Application of Electrical Resistivity Soundings to Identify Unstable Areas, "Tghat-Oued Fez" District as a Case Study (Fez – Morocco)

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Abstract. Measurements of 72 vertical electrical soundings (VES) using a Wenner-Schlumberger electrode array configuration were conducted on "Tghat-Oued Fez" district of Fez city. The purpose of this study is to identify voids inside basement, to prevent collapse and landslides in urban areas. The natural parameters acting to accelerate the phenomenon are mainly the tectonic activity, topography, and lithology. The studied area is close to the major active south rifain fault, marked by a steep slope and heterogeneous lithology, which is composed of a glacis surface, marls, and conglomerate deposits. We suspect the presence of week zones inside the marls layer because of the presence of gypsum which left many voids and cavities due to dissolution.

Thirteen iso-resistivity maps resulting from VES measurements were created. The electrical survey has accurately detected and located high resistivity anomalies inside the conductive marly formation between 7 to 15 meters depth. The survey results suggest that VES is a viable geophysical tool to explore electrical anomalous linked to medium vulnerable to lands movement.

Keywords: Vertical electrical sounding, Cavity detection, wenner-schlumberger, Resistivity

1 Introduction

During the last four decades, the urban area of Fez continues to develop locally on more or less unstable grounds, in particular its northern limit. These are linked to rapid population growth coupled with various natural factors such as the tectonic regime, morphology, bedrock lithology, and entropic action. All these parameters generate an imbalance unfortunately leading to tragic events. As the statistics show, most of the disorders of these large buildings can be due to foundation soils incompatible with the type of construction. Other types of disastrous disorders inducing heavy losses in infrastructures requiring more expenses are related to the lithological nature of the subsoil, in particular to the volumetric modifications of the clay soils (shrink-swell capacity) or to landslides on the slopes, affecting buildings, roads and structures in particular in the Oued-Fez sector.

Considering its exceptional panoramic view, the Tghat-Oued Fez districts are in great demand for new construction. In this context, the main purpose is to prospect and identify possible cavities and voids. A geophysical survey campaign was carried using VES method, aim to highlighting anomalies caused by the presence microcavities and cracking with high resistivity, inside very conductive marls. The main objective is to identify the most vulnerable sectors to risks (land subsidence, collapse, landslide, etc.), linked to the behavior of the underlying materials, in this zone, subject to strong urbanization.

2 Geology of the study area:

2.1 Overview

The Geology of the region, the geomorphological nature, , as well as the anthropic actions, combined with climatic conditions and sometimes with tectonic and seismic activities to make this area, a region at high risk of potentially very destructive collapse.

The study area is located on the southeastern side of Jbel Tghat. Its geological nature surveyed on the surface and the location of the sounding points are shown in **(Fig.1, 2)**. From a structural point of view, it is located in a compressive context with high tectonic, morphological, and significant sedimentary activity. Indeed, the Tghat structure **(Fig.1)** is an elongated East-West direction relief, south of the frontal limit of the "pre-rifain complex". It is a massif with a Jurassic formation heart and Miocene coverage. Its 873 meters above sea level, makes it strongly straightened and dominating more than 400 m of Fez plain.

Saïs plain has evolved from a foreland basin before the Miocene to a continental endorheic basin in the Pliocene and then to an inclined plateau in the Quaternary [Charroud et al 2006, 2007; Cherai et al. 2008]. This development has enabled a variety of deposits depending on different environments.

