INVESTIGATION OF SIMILARITY BETWEEN ELECTRICAL RESISTIVITY RESULTS (VES AND ERI) AT KARSTIC REGIONS, ANTALYA, TURKEY

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ABSTRACT
As in the case of Antalya, the region consisting of rocks which could not resist to abrasion and easily soluble is defined as karstic terrain and characterized by surface collapse, small or large sized dissolution voids on rock surface. Formation and enlargement of voids may cause dangerous situation during construction and substructure work. Therefore, it is important to determine the location, type and dimension of caves. Geophysical investigations are important in determining the geometries of geological subsurface structures like caves, voids etc. For determining subsurface profile and characteristic of soil/rock, surface geophysical methods are successfully applied. Electrical resistivity procedures are the most important and most commonly used methods for determining near subsurface profiles. Using these methods, near surface profile, cavernous and weathered zones can be determined easily. In this study, near surface profiles were determined by utilizing both 2D Electrical Resistivity Imaging (ERI) and Vertical Electrical Sounding (VES) methods at Akdeniz University campus and Masa Dagi region. The main purpose is to investigate the similarity of VES and ERI results. Since the ground surface is covered by soil, the results obtained from 2D ERI analyses at Akdeniz University campus compared with only VES analyses. Around Masa Dağı location, since topographic cross-section of the region is clearly seen, 2D Electrical Resistivity results were compared with VES and with topography. Analyses were applied, and presences of subsurface cavities were determined using resistivity values from both electrical methods.

Keywords: *Electrical Resistivity Tomography, Vertical Electrical Sounding, ERT, VES, Karstic Region*

INTRODUCTION
Antalya is situated at the southwestern part of Turkey. Antalya cool-water deposits which are named as Antalya Travertine by Poisson (1977) and specified as Tufa by Glover and Robertson (2003) expands from the Aksu River in the east, to the Antalya Nappes and Beydağları Autochthonous in the west, from the Gulf on Antalya in the south and to the Taurus Mountains in the north. Antalya tufa ($CaCO_3$) spreads approximately 630 km^2 area (İnan 1985) (Fig 1). City is mostly comprised of calcareous rocks like tufa. The region which is comprising of rocks (tufa, travertine, dolomite etc.) that could not resist to abrasion and easily soluble is defined as karstic terrain. These regions are characterized by collapse on the surface (e.g. sinkhole, doline etc.) and small or large sized dissolution voids on subsurface geological structures. Formation and expansion of these voids are important of causing dangerous situation during or after construction, infrastructure work. Therefore, it is important to determine the location and dimension of karstic features. Geophysical investigations are helpful to determine these subsurface features and near-surface maps are prepared easily.
There are numerous geophysical methods to detect subsurface geological structures. Electrical Resistivity (ER) is one of the most popular geophysical methods of near surface investigations in the field (Aktürk and Doyuran 2012). This technique has been improved during last two decades in the way of data acquisition systems and these developments made it easier to use and obtain data. After these improvements the method called as Electrical Resistivity Imaging (ERI) (Aktürk and Doyuran 2012). According to ASTM Standard Guide for Selecting Surface Geophysical Methods (ASTM D6429-99), ERI is the best and convenient method for researching of near surface but at least two methods are combined in most of the geophysical studies for improving the accuracy. Vertical Electrical Sounding (VES) used in studies (Zarroca et al. 2011; Stan and Stan-Kleczek 2014) for correlation with ERI results. These geophysical methods are helpful in the rough areas because they are suitable to achieve near surface geological characterization non-invasive. It is very important because of invasive methods like borehole coring cannot be used in protected areas like natural parks or hilly areas (Stan and Stan-Kleczek 2014). VES, which is a conventional

method for 1-D resistivity surveys, chosen as a complementary method for ERI to make a perfect superposition in this study. These two geophysical methods made possible to draw boundaries between subsurface geological structures and karst characteristics like caves.

