

# Geophysical prospecting in the Doukkala area (Swalah commune) in Morocco

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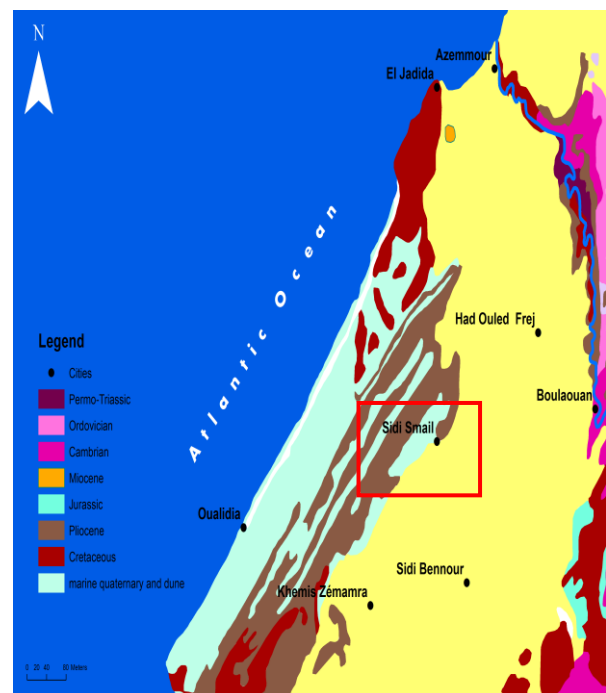
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**Abstract.** The collapse of the subsoil creates a risk for the population whether it is urban or rural. Each year, the damage caused by these collapses has considerable socio-economic consequences, and the damage costs are very high. Thus, the detection of these areas of collapse in urban and rural areas is important to prevent and avoid socio-economic consequences, and to establish a preventive risk planning to have a better protection of people and goods. The commune of Swalah, study area, belongs to the province of El Jadida which is part of those areas of Doukkala exposed to the risk of collapse due to the presence of underground cavities. These cavities are potentially dangerous for humans, especially in urban areas. They have different extensions that can be caused by natural or anthropic origin. Their size, as well as the physical properties of the external environment in which they are located, allow the use of different geophysical methods. The use of these geophysical methods is the best to detect and delineate cavities in this region. The present study was based on a geophysical campaign of vertical electrical soundings. Indeed, 50 electrical soundings were modeled and reinterpreted and allowed to detect and delineate any potential cavities in the region.

## 1 Introduction

In many areas, the existence of ancient natural or artificial cavities constitutes a permanent major risk for the population and is, in most cases, the cause of collapse of buildings [1,4]. These underground cavities have been abandoned for centuries without any security measures.

The Swalah region is one of the regions of Doukkala exposed to the risk of collapse of underground cavities. The electric resistivity measurements by the electric geophysical method make it possible to determine a strong contrast of the resistivity between the geological host and the cavity itself [2]. Under these conditions, the use of the vertical electrical sounding method based on resistivity becomes necessary. In this context, a campaign of 50 electrical soundings was conducted in the study area. Its main objective is to study the stability of the ground and to establish maps defining the zones at risk, by identifying the extension of dissolved gypsiferous formations in the first 200 meters. This geophysical method has already been used successfully for subsoil exploration in other contexts [3]. These studies showed that the presence of a cavity could be detected by the contrast of resistivity.



