Characterization of a buried quarry by historical analysis of satellite images integrated with electrical resistivity tomography, East Cairo area, Egypt

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Research Article

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Abstract

East Cairo is characterized by abundant quarries that have been used as landfill sites for solid waste. These sites have become part of the urban sprawl of New Cairo, and their detection became difficult from the ground surface. In this study, analysis of multi-temporal high-resolution satellite images and electrical resistivity tomography (ERT) data were used to detect and delineate a buried landfill site located near the Ring Road, East Cairo, Egypt. Analysis of changes detected on the satellite images revealed that the study site was a WNW-oriented Quarry until 2005 and then randomly filled with heterogeneous solid materials. ERT survey was planned based on the result of change detection. On the plan view, the ERT measurements have outlined the electrically conductive zones which are occupied by filling material and distinguished them from the resistive zones that symbolize the natural soil areas. By assimilation of the satellite images and the ERT results, two distinguished geoelectrical units could be perceived; Unit-1 (the upper unit) is characterized by low to moderate resistivity values being the solid waste materials, while Unit-2 (the lower unit) is characterized by high resistivity values that characterize the original soil (bedrock). The closely spaced grid of ERT profiles and the detailed topographic map helped in mapping and delineating the contact between the bedrock and the filling materials. Several parameters could be addressed and were used for characterizing the unit of interest (Unit 1) including ground surface elevation, depth of the lower boundary of Unit-1, and thickness variation of this unit across the investigated site.

1. Introduction

Cairo is one of the fastest-growing metropolises in the world. During the last decades, East Cairo witnessed extensive uncontrolled blasting for sandstone and gravel quarrying. Recently, sites of the old quarries are filled with solid waste materials and become masked by constructions.

Analysis of satellite images of different dates for a certain site are used to detect the surficial increase/decrease of the site geometry (Asokan et al. 2020). Historical analysis of Landsat ETM, ETM + and OLI images from 1995 to 2009 enabled the detection of the quarrying history of the east Cairo area and the degree of urbanization through the last decades. The historical analysis of the satellite images provides the temporal and spatial change of the quarries' perimeter but does not provide quantitative data about the depth and volume of the landfills.

Geophysics has been used successfully to investigate dumpsites and has proven a valuable tool in this field. The most significant advantage of geophysical technologies is that they are non-destructive, non-invasive tools and cause no damage to subterranean structures and materials (Reynolds, 2011, Caterina et al. 2019, Naveen et al. 2021).

Therefore, in this study, change detection analysis was integrated with several NW and NE-oriented ERT profiles. ERT detection approach is based on the contrast of the electrical properties between the filling materials (solid waste) and the original rocks. Filling materials, which are composed mainly of loose sand and gravel and waste materials exist in a lateral and vertical juxtaposition with the original rocks. The filling materials are characterized by relatively low resistivity values than the original, compacted, bedrocks.

This integration between change detection using multispectral satellite images and the electrical resistivity analysis could be successfully used to quantify the buried landfill material at the investigated site and provided an effective approach that can be applied for buried landfill mapping in similar conditions.

2. Geological Setting

East Cairo is covered by Cenozoic rock succession including, from older to younger, Mokattam Formation (Middle Eocene), Maadi Formation (Upper Eocene), Gebel Ahmar Formation (Early Oligocene), and Hommath Formation (Miocene Age). Oligocene rocks form the most prominent stratigraphic units exposed in the region east of the Cairo City between the Cairo-Suez district and Qattamiya-El Sukhna district (Fig. 1). The Oligocene rock succession is essentially developed into alluvial siliciclastic sequence. as multi-stories of fault-controlled incised valleys(Selim 2017). Exposures of this rock unit unconformably overlie the Upper Eocene deposits of Anqabiya and Maadi Formations and underlie the basalt flows and/or the basal beds of the Hommath Formation with a nonconformity relation (Ismail and Abdelghany 1999). Oligocene sediments are structurally controlled (Moustafa et al. 1985, Moustafa and Abdallah 1991), usually restricted to structural lows, and bounded by NW-oriented faults. The Paleogene sequence of East Cairo was deposited in E-W oriented graben system bounded from North and south by E-W to WNW-ESE oriented faults (Fig. 1).

In the investigated site, Gebel Ahmar Formation is represented by varicolored medium to coarse-grained and cross-bedded sandstone with lenses and thin beds of gravel. The gravels are flint and fragments of silicified wood and mostly of pebble size. The sands and gravels are usually loose or poorly cemented, except for the fracture zones where silica and iron-rich solutions increase their cementation and consolidation (Fig. 1).

