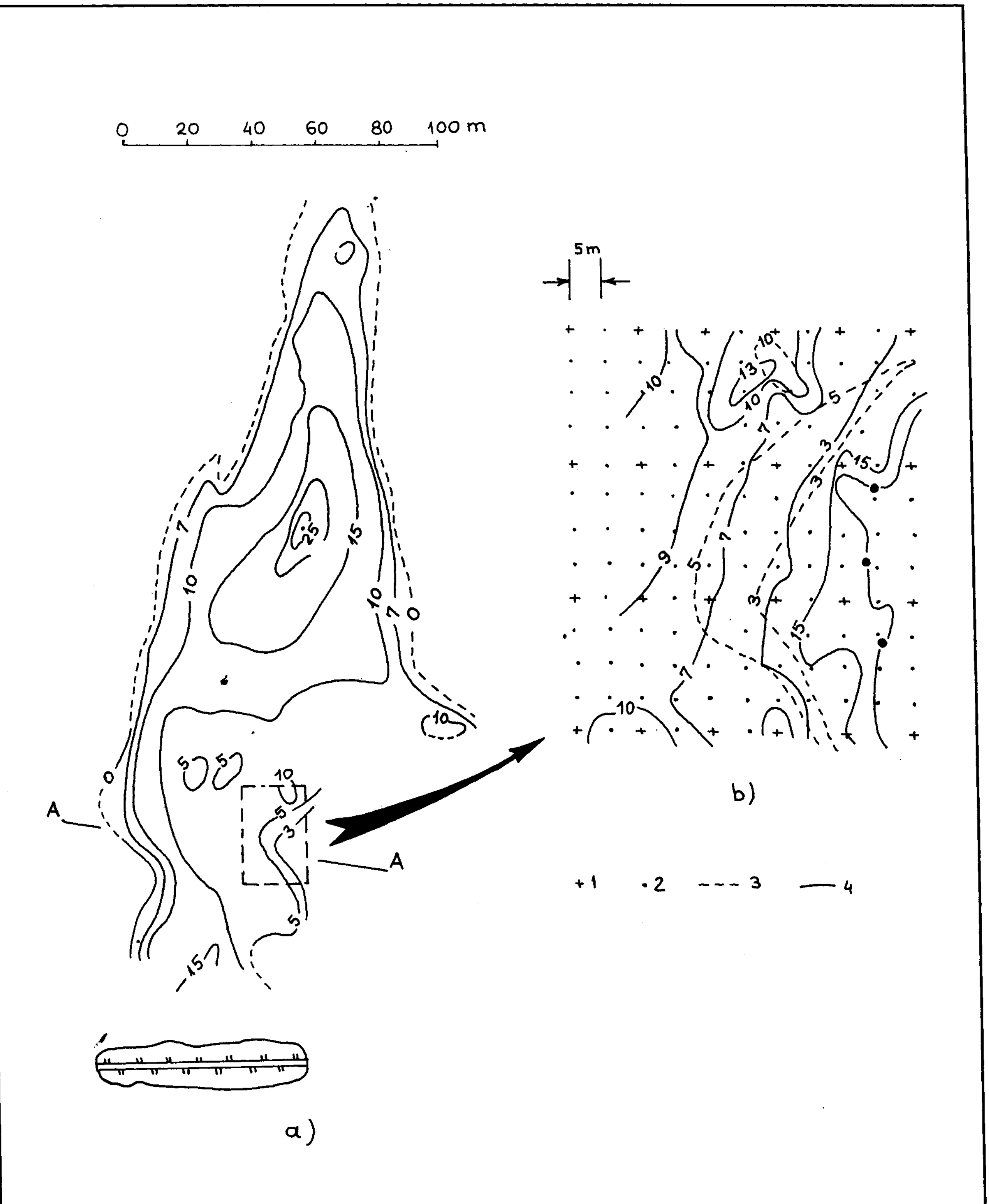


Fig. 11. The map of the thickness of the deluvial proluvial deposits (a) especially in the detailed sector (b) which constructs the Gruemira reservoir. 1) The centres of the electical soundings of the survey grid, 2) the centres of the electrical soundings of the detailed grid, 3) isothickness drawn according to the soundings of the survey grid, 4) isothickness drawn according to the detailed grid.