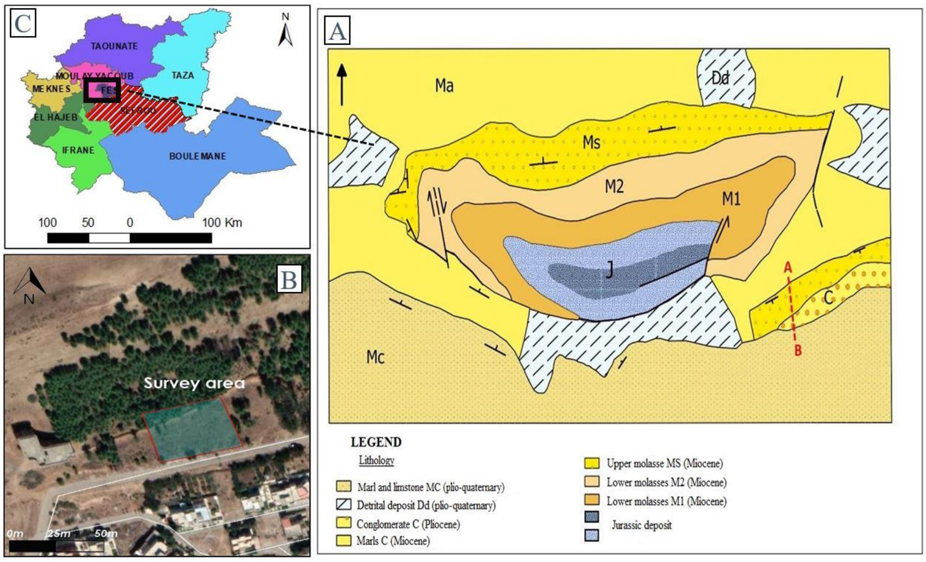

Fig. 1. A Tghat massif geological map, based on the geological map of Fez with the location of the AB geological section. B Satellite image (taken by google earth) showing the survey area. C Fez-Meknes region.

2.2 Lithostratigraphy

In our study area, the southeast part is generally composed of Mio-plio-quaternary materials **(Fig.2, 3)**. These are three well-defined formations:

Glacis surface: are mainly distributed on the southern side of Tghat, with smaller thicknesses in our study area. The thickness of the formation varies depending on the location between 0.5 to 5m, this layer is predominantly made up of rounded elements (pebbles and gravel) which come from the erosion of the overlying pudding drowned in a greenish to whitish marly matrix.

Marlstone formation. these are the greenish to whitish marls of the Oued-Fez, which contain concreted gypsum, reflecting a lacustrine environment with intense evaporation; this formation is described in previous work [Taltasse, 1953; Ahmamou, 1987, 2002; Fassi, 1993, Charroud et al, 2006, 2007, Cherai et al. 2008]. It is a fairly homogeneous and compact unit in depth. However, these marls are sensitive to water and lose their surface characteristics, constituting a swelling and slippery formation towards the south, the marl outcrops have generally gentle slopes but in some places can be locally steeper (between 10 to 15 degrees). Many signs of instability are visible in the study area and throughout the south side of Tghat.

Conglomerate formation. are terrigenous detrital deposits, it is a pudding of mostly rounded elements, the elements of which vary from a few millimeters to 30 centimeters, its a polygenic conglomerate of probably Liasic and Miocene origin.

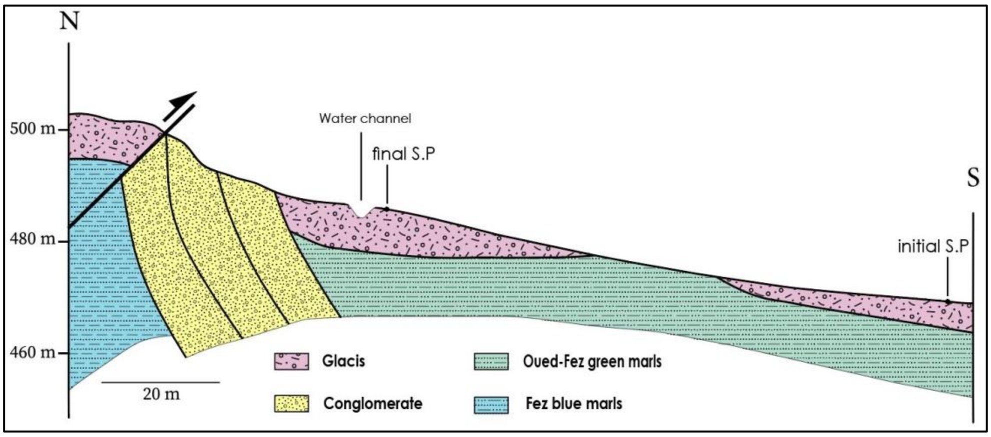

Fig. 2. N-S oriented geological section of the study area showing the layout of the outcrops in the study area.

