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Pricking Probe (PriP) method and its applicability

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ABSTRACT:
Pricking Probe (PriP) method enables the description of the near-surface debris distribution using simply a T-shape metal rod with a sharp peak and pushing it into the soil into a given depth equidistantly along a profile. It is registered whether the rod reach the given depth (mostly 0.3 m is applied). This technique was successfully applied beside of archaeological measurements in karts studies: sinkholes have been delineated, fractures and fracture zones were localised and the direction of geological structures were determined. If the soil is very thin the modified version of the Pricking Probe, the mPriP can be successfully applied for the characterisation of fractures. Three field examples will be presented in each situation verified by geoelectric results. PriP results proved however to be less uncertain than the geoelectric ones.

Keywords: Pricking Probe; archaeology; geology; karst

1. Introduction

There are numerous tools applied in engineering geology to measure mechanical resistance of the soil. The most common among them is the standard penetration test [1]. SPT is a dynamic penetration test designed to provide information on the geotechnical engineering properties of soil by recording among others the peak- and cone pressure values with depth. At the same time, the PriP technique, which will be presented here, gives one single value about the peak pressure. Namely, it tells if the peak pressure is lower or higher than a certain threshold value.

The PriP technique and its modified version, the mPriP are much more mobile, simpler and economiser than the SPT, which may have limitations in accessing of field sites. In spite of their simplicity the PriP and its modified version, the mPriP techniques are very effective in resolving geological and archaeological problems or verify results obtained by any other methods.

At first a short introduction will be given into the application of the PriP and mPriP, then three field examples will be presented to demonstrate their applicability: 1. an archaeological prospection; 2. Determination of the main structural directions in a karstic area and delineation of hidden sinkholes; 3a. Characterization of the fracture system of an area with relatively *thick* soil; 3b. Characterization of the fracture system of an area with relatively *thin* soil. The here presented field studies were published in details in [2-4].

2. Methods

Methods similar to the Pricking-Probe have been known for a long time (e.g. in searching for survivors of avalanches), but the first attempt to get quantitative information by using this approach was performed by [2]. Systematic Pricking Probe measurements can be carried out either along a profile (Fig. 1.) or over an area. A T-shape metal rod with a sharp peak is pushed into the soil to a given (e.g. 30 cm) depth. If it penetrates into the soil gently a value of $k = 0$, otherwise a value of $k = 1$ is assigned to the pricking probe position.

Noise due to roots of trees is able to deny the probe to get into the required penetration depth. Such plants can however be seen therefore it is not difficult to treat the errors they produce. Hollows of animal origin could also distort PriP results, but k averaging diminishes their effect rather well. The most dangerous noise source is human activity, such as building operation or agricultural activity which may severely influence the PriP results by reorganizing the near-surface debris distribution.

Due to the aforementioned localized, random features it is recommended to calculate a robust parameter, an appropriate average of the k value. The arithmetic mean of the obtained k values in five/nine neighbouring points can well eliminate random features.

In this way the debris distribution of the sub-soil can be determined by the PriP. It allows us to draw conclusions e.g. about archeological remnants, geological features such us fractures, basement depth, or position and size of sinkholes.

Its modified version, the modified Pricking Probe (mPriP) is recommended to use in areas with very thin cover. It measures the depth in which it hits debris using the scale which is engraved on the rod. Although PriP could be used also in such areas with small pricking depth its application is more circumstantial and less fruitful than that of the mPriP.

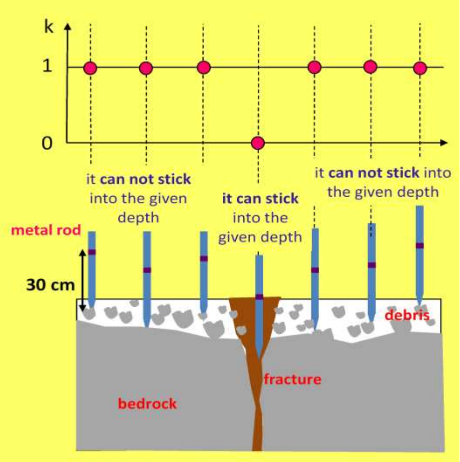

Figure 1. Performance of the PriP method. Scheme of its operation and data presentation.

