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Some Remarks about the Geoelectrical Exploration of Buried Bodies*

O geoelektričnem raziskovanju pokritih geoloških struktur

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It is well known from laboratory and mathematical model investigations, that the depth range of the resistivity method is comparatively small, as far as the direct location of various buried bodies is concerned. In many cases the geological and hydrogeological field relations are, however, suitable to be find out by an indirect way. Under favourable conditions, some resistivity anomaly is measured that has not been caused by the sought body itself, but chiefly by surrounding and overlying rocks. The »anomalous body«, comprising besides the examined body some major or minor part of its vicinity, might be of substantially larger dimensions than the sought body itself, or could lie shallower, and might cause a measurable anomaly. Streaming potential anomalies, sometimes related with sought bodies, offer another possibility of the indirect investigation method. In the paper some case histories concerning the indirect detection of buried bodies are shortly described.

Iz laboratorijskih in matematičnih modelnih raziskav je dobro znano, da je globinska dosegljivost upornostne metode sorazmerno majhna v primerih, kjer gre za neposredno iskanje skritih teles. Geološke in hidrogeološke razmere pa marsikje dopuščajo posredno določanje. V takšnih razmerah izmerjenih upornostnih anomalij ne povzroča iskano telo samo, temveč predvsem njegova okolica. »Anomalno telo«, ki obsega poleg iskanega telesa večji ali manjši del njegove okolice, je lahko znatno večje kot iskano telo, ali pa leži plitveje in more povzročiti merljivo anomalijo, ki odkrije skrito telo. Anomalije lastnega potenciala, ki jih povzroča pronicanje vode v razpokani hribini, so ponekod v zvezi z iskanimi telesi in nudijo drug način posrednega ugotavljanja. V prispevku je na kratko opisano nekaj primerov posrednega določanja skritih teles.

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Introduction

The depth penetration, i. e. the sensitiveness, of the resistivity method — preferred by explorationists for interpretation, technical and economic reasons — is comparatively small, as far as the direct location of various buried bodies is concerned. For example in the horizontal resistivity profiling using the Wenner array with suitable electrode spacing one only registers approximately a 10 % change of apparent resistivity (anomaly) when a ball-like ore body of very low resistivity lies at a depth equal to the ball diameter (R. G. Van Nostrand, 1953). Deeper situated bodies cannot be discerned directly, for the anomaly must be at least two times the error of measurements, being in geolectrical exploration about 5 %. The mentioned 10 % change too can hardly be analysed in the field conditions. Even worse results are obtained on the field having a thick low resistivity surface layer (J. Lapajne, 1968).

Here and there the geological and hydrogeological relations are favourable for an indirect reasonning. An underground hollow or a buried bauxite pocket in carst conditions, for instance, are hardly to be meet with by drilling or an other direct exploration method.

In kartified regions, however, the water has an important role.

An increased rock moisture and water in fissures, caverns, channels, and caves is usually the cause for the formation of a low resistivity anomalous body. Karstification, in which water is the most important factor, usualy creates high resistivity bodies. Streaming potential anomalies, sometimes connected with sought bodies, offer another mode of the indirect detection. Streaming potentials are natural potentials of electrokinetic polarization, caused by water movement through porous and/or fissured media.

In the same manner the pocket-like bauxite deposit could be found indirectly by measuring of geophysical parameters of the overlying layers.

At any exploration work the theoretical limits must first be realized. One can obtain a preliminary information very quickly from already existing master curves. If that is not sufficient, a given problem is solved by laboratory or preferably mathematical modelling. Field measuring of a well-known structure might also be roughly regarded as model examination. The weakness of such a model is that one can neither change at will its parameters nor control efficiently enough various perturbations; and its strenght lies in the circumstance that the serviceability of a given method is tested under natural conditions. By field testing one may realize the possibility of indirect ascertainment.