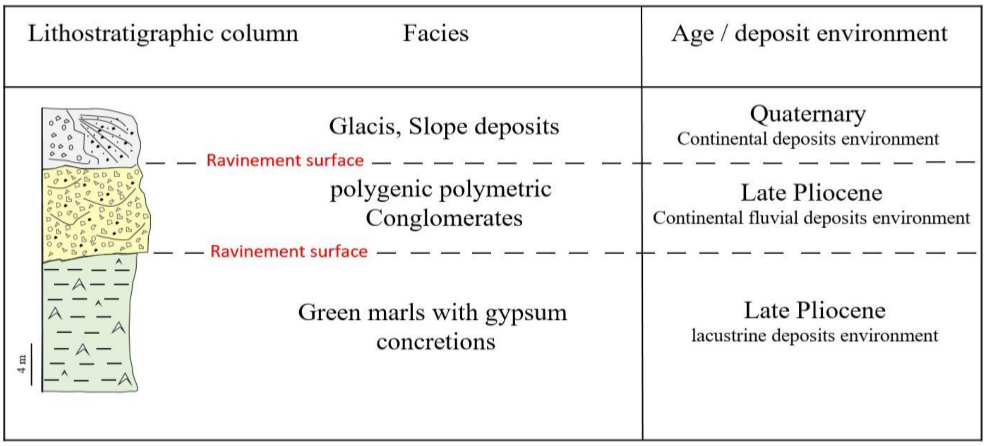

Fig. 3. Lithostratigraphic column showing the 3 sets described in the study area.

2.3 Study area

The study area is located on a parcel north of the urban limit of Fez city. It covers 2000 m2. Among different reasons the choice of this site was guided by the fact that it presents a great panoramic interest, therefore susceptible to new urban development and sprawl projects, besides we were able to identify on the close building walls as well as on the surface, cracks, soil collapse and sometimes landslides. However, the geological formations nature is not sufficient enough to allow us to have an idea about the spatial organization of these cracks and voids. Doubts remain about the presence of new cracked construction probably due to the behavior of the underlying layers. we try to resolve this problem by the adequacy of combining geological field-work with geophysical techniques of investigation.

3 Methodology

Geophysical prospecting methods have proved a very useful tool for determining the location and size of cavities below the surface [Militzer et al., 1979; Smith, 1986; Beres et al.2001; McGrath et al. 2002; Thierry et al. 2005].

The VES investigations were performed by using The Syscal Pro manufactured by IRIS Instruments using Wenner-Schlumberger (W-S) configuration [Pazdirek and Blaha 1996]. This method involves the supply of direct current (I) into the ground through a pair of current electrodes and the measurement of the resulting potential (ΔV) through another pair of electrodes called potential electrodes **(Fig. 4)**. The calculation of the apparent resistivity was performed using the resolution of the laplacian electrical potential equation in spherical coordinates:

$$\nabla^2 V = \frac{d^2V}{dr^2} + \frac{2}{r}\frac{dV}{dr} = 0 \qquad (1)$$

In our case (a quadruple W-S at surface **(Fig. 4)**) and according to Ohm’s low in hemispherical medium, the resolution of equation (1) gives the apparent resistivity formula, ρ_a, as follow:

$$\rho_a = \frac{\Delta V}{I} \times \pi n(n+1)a \qquad (2)$$

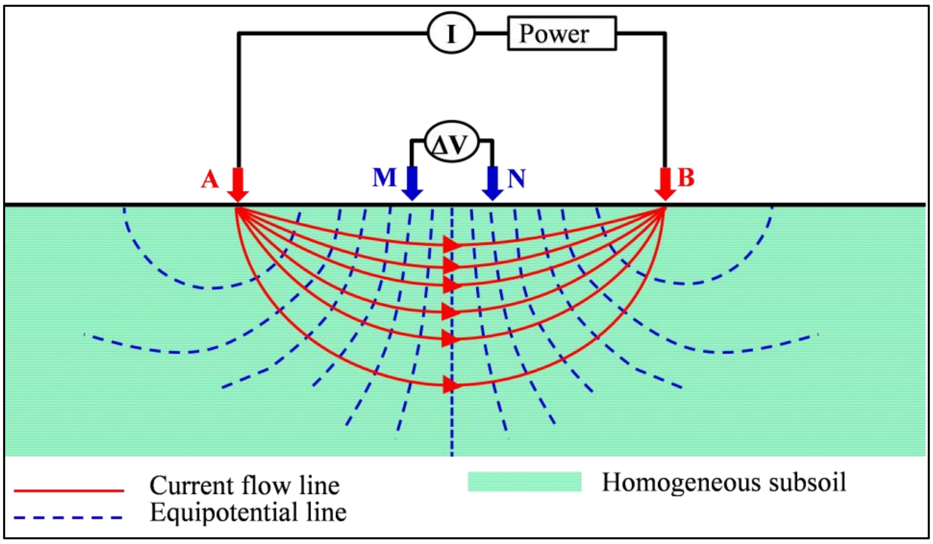

Fig. 4. Wenner-Schlumberger array (MN=a; AM = n x a) and distribution of electric field underneath in homogeneous medium.

3.1 Field Investigations

VES is essential to give a judicious interpretation of the results as well as a real depth to the model, in order to characterize the different geological formations and the detection of possible voids. The VESs were deployed as a set of 9 equidistant profiles **(Fig. 5)** each consisting of 13 AB spacings, between 4 and 160 m to reach depths of 20 m, making sure that we have crossed the marls.

This potential method giving access to the electrical resistivity of different layers. It is well suited to differentiate the 3 formation sets, given the enormous contrast of resistivities as evidenced by the first tests.

The first sub-surface level corresponds to the glacis deposits, with variable resistivity (10-132 ohm-m) and thickness between 0.5 to 4 m.

A second level matches to the marly deposits, the relatively low average resistivities obtained, correspond well to a homogeneous facies of variable resistivity (3.8-12 ohm-m).

The underlying resistance level in the study area corresponds to the conglomerate level at depths of more than 17 m with a resistivity between (110-640 ohm-m).

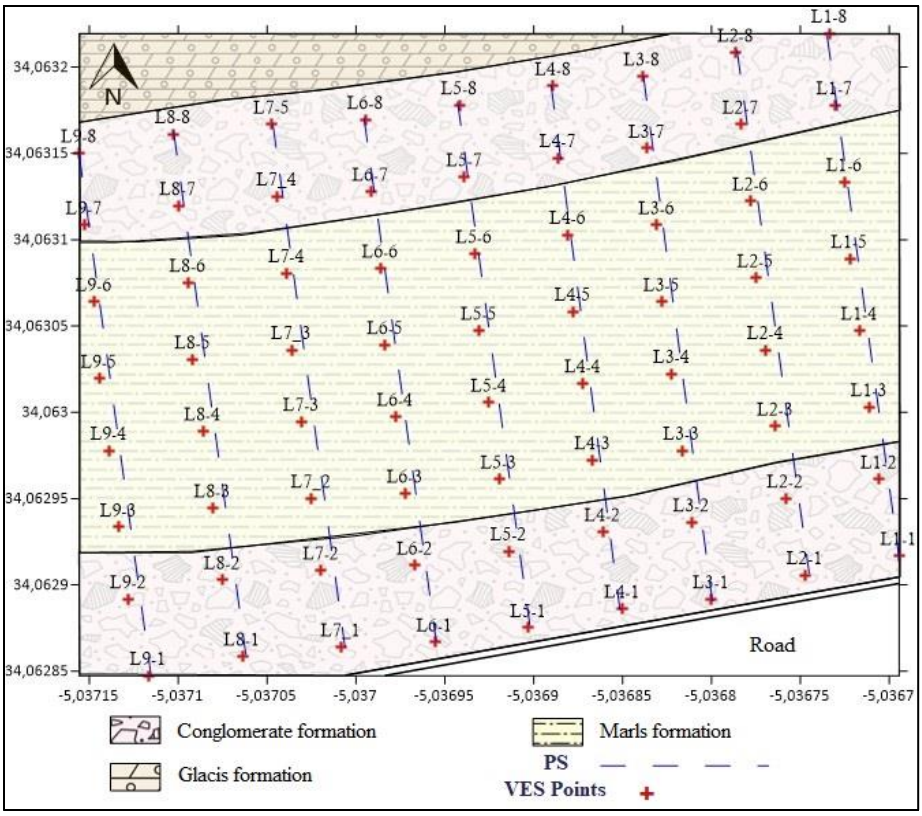

Fig. 5. Location map of VES survey points with the geological distribution of the surface layers in the investigation site.