PriP and mPriP results will be compared with those of Electrical Resistivity Tomography (ERT). ERT is one of the most often applied geophysical techniques for shallow subsurface investigations [5]. In the ERT method a direct current is passed through the ground between two metal rods, which are called current electrodes and the electric potential difference is measured between another two rods, called potential electrodes. The distortion of the equipotential lines allows estimating the resistivity distribution of the subsurface. The electrodes are placed equidistantly along a line at the ground surface. A computer controlled automatic measuring system determines the actual current and potential electrodes. In this way a resistivity section can be presented below the profile (see e.g. in Fig. 7b).

According to the position of the electrodes, different configurations can be used. In this study Wenner-Schlumberger (W-S) configuration has been used where the electrode sequence is current-potential-potential-current electrode. The distance between the first two electrodes and between the last two ones is the same for this array. The electrode spacing, the distance of the consecutive electrodes was 0.5 m. In the field measurement a Syscal Pro Standard & Switch system was applied.

The measured values have to be inverted to obtain a resistivity section which can be interpreted for geological purposes. For the inversion the EarthImager 2D Version 2.1.7 [6] code was used. The RMS value which describes the fitting of the data and those of the ones calculated from the inverted model proved to be reasonable for all inversions without removing data.

3. Field studies

3.1. An archaeological study

This archaeological study was published by [2]. The Palaeochristian cemetery chapel in Sárisáp was already excavated in the beginning of the twentieth century, and then it was re-buried, and later forgotten. Recently its re-excavation is planned. As a first step, the chapel is to be re-found again. It is known from [7] that the area of the chapel is 11.2 m x 5.5 m, and it is situated somewhere in an area of 25 m x 30 m.

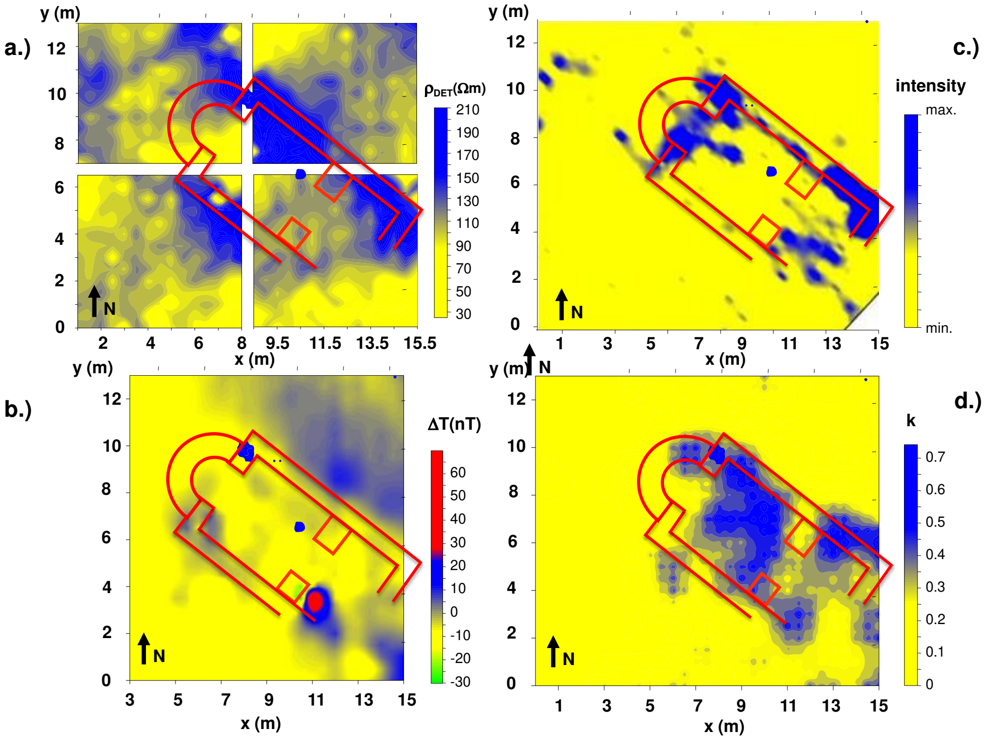

Figure 2. Results of three standard geophysical methods and of the pricking probe with the layout of the chapel: a.) geoelectric method, b.) magnetic method, c) georadar, d) pricking-probe.