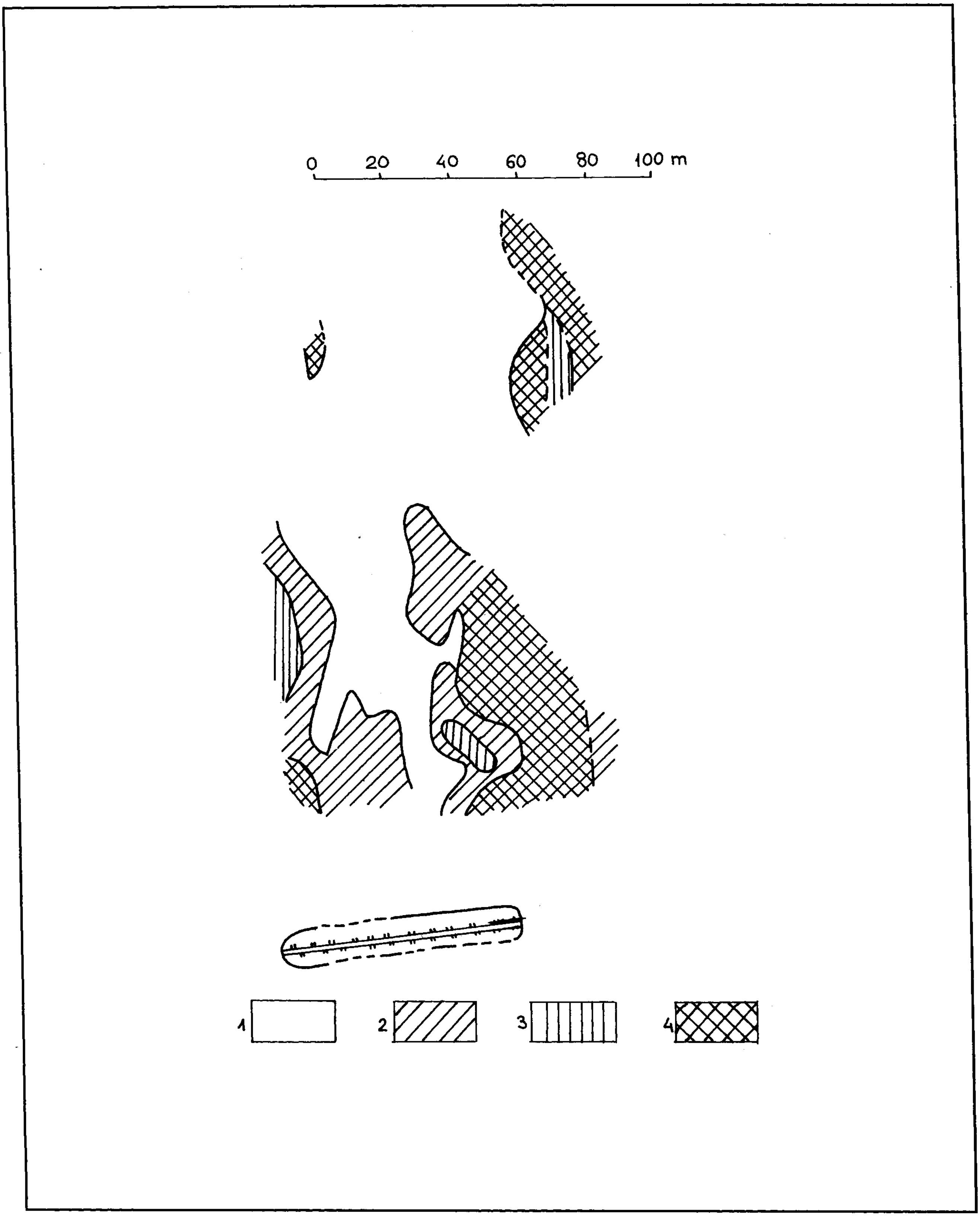


Fig. 12. The map of the types of the apparent resistivity curves in the zone of Gruemira reservoir. 1) Two-layer curves, 2) three-layer curves of the A type, 3) the three-layer curves of the HA type in the karst sectors, 4) the four-layer curves of the KH type and three-layer curves of H type in the sectors with more intensive karstification.