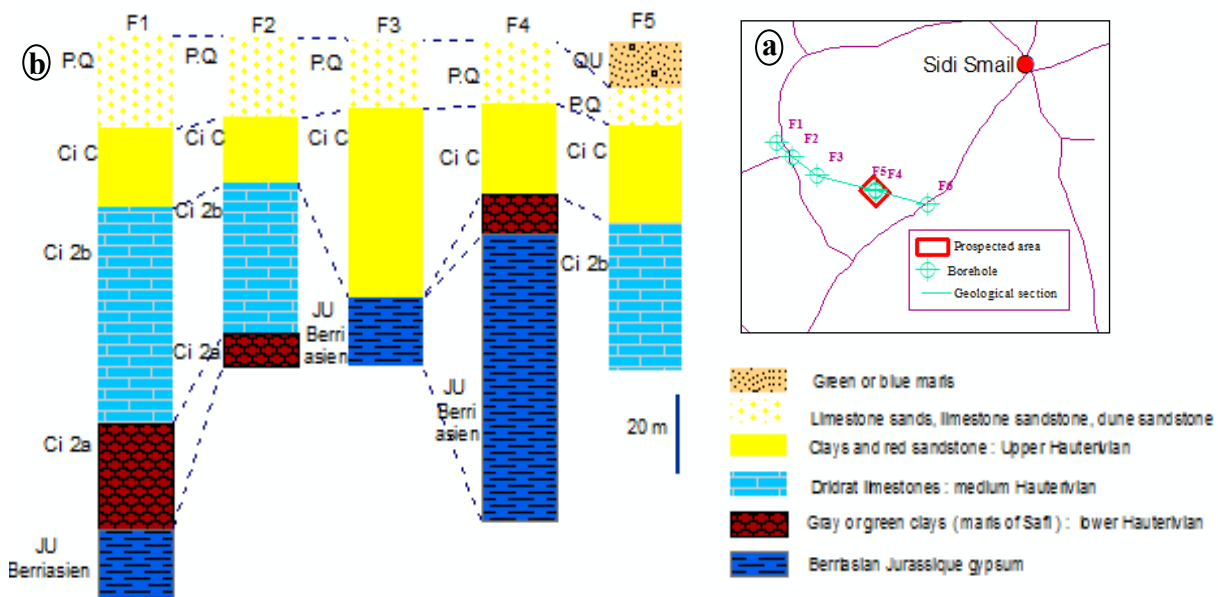
**Fig. 1.** Location of the study area on the geological map

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## 2 Study area

The studied area, Sidi Smail province of El Jadida is part of Abda-Doukkala located in the East (Fig.1). From a geological point of view, the study area is related to the Moroccan Meseta and more particularly to the central zone. The stratigraphic series is represented by a Paleozoic basement on which rests, a sedimentary series ranging from Permo-Trias to silty quaternary [5]. The regional geological section (Fig. 2) using boreholes F1, F2 F3, F4 and F5 reveals the existence of four large lithostratigraphic sets with a thickness of 140 m, which are materialized by alternating sandy and sandstone formations as well as red clays of Upper Hauterivian

age. These sediments are followed by a serie of gray and green clays. Borehole 4 located in the center of the study area, crosses a Jurassic Berriasian formation composed of gypsum limestones, with a power of up to 200 m where gypsum occupies an important place [6]. Dridrat limestones are probably not deposited in the studied or eroded zone [7]. In this carbonate medium (limestone) and sulphate medium (gypsum), chemical alteration is very frequent and causes the appearance of cavernous zones in the study area [8].



**Fig. 2.** The correlation between boreholes lithology. a) Implanting boreholes b) Correlation of boreholes

## 3 Goelectric prospecting

The vertical electric sounding method used in this study is based on the injection of an electric current between two current injection electrodes A and and the measurement of a potential difference V between two other electrodes of potential M and N [9].

We deduce the apparent resistivity of the subsoil:

$$P=K.(V/I)=2\pi/(1/AM-1/AN-1/BM-1/BN).(V/I) \quad (1)$$

K : The geometric coefficient of the device only function of the distances between electrodes.

The studied area (Fig.4) was prospected during a geophysical survey of 50 electric survey spaced 10 m, of which 33 SEV were made with AB = 2000m and 17 SEV for AB = 1500m. The Schlumberger configuration used in this work requires the alignment and the symmetry of the electrodes referring the centre O with MN / 2 and AB / 2 [10]. The raw data are first represented as curves  $\rho_a = f(AB / 2)$  in a bilogarithmic coordinate system. These curves were interpreted automatically by mathematical inversion using the IPI2WIN software [11].

The solution obtained is not unique, but the calibration of this interpretation with nearby drilling helps to remove some of these uncertainties. By collecting the results of this interpretation of each of the soundings, we made

geoelectric cuts along the selected profiles. Subsequently, the apparent resistivity values represented in the form of apparent resistivity maps for line lengths AB = 100,200, 1500 and 2000 m.