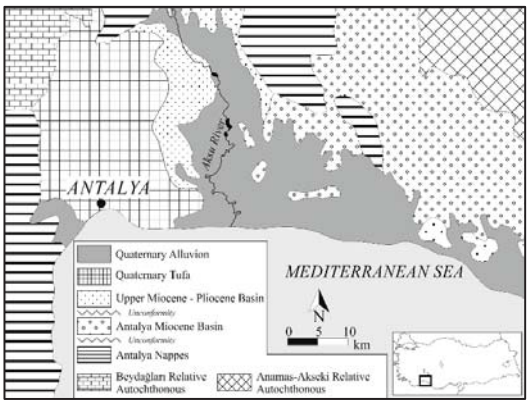

Figure. 1 Geological map of Antalya (Akay et al. 1985)

The aim of this study is to investigate the subsurface karst characteristics and variability of resistivity values of karst features by utilizing ERI and VES in Antalya. The geological observations and geophysical investigations have been carried through at Akdeniz University campus area in Konyaaltı and Masa Dağı region in Kepez (Fig 2). As a result, subsurface cavities were determined and illustrated using 2D colorful images.

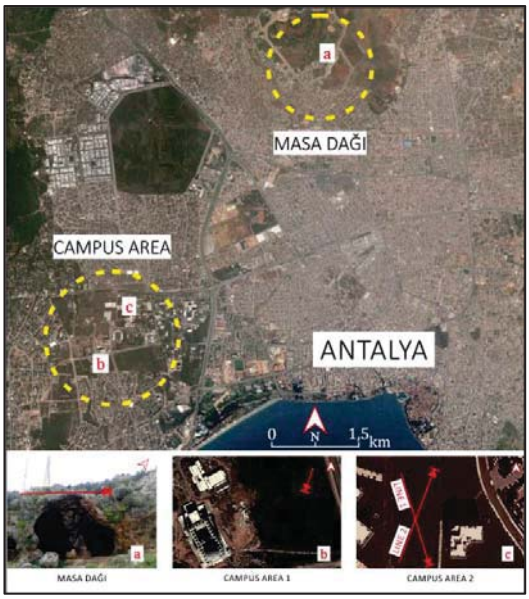

Fig. 2 Study areas showing ERI regions (yellow circles) and ERI profiles (red lines) with Masa Dağı and Campus Area views

MATERIAL AND METHOD

Electrical Resistivity (ER), also known as Direct Current Resistivity (DC Resistivity), is one of the oldest geophysical techniques in the field of subsurface geophysics (Aktürk and Doyuran 2012).
Traditional methods need more time to get the subsurface resistivity values, thus, Electrical Resistivity methods were well developed in the early 1900s. Determination and estimating of geological structures under the sediment cover are very important, however it is difficult without using electrical geophysical methods (Magnusson et al. 2010). According to Drahor (2006), the

integrated geophysical methods are usable to determine the buried structures, especially archaeological ones under the thick soil. Geoelectrical methods are useful tools to estimate physical properties of subsurface geological structures like thickness and elongation (Magnusson et al. 2010). ER technique has been developed in the way of data acquisition systems and after the development of multi electrode resistivity systems and operating software, the method has been called as Electrical Resistivity Imaging (ERI) (Aktürk and Doyuran 2012). ERI method is basically a continuous image of the subsurface geological units. It is a geophysical tomography method which based on injecting electrical current into the ground with a couple electrode system (current electrodes) and measuring the potential difference between another couple electrode system (potential electrodes). The process consists of settling electrodes along a straight profile by using a specific electrode interval. The distance between electrodes is specific for chosen electrode array (Wenner-Schlumberger and Wenner-Alpha). Interval length is important because of affecting the resolution and the depth of the visual image. After settlement of the electrodes, electrical current passed into the subsurface material and the potential difference is measured. The ratio between potential and current is calculated as electrical resistance of the subsurface material. Measuring is controlled by a device which has a software. ARES Automatic Resistivity System equipment, is a product of GF Instruments, was used in this study. Equipment define electrodes as potential or current simultaneously until the end of the measurement. The measured resistance is multiplying by a geometric factor (k) is related with chosen electrode geometry to convert the measured resistivity to the apparent resistivity (Aktürk and Doyuran 2012). True resistivity value is computed from apparent resistivity value with different methods (Drahor 2006). A pseudosection is a depiction of measured and calculated resistivity values, it is also a visual image of the subsurface. A mathematical process called inversion is applied to acquire more precise pseudosection with these resistivity values. All inversion processes done with RES2DINV (2004) software. Inversion is a basic step in modern resistivity tomography surveys. Apparent resistivity values inverted to true subsurface resistivity values to disclose the thickness and depth of resistivity layers in the subsurface (Aktürk and Doyuran 2012). The true resistivity distribution in the subsurface is gained from the result of this computation (Drahor 2006). So, after the measurement, three pseudosection visual images obtained. They are measured, calculated and inverse model images. The measured pseudosection is the naked picture of the subsurface. The inverse model pseudosection is the best resistivity image that closed to real resistivity value.