3.2 Interpretations

The iso-resistivity maps were generated from the 72 executed VESs using the minimum curvature method [W. H. F. Smith and P.Wessel 1990]. Each map shows the resistivity behavior in horizontal surface for each AB length corresponding to 0.125 times depth in the case of S-W configuration. The resulting maps help monitor the evolution of resistivities in tree directions. They make it possible to have an idea about the sedimentary facies distribution and the presence of possible fissures and voids inside those layers.

4 Results and discussion

For small AB spacings (4m and 8m), the lateral variations in apparent resistivity mainly represent variations in the composition of the surface materials. In our case, the more resistive areas on the surface are associated with the compaction of the subsurface sediments and the presence of slope deposits attributed to the glacis formation. The less resistive zones begin to appear at a depth of 1.5m, associated with the sectors where the marl is the main outcropping material. The lateral variations in resistivity can be explained by lateral variations in the formations nature, especially small AB spacings.

The slope material horizon is complex, by its varied composition and the resulting differences in resistivity. It is partly because of this complexity that the measured apparent resistivity does not give the same distribution for this layer.

This surface distribution is justified by the fact that the slope is more or less significant over the entire northern and southern part of the study area, the lowest resistivity values are obtained at the spots where the slope is low.

At a depth of almost 2.5 meters **(Fig. 6, a)**, we can distinguish the presence of a homogeneous layer, associated with the conductive marl formation which dominates the subsoil. In the southern part, we noted low resistivity values (between 12-16 Ω.m), before passing to a purely marly environment, which can probably be attributed to a glacis-marl passage which evokes rather a soil compression linked to the slope and proximity to the road.