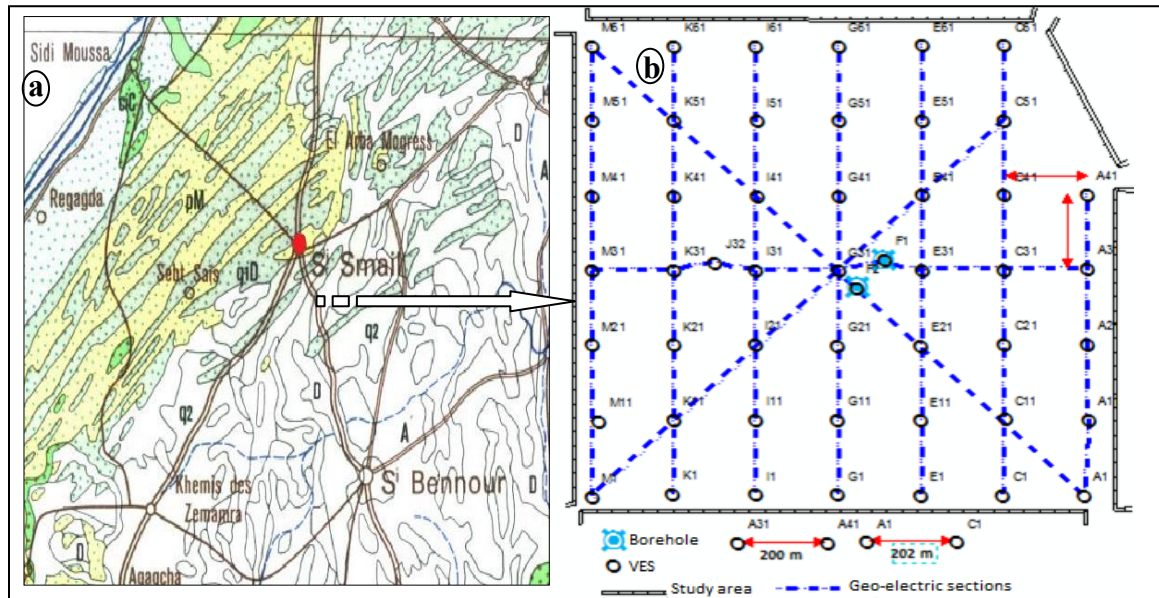


Fig. 3. The location map of electrical soundings. a) Location of the study area b) Geophysical survey

## 4 Result and Discussions

### 4.1. Geoelectric Sounding interpretation

The inverse modeling of the 50 soundings leads to remarkable curves, according to the shape of these curves, one distinguishes 3 families of electrical soundings (1, 2, 3) (Fig.5). Family 1 includes 24 electrical sounding, it reveals the existence of 5 layers: a very thin cover less resistant 20-70 ohm.m consisting of fine sand and calcareous sandstone (R1), a C1 conductor (2-18 ohm. m) characterizes the clay formations, a Resistant R2 (70-1000 ohm.m) formed of limestones reaching a depth of about 40 m and a C2 conductor (1-24 ohm.m) above the Jurassic formations moderately resistant with a depth ranging from 126 to 210 m. Family 2, consisting of 3 soundings, shows the silty quaternary (sandy-clayey silts) in contact with a conductive greenish marl formation (7-16 ohm.m), which rests on a conductive layer formed of gypsum with fractured limestones, the whole thing is based on Jurassic age formations.