Vertical Electrical Sounding method is one of the oldest resistivity methods (Loke 2004). It is used for detect the resistivity values of horizontal layers on a straight vertical line. VES is a conventional method for 1-D resistivity surveys. If it is composed of horizontal layers, VES gives the best identification of subsurface and method has been widely used for exploration mineral, petroleum and groundwater resources (Loke 2004). Schlumberger method is generally preferred in VES analyses than Wenner methods because of moving just two electrodes until end of the measurement (Telford et al. 1990). As it mentioned, Schlumberger method has advantages in depth analysis then Wenner. Hence, it is suitable in determining depth of geological structure's top points and possibly determining bottom point when it is near surface (Telford et al. 1990). During the measurement, current electrodes need to move and a resistivity value measured at every layer until reaching the maximum distance. If resistivity values needed to be measured at deeper zone, interval of potential electrodes expanded and current electrodes can move again like at the beginning. There are a few electrode arrays in all resistivity methods and each method has a specific function for analyzing subsurface. In this study Wenner-Alpha and Wenner-Schlumberger methods were used to determine the subsurface visual image with ERI and Schlumberger method were used to determine the subsurface visual image with VES. Pseudosections of ERI method is compared with VES results, which done at same area, to specify degree of similarity with VES comparatively.

DISCUSSION AND CONCLUSION

ERI, which is the major method for this study, is done at all regions by using two methods, Wenner Alpha and Wenner Schlumberger. It is an assumption that there are many layers and data points in subsurface. Each of their true resistivity is given by an apparent resistivity by multiplying with a constant. The Root-Mean-Square (RMS) value of between 2% and 5% should be used depending on the quality of the data (RES2DINV Manual 2010), after inversion process with 5 iterations. By the

way it could be more than 5% at solid rocks or mixed soil because resistivity values can not be measured easily at that type soil or rocks.
The study in Kepez, measurements done at one region in Masadağı. Region consists of tufa unit especially has a cavernous structure and caves are also seen (Fig 2a). Masadağı is a rough area, for this reason electrode arrays can't be done at long range. The length of profile was only 20.0 m with 1.0 m electrode interval at Masadağı region. Because of short range measurement, the depth of analysis is only nearly 4.0 m. ERI pseudosections Wenner Alpha (Fig 3a) and Wenner Schlumberger (Fig 3b) arrays were analyzed with 3.4% and 3.3% RMS error.