Field examples

Trial Resistivity Survey of Bauxite Deposits in Istria (Yugoslavia)

In Istria Bauxites occur in pockets in the Cretaceous limestone. Their hanging wall is Eocene limestone (fig. 1 b). The electrical resistivity of the bauxite being considerably lower than that of the limestone, the horizontal resistivity profiling seemed to be the most adequate investigation method. The average resistivities are:

Cretaceous and Eocene limestone	1000—3000 Ohm. m
Bauxite	100— 300 Ohm. m

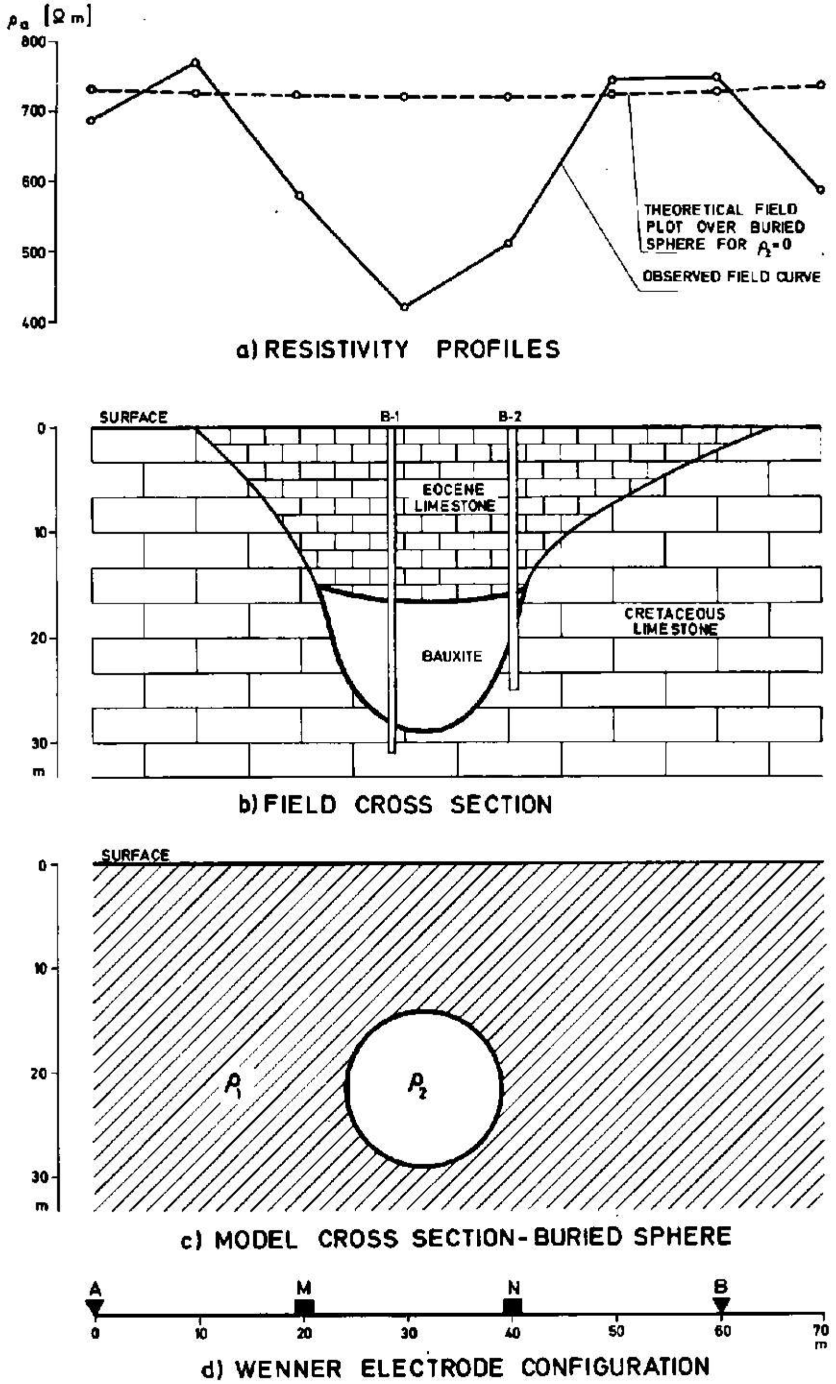


Fig. 1. Comparison of observed resistivity profile over bauxite deposit and theoretical field plot over buried sphere. B-1 and B-2 bore holes (Istria — Yugoslavia)

The survey of already discovered bauxite bodies below remnants of Eocene limestone has proved that under such geological conditions bauxite can generrally not be directly proved by resistivity investigations, as the bauxite pockets either are too small or lie too deep. Therefore initial trial examinations were carried out above the beds overlying the bauxite bodies to realize the possibility of indirect ascertainment. Figure 1 a shows, in solid line, one of the observed resistivity curves obtained by Wenner elecrode configuration (fig. 1 d). Similar results were obtained by other electrode configurations and on other deposits as well.