By the time of the excavation the entrance had already been destroyed. Nowadays, the wall remnants are supposed to be at a depth of 0-1 m covered by clayeysandy sediments. According to the original document, the chapel is W-E oriented. The topography is relatively flat and there are no geomorphologic indications for the buried chapel.

At the time of the first measurements, due to the dense vegetation onsite, it would have been difficult to locate the chapel by applying common geophysical methods therefore we preferred to use systematic Pricking Probe (PriP) technique. By using it, the chapel could easily be found. Later on, when the area was mopped-up from undergrowth, detailed PriP experiments were undertaken. In the restricted area geoelectric, magnetic and georadar measurements have been carried out, as well, enabling the comparison of the results of all of these methods (Fig. 2.).

The layout of the chapel is laid on the maps in Fig. 2 on the basis of the earlier partial excavations. Its orientation was however not given precisely in the documents. Among the conventional geophysical tools the georadar provided the best results presenting rather well two walls. The geoelectric method could well display two walls, as well, but its result is rather noisy. For the magnetic method the material of the wall was not ideal, thus its result is week. The PriP was noise-free and could well describe the debris distribution due to the chapel. It gave a remarkable anomaly also inside the former building due to the debris originating likely from the roof and the walls and its mosaic basement.

By the PriP one can get an image about the subsurface distribution from different depths by applying different penetration depths. The results of such a **sounding** are presented in Fig. 3. Of course with larger penetration depth the probability that the rod hits into a rock increases (note that the scales are not the same for the subfigures in Fig. 3). With the highest, 60 cm penetration depth (Fig. 4) the layout of the chapel was very well presented including also the shape of the apses. The entrance was destroyed already in the time of the excavations according to [7]. The PriP was therefore able to position the remnants of the chapel and to describe its details remarkably well.

With the PriP technique successful reconnaissance measurements were carried out in the case of dense undergrowth, which would have been hardly possible with standard geophysical methods. In the detailed investigation the pricking probe proved to be also competitive. Only the georadar was able to provide high quality images about the chapel walls, but some details are not clearly seen, or can hardly be recognised in contrast to the PriP maps. The imaging power of the PriP technique, especially with a 60 cm pricking depth, proved to be superior to that of the applied geophysical methods.

It is also possible to carry out PriP measurements with a few different pricking depths in the same area. It is called PriP sounding, and, as we have found, it is especially useful. Among common soil conditions the method can be universally applied, except in presence of significant posterior debris distribution. For a deeper insight it is advisable to remove the uppermost soil layer.

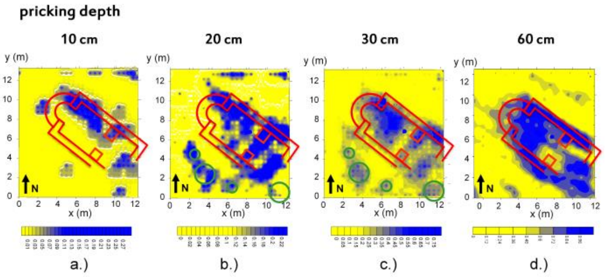

Figure 3. Sounding with the PriP technique with pricking (penetration) depths of 10, 20, 30 and 60 cm. The scaling is depth-dependent.

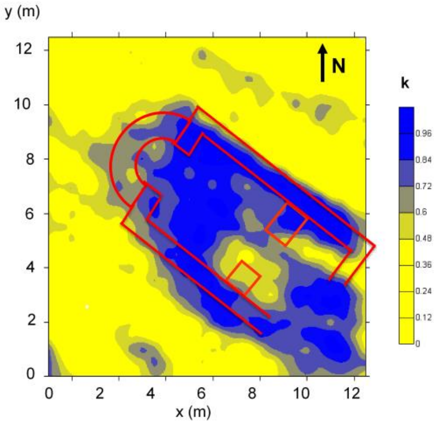

Figure 4. Filtered isoline map of the PriP results applying a penetration depth of 60 cm and horizontal grid distance of 50 cm, together with the layout of the chapel

3.2. A karst study by the PriP

The very first geological measurements by the PriP were made in Homód-árok, Bakony Mountains, Hungary [3]. During carrying out geoelectric measurements in the karstic area the electrodes went easily into the soil in certain areas, while elsewhere they always hit debris. We assumed that this systematic debris-distribution contains information about the local geology.