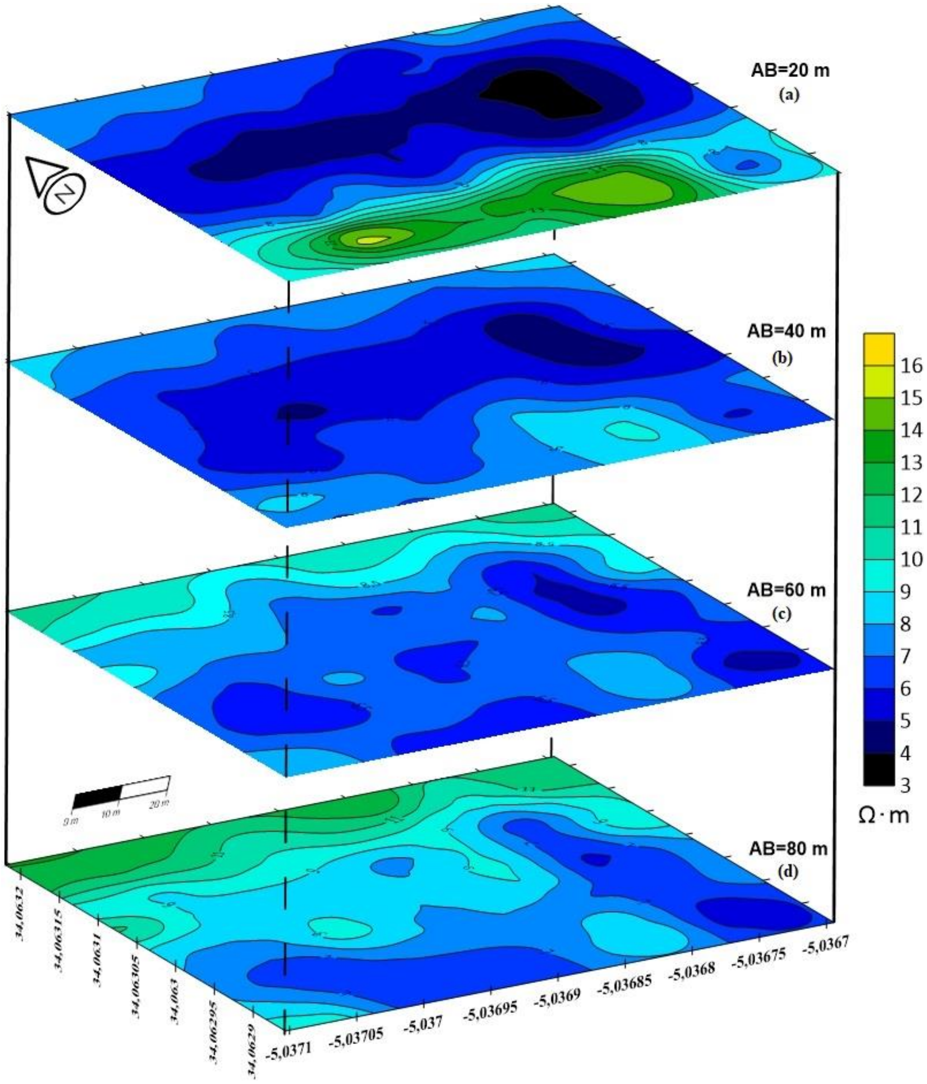

Fig. 6. Iso- resistivity maps for AB = 20, AB = 40, AB = 60, AB = 80.

With AB spacing between 40 m to 60 m **(Fig. 6)**, on a rather flat topography in the region, led to believe that the surface of the marly layer was also flat, the distribution of apparent resistivity highlights a homogeneous subsoil, the relatively low resistivities obtained on these iso-resistivity maps, correspond well to the facies rich in marl which contain many gypsum concretions. At this depth, the rock is soft, means it is more vulnerable to alteration, gypsum goes into solution or easily erodes and forms voids, pipes, and cracks.

Marls are easily detected on the iso-resistivity maps, on the one hand, because of its low resistivity and on the other hand because of its generally large thickness (15m on average).

The lowest resistivities are obtained in-depth where the thickness of the marl deposits are larger. In cases where the apparent resistivity of the last layer is less than 13ohm-m, it can be assumed that the top of the conglomerate horizon is not reached yet since it generally has a resistivity higher than 20 ohm-m. Furthermore, the marly layer includes high resistivity anomalous zones higher than the rest of the region **(Figs. 6, b, c, d and Fig.7, e)**, It is likely associated with the presence of cracking or alteration. Less pronounced, which can be attributed to natural fissures and zones of weakness within the soil.

The iso-resistivity map with AB spacing between 60 m and 120 m reflects another anomaly that is added to confirm our opinion. It is obvious that resistivity values in the central part better defined on **(Fig. 7, e)** are higher than side parts, These may correspond to a possible cavity inside the marly conductive layer.

Analyzing the results of the real data on the iso-resistivity maps with AB spacing between 80 m to 160 m **(Fig. 6, d and Figs. 7, e, f, j, h)**, with a depth of investigation between 10 m and 20 m, we can notice a cloud of significant apparent resistivities within the longitude values –5.03685 and -5.0368 elongated south-north. In this case, the layer with conductive materials showed resistive anomalies, a vertical structure is identified, this discontinuity seems probable to indicate a possible cavity of significant size, which extends in-depth, there has moreover several cracks and fissures which sometimes appear even on the surface in this sector. This zone can be interpreted as a cavity filled with loose sediments and can be considered as the main reason for the subsidence of the middle zone of the parcel.