Let us try to interpret the observed anomaly with the model presented in figure 1 c, i. e. with a buried sphere. The corresponding theoretical field plot is shown in figure 1 a by dotted line. It is evident that the bauxite body itself causes a change in apparent resistivity less than the average error in measurements. Thus the anomaly could mainly be attributed to the Eocene limestone cover. The thickness of the Eocene limestone over bauxite deposits is usually somewhat greater than elsewhere. However, this could not be the reason of greater changes in the apparent resistivity, as there had not been observed an essential difference between the resistivity of Eocene limestone, provided it is compact and not marly, and the resistivity of the Cretaceous limestone.

One has to find another interpretation. It could be supposed that the presence and the genesis of bauxite bodies is connected with the sedimentation and/or change of the overlying Eocene beds to such an extent, that the average physical properties of the hanging wall are considerably changed. Bending of younger strata, caused by the shrinkage of volume of terra rossa during its diagenetic alteration into bauxite, had resulted in flexuring and finaly in circular faulting (fig. 2 b). The overlying beds show characteristic plate-shaped depressions. Eocene beds in those depressions may have an increased moisture content, as the thin marly intercalations in the limestone detain the moisture. Besides the Eocene layers fissured slightly during the bending and settlement processes, the fissures being later filled by low resistivity materials, mainly by clay. Moisture, marl and clay may reduce the resistivity of the Eocene cover above the bauxite ore bodies. Therefore the Eocene cover itself may cause considerable decrease of the apparent resistivity.

The above suppositions lead to the »filled sink« models. One of the possible models is presented in figure 2 c. The theoretical field plot, shown by dotted line in figure 2 a, fits perfectly the observed field curve.

Further quite successful investigations, based on the above statements, had been carried out (J. Lapajne, 1969 and 1974).

Trial Resistivity Survey of the Željne Karst Caves

A system of caves was explored in detail by speleologists in the karst area of Željne in Southeastern Slovenia (Yugoslavia). Thus, it was a good example for field model investigations. Figures 3 a and 3 b show a part of those measurements (solid line curve) and the corresponding field cross section.

Let us try, like in our first example, to interpret the anomaly with a »direct model« — buried cylinder in this case. The theoretical anomaly (dotted line in

