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Detection of cavities in gypsum

Emin U. Ulugergerli and İrfan Akca

Ankara University, Engineering Faculty, Geophysics Eng. Dept., Besevler, Ankara, 06100, Turkey
e-mail: E.Ugur.Ulugergerli@eng.ankara.edu.tr

Abstract: Existence of cavities and weak zones on gypsum was explored in a boarding school property by using direct current resistivity, ground penetrating radar and seismic refraction methods. Two-dimensional inversion of the direct current resistivity data and evaluation of other methods pinpoint eight cavities and two weak zones as well as their possible interconnections. The drillings at selected locations confirmed the existence of these cavities nearby or extending underneath the buildings at the depths of 1 m to 7.50 m.

Key words: *Gypsum, DCR, GPR, cavity, 2D inversion*

INTRODUCTION

Three geophysical methods; direct current resistivity (DCR), ground penetrating radar (GPR) and seismic refraction methods were conducted to investigate cavities in a boarding school property in Sivas, Turkey. The main geological unit of the area is evaporates (Figure 1). The exploration area is a campus of a three-floor primary school and a five-floor dormitory (Figure 2). All buildings were built on a gypsum unit 30 years ago. Malfunctioning of the drainage and rain gutter systems caused leakage to the base of the both buildings. Reaction with water caused the gypsum to dissolve and created various size cavities, some of which extend underneath the buildings. Locating the cavities and weak zones is necessary in order to take precaution for the buildings. Since the target areas were mainly nearby and underneath the buildings, the cost of the mechanical soundings and their possible damage prohibited the drilling works. To reduce the cost and keeping in mind the non-destructive nature of the geophysical methods, DCR, GPR and seismic refraction methods were selected for the investigation.

To the north of the dormitory, the area is covered by young trees. The supporting wall of the dormitory is 1.5 m high. The wall around the playground is 0.5 m high and delineates the boundary of the garden. The area between the buildings, including playground, are covered with concrete. Three locations were selected as working areas (Figure 2). Site-A is at the north of the dormitory and under the trees. Site-B in the playground was investigated to search if there are connections between the possible cavities beneath the school and dormitory buildings. Last site around the dormitory consists of 3 profiles named by YE1, YE2, and YE3. YE1 was just 0.5 m away from the main wall while YE2 was 1 m away (Figure 2).

In each site, geophysical methods were employed according to their capabilities and restrictions. Understanding of the limitations and capabilities of the employed methods may allow the user to get adequate results even if the environmental conditions are very restrictive. Therefore, brief description of DCR, GPR and seismic refraction methods is given in the following sections.

DCR Method

The DCR method is one of the common methods to investigate shallow depth structures (e.g. van Overmeeran and Ritsema 1988, Dahlin 1996, Candansayar and Başokur 2001). The direct current is injected to the ground via two steel current electrodes, and potential differences are recorded between two potential electrodes. Recorded potential differences depend on the electrode configuration and geological structures.

Multi-electrode system of the Scintrex was used in this work (Figure 3). The system has 25 electrodes and does the recordings according to selected configurations, simultaneously (e.g. Griffiths et al. 1990, Loke and Barker 1996).

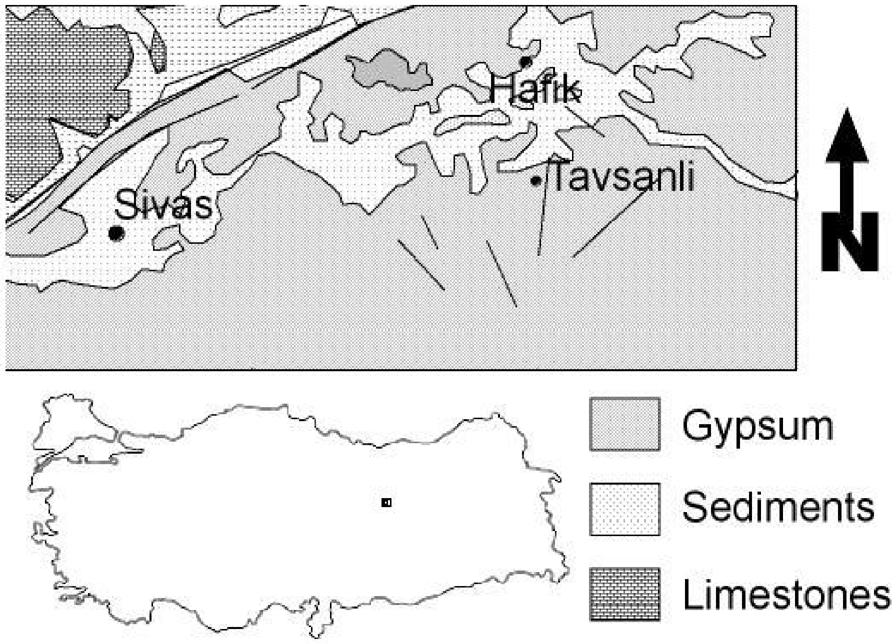

FIG. 1. Geological map of Sivas, Turkey.