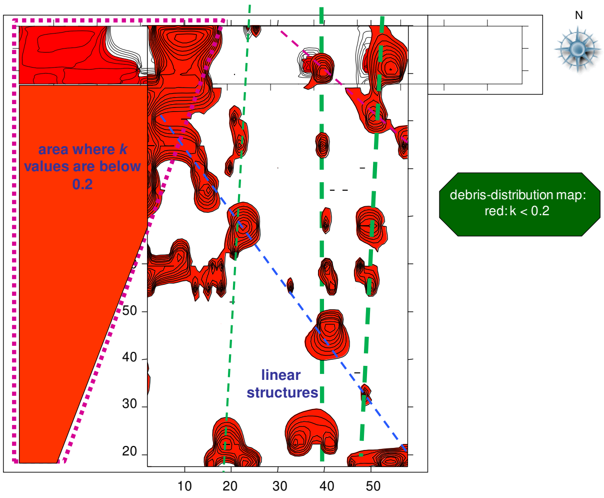

Figure 5. Debris-distribution map presenting only k values below 0.2. Dashed lines connect low *k value* dots: the green lines are in about N-S direction, the blue one in NNW-SSE direction.

Fig. 5 presents the areas where the average *k* value was below 0.2 that is where there was only a small amount of debris. Two areas are clearly distinguishable from each other: in the western part of the area there are everywhere small *k* values; in the eastern part at the same time small *k* values occur only in smaller areas which are organized along lines mostly in about NS direction. This is one of the most characteristic structural directions of the study site. The dots with small *k* proved to be sinkholes.

Fig. 6 highlights all *k* values. Connecting the areas where *k* is large, two main directions are seen: the NW-SE, and the NE-SW ones. These are also characteristic directions in the study area.

It was shown that the debris-distribution in the study site is systematic. On the basis of the PriP measurements the area could be divided into two parts. In the eastern one even linear structures in different directions were detected, which are all in good correlation with the principal geological directions of the area. Small *k* values seem to refer to sinkholes while large *k* values most likely to elevated bedrock surface.

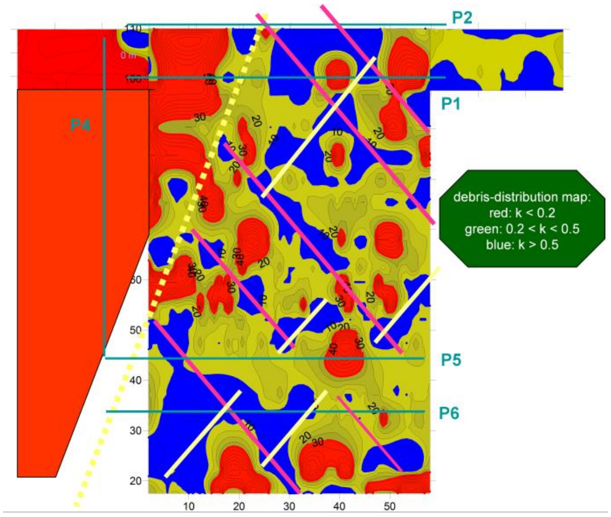

Figure 6. Debris-distribution map. Continuous lines connect areas with a large amount of debris. The direction of the purple line is about NW-SE that of the yellow line is NE-SW.

3.3a. Characterisation of a fracture system by PriP

Kádárta, Bakony Mountains, Hungary, where the measurements were undertaken, lies approximately 1 km northeast from the city of Veszprém. The Kadarta aquifer consists of 1000 m thick well stratified, highly fractured middle-Triassic dolomite [9], which is in an elevated position, forming a large plateau.

The spatial frequency of fractures is one of the crucial parameters influencing the hydraulic functioning of a karst system. Fractures are also important in engineering and geotechnical practice. They affect the stability of engineered structures and excavations [9].

Most effective geophysical methods for identifying (individual) fractures and/or fracture zones are VLF-EM e.g. [10], VLF-R [11], RMT [12], EM-34 [13], Electric Resistivity Tomography [14]. The resolution of these methods with the exclusion of the geoelectric ones is however smaller than it was required in this study, where fractures were expected to be in even less than 1 m distance.

Geotechnical tools would be perfect for fracture mapping in small scale, but they provide only point-like information. These methods are expensive and their application is strongly limited by field conditions, such as topography, artificial constructions or vegetation, which make the access to the study area difficult or even impossible.