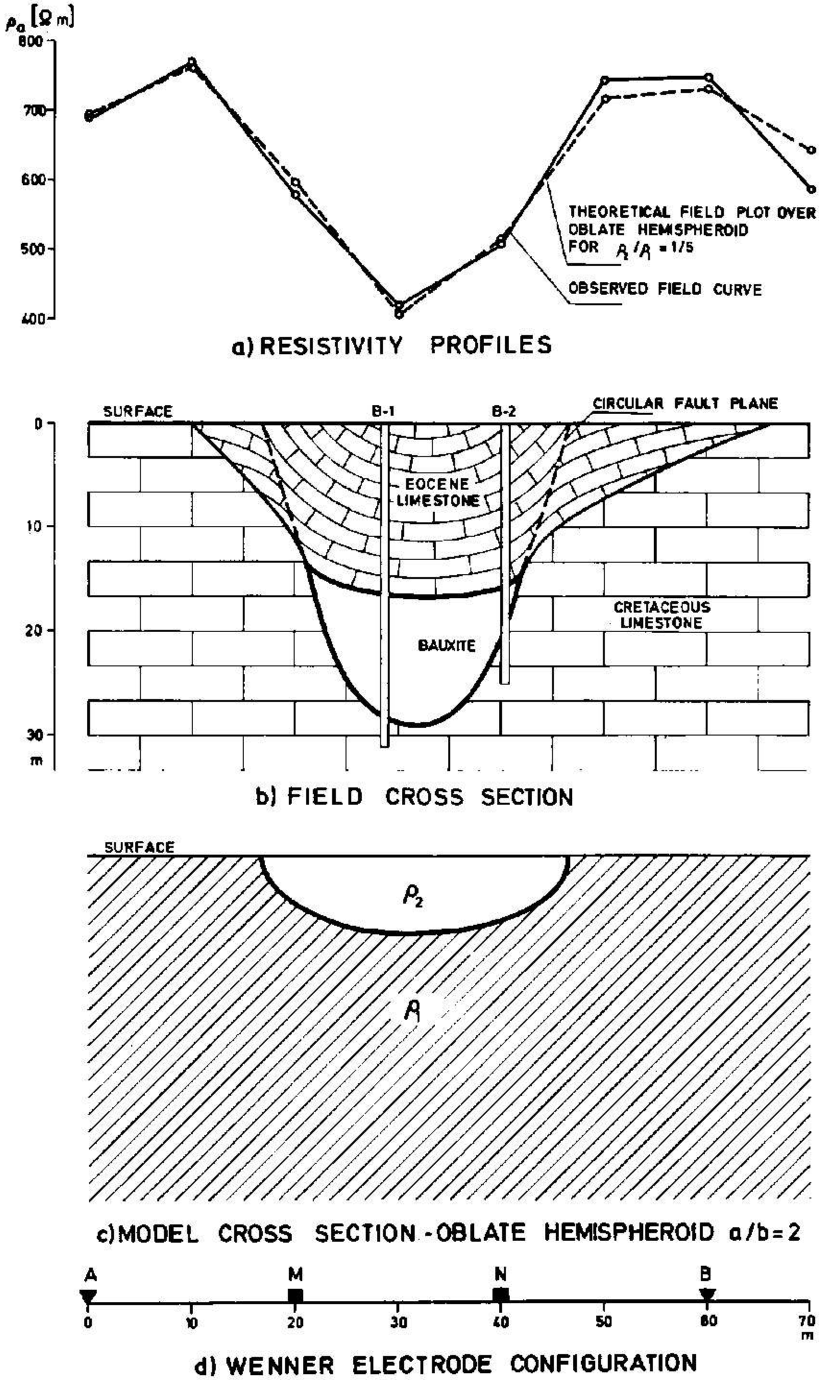


Fig. 2. Comparison of observed resistivity profile over bauxite deposit and theoretical field plot over oblate hemispheroid (Istria — Yugoslavia)