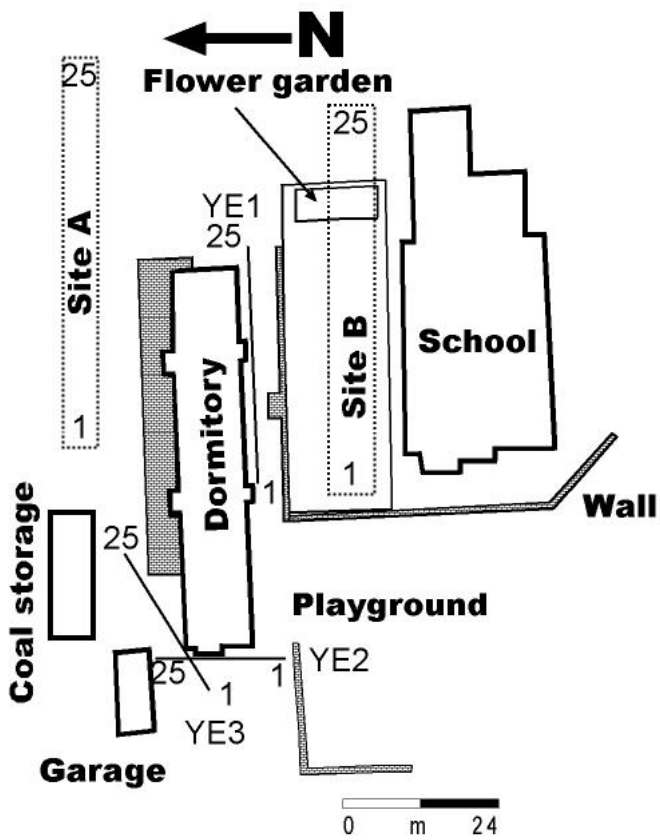

FIG. 2. Location of survey areas in campus area. Numbers indicate starting and ending point of the profiles.

Electrode spacing is set to 1 and 2.5 m. Ten levels of measurements were carried out. 130 apparent resistivity measurements were collected in each profile. Collected data is evaluated using two-dimensional inversion code (Uchida and Murakami 1990, Uchida 1991). The DCR method requires contact to the soil directly; thus, concrete cover and pavement have to be drilled to use the method in covered areas. Since there is no other restriction for this method, it was performed in all sites to get geoelectrical information about the subsurface.

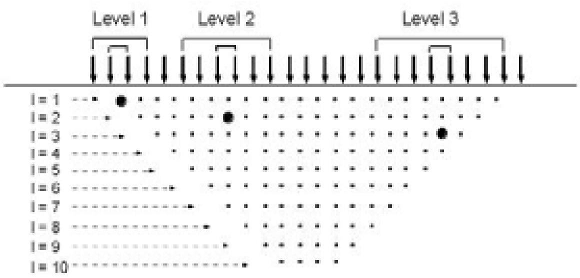

FIG. 3. Data gathering with multi-electrodes system in ten levels. Small dots show the covered area. Large dots indicates the recorded data related configuration given above the figure.

GPR Method

GPR methods measure the travel time of an electromagnetic wave transmitted from a transmitter antenna, reflected from the subsurface, and received via receiver antenna (Figure 4). The principles of the GPR method have been described extensively in the literature (e.g. Davis and Annan, 1989, Ulriksen, 1982, Morey, 1974). EKKO1000A GPR equipment with 25 MHz antenna is employed. The antenna separation is 4 m. and the measurement interval 0.5 m. The commercial processing software, Win_EKKO-Pro® (Sensor and Software) was used to process the collected data. Sampling interval is set as 1.6 ns, very low frequency filter (dewow), high frequency filter and gain correction were applied to raw data.

On the Radargram section, the amplitudes of reflected EM wave are presented with horizontal distance axis in meters and vertical traveltime axis in nanosecond (ns). Since the EM wave velocities may be estimated, then, approximate depth is given as:

$$\text{Depth} = \text{travel time} * \text{Vmedium} / 2 \qquad (1)$$

where V_{medium} is the velocity (m/ns) of the main geological unit in which the EM wave travels. Since the method does not require direct contact of the antennas to the soil, it can be used even over the concrete cover. However, manmade structures such as pipelines, power lines, etc. above- and / or under the ground, or roots of trees affect the GPR data quality severely. Therefore, the GPR survey was conducted only in Site-B (Figure 2).

EM waves (a) can travel from the transmitter to the receiver through the air (direct wave), and (b) can also bounce from the walls of the buildings. The necessary time (T) for the EM waves traveling through the air, and reflect back from the buildings to the receiver may be calculated approximately as:

$$T = (2 * \text{distance}) / V_{air} \qquad (2)$$

that is,

$$T_{school} = 10\ \text{m} / 0.3\ \text{msn}^{-1} \approx 33\ \text{ns} \qquad (3)$$

and

$$T_{dormitory} = 22\ \text{m} / 0.3\ \text{msn}^{-1} \approx 73\ \text{ns} \qquad (4)$$

where velocity of the EM waves in the air is taken as 0.3 m/ns, and the average distances to school and dormitory from the GPR profiles are 10 m and 22 m, respectively. Thus, reflections from walls should only be observed within the 33 – 73 ns. In other words, these reflections mask all the information up to 73 ns. The rest of the data should contain information about the subsurface.

Seismic Refraction Methods

Seismic methods are also commonly used in shallow depth investigations. The method is based on recording the travel time of an elastic wave created by hitting a steel plate with a hammer, refracted from an interface at the subsurface, and received via geophones on the surface. ABEM Terraloc MK6 24-channel seismic recording equipment was used in this survey. Geophone interval was set 2.5 m. During the survey the P wave travel times were considered. First arrivals to each geophone are marked and extracted from the data (Figure 5). Commercial package, SeisOPT was used to evaluate the data. The result of 2D inversion for each profile reveals horizontal and vertical velocity variations of subsurface.

EVALUATION OF THE METHODS

In general, limitations of the geophysical methods may prevent obtaining meaningful information about the underground structures. We should realize the limitations and the capabilities of each geophysical method, and then adapt it to the specific conditions of the area under investigation.

Seismic methods are capable of imaging the basement rock under the weathered surface layer. 2D modeling exposes rises and falls of sub surface interfaces and may help to get picture of intact units. Once the target depth is estimated using seismic method, we can apply other geophysical methods with appropriate field parameters. Long wavelength (>5 m) used in seismic methods can not resolve small scale objects such as small cavities and cracks. In addition, areas covered with high velocity material such as concrete or compacted ground will not allow the generation of the refracted waves. In such case, the seismic refraction method is not suitable to detect a low velocity base overlaid by high velocity surface layers. In our working area, high velocity of the concrete (≈1600 m/s) at the surface prevents obtaining information from the deeper layers (<600 m/s). Thus, the method can only be used on where there is no firm cover. Therefore, the method was employed only in Site-A.