To be able to detect fractures by the ERT method its electric resistivity value has to be different from that of the host rock. If the cracks in a host rock are filled with clay or water, this criterion is satisfied, since their resistivity is less than 20 Ωm contrary to the several thousands of Ωm of the limestone or dolomite. If the fractures are empty their resistivity is very large. This strong variability of fracture resistivity can be confusing in the interpretation if the fractures are close to each other. For this reason the fracture measurements were carried out following a rainy period to assure that the fractures are water filled thus electrically conductive.

Although resistivity methods are suitable for detecting and localising fractures, it is always very useful to apply multiple methods for the verification of results. For this reason the Pricking Probe Method (PriP) was applied [4].

In the northern part of the area, where the bedrock is covered by 10-80 cm soil, the fractures which reach close to the surface are detectable by PriP due to that the fine sediment/rock volume relation is more in their filling material than elsewhere. The probe hits a rock less likely here than elsewhere. The PriP method is supposed to be able therefore to: 1. separate differently fractured zones; 2. localise fractures; 3. give information about the significance of the fractures. The closer are the fractures to the surface and the wider they are, the better they are expected to be seen by PriP. These are the key parameters also in the vulnerability studies.

In the PriP method we assumed the existence of fractures, where the k_5 value (that is the running average calculated from 5 consecutive data): 1. was below 0.2; 2. had a strong local minimum; 3. had a strong contrast in adjacent zones (see e.g. zones 8, 9 and 10 in Fig. 7a). In situations 1 and 2 the probability that the probe hits rocks is smaller due to that they are filled with fine sediments. In case 3 the change must occur due to the changes in the quality of the rock unit or the changes in the thickness of the cover. Both of them may occur due to structural changes, e.g. a fault, which also refers to the existence of a fracture. It means that all of these features correspond to fractures.

Fig. 7 presents PriP results (Fig. 7a) and compares them with the ERT ones (Fig. 7b, 7c). Small *k* values correlated mostly very well with the small near-surface resistivity values obtained from the ERT. Fractures filled by clay and/or water have namely small resistivity.