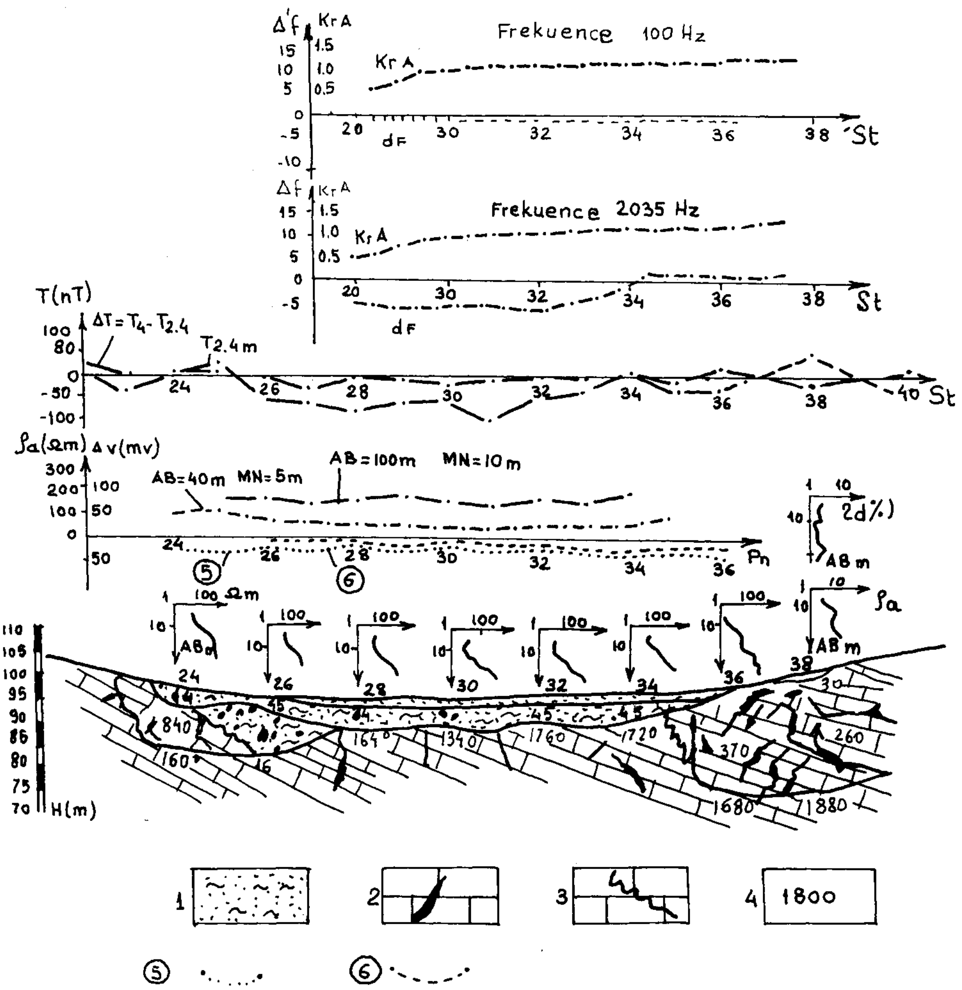


Fig. 13. The geological-geophysical section A-A in Gruemira 1) Subargillite cover, 2) intensive karstified limestones 3) karstified limestone, 4) the values of the resistivity in ohm-m, 5) self-potential observed after the rain, 6) self-potential observed in dry weather.