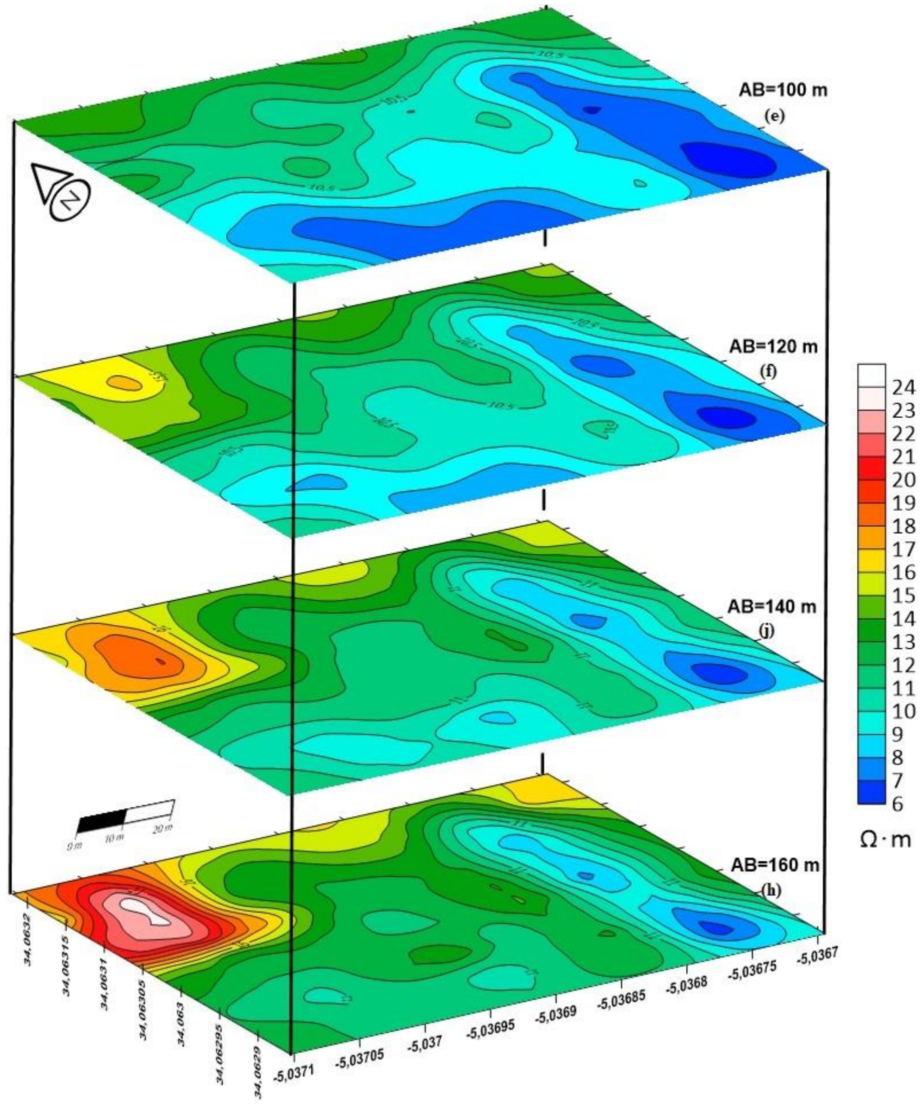

Fig. 7. Iso-resistivity maps for AB = 100, AB = 120, AB = 140, AB = 160.

The last iso-resistivity maps **(Figs. 7, j, h)**, reflects the lateral variation over a horizontal plane at a depth of about 20 m. It indicates the beginning of the conglomeratic formation, the presence of these facies in the northwest part of the parcel, illustrated with a large thickness that extends deeply. The northwest part of our study area shows massive deposits of conglomerate, those formations are verticalized due to the pre-rifain compressional tectonic regime, oriented to the south in Tghat mountain. The presence of this layer at this depth especially in the northern part comes to confirm the results obtained by geological mapping.

5 Conclusion

The study has demonstrated that the non-destructive investigation method of electrical soundings allows on the one hand to locate the 3 horizons and to estimate their thickness. The geological units are distinguished from one another by their signature of highly contrasted electrical resistivity. However, we note a significant spatial variability within some of these units, marls is certainly the element most recognizable by electrical measurements. Interpretation of Wenner-Schlumberger configuration resistivity data revealed the presence of high resistivity anomalous zones that have been attributed to possible fissures or small cavities

In this work we identify weakness zones (areas with potential risk evidenced by cracks and voids in-depth). Consideration must be given to this phenomenon in the urban planning process and development. In our case, it requires other additional complete VES surveys at the south limit of the urban area of Tghat mountain, to define the necessary preventive measures.

A better geotechnical knowledge of the underlying layers would also be beneficial seeking to minimize the risk of the possible collapse and landslides. From a geotechnical point of view, all the new infrastructure and facilities must be located in a stable area to avoid construction disorder which represents a high financial impact for many owners.

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