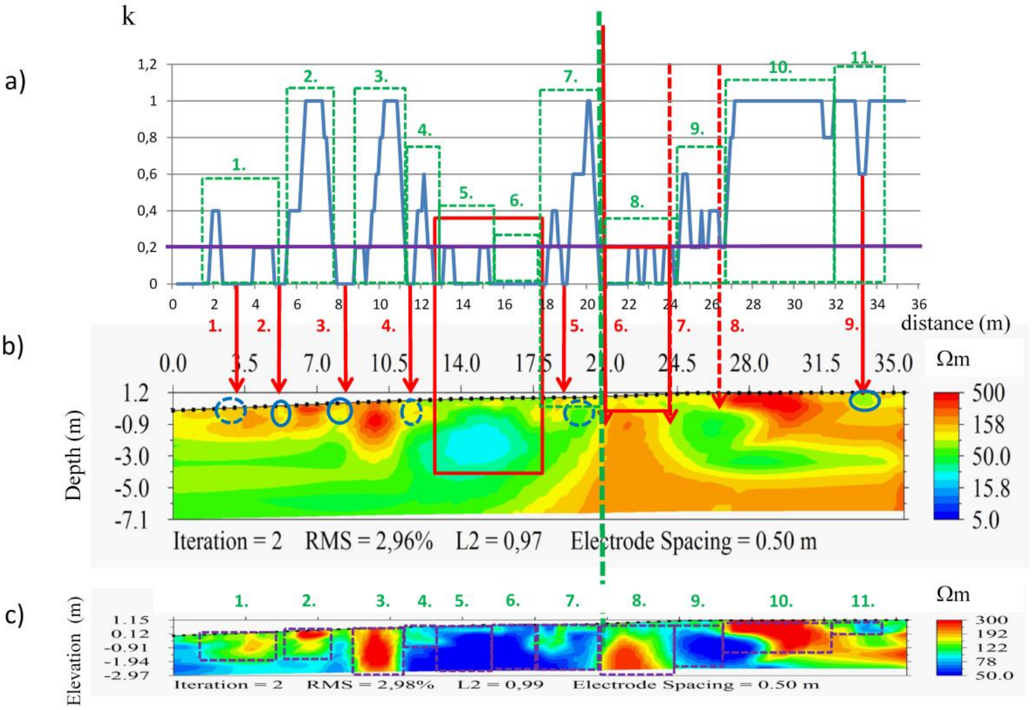

Figure 7. P1 field results. **a** Pricking-Probe results; **b** Deep ERT section; **c** Shallow ERT section. *Violet line* presents the *k*=0.2 level. *Red continuous line rectangles* delineate the *wider blocks*, where *k* is less or equal to 0.2. Blocks, in which *k* values are in about the same range are denoted by *green dotted line rectangles*. The same blocks are presented in *violet rectangles* in the shallow ERT section. *Red arrows* display the supposed fracture positions on basis of the PriP results. The fractures, which are assumed to correspond to them, are presented by *ellipses* on the ERT deep section. If they are less unambiguous, they are shown by *dotted line*.

In Fig. 7c the green dotted line rectangles delineate sections where the *k* values are in the same range. These sections were displayed also in the deep (Fig. 7b) or shallow (Fig. 7c) ERT section depending on which of them is supposed to show the corresponding features. Red arrows start from positions where *k* is less than 0.2, where there is a strong local anomaly (e.g. at 33.3 m) or where *k* values change suddenly (e.g. at 24 m). The arrows point to the corresponding structures on the ERT sections. These structures are indicated by ellipses if they are resistivity minima and supposed to represent fractures. Unambiguous structures are delineated by continuous lines while ambiguous structures are indicated by dotted lines.

The local *k* minimum anomalies are mostly located in 0-21 m, the *k*-jump anomalies (with the exclusion of the 9th fracture) in 21-35 m. Since they are separated at 21 m where there is a drastic change in the depth of the solid dolomite (see Fig. 7b) a link may be supposed between the behaviour of the *k* values and the depth of the solid dolomite. In 0-21 m fractures are displayed by small *k* and small resistivity values. *k* values display however also fractures, which are not clearly seen in the ERT sections (at 3 m and 11.5 m).

Between 13 m and 18 m there is a wide *k* minimum zone. It corresponds to the small resistivity zone in the ERT section which is assumed to be highly fractured. In this zone the probe hits a rock with lower probability, resulting in smaller *k* values. Between 21-28 m, (fractures 6-8), there are sharp changes in the level of the *k* values, which refer to changes in the subsurface conditions. The positions of these shifts correspond to resistivity changes as it was expected. It has to be noted that where *k* level changes there is always also a *k* minimum. It means that the blocks with different fracturing are separated by fractures. The structural changes had to be developed along them.

The best correlation between *k* values and resistivities are obtained for the resistivity values in about 0.3 m depth. This is logical, considering the 0.3 m pricking depth. It also explains the small *k* values between 21 m and 23 m, because the PriP does not reach the electrically resistive horst structure. All PriP features can thus be explained on the basis of the shallow resistivity section.

Also fracturing maps can be constructed using the PriP results (Fig. 8). The displayed quantity is *1-k* in percent. In the lack of fractures *k* is equal to 1 (fracturing is 0%), while where the rod is going into the soil without hitting a rock (because there are not unweathered rock matrix elements) *k* is equal to 0 (fracturing is 100 %). The larger is the volume of the unweathered rock matrix elements in a given volume the smaller is the probability that the rod can penetrate into the given depth, the larger is *k* and the smaller is the fracturing.