3. Historical Analysis Of Satellite Images

3.1. Methodology

In this work, historical analysis of satellite images was used to analyze and map the spatial growth and filling history of the quarry and the growth of urbanization in the study area. Five cloud-free Landsat ETM, ETM + and OLI images acquired in 2000, 2005,2006, and 2009 have been pre-processed using the commercial software ENVI 5.3. Outline of urban and quarries have been mapped using ArcGIS 10.3.

3.2. Image Analysis and Results

Processing and analysis of satellite images revealed the following history of the quarrying activities in the area. The study area is located to the east of the Cairo-ring Road. Before 1995, this area was a barren desert covered by a dry drainage network and located 4 Km to the east of Nasr city (east Cairo) as shown in Figure (2 left). It witnessed intensive quarrying in the period from 1995 to 2001. False-color composite (FCC) 742 of the Landsat 7 ETM shows one quarry in the northern part of the study area in 1995 (Fig. 2 right). The FCC of ETM + shows three quarries occupying the northern and southwestern parts of the study area in 2000 (Figs. 3A and B).

From 2001 to 2006, quarrying activities decreased significantly in the study area as indicated by the slight increase in the northern quarry (Figs. 3C and D). The quarrying activities were ended by 2006 and the process of backfilling began when the site was rehabilitated for construction (Figs. 3E and F). Satellite images show a steady increase in urban areas in the southeastern part of the study area from 2001 to 2006 (Fig. 3). The year 2009 witnessed the first construction works in the old quarries (Fig. 3F).

4. Electrical Resistivity Tomography

4.1. Method Statement

Resistivity tomography is an advanced development of the traditional sounding method. Enhanced data quality and resolution provide continuous two-dimensional resistivity models. Electrical resistivity Tomography is a powerful approach used to detect the waste dumps in a faster, cheaper, and non-destructive manner (Feng et al. 2017, Zhao et al. 2020, Ibraheem et al. 2021, Piegari et al. 2022).

In the ERT survey, twenty-four or more electrodes are set-out in a regularly spaced array, connected to a computer-controlled resistivity meter via multi-core cables. Unit electrode spacing is determined by parameters such as profile length, desired resolution, and targeted depth of penetration. A switching unit takes a series of constant separation readings along the entire length of the electrode array. The separation between sampled electrodes is then widened to increase the effective depth of penetration and the procedure is repeated down to the proper number of depth levels.

4.2. Data Acquisition

The ERT data were measured at the investigated site along 16 profiles (P1 to P16) as shown in Figure (4) to locate the landfill zone and determine its lateral/vertical extensions, where the arrows indicate the end of the ERT profiles. For profiles P1-P10 and P15-P16, the Syscal Pro switch instrument was used with 24 electrodes spaced at 5 m to cover a surface distance of 115 m and to attain an investigated depth of about 24 m below the ground surface. For profiles P11, P12, P13, and P14, we have adopted the electrode spacing at 3 m to cover a surface distance of 69 m and to attain an investigated depth of about 14 m below the ground surface due to the site inaccessibility. Along the ERT profiles, topographic values of the measuring points were precisely determined, and the ground elevation was involved in the ERT data inversion process.

4.3. ERT Data Processing

The measured resistivity values were processed by RES2DINV software (Loke 2010), which is automatically designed to construct two-dimensional resistivity models of the subsurface. The measured data were plotted as "Apparent Resistivity Pseudo-sections" to check the data quality and the measured points` distribution. Applying "Least-Squares Approach" the processed apparent resistivity data was inverted to true modeled 2D resistivity sections. The color palette of the sections reflects the value of the calculated resistivity. The red colors and their gradient indicate high resistivity zones (resistive layer or body). Meanwhile, the blue color and its gradient indicate low resistivity zones (conductive layer or body).

4.4. Data Inversion

The ERT data were inverted line by line and a unified color scale (pallet) was applied to all ERT sections to define a specific resistivity range for each lithologic type and to facilitate the correlation among the ERT sections. Selected examples of the inverted ERT sections are given in Figures (5, 6, 7, and 8).

4.5. Results and Discussion

The ERT has successfully revealed the electrical resistivity variations in the investigated section in both horizontal directions, as well as the vertical direction. These resistivity changes could be interpreted in terms of geology to differentiate between lithologic units and to describe the physical conditions of the sub-soil at the investigated site. Laterally, the ERT survey has outlined the electrically conductive zones (blue/green-colored zones in Figs. 9 and 10) which are occupied by the backfill material, and the resistive zones (red/yellow-colored zones) which represent the natural soil areas.