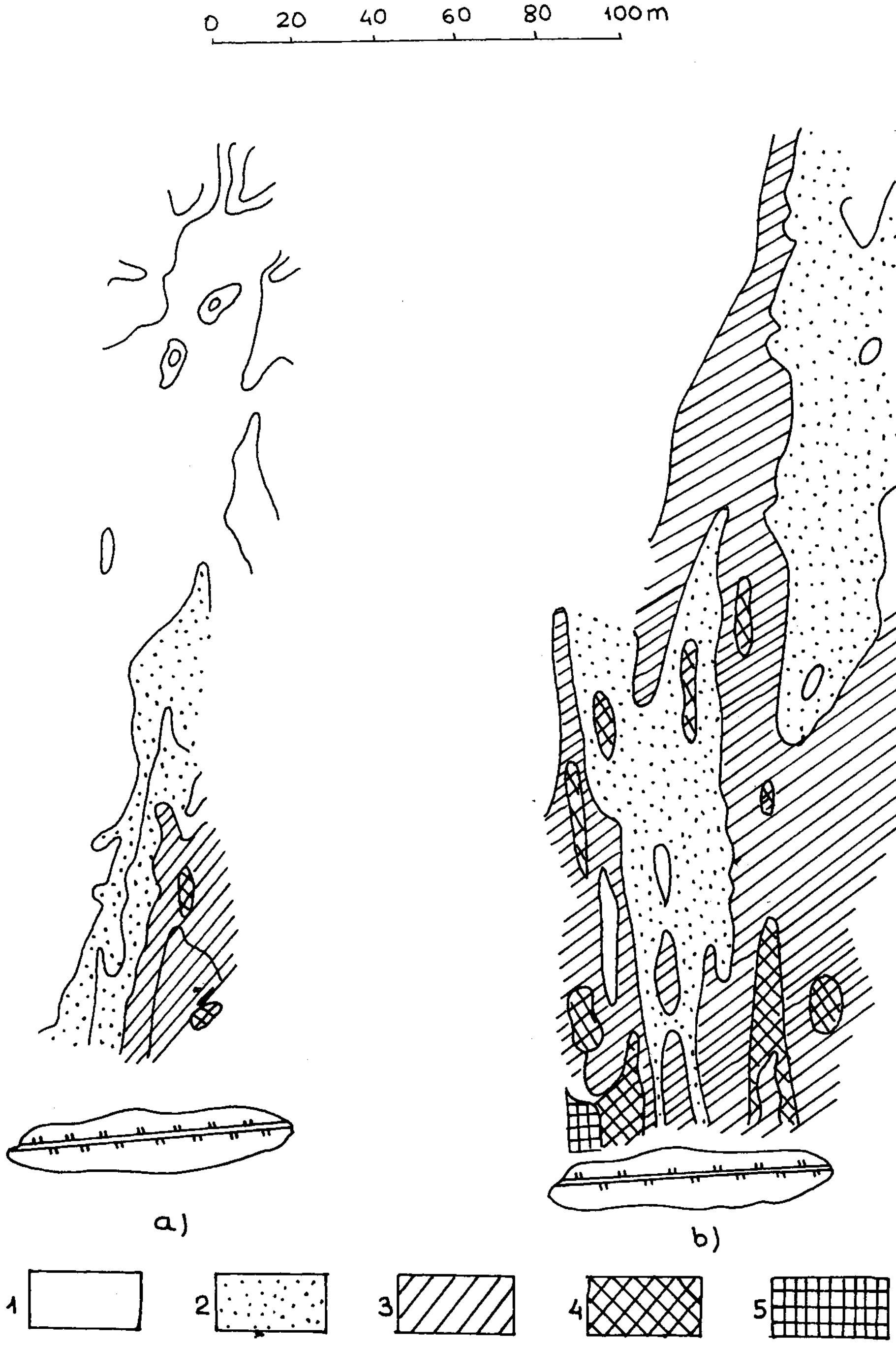


Fig. 14. The map of the concetration of the filtrations according to the self potential data of Gruemira reservoir. a) Observed in dry weather, b) after the rain. The self potential values higher than 1) -10mV, 2) -10 up to -20 mV, 3) -20 up to-30 mV for the filtration zone, 4) -30; -35 mV, 5) smaller than -40 mV for sectors with intensive filtration.

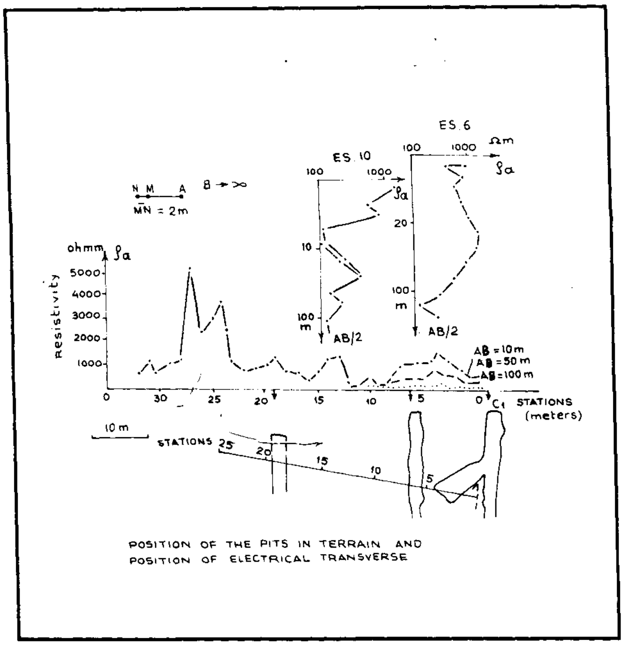


Fig. 15. The apparent resistivity anomalies over a system of underground cavities in the limestones, near the dam of Gruemira reservoir.