Since the EM waves can travel both in the ground as well as in the air, GPR methods can detect the events occurring in both media. Properly kept observer logs are very vital in the interpretation of GPR data. Using the observer logs, the interpreter may differentiate the real underground features from unwanted side effects (posts, walls, trees, etc.). Modeling schemes may help to identify and eliminate the unwanted events within the data. But it also requires preliminary information about the source of cause. GPR methods are capable of imaging small lateral discontinuities better than seismic methods, due to their shorter wavelengths (<0.5 m). In our case, small lateral discontinuities are related to subsidence areas. Air or water, filled cavities, cause polarity reversals in amplitudes of the EM waves. Therefore, in noise free areas, GPR methods are capable of finding the small scale cavities, and delineating the zones bearing various geological problems.

DCR methods have difficulty in discriminating massive rocks (especially crystalline ones) and air-filled cavities, since both possess high resistivity values in geoelectrical sections. The area under investigation contains no crystalline rocks; therefore, almost all anomalies with high resistivity values should be associated with the cavities. Multi-electrode imaging systems allow the user to obtain sufficient data, to employ multi-dimensional inversion schemes and to map underground structures. Two-dimensional inversion routines produce a smooth picture of the subsurface (e.g. Loke and Barker, 1996), hence it can not easily resolve sharp boundaries or discriminate very small features. In addition, all structures appear larger in size.

SURVEY RESULTS

Seismic refraction method was employed to determine the base-rock topography. Three profiles were deployed in Site-A, at the north of the dormitory.

The results of the 2D inversion of the first arrivals are given in Figure 6. Sections present as changes in velocities with respect to the distance (horizontal axis) and depth (vertical axis). A high velocity unit (dark-blue and purple, v >2000 m/s) located under the average depth of 8 m corresponds to the base-rock. Therefore, the target depth of investigation is 10 m from the surface.

The GPR method was only applied in Site-B. If it had been applied in Site-A, reflections from the roots would have masked the information sought for. Six profiles were measured in Site-B. As an example, only Profile-1 is depicted in Figure 7. All profiles were parallel to the buildings and the antennas were perpendicular to the profiles (Figure 4). Hence reflections from the buildings were systematically observed in GPR sections. We expected that the rest of the data disclosed some information from the subsurface. The data below the 100 ns was interpreted (Figure 7). All underground structures, like concrete-channel, concrete-cover, and power-line caused anomalies in the data. Specifically, the intra-bed reflections observed between 15 and 25 m (A in Figure 7), and the discontinuity between 35 and 42 m (B in Figure 7) are significant. The former is related to the subsidence area which we are interested in, the latter is a concrete channel containing the water and heating pipes, and the power-line. Level map also helps to identify the discontinuity in the data. In Figure 8, horizontal-axis corresponds to the trace-numbers, vertical-axis corresponds to the number of samples related to travel-time, and the third axis corresponds to the profile number. Blue color indicates anomalous zones. First zone (A in Figure 8) is associated with subsidence area while second one (B in Figure 8) is the concrete channel.

The DCR data were collected along 12 profiles with 2.5 m electrode spacing in Site-A and -B. All profiles are 60 m long. Additional three profiles were conducted around the dormitory. The electrode spacing was set to 1.5 m. in YE1 and 1 m in YE2 and YE3. We had to reduce the number of electrodes at YE2 since the distance was 20m.

All electrode holes were drilled with an auger till reaching below the concrete pavement then 30 cm electrodes were inserted and tightened with mud. Pseudo three-dimensional sections were constructed using the results of 2D inversion of the all profiles in each area (Figure 9 and 10). The profiles nearby the building were presented as 2D geoelectrical sections (Figure 11). Note that color scales are natural logarithm of the resistivity values in all DCR sections

The results presented in Figure 9a belong to the profiles in Site-A. Iso-surface map of 150 ohm-m is presented in Figure 9b. Two highly resistive local units (blue regions, ρ>150 ohm-m) can be traced in the section. The first anomaly (A in Figure 9a) is between 0-10 m at the western side (towards the coal storage, Figure 2), and the second one (B in Figure 9) is between 20-24 m. The second anomaly is seen at both sides of the section (Figure 9 b) indicates the sewer system. Large anomaly between 40-55 m at the eastern side belongs to intact gypsum unit which emerges from ground farther away along the profile. Sewer system and surface of the intact unit can be clearly seen in section given in Figure 9.

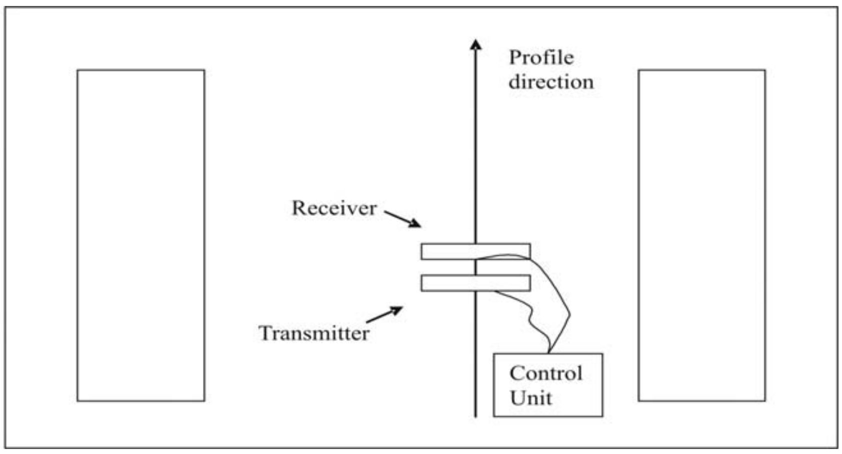

FIG. 4. GPR setting. Antenna orientation was perpendicular to the profile direction.