Vertically, the investigated section comprises two geoelectrical units [Unit (1) up and Unit (2) down] as indicated in the ERT sections (Figs. 5 to 8). Correlation of ERT results with the previous geologic studies and the available borehole information revealed that the two units are embedded in one geologic bed of the Quaternary age and composed mainly of sand, gravel, ,and silt with different mixing ratios. Unit (1) is represented by a friable soil composed of sand and silt with some gravel. It could be described as a heterogeneous, man-made backfill material with low to moderate resistivity values of up to 200 Ohm*m and variable thickness ranging from 2.0 m to more than 20 m. The low resistivity response of this unit could be attributed to the existence of wet soil due to near-surface water leakage and/or dominance of fine sediments. Unit (2) represents the naturally compacted soil with high to very high resistivity values exceeding 1000 Ohm*m.

5. Integration Of Ert And Satellite Imagery

The ERT results were used to estimate the geometrical parameters of the backfill unit [Unit (1)] including its areal extension, the elevation of the lower boundary, and thickness. These parameters were posed on an old satellite image to match the geophysical results with the land features. First, the topographic values (elevation) of the ground surface along the ERT lines were determined and contoured to provide the ground surface elevation map in meters above sea level (m asl) at the investigated site as shown in Figure (11 a). The ground surface at the time of the ERT survey is almost leveled with elevation values of 209.5 to 210 m asl.

Second, the elevation of the lower boundary (bottom) of Unit (1) was picked from the ERT sections and mapped as shown in Figure (11 b). Elevation of the lower boundary of this is varying from 187 m asl at the north and western parts to 210 m asl (almost the ground surface level) at the south and eastern parts. This means that Unit (1) is absent in the eastern part, where the base of this unit is shallow in the southeastern part and deepens towards the west and northwestern parts.

Third, the thickness of unit (1) could be obtained by subtracting the elevation of its lower boundary from the ground surface elevation and it was varying from 2.0 m to more than 20 m. Thickness values were mapped as shown in Figure (11 c). It is obvious that Unit (1) is thin in the southeastern part and attains its maximum thickness in the west and northwestern parts.

In the end, the backfill area as outlined from the ERT survey was correlated with a historical satellite image as shown in Figure (11 d). This correlation revealed a good matching between the geophysical results and the borders of an old quarry located at the north and western parts of the site. It could be verified that the investigated site was exploited as a sand quarry until 2004/2005, and the major quarrying activities were concentrated in the western and northwestern parts where deep excavations were done as indicated by the steep cuttings on the satellite image (Fig. 11d). When the quarry has been closed, the quarrying heterogeneous materials were reused to fill in the excavated parts. So, the backfill material attained its maximum thickness at the western and northwestern parts as shown in Figure (11 c).

6. Conclusion And Recommendations

For proper design and possible risk mitigation in engineering projects, it is essential to describe the subsurface and soil characteristics to save people, infrastructure, and the environment. Geophysical approaches are particularly valuable in the geotechnical assessment of engineering sites. Electrical resistivity imaging integrated with the historical analysis of remote sensing images provided a powerful approach used to precisely outline an old quarry occupied partly by a backfill material. Moreover, the geometry of the backfilled area, including areal extension, thickness, and depth, was determined. The investigated site is highly heterogeneous, and the soil is widely altered laterally and vertically. So, before constructing buildings and facilities, it is recommended to assess the soil compaction and stiffness by using Seismic Refraction (SR) and Multi-channel Analysis of Surface Waves (MASW) surveys.