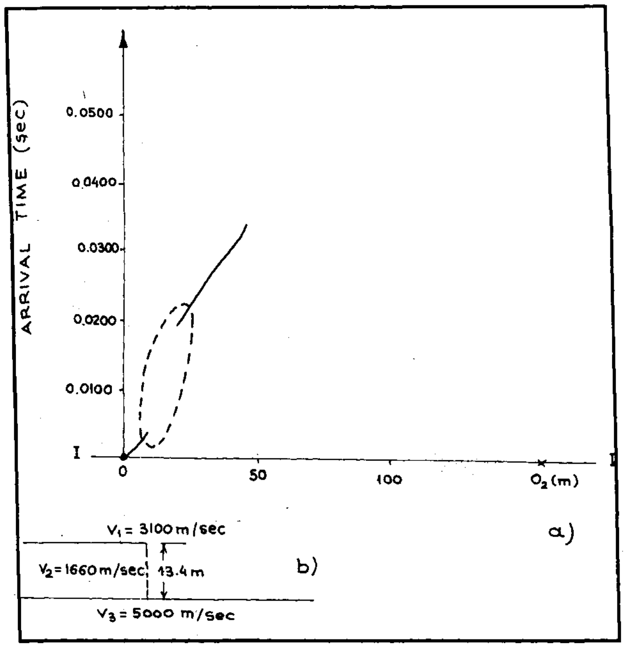


Fig. 16. The direct and opposite travel-time graphs of the refracted waves according to the geoelectrical section A-A in Gruemira.

result of the influence of the limestones under the level of the groundwater, which have a lower resistivity then the carstifed limestone overlaying this level (Fig. 5).

The existence of the karst zones was also proved by seismic surveys. The interpretation of the results proves that there is a three-layered zone in the left margin of the profile and a two-layered section in the right one (Fig. 16). Between these two margins, a disjunction fault exists in a step form. 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, which is presented only in one sector of the profile, shows low seismic wave velocity indicating the presence of the carstified limestones.

The argillitezed karst sectors have been indicated by magnetic and the induced polarization data. Over these sectors, magnetic and induced polarization anomalies are found (Fig. 7, 13). These sectors are also clearly seen in the logging diagrams by using the increased intensity of natural gamma-ray (Fig. 9).

The caverns filled with clays or bauxites are effectively found even by the method of radiowaves with a high frequency, up to 10 MHz (Fig. 17). As can be seen in the figure, three zones where the radiowaves are observed between the two boreholes are 180 m far away from the each other. Through the holography or the intersections way, the position, form and dimensions of the cavities have been precisely determined. Cavities have a cross section varying between 200 and 400 m^2, at a depth of 20-90 m. This method has proved to be successful even for the detection of the cavities filled with saline water in salt deposits (Fig. 18).

The loose clay and subargille deposits, that cover the limestone in the studied karst zones, have a relatively higher resistivity values varying between 20 and 80 ohm-m (Fig. 19). This reveals that they are not pure, but carbonatic or permeable.

In the Zagora reservoir near Shkodra, which shows similarity with Gruemira, some pipes were found in the subargillite that cover the limestone. These pipes were described in the first paragraph (Photo 6). Over these pipes, a maximum of the apparent resistivity was found, with a small amplitude, about 20-50 ohm-m, measured with pol-dipol array with separation of AO=15 m (Fig. 5). These anomalies are also similar to the anomalies found in covered limestone crests over carbonatic or pebble layers.

The gravity microsurvey helps to examine the other alternatives. The density of the clays and subargillites varies between 1800 kg/m^3 and 200 kg/m^3. Their density reduces to 113 kg/m^3 when they are loose and dry. Therefore, the gravity values show minimum over the pipes (Fig. 5). The intensity of the anomaly increases for the second derivative of the vertical component of the gravity g_{zz} (Fig. 5). But, such minimum are found also in cases where the thickness of the loose deposits increases. For this reason, the gravity microsurvey was accompanied with electrical soundings in order to study the variation of the top of limestone.

CONCLUSIONS

1) The study of karst phenomenon, the differentiation of karstified zones and the detection of the underground cavities are conducted effectively by the use of integrated methods.

2) The karstified sectors can be distinguished from the compact limestone by using the resistivity sounding curves of