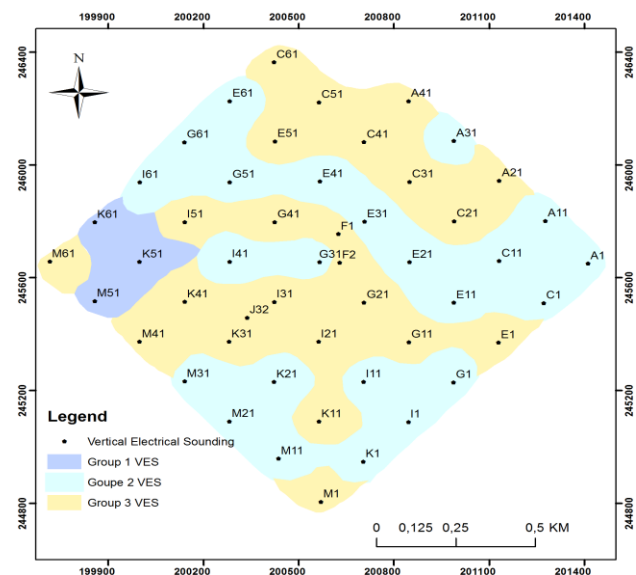
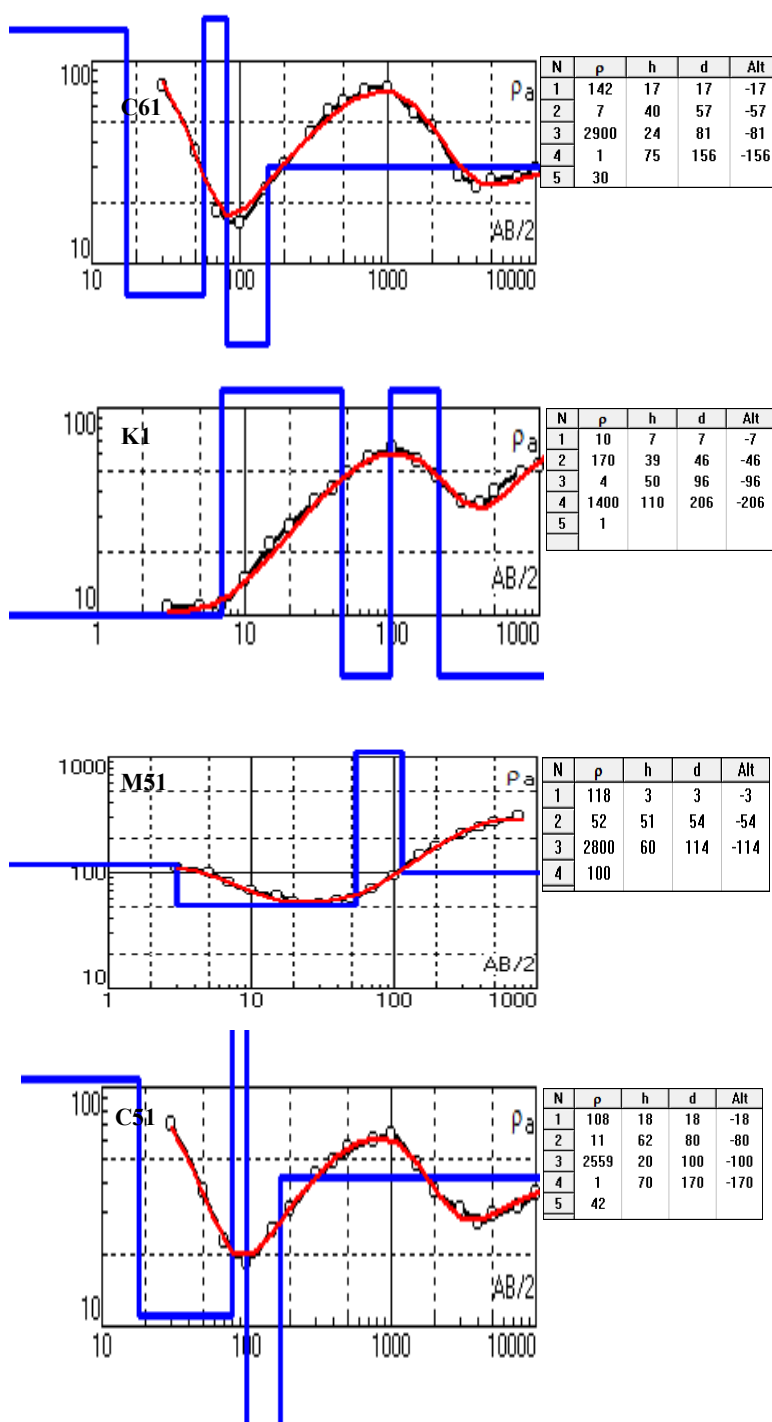


Fig. 4. Families of VES



**Fig. 5.** Electrical soundings and their interpretations M51, C51, C61, K1.

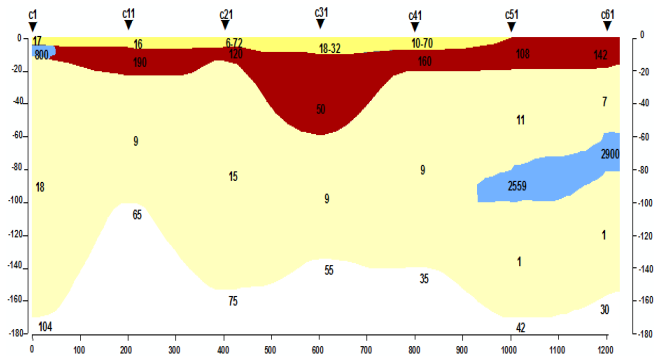
Family 3 is characterized by 4 layers with the exception of some electrical soundings, first there is a conductive red clay layer that extends in the first 10 meters deep, then a very resistant series (100 to 1010 ohm.m) with an estimated thickness of approximately 6 to 52 m, which can be identified with Plioquaternary limestones,

resting on a conductive formation (4-20 ohm.m) thick of gypsum nature. Soundings k1 (Family 1) c51 and c61 (Family 2) m51 (Family 3) represent very strong anomalies, they will be illustrated in the geo-electric sections with other soundings (figure.6.7.8).