Declarations

No conflicts of interest

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Figures

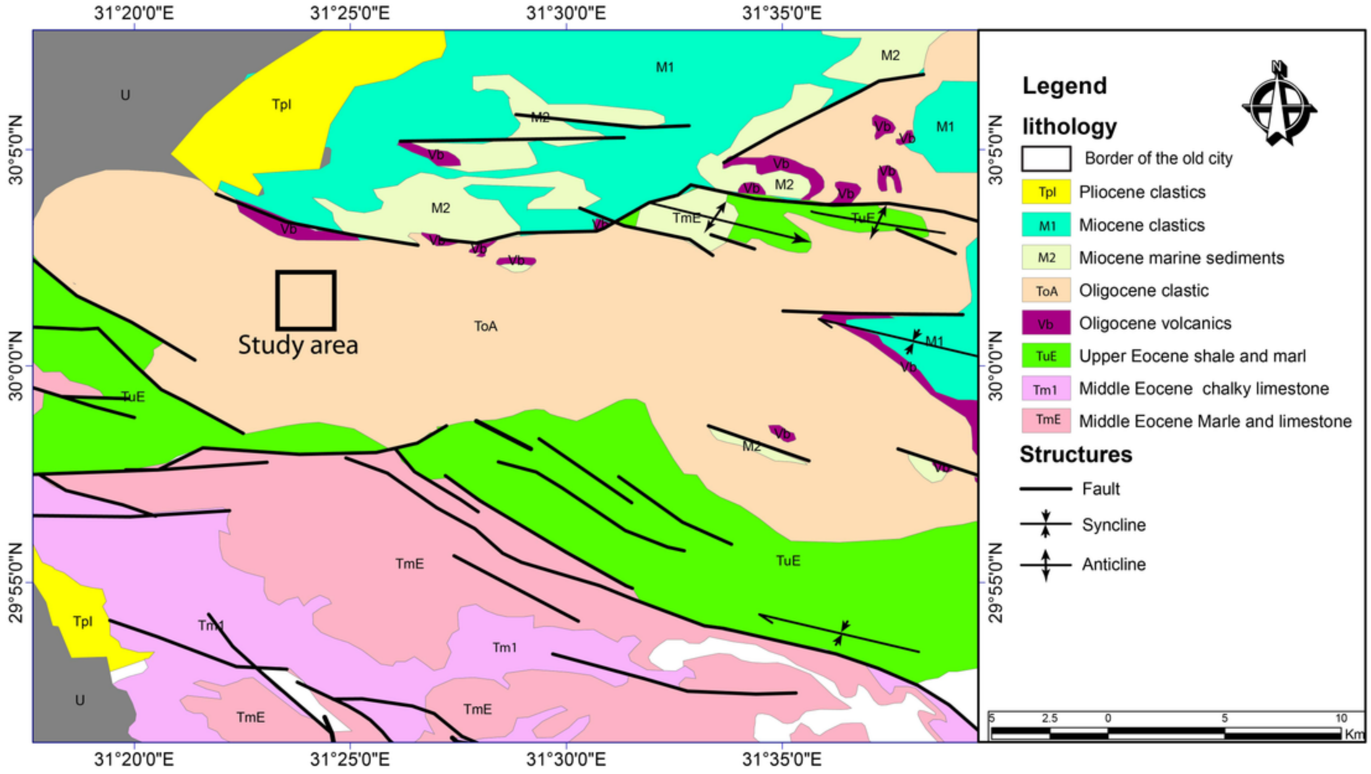


Figure 1

Geological map of East Cairo area (modified after EGSMA 1983)

Figure 2

Landsat ETM 1995. The left image shows the location of the study area at 4 Km east of the old city with no quarries, and the right image shows only one quarry in the northern part of the study area.

Figure 3

Landsat images show the history of quarrying activities and the progress of the construction works in the area under study from 2000 to 2009.