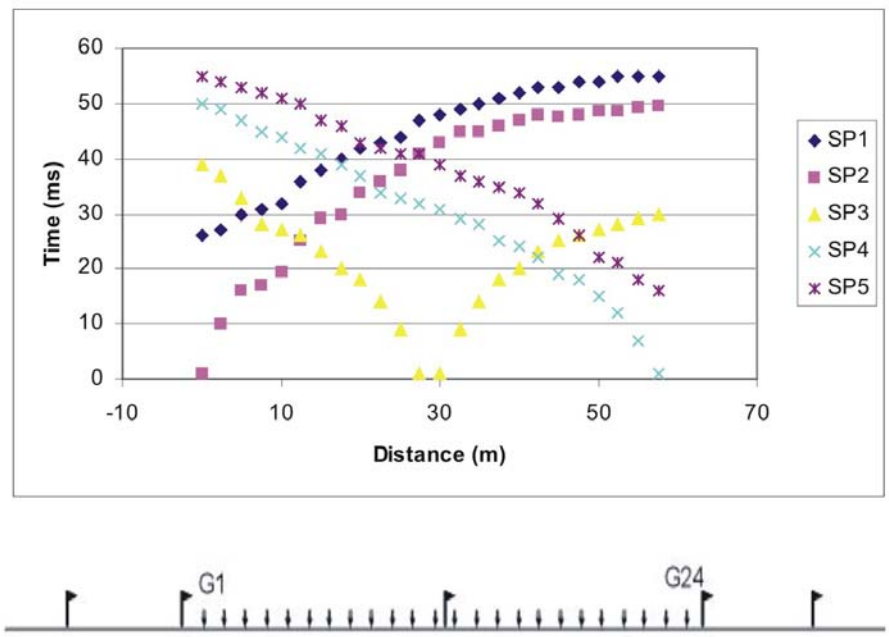

FIG. 5. Seismic survey setting and first arrival times to each geophone. Small arrows points the geophones while flags are shot points.

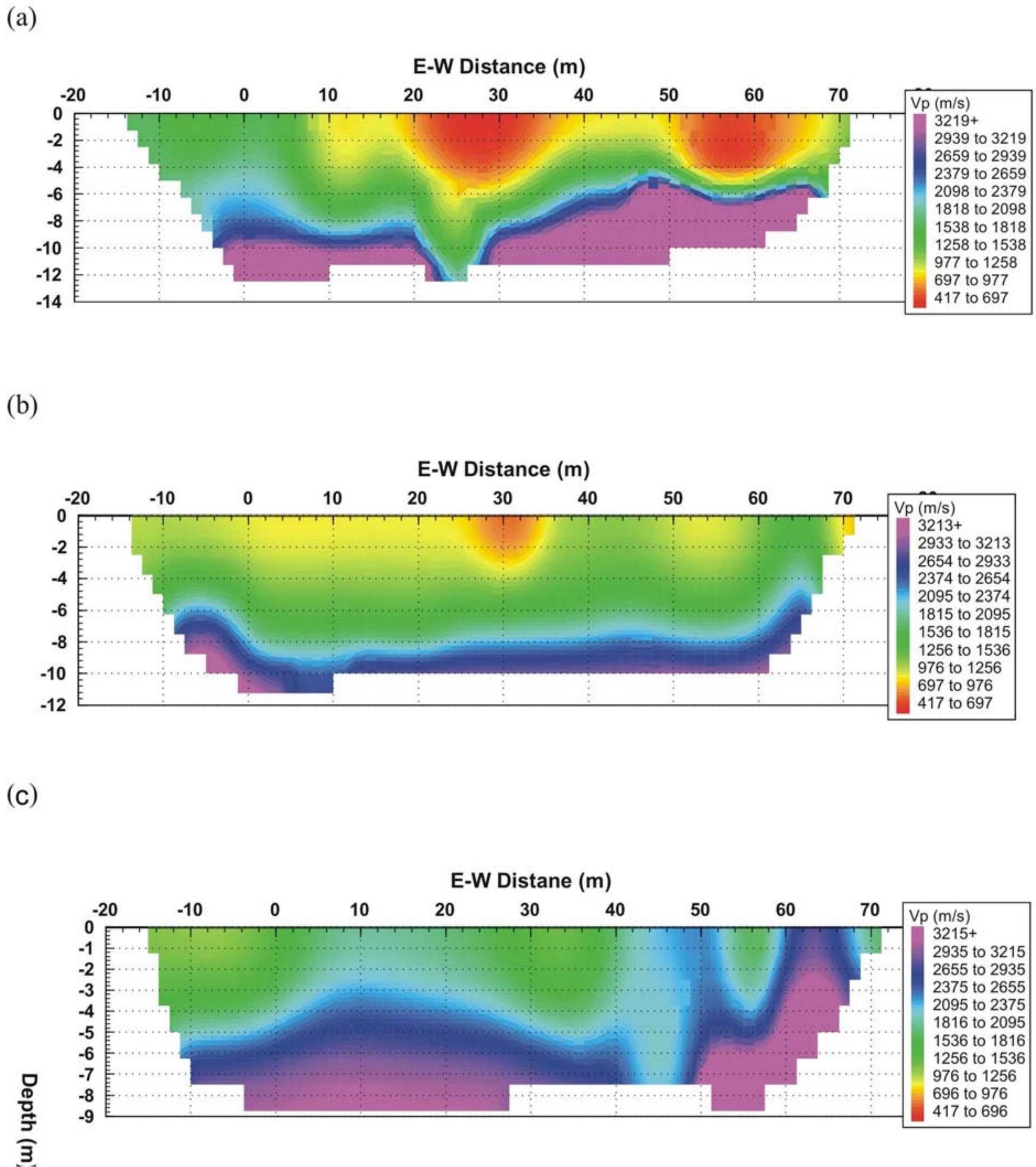

FIG. 6. P wave velocity section from 2D inversion result of seismic data gathered in Site-A.