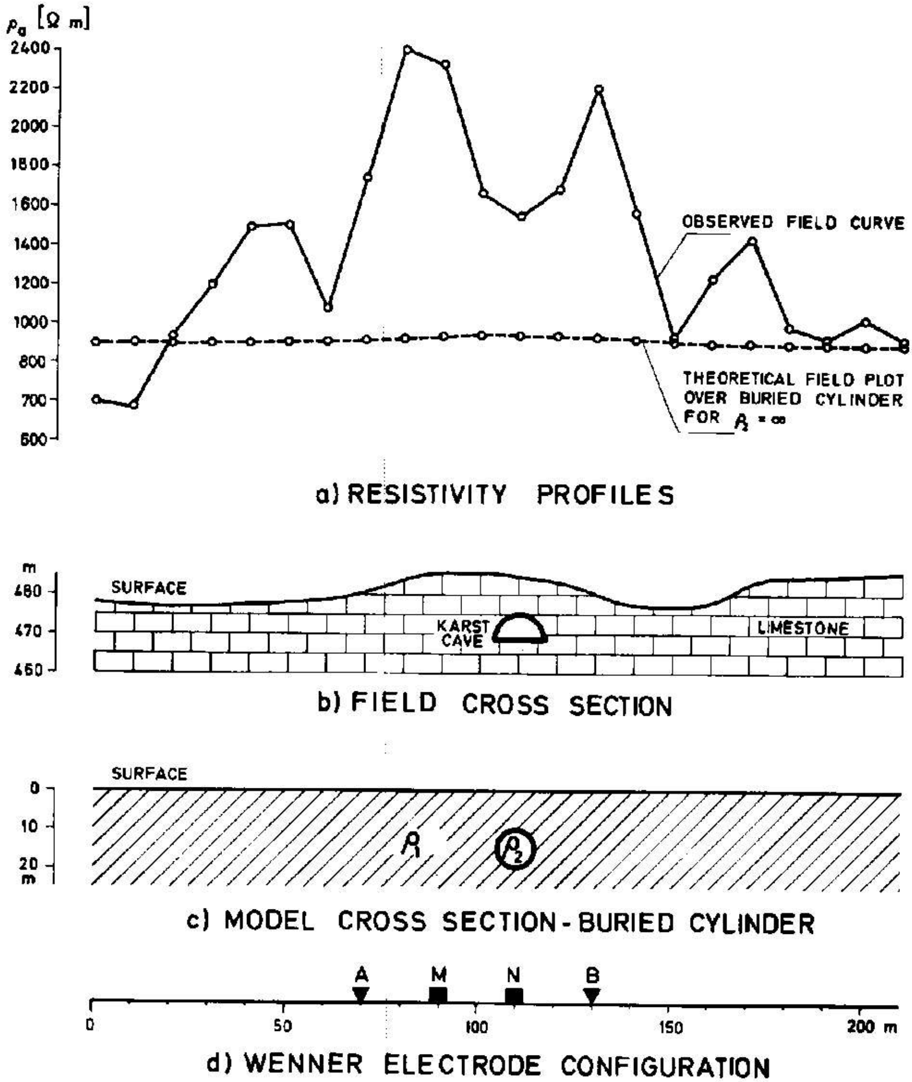


Fig. 3. Comparison of observed resistivity profile over karst cave and theoretical field plot over buried cylinder (Željne karst caves in Slovenia — Yugoslavia)

fig 3 a) over a given model with appropriate geometrical parameters shows only a slight change in apparent resistivity. Therefore this model is unsuitable. The simplest model, which suits quite well the observations, is a high resistivity vertical dyke. The model is presented in figure 4 c. The corresponding theoretical field plot is given by dotted line in figure 4 a. The fittnis is not perfect, yet satisfactory.