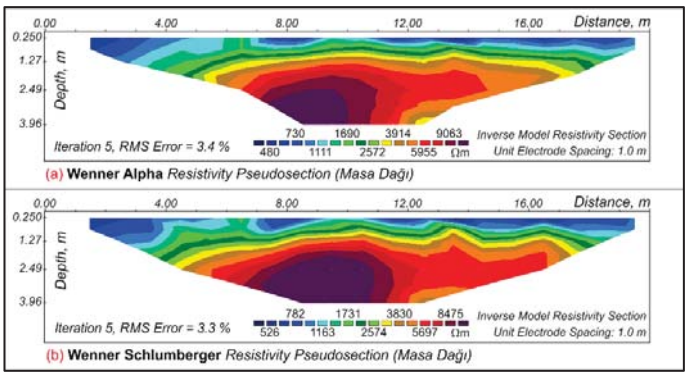

Figure 3 (a) Masadağı Wenner-Alpha pseudosection, (b) Masadağı Wenner-Schlumberger pseudosection.

After inversion process apparent resistivity values increases at nearly 2.5 m depth so that cavernous structure was expected to detect. After modelling, apparent resistivity was computed nearly 10000 Ωm at 2.40 m by Wenner-Alpha and more than 9000 Ωm at 2.50 m by Wenner Schlumberger. As mentioned above, these values give the clue to the existence of the cave. The cavernous structure was clearly detecting from pseudosections with around 9000 Ωm. Higher resistivity areas are superimposed with cave accurately with Wenner-Alpha (Fig 4a) and Wenner-Schlumberger (Fig 4b) pseudosections and also nearly 16000 Ωm resistivity value was detected with higher resolution resistivity images of both methods (Fig 4c-4d). The region has clearly visible topographic view so pseudosections were superimposed perfectly and cave was completely detected by ERI measurements. VES mesurements were done at two points on the ERI line (12.0, and 13.0 m) and nearly 80% compatibility was observed with pseudosections (Fig 5).

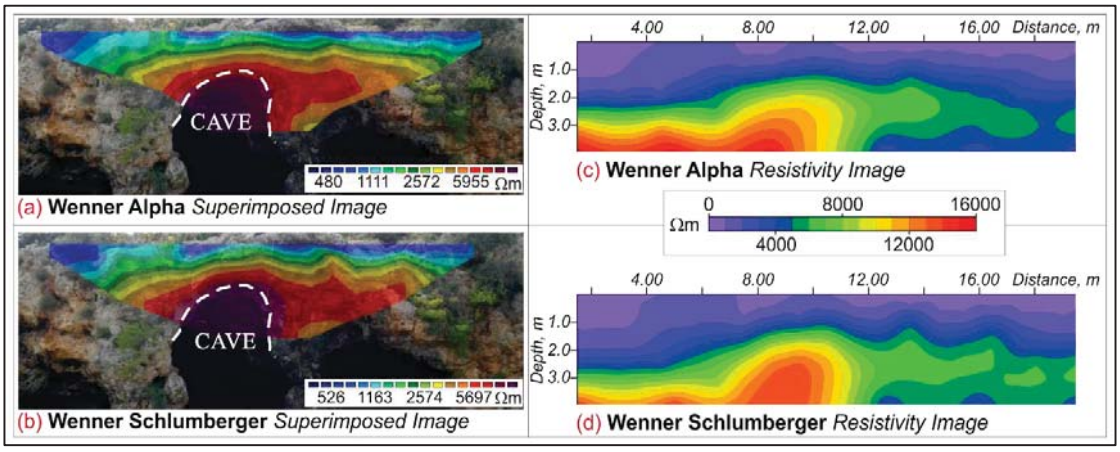

Figure 4 Masadağı region (a) Wenner-Alpha superimposed image, (b) Wenner-Schlumberger superimposed image, (c) Wenner-Alpha modelled resistivity image, (d) Wenner-Schlumberger modelled resistivity image