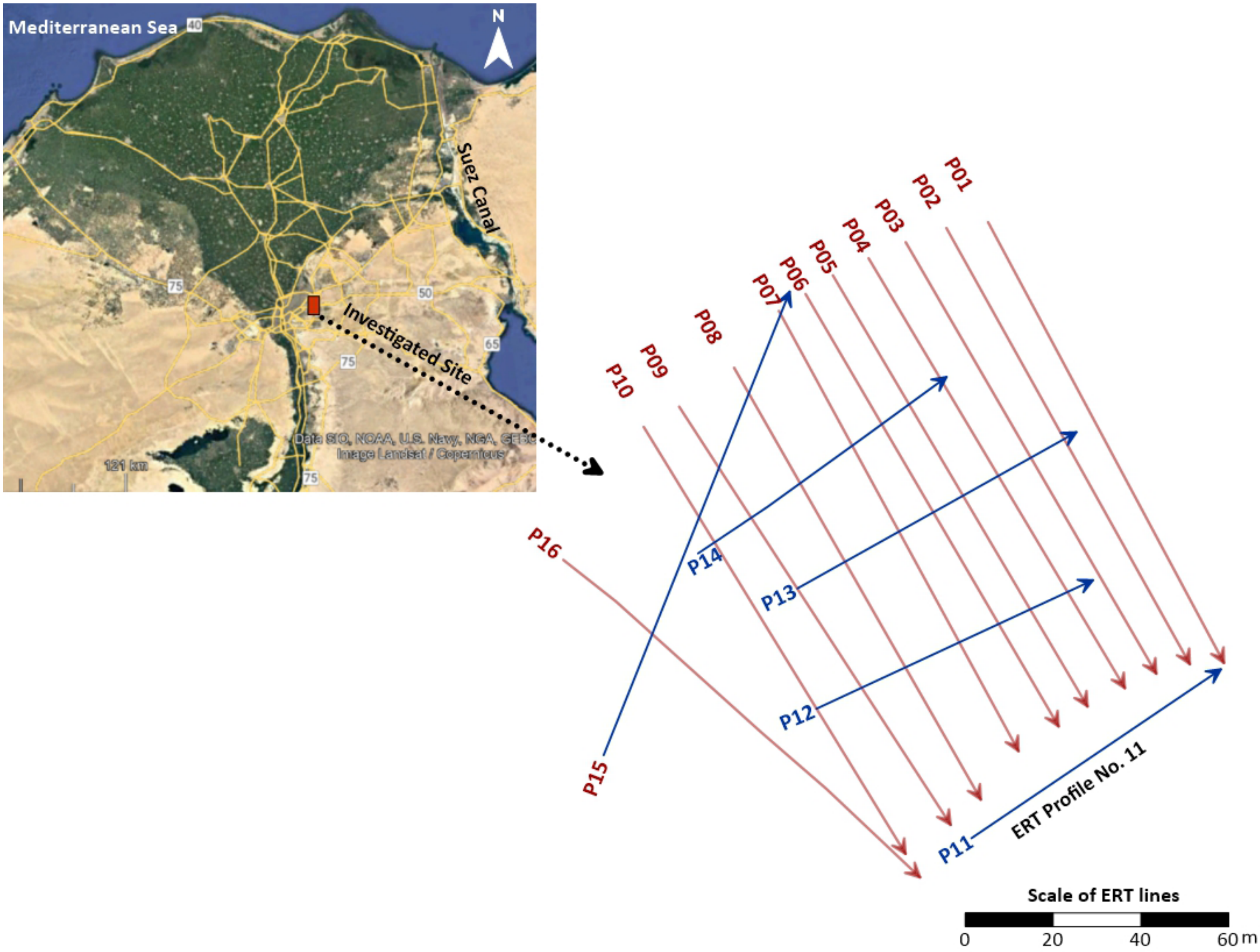


Figure 4

Location and orientation of the ERT profiles in the investigated site.