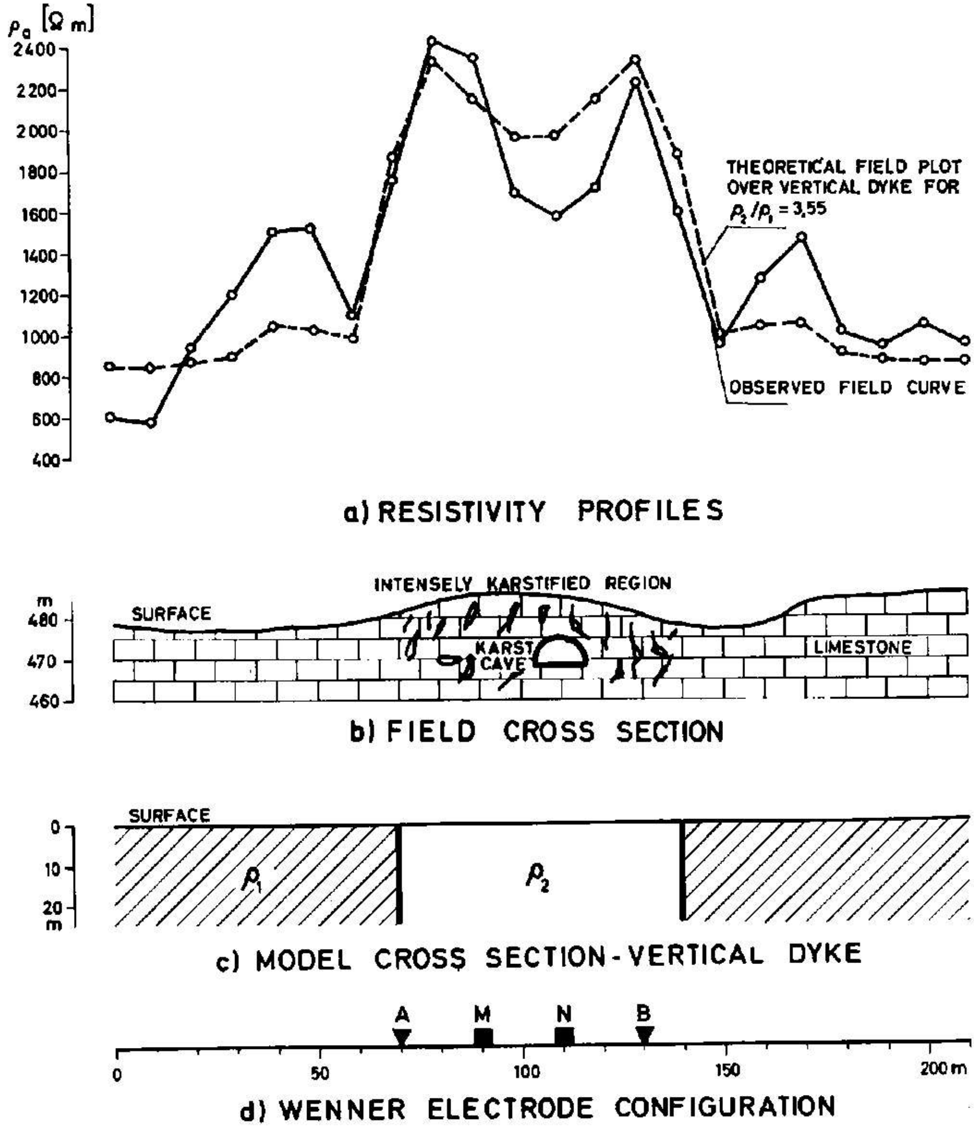


Fig. 4. Comparison of observed resistivity profile over karst cave and theoretical field plot over vertical dyke (Željne karst caves in Slovenia — Yugoslavia)

The interpretation of this apparently strange model is very simple: the vertical dyke corresponds to an intensely karstified region (fig. 4 b). This karstified region has substantially larger dimensions than the karst cave and, what si even more important, it is an »outcropping anomalous body«. The karst cave may very likely lie in the central part of the »anomalous body«.