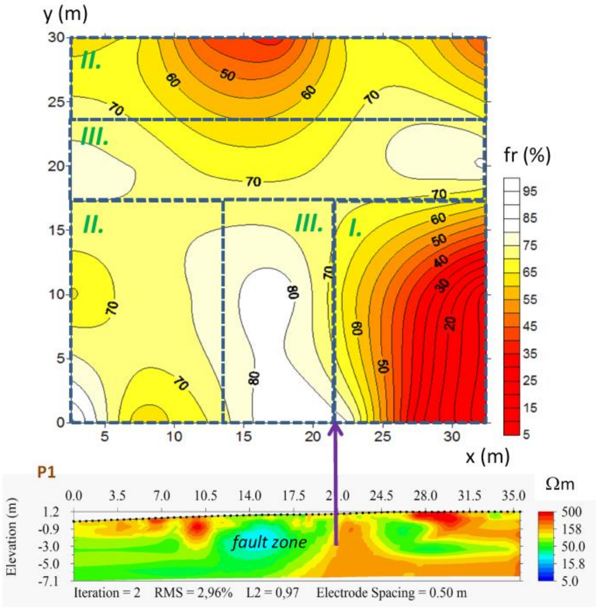

Figure 8. Fracturing map calculated from the *k*-distribution map and (below) the ERT section. *Zones I-III.* correspond to different fracturing areas: *I.* massive dolomite; II. fractured dolomite; *III.* very fractured dolomite/fault zone. The *vertical line* connects the location of the fault on the resistivity section with its correspondent *k* transition on the fracturing map.

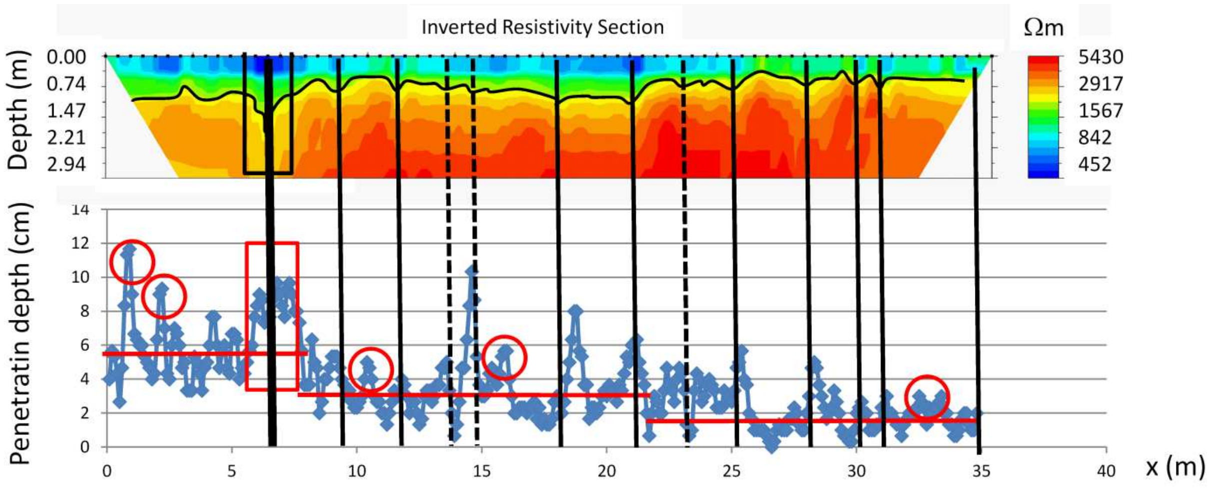

Figure 9. Fracture detection. a) apparent resistivity values determined by ERT. b) resistivity values determined by ERT. c) mPriP curve. Black curve: A resistivity isoline, demonstrating the bedrock surface. Black lines are at the locations of supposed fractures on basis of the resistivity section. The dotted ones refer to not as significant fracture. Red ellipses: mPriP maximums without any pair in the resistivity section. Red line: basic PriP level in the given section.

The obtained PriP fracturing map can be divided into three areas according to the fracturing level. In zone *I* are the smallest values. Here the rock unit is very solid. In zone *III*, where are the largest values, the rock unit is strongly fractured. Zone *II* is a transition zone. Zone III in the bottom middle of the map corresponds to the fault zone shown by the resistivity section in Fig. 8. It is still a question whether the other zone *III* is also a fault zone. The low fracturing values in *x*=10-20 m, y=30 m are most likely artificial due to abandoned building materials.

It was shown that in most situations PriP is able to locate and characterise fractures and fracture zones and to determine the fracturing level of an area. PriP gives a direct image about the fracturing of the near-surface region of an area. Fracturing can also be calculated from the ERT values but they are function of – among others – the water content of the given rock, which itself depends on many parameters (time and quantity of the rain before the measurements, thickness of the cover, etc.). Thus the fracturing obtained through the ERT method is more uncertain.

The PriP values correlated the best with the shallowest ERT values, as it was expected. The correlation increased with decreasing fracturing as ERT could better separate fractures. ERT anomalies are formed by integrated volumes, PriP is point-like. Disregarding from the most fractured areas the correlation of the PriP and near-surface ERT values proved to be at least reasonable (>0.4). In these zones there are distinct fractures which proved to be well localisable by both methods.