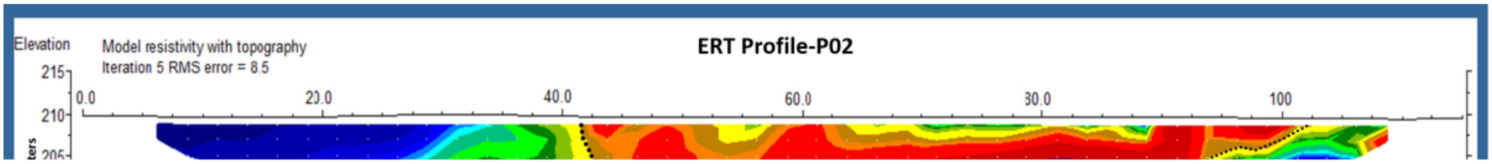


Figure 5

2D section obtained from resistivity data inversion along Profile-P02

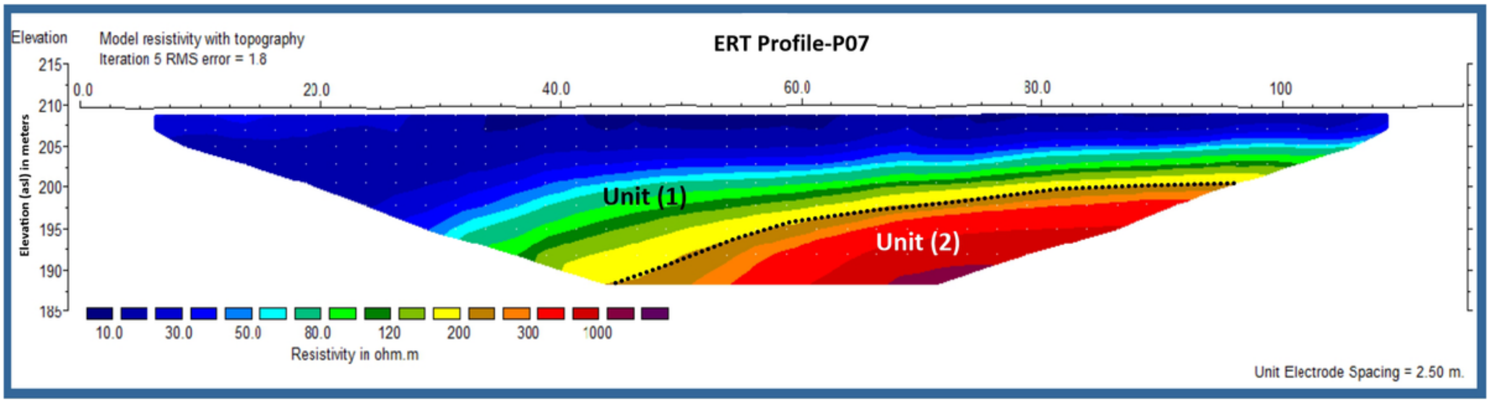


Figure 6

2D section obtained from resistivity data inversion along Profile-P07

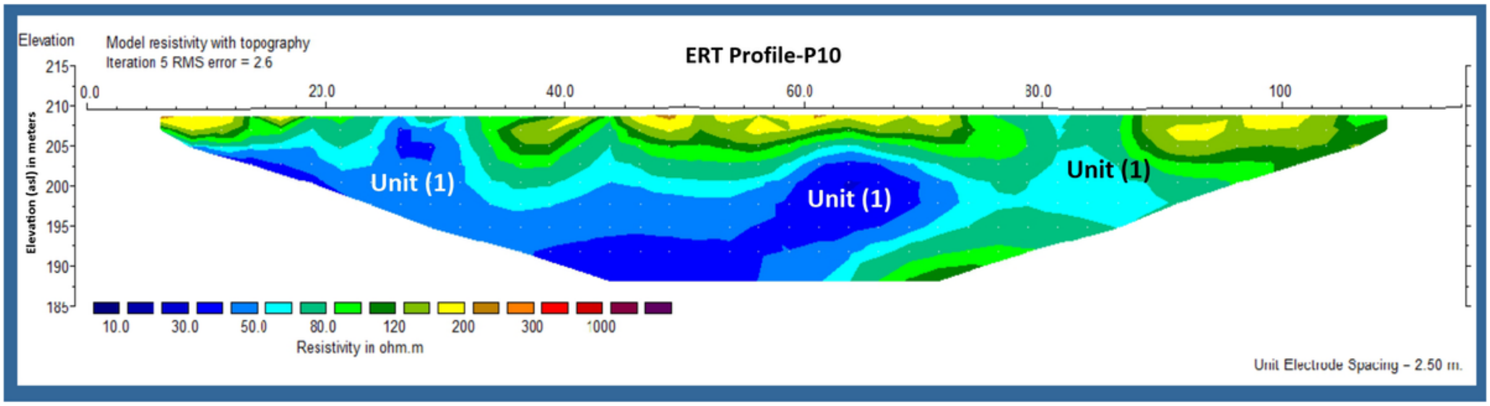


Figure 7