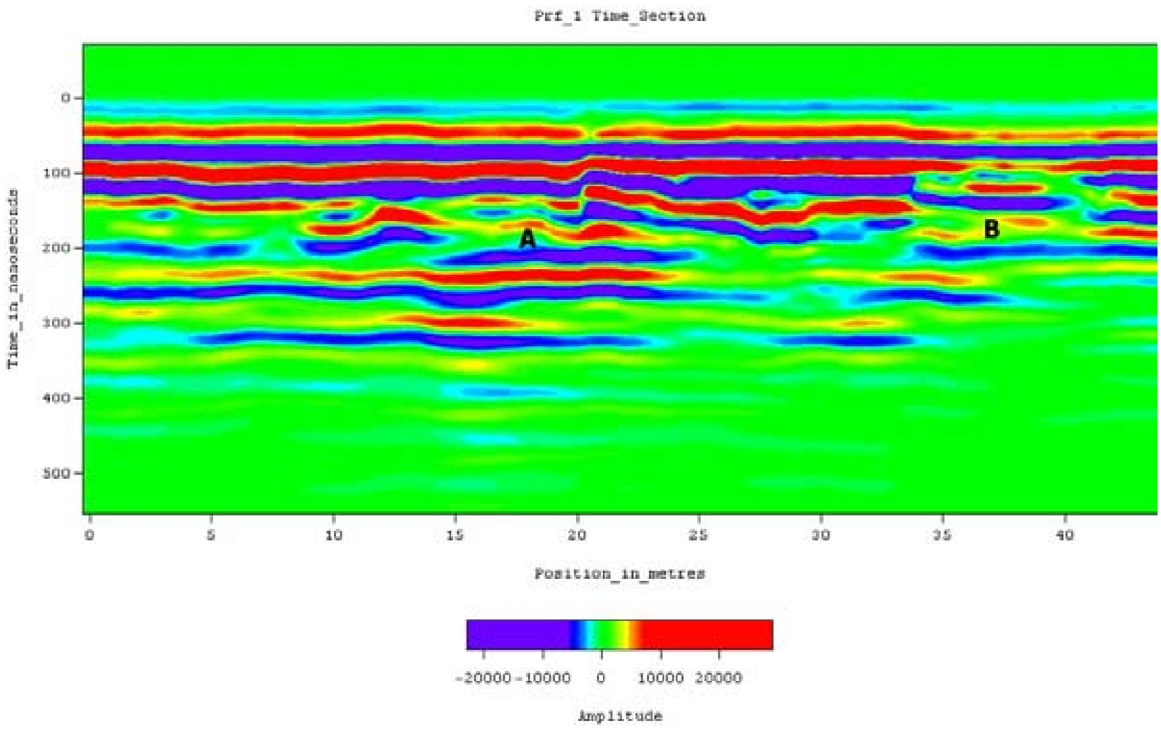

FIG. 7. Radargram of Site-B. Vertical axes is travel time in ns horizontal axes is distance in (m). Letters are explained in the text.

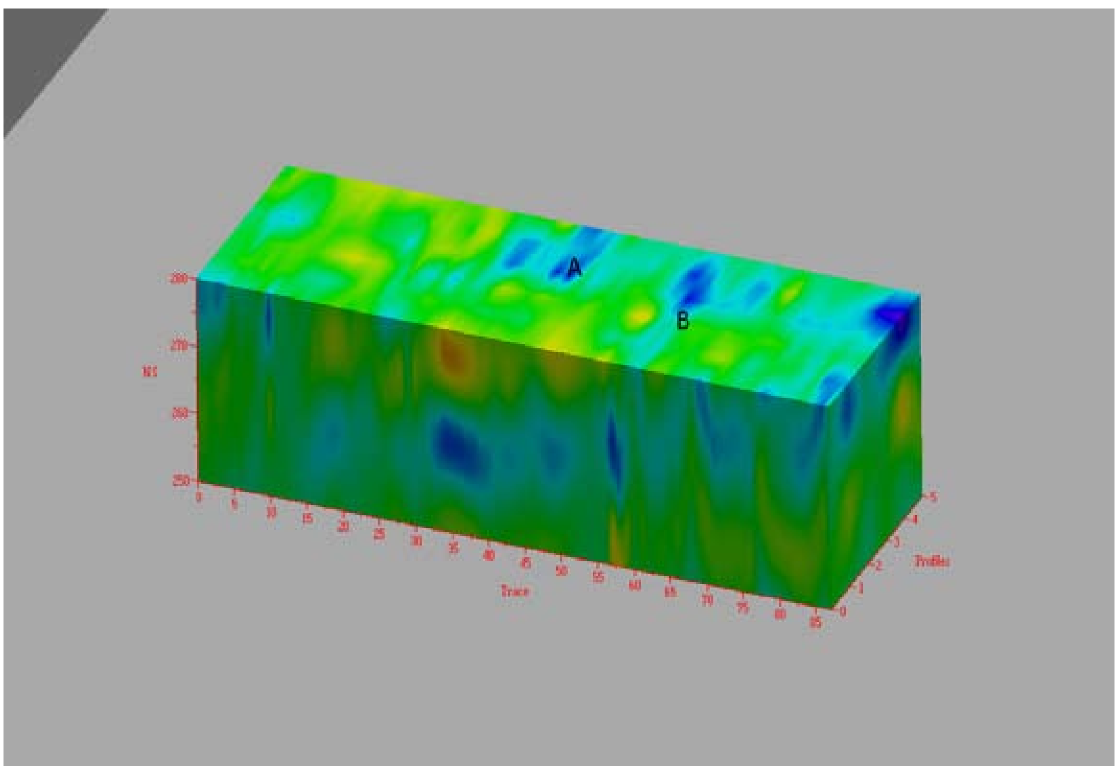

FIG. 8. Pseudo 3D visualizing of all GPR profiles. Letters are explained in the text.