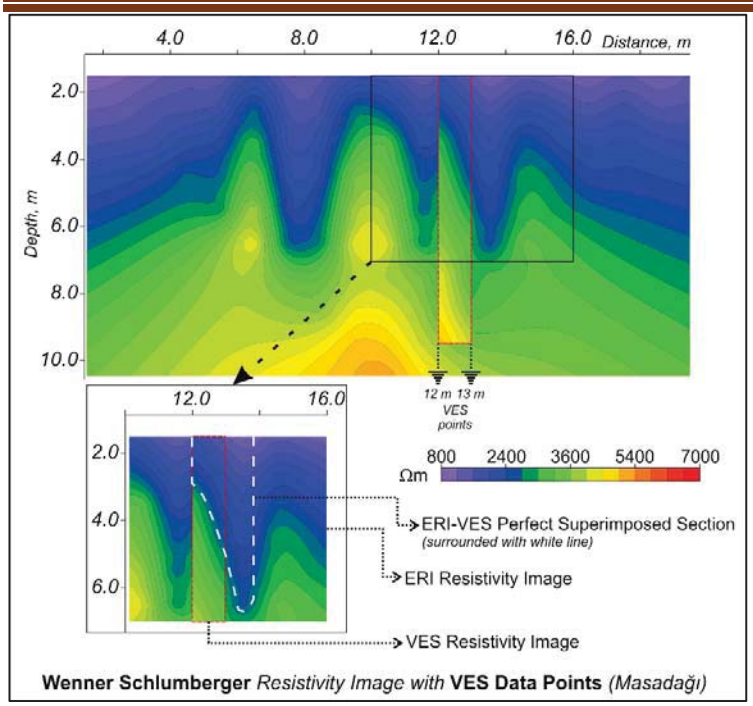

Figure 5 Masadağı region Wenner-Schlumberger resistivity image overlapped with VES points

The study in Konyaaltı, measurements were done at two regions in Akdeniz University Campus Area. Topographic cross sections cannot be seen well in campus area so that ERI measurements need to be compare with another geophysical method. Campus Area 1 is a region with bushes (Fig 2b) so the measurement could made at 48.0 m profile length with 1.5 m electrode interval. Elongation of array should increase the depth of penetration but because of woodland, methods could only penetrate around 7.0 m depth with RMS errors 7.2% at Wenner-Alpha (Fig 6a) and 7.0% at Wenner-Schlumberger (Fig 6b). Inversion process was difficult to modelling true resistivity because of the dryness of the soil so RMS errors were more than 5%. Whole profile, after 4 m depth, high resistivity section, around 12000 Ωm, detected by ERI with both methods. A cavity prediction can be done by these resistivity values or soil type couldn't let electrical current penetrate easily. Under normal circumstances, electrical resistivity of limestone cannot reach 12000 Ωm value so this give a clue for cavernous limestone or an underground cave.

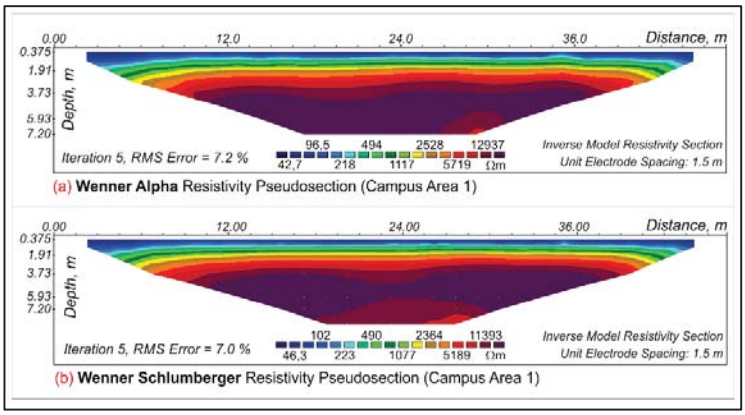

Figure 6 Campus Area 1 region (a) Wenner-Alpha pseudosection, (b) Wenner-Schlumberger pseudosection

Campus Area 2 has clear topography, so arrays were performed perfectly. In the area, measurements were done at two profile lines (Fig 2c) and they were overlapped at midpoints. Due

to topography, the length of profile was 128.0 m with 4.0 m electrode interval at both profiles with less than 2.0% RMS error. At first profile, modelled resistivity values were maximal 800 Ωm between 38 m to 72 m at settlement of electrodes and depths 5.0 m to 12.0 m (Wenner-Alpha in Fig 7a and Wenner-Schlumberger in Fig 7b). But at second profile, modelled resistivity values were maximal nearly 600 Ωm between 8 m to 60 m at settlement of electrodes and same depths 5.0 m to 12.0 m (Wenner-Alpha in Fig 7c and Wenner-Schlumberger in Fig 7d). This means a cavernous structure at depths 5.0 m to 12.0 m was detected from the beginning of profile 2 to midpoint of profile 1.