2D section obtained from resistivity data inversion along Profile-P10

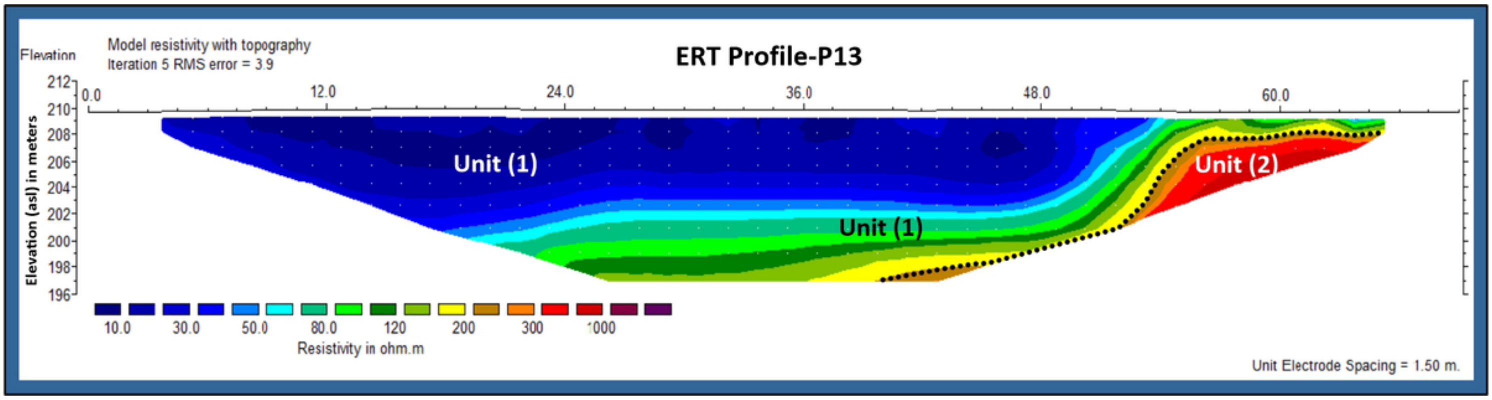


Figure 8

2D section obtained from resistivity data inversion along Profile-P13

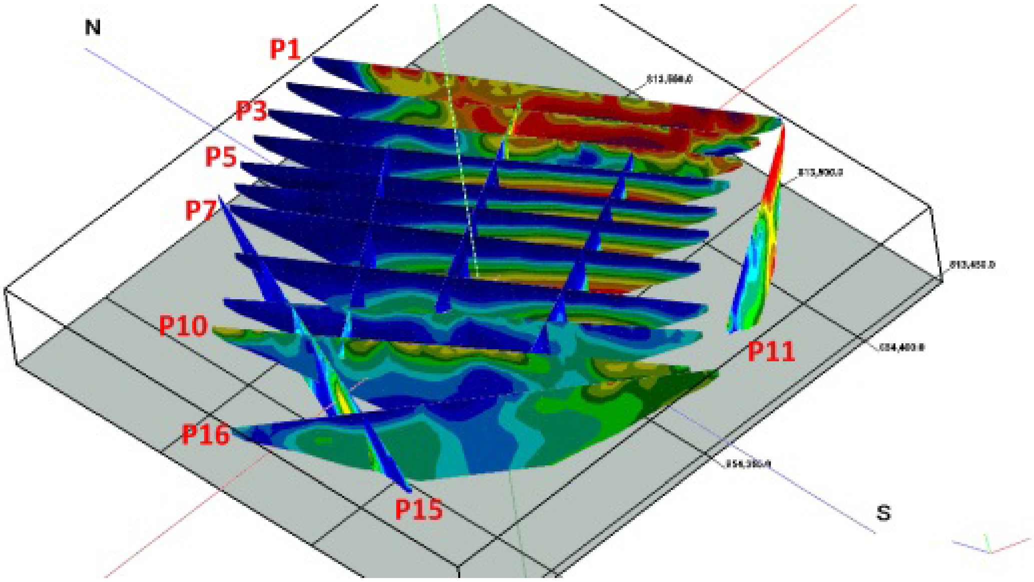


Figure 9

ERT sections assembled in a 3D fence diagram (view from SW)