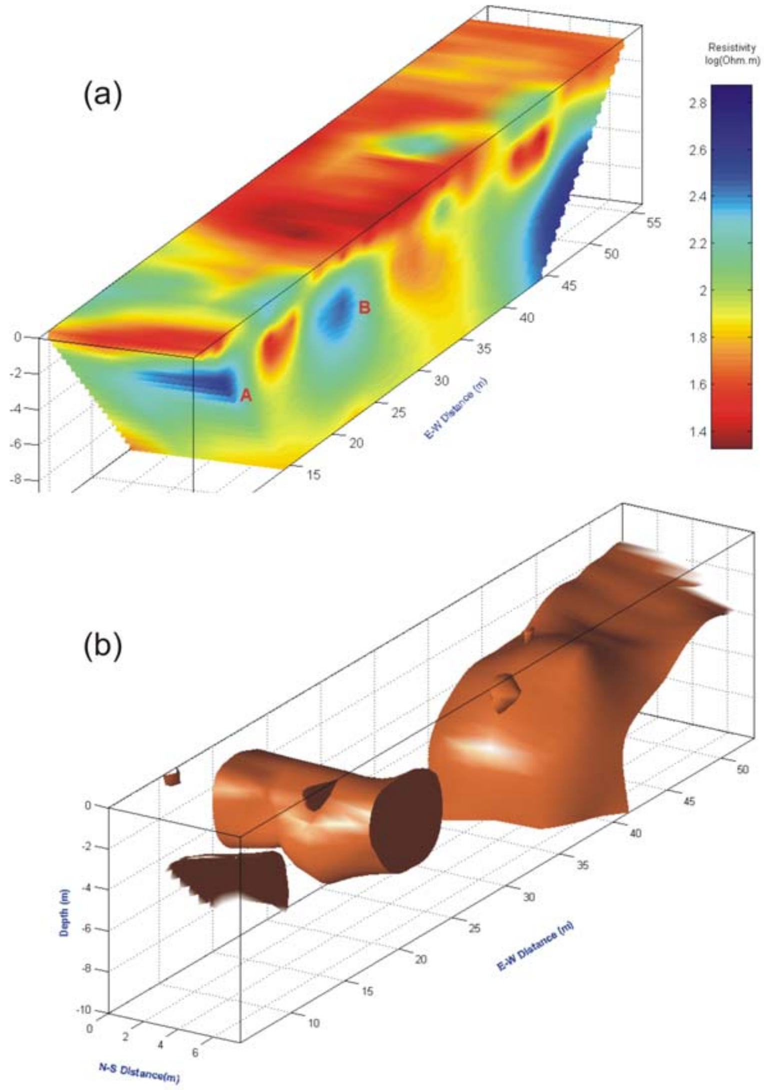

FIG. 9. Site-A **(a)** Geoelectrical model. The model was created from 2D inversion result of each profile which extends in E-W direction. **(b)** Imaging only high resistivity values (~150 ohm) to see the target structure. Color scale is natural logarithm of values.

The playground between the school and the dormitory has some local subsidence areas, some of which extended into Site-B (Figure 10 a and b). Four high resistivity zones (blue regions, ρ>150 ohm-m) deserve further attention. First one is between 15 - 20 m from western side of the 3D block diagram (A in Figure 10a). Second one (B) is located below the 2 m depth at the western edge. Third one (C) is a continuous blue anomaly around 35 m, and indicates the concrete channel. Shallow large anomaly (D) towards the eastern end of the site (45 - 55 m) is the concrete bottom of the flower garden. Iso-surface map of 150 ohm-m is given in Figure 10 b. Complex shape points out a highly resistive vein-like structure, possible connections between the cavities in the area.

DCR profile YE1 was at the south of the dormitory and 0.5 m away from the wall. The results are presented as a geoelectrical section (Figure 11a). Noteworthy anomalies are at 10, 14 and 20 m. Bottom of the first one is at 5 m depth and the second one is shallower (1 m). The last anomaly consists of two parts; between 1 and 2 m and below 2 m depth. Profile YE2 was located at western side of the dormitory and 1 m away from the side-wall (Figure 11b) and extended from north to south. Two anomalies at 6 and 17 m are significant. Continuous blue anomaly, dipping from north to south, connects both structures. Profile YE3 was between dormitory and coal storage (Figure 11c). Last part of the geoelectrical section (after 16 m) has a large anomaly which extends from 1 m to 3 m depth.