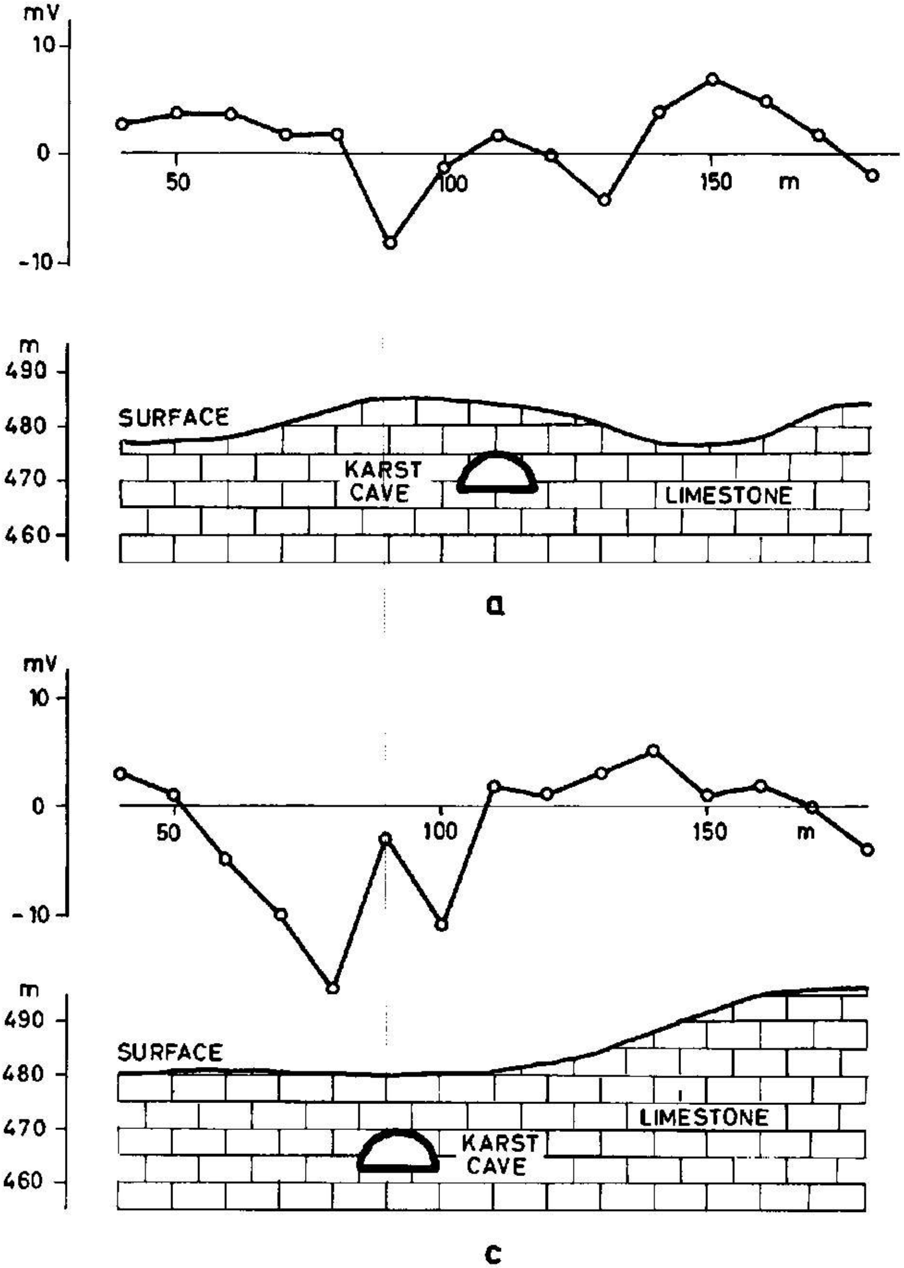
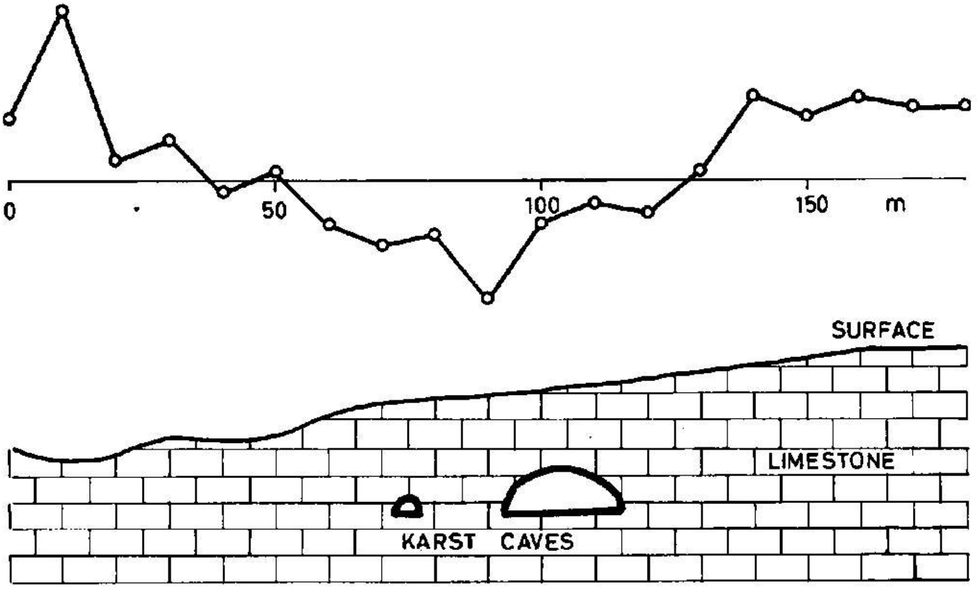
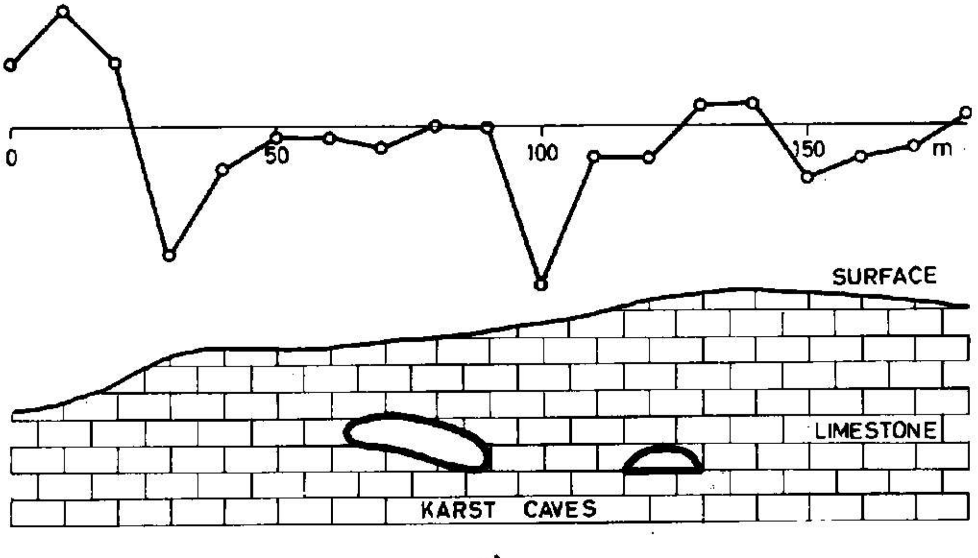