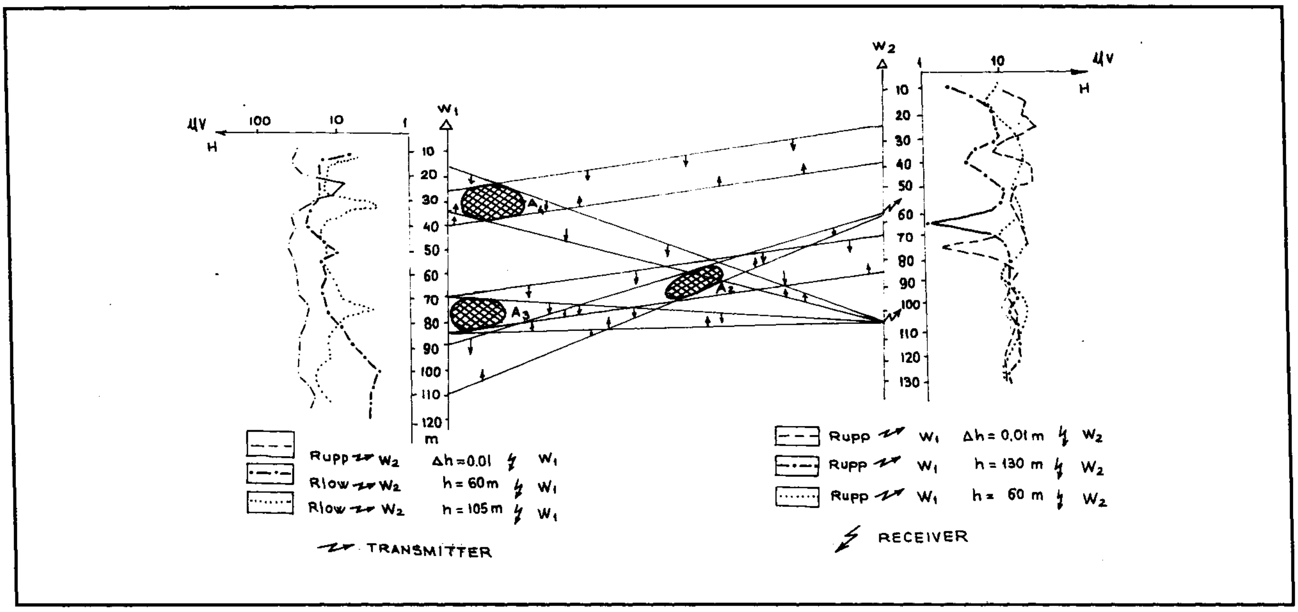


Fig. 17. The results of the radiowaves surveys for the search of karst cavities in the limestones of Albania Alps. H(rv)-the intensity of the electromagnetic field in microvolt, h-the depth of boreholes in metres SH-9 and Sh-12 the boreholes; A2, A3, A4 the absorbation anomalous zones of electromagnetic waves. Ms-receiver is displaced syncronously with transmitter. Mp-receiver is displaced while the transmitter is kept motionless, for example in borehole Sh-12 at the depths 60 m and 105 m, respectively.

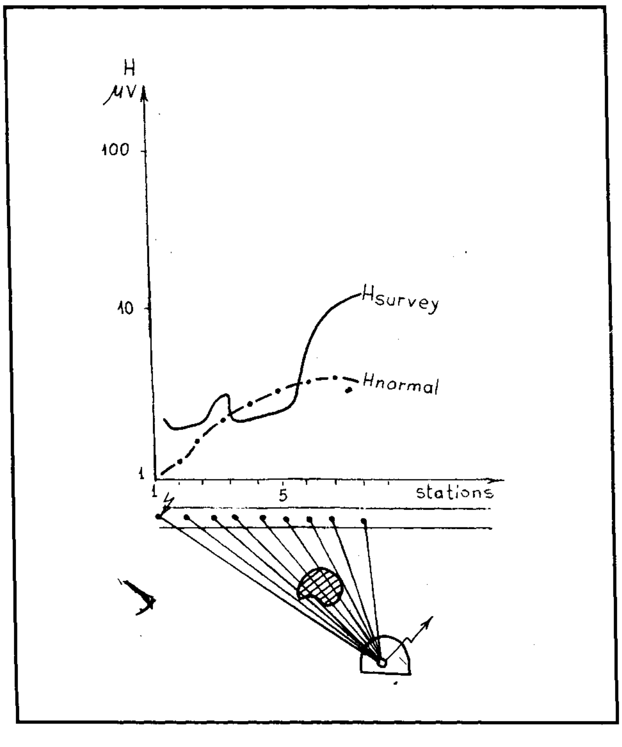


Fig. 18. The results of radiowaves surveys for the search of cavities filled with saline water which are situated between rock salt and the deposits (According to R. Ballta) Hn-intensity of the normal EM field. Hv-intensity of the surveyed field Dh-Radiotransmitter M-Radioreceiver.