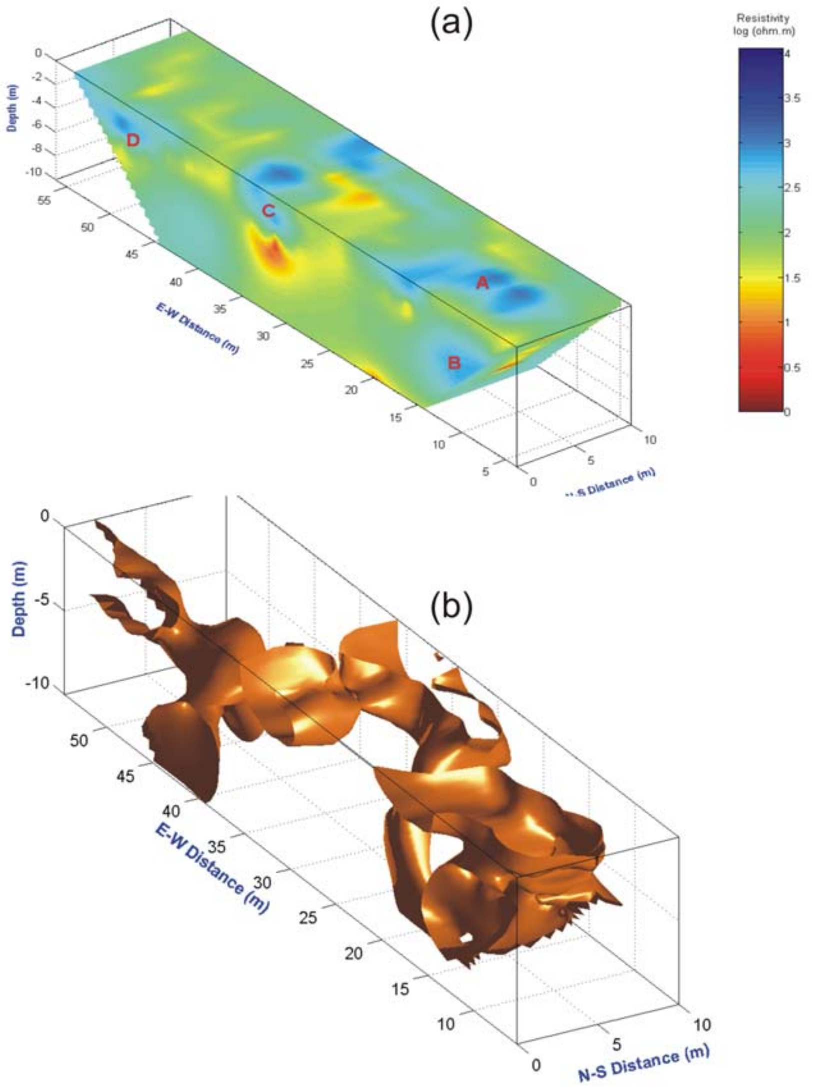

FIG. 10. (a) Geoelectrical model of Site-B. The model was created from 2D inversion result of each profile which extends in E-W direction. **(b)** Imaging only high resistivity values (~150 ohm) only to see the target structure. Color scale is natural logarithm of values.

DRILLINGS

Based on the results of the geophysical surveys, ten locations were selected (Figure 12). and drilled (Figure 13). First, second, and third soundings were between coal storage and dormitory (along the YE3) and western side of the dormitory along YE2. All three drillings were terminated in the intact gypsum at 10 m depth. Shallow parts were brown clay-filling with mixture of sand, gravel, and gypsum crystals over a loose unit consisting of altered gypsum crystals and clay with anhydrides. The SPT test was performed in the first hole between 1.50 m and 1.95 m. The un-normalized count was 30 (9/13/17) indicating damaged (dissolved) unit. Pressured water pumping test in the second hole, where a cavity was discovered between 5.50 and 6 m, resulted in total loss of water.

Second group drillings was completed in Site-B. Sounding locations were selected according to anomalies A and B in Figure 10. Anomaly A was drilled in 3 locations while B has only one sounding. All soundings started with sandy clay units including gypsum crystals. Fourth drilling intersects two cavities at 5.0-5.50 m and 6.00-7.50 m. The fifth one hit two cavities at 5.50-6.00 m and 6.50-7.00 m. On the other hand, the sixth and the seventh drillings hit only one cavity each, at 6.00-6.50 m. Water pumping test was applied to every hole, and the test confirmed substantial amount of leakage from these drillings.

Third group soundings were located in front of the dormitory, and the drillings were performed according to the anomalies seen along YE1. Eighth drilling has encountered two cavities; first one is between 2.50 to 3.00 m, and second one is 4.00 to 4.50 m. Ninth sounding did not hit the shallower cavity, but found the deeper one. Last drilling reached the largest cavity between 1.00 to 5.00 m.

In general, relative location of the cavities to each other, the shape of the anomalies in pseudo sections, and the result of the pressured water pumping test indicate that the drained and leaked water accumulated beneath the buildings and dissolved the gypsum and formed the cavities then leaked further away and accumulated again. The accumulation was possibly controlled by the weak and the crack zones and thin sandy layers or lenses. As a result, many cavities together with a channel system connects them occurred in a large portion of the school property.