Fig. 5. Observed self potential profiles and the corresponding field cross sections (Željne karst caves in Slovenia — Yugoslavia)


0
50
100
150
m
SURFACE
LIMESTONE
KARST CAVES

b


0
50
100
150
m
SURFACE
LIMESTONE
KARST CAVES

d

Trial Self Potential Survey of the Željne Karst Caves

The karst caves area of Željne had been cxplored also by self potential survey. Some results of those investigations are shown in figure 5. The examples *a* and *c* clearly show that two minima are associated with one karst cave. Thus, the self potential anomaly over karst cave consists of two minima, one on either side of the cave. For a sistem of two neighbouring karst caves (examples *b* and *d*) the corresponding anomalies are combined into one anomaly with three minima; the central minimum might be considered to be a composition of two minima.

The discussed negative self potential anomalies may be interpreted as streaming potential anomalies, caused by filtration of precipitations through fissured and karstified limestone. The filtration is most intense in the »intensely karstified region«, discussed in the previous section. Therefore one would expect the anomaly to be one minimum over the cave or a broad negative anomaly over the mentioned karstified region. The following possible reasons explain why this is not the case:

— The karst cave considered to be a true drain channel. The flow rate across the overlying rocks is high, but is of short duration, while the percolation rate through the adjecent beds is rather low and of long term.

— The rocks overlying the cave, show a high permeability. As it vas established (M. V. Ahmad, 1964) "the streaming potential increases slightly as the permeability decreases", the negative anomaly must be reduced above the cave. In other words, above the cave the average free furface area of fissures is very likely greater than away from the cave, i. e. on both sides. As it was found (V. A. Bogoslovsky and A. A. Ogil'vi, 1972), the absolute values of streaming potentials decrease with the increase of opening of fissures.

Possibly other factors too might contribute to the splitting of the anomaly in two minima.

Summarizing, we may state that self potential survey is an indirect method useful for karst cave investigations, particularly if it is run simultaneously with resistivity survey. The expected self potential anomaly consists of two minima, which confine the region where a cave might occur. The self potential profile in figure 5 a is a "school example" of such anomaly.

Conclusions

In the paper some examples are given to illustrate an indirect method available for geoelectrical exploration of buried bodies. In indirect ascertainment the observation of the geological conditions of a particular area is very important. This work starts with the primary rcconnaissance. Proper interpretation of trial geophysical survey, which usually has to be done before detailed investigations for economic reasons, reveals additional geological information.

The indirect methods proved to be useful as they make always the possibility of penetrating deeply.

Two other surface geoelectrical methods, not discussed in the paper, enable to inrease the direct depth determination in some cases. If the examined body in an artificially created primary electric field polarizes so powerfully as to create a measurable secondary electric field, the method of induced polarization can be successfully used, measuring either the slow decay of voltage in the ground, or low-frequency variations of earth impedance. Whenever a part of the examined body is accessible, e. g. through an outcrop or a borehole, it is possible to create a relatively powerful electric or electromagnetic field in the explored structure by positioning one current electrode in the enclosed body. Such a measuring process is known as the exitation-at-the-mass method or mise-a-la-masse method.

Hence, let us summarize that with geoelectrical methods an increase of the depth determination, i. e. of the sensitiveness, might be expected in three manners:

— with indirect ascertainment,
— with measuring a secondary field, and
— with direct introduction of electric current into the body examined.

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