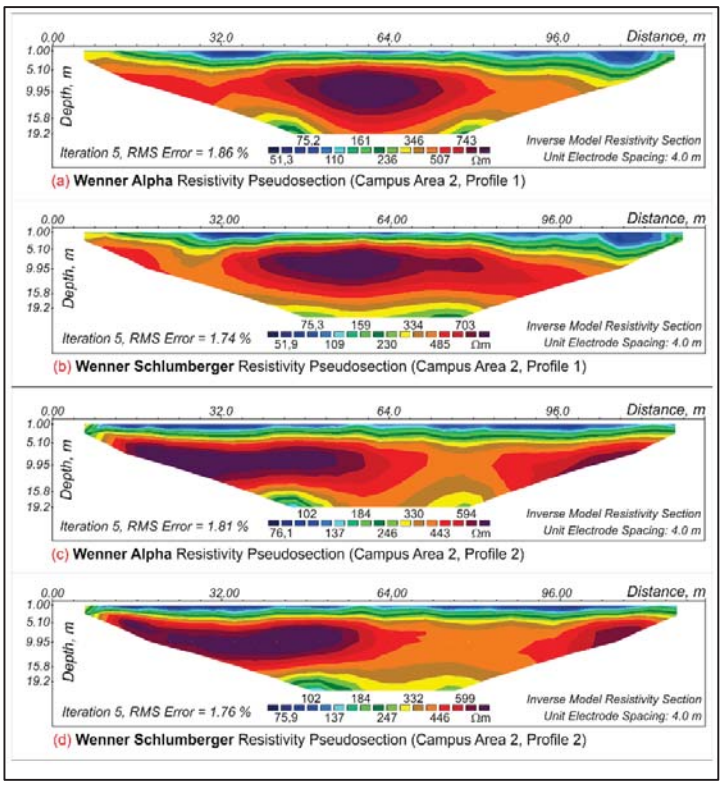

Figure 7 Campus Area 2 region (a) Profile 1 Wenner-Alpha pseudosection, (b) Profile 1 Wenner-Schlumberger pseudosection, (c) Profile 2 Wenner-Alpha pseudosection, (d) Profile 2 Wenner-Schlumberger pseudosection

VES is done at Campus Area for compare subsurface images because of invisible topographic cross section. VES method used first in Masadağı to understand cave structure well (Fig 5) then it was adapted to Campus Area results. At Masadağı, VES measurement done after ERI, near the column of cave chosen for analysis to see resistivity match perfectly. 12th m and 13th m points of ERI profile were chosen for VES data. Because of penetrating to depth of Wenner Schlumberger method is better, VES match with this method clearly as shown in Fig 5. After VES and ERI measurements, average 3000 Ωm calculated electrical resistivity value shows the existence of a cave or a mostly cavernous structure. By this prediction, ERI analysis in campus area will compare with VES results correctly even though the area has covered topographic section. At campus area 1 there is only one VES point performed because of bushes in the area. VES was done at 25th m of ERI profile and superimposed perfectly until 5m depth and also overlapped until 10m depth less-than-stellar (Fig 8a). There is 150 Ωm difference between ERI and VES results near surface, but while penetrate deeper, difference between results reach 400 Ωm (Fig 8b). It is clearly that, one VES point couldn't verify the whole ERI profile, so that for better comparison, VES points should increase in number. At campus area 2, there were 7 VES points performed at profile 1 (Fig 9a) and 5 VES points performed at profile 2 (Fig 9b). So that continuous picture of VES data points could be constituted at campus area 2 clearly. At profile 1, from 32m to 80 m, 7 VES analyses executed to

understand soil profile. Higher resistivity points, 40m-48m-56m, also showed same resistivity values with VES. It is clearly seen, from 40m to 56m, beginning from 15m depth, electrical current couldn't penetrate easily so resistivity values increased. Resistivity values can't reach more than 500 Ωm so that porous soil may be overburden and cave existence ineffable properly.