In this area a very significant fault zone was discovered on basis of the fracturing maps by both methods. The interpretation of the PriP was uncertain only in about one tenth of the area, most likely due to the man-made change. In the not intensively fractured areas a lot of individual fractures have been localised, at an average distance of about 2-3 m.

3.3b. Characterisation of a fracture system by mPriP

In the same study site in Kádárta just a few meter distance from the PriP measurements, in the other side of the fault another method had to be applied. In this area - due to the very shallow bedrock - it seemed to be more logical to measure the depth where the rod hits a rock. It could be achieved by utilising the scale which was carved on the rod. The results of these measurements, which are called modified Pricking Probe (mPriP) are seen in Fig. 9b.

The mPriP values are compared with the calculated resistivity values (Fig. 9a.). The resistivity isolines present the bedrock surface as it is shown by the black curve. Where there is a sudden depression in the bedrock, there must be fracture. These structures correlate very well with the mPriP maximum, as it was expected. Many mPriP anomalies are however not present in the resistivity image most likely due to the higher resolution of the mPriP. The red lines in Fig. 9b present the base line of the mPriP values in the given section. This is the depth from which the fractures start to deepen. These depth levels are also seen in the ERT image.

The mPriP was able to determine the depth of the bedrock thus also the position of the fractures. It seems to be able to distinguish fractures even better than the ERT, the only geophysical tool which enabled the characterization of the fracture system of the study area.

4. Conclusions

Simple geotechnical tools, the PriP and mPriP were developed to determine the mechanical characteristics of the subsoil. Since PriP gives an estimation of the debris quantity in a given volume below the measuring point it is able to describe the debris distribution. An archaeological and two geological applications of this method were presented. In the archaeological study it was the most effective method among the four investigated ones. It could find the buried remains of a chapel even in very dense vegetation and later on to give a good description also about its actual state utilizing also its capability to get information from different depths.

In the first geological study (Homód-árok) the PriP data proved to be systematic thus they were supposed to contain geological information. The studied area could be separated into two parts. The first one proved to be homogeneous. In the other linear structures were present which correlate well with the main structural directions of the area. Low PriP values appeared at the sinkholes.

In the second geological study (Kádárta) fractures could be localized applying PriP. The PriP results showed very good correlation with the ERT results in areas which were not changed by human activity.

In the same area, but in the other side of the large fault, a modified version of this method, the mPriP was used. If the soil is very shallow, its application is faster and more effective. It presented the fractures very well, in good correlation with the ERT results. It displayed however more fractures, most likely real ones, demonstrating that its resolution is better than that of the ERT method.

Both the PriP and the mPriP methods proved to be effective in the presented studies offering a new tool in such kind of investigations. Since the ERT was the only applicable geophysical method in the presented geological investigations it is very important to have a verification method. The presented geotechnical methods proved to be even more effective sometimes. They may an image with higher resolution and in their interpretation there are fewer uncertainties than in that of the ERT. They can also be applied in areas where it is very difficult to carry out other measurements, e.g. in dense vegetation, or in high mountains.

Finally strengths and weaknesses of the PriP technique are summarized:

Strengths of the PriP method: 1. it does not require large investment; 2. its application and data interpretation are very simple; 3. It can be used even among very unfavourable field conditions (dense vegetation, extreme topography, rainy weather); 4. It is able to provide information also about the edges of the study area which may not be possible by other methods; 5. It can be applied simultaneously with other geophysical methods since they do not disturb each other; 6. It provides complementary information to the geophysical results; it may show some details remained hidden using standard geophysical methods.

Finally the weaknesses of the PriP and possibilities for their elimination: 1. A major disadvantage of the standardized PriP method is a possible damaging of sensitive objects below the surface in archaeological measurements; 2. Roots of trees may produce pseudo-anomalies. Elimination of such problems requires either a slight diversion of the measuring profiles from the trees, or omitting the suspected values; 3. In case if large physical effort is required, data acquisition may be somewhat subjective. It can be handled as a signal/noise problem; 4. Penetration into compact, hard soils or into larger depth may need too large physical efforts. This problem could be solved by using machinery designed to perform PriP measurements; 5. Posterior debris displacements may distort the interpretation.

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