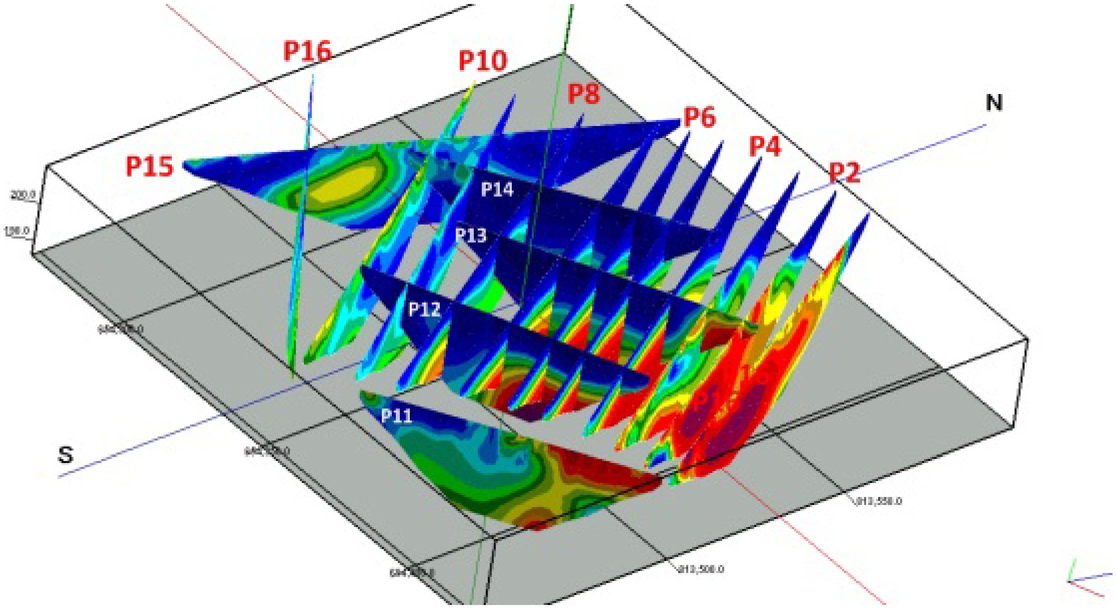
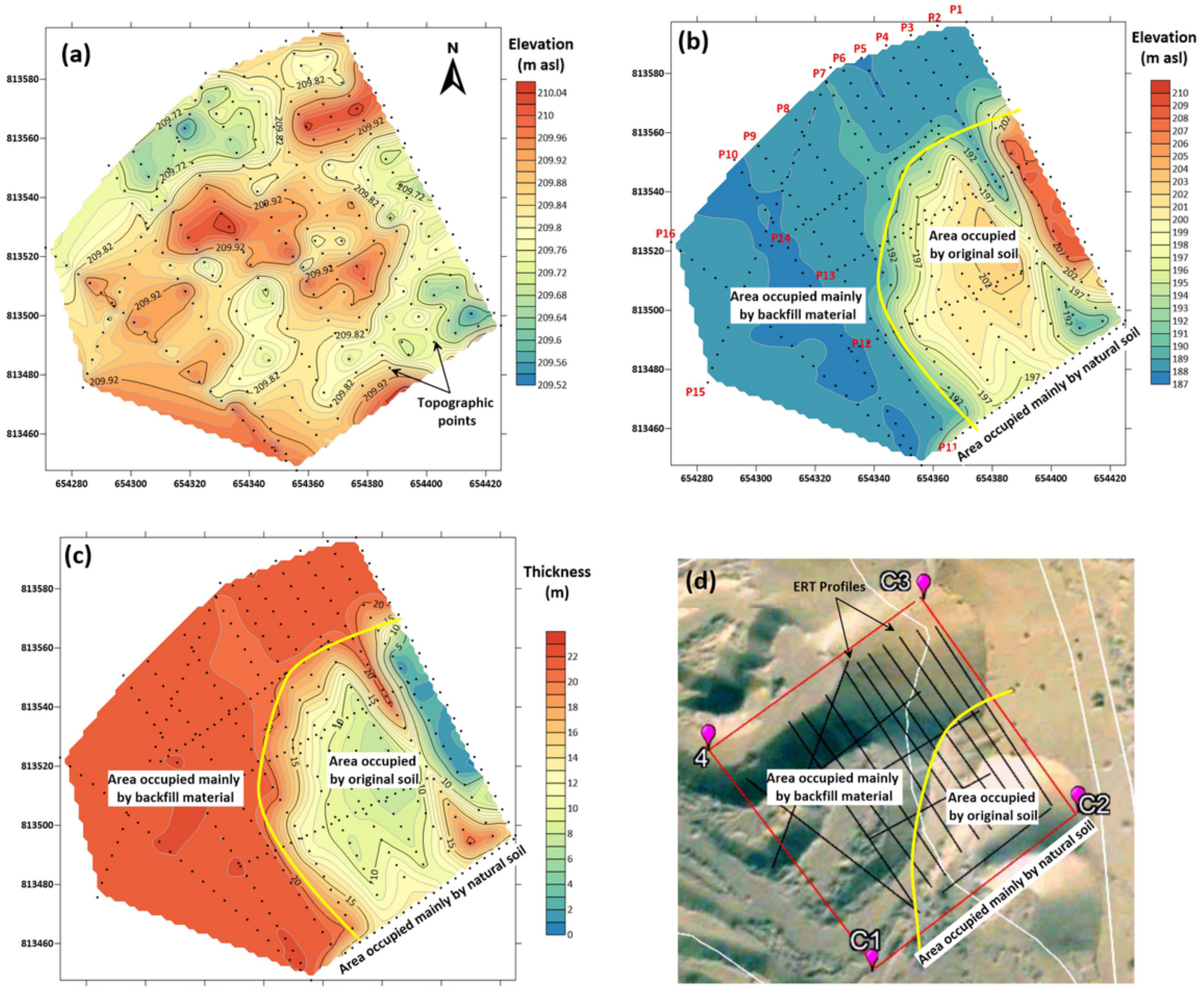


Figure 10

ERT sections assembled in a 3D fence diagram (view from SE)



(a): Ground sutface elevation of the investigated site (m asl)

(c): Thickness variation of Unit (1) in meters

(c): Elevation of the lower boundary of unit (1) in meters asl

(d): ERT Profiles showing a good correlation with a historical sattelite image

Figure 11

Geometrical data of Unit (1) matched with the landforms of an old quarry