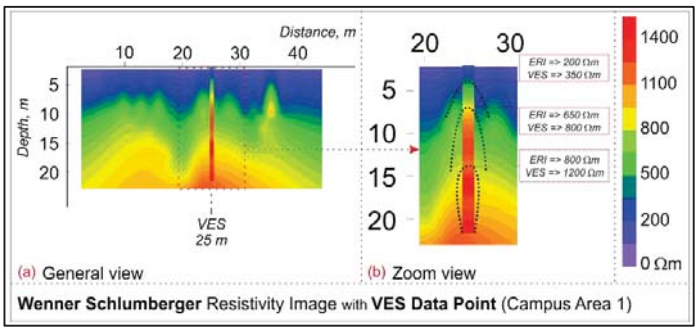

Figure 8 Campus Area 1 region Wenner-Schlumberger resistivity image overlapped with VES point

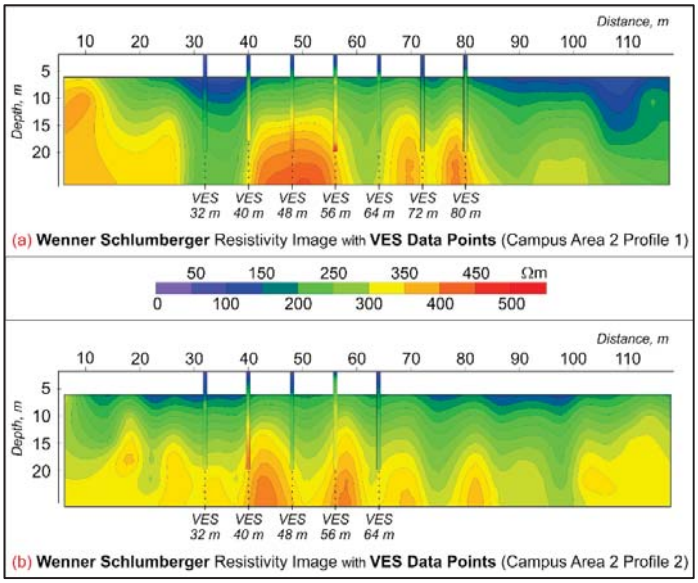

Figure 9 Campus Area 2 region Wenner-Schlumberger resistivity images overlapped with VES points (a) Profile 1 (b) Profile 2

In Masadağı, analysis could not done at long distance because of topography but this section give the best results for detecting subsurface cavernous structures. In region, prominent cave was located on subsurface images clearly, with ERI and VES analyses. In Konyaaltı, analyses could done at long array distances easily, but topographic cross section could not be seen like Masadağı, so VES analyses were used to comparison with ERI results as in Masadağı. It is important that VES analyses should be done on ERI profile to make a VES profile, otherwise as in Campus Area 1, VES analyses could not give a good comparison. There were 7 VES analyses in profile 1 and 5 VES analyses in profile 2 at Campus Area 2, so that VES profile clearly superimposed with ERI results.

In conclusion, ERI and VES are important for detecting subsurface cavities, geological structures, archeological remains etc. But it is important that choosing the best array (e.g. Wenner, Schlumberger) for the study. At depth analyses VES is important method for determination so ERI can't be used instead of VES but near surface analyses let ERI and VES get same results. Therefore, ERI should be preferred in near surface analysis because of giving analysis results in a shorter time.

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