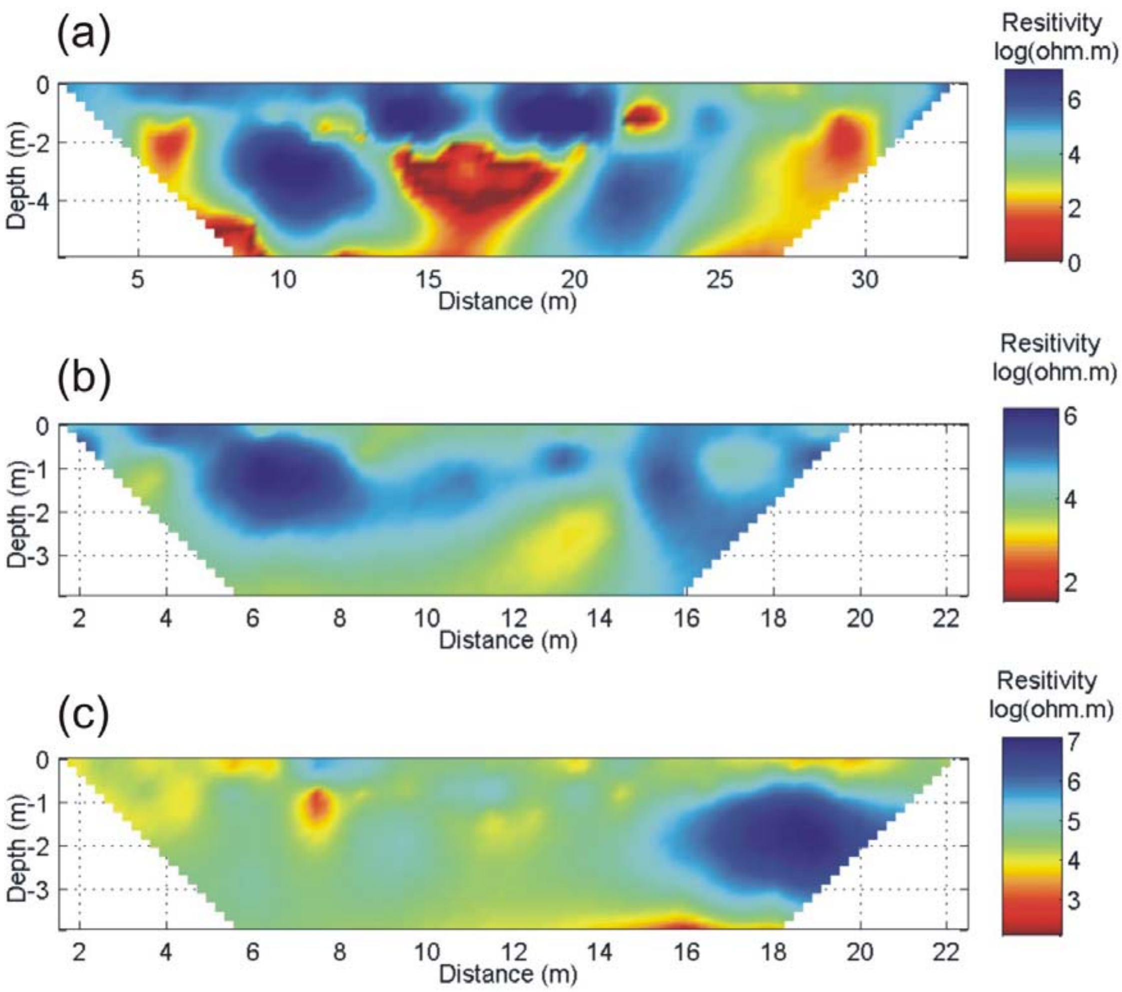

FIG. 11. Geoelectrical section from 2D inversion result of DCR data gathered in profile YE1 **(a)**, YE2 **(b)** and YE3 **(c)**. Color scales are natural logarithm of values.

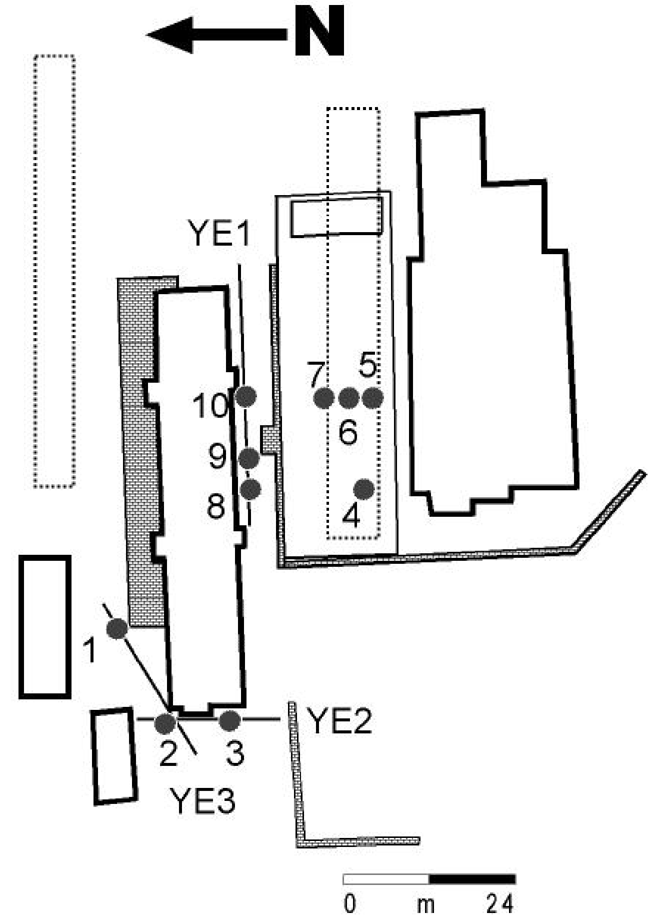

FIG. 12. Suggested drilling locations.

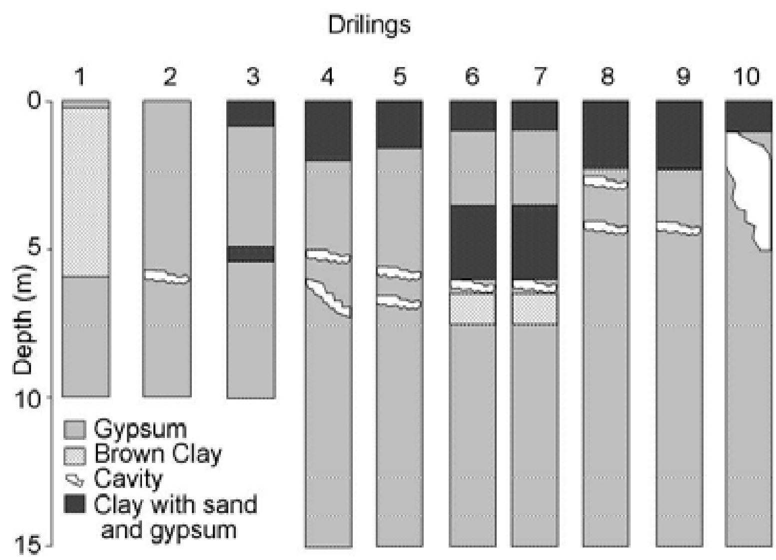

FIG. 13. Logs of the drillings. Locations are given in Figure 12.

CONCLUSION

Three geophysical methods were employed to locate cavities and weak zones in gypsum. The surveys were carried out in a settlement area. Manmade structures were inscribed into the observer-log, and they were taken into consideration during the interpretation.

2D inversion of the data obtained from direct current resistivity and seismic refraction methods exposed detailed images of subsurface.

Ten locations were suggested for mechanical drillings. Cavities were found at eight locations, four of which extend beneath the buildings. Pressured water pumping test confirmed that they are not isolated cavities. Location of the cavities and pattern of the anomalies in 2D pseudo sections indicate that the cavities are interconnected through a vein-like channel system formed by the dissolving gypsum. Apart from the above, weak zones found in the last two drillings may also require attention.

Results of this study prove that; well understanding of the limitations and capabilities of the employed geophysical methods may allow the user to get adequate results even if the environmental conditions are restrictive.

Based on the results of this geophysical study, the necessary precautions will be undertaken by the local authorities to whom the report was presented.

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