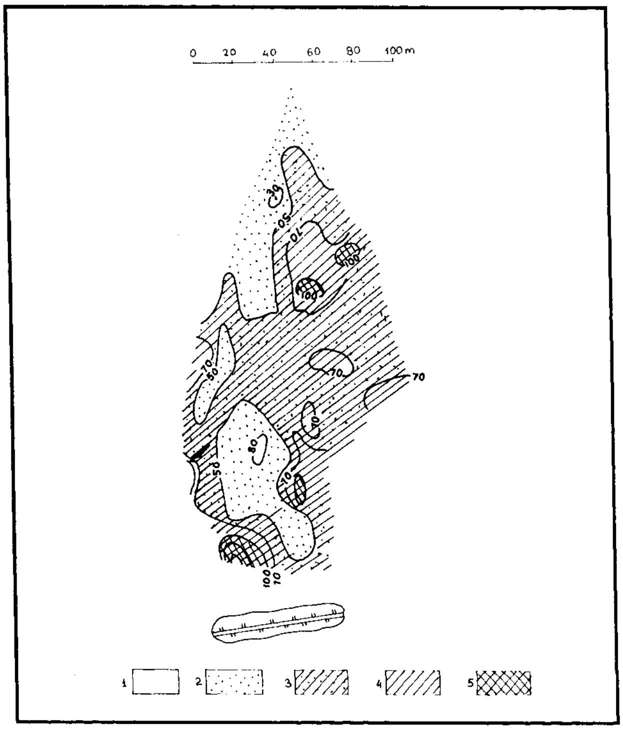


Fig. 19. The resistivity map of the clay deposits of the zone where Gruemira reservoir had to be built. Resistivities less than: 1) 300 ohmm, 2) 30-40 ohmm, 3) 50-70 ohmm, 4) 70-100 ohmm, 5) more than 100 ohmm.

the type KH and HA or A. The direction of the electrical anisotropy of these sectors does not coincide with the stratification of the limestones. In addition to the resistivity method, we also used the seismic refraction surveys of high frequency.

3) The caverns which have a radius about 1 m and close to surface have been detected by using conventional gravimeters with sensitivity of 0.01 mgal.

4) In order to detect the sectors of karstified limestones and the caverns filled with clay, apparent resistivity soundings are coordinated with induced polarization soundings and with magnetometric microsurvey of high precision. Good results are also obtained by the method of radiowaves with a high frequency up to 10 MHz.

5) We have tried to detect the pipes in the loose subargillite deposits through the electrical profilings and the gravity surveys. The first results are positive, but the problem is still in the experimental phase.

6) The results of the geophysical surveys have been proved by boreholes where the electrical, radioactive and acoustic logs were also measured.

7) By the evaluation of geophysical data, physical-mechanical properties of the loose deposits and basement rocks were determined.

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Photo. 1. Karstic microrelief

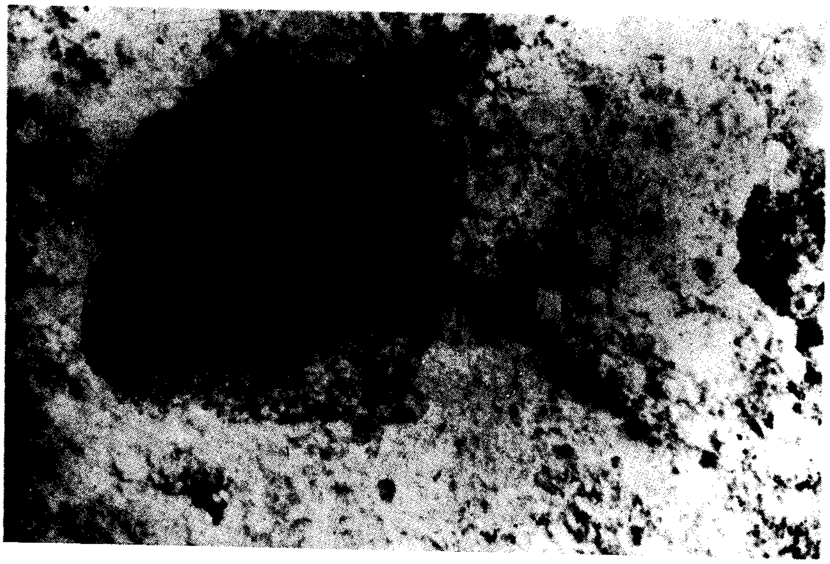

Photo. 2. Karstic microrelief

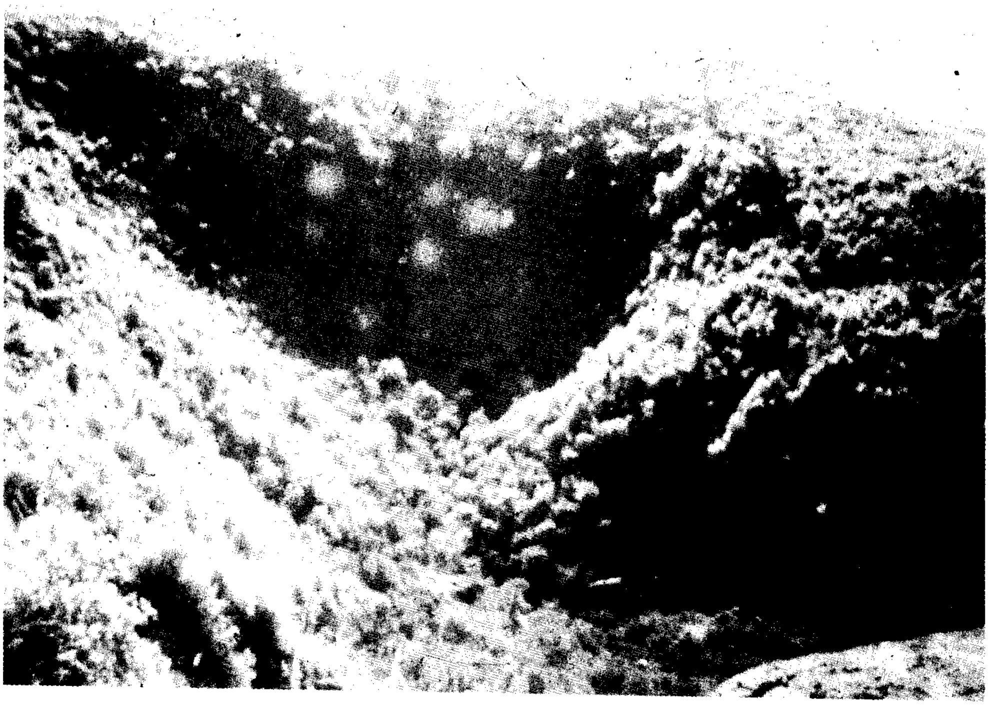

Photo 3. Wide valleys through carbonate massifs

Photo 4. Canyons through carbonate massifs

Photo 5. Inner view of a cave near Shkodra city

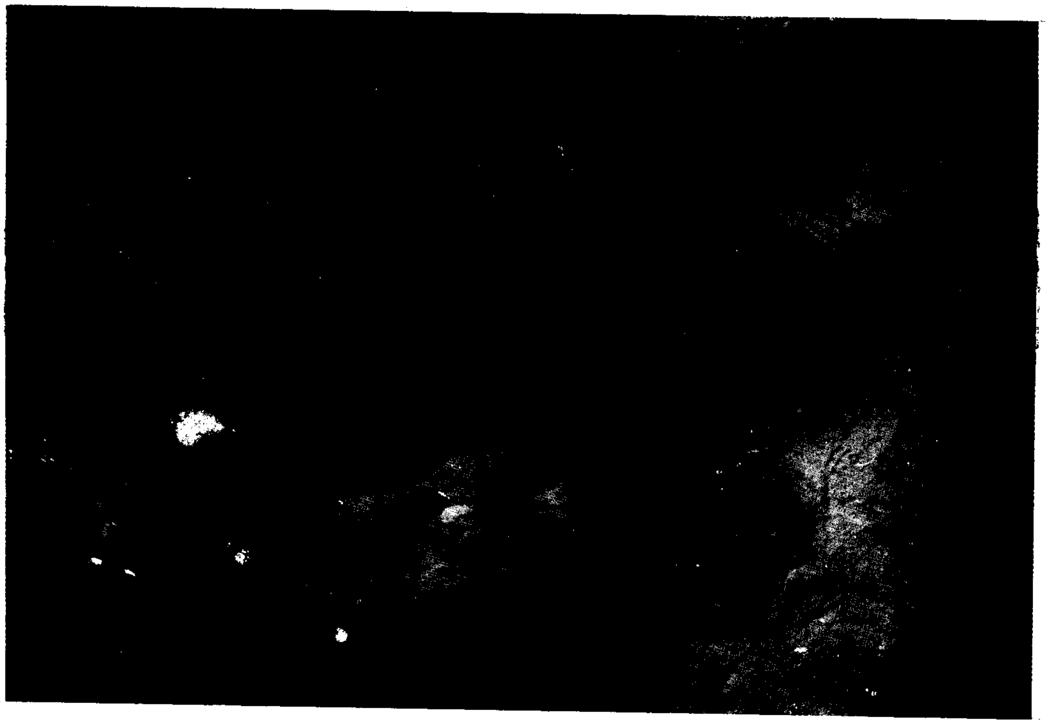

Photo 6. Chimney in the loose subargilles over the limestones of Zagora, near Shkodra.