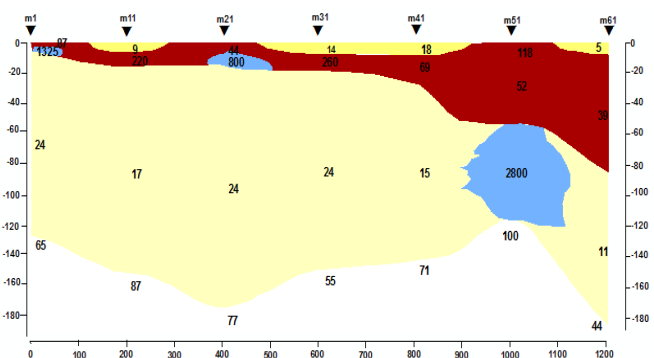
#### 4.2. Geoelectric Cross section

Several geo-electric sections based on the inversion of the electrical soundings were realized, Only the most representative sections will be presented: m1m6, c1c6, a1m1 (fig.6,7,8). In the region of Abda-Doukkala the tertiary tectonics gave its structure to this region, the Paleozoic formations under the secondary cover, are subjected to Hercynian deformations between the Oulad Ziane fault and the Drabla-Sidi Smaïl fault, and the NS SW-NE to EW folds are often exposed to these Hercynian tectonic elements [6].

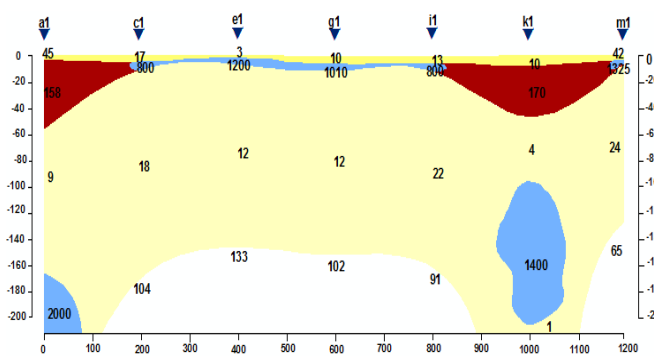
The geo-electric sections carried out have the same succession of layers, with thinning of the superficial part (1-20 m), increase of the resistivity (800-1000 ohm.m) of the layer of Plioquaternary limestones when they are fractured, and the presence of a formation of gypsum limestones which extends under all the electrical soundings of the sections, and rests on moderately resistant Jurassic series. The sections show several variations of resistivity. We are interested in the very resistive zones represented by the blue colors. On the section c1c61, we are in the presence of a high resistivity anomaly (2900 ohm.m) under C51 very comparable to the anomaly under C61 (2900 ohm.m) as for its resistivity and its thickness of 20 m for C51 and 24 m for C61. Both are followed by a very conductive layer (1 ohm.m) over a thickness of 70 m for C51 and 75 m for C61. These two resistant anomalies can be explained by a cavity probably filled with air located in a zone of Upper Jurassic gypsum and limited in its lower part by a conductor which corresponds to a salt-laden water accumulation. On the section a1m1, the resistivity of the gypsums increases from (4-9 ohm.m) to (1400-2000 ohm.m) under k1 and a1 and decreases again under k1 to 1 ohm.m from 206 m of depth, which can be explained by the presence of a probable cavity in the gypsums filled in its lower part by a conductive material. Another anomaly developed by dissolution of gypsum with a resistivity of (~2800 ohm.m) under m51, extended vertically over 110 m thick and begins at 50 m depth. In all the sections and inside the detrital limestones of the Plioquaternary zone appear areas with high resistivity values between 800 and 1325 ohm.m correspond to the fractured limestones.



**Fig. 8.** Goelectric section according to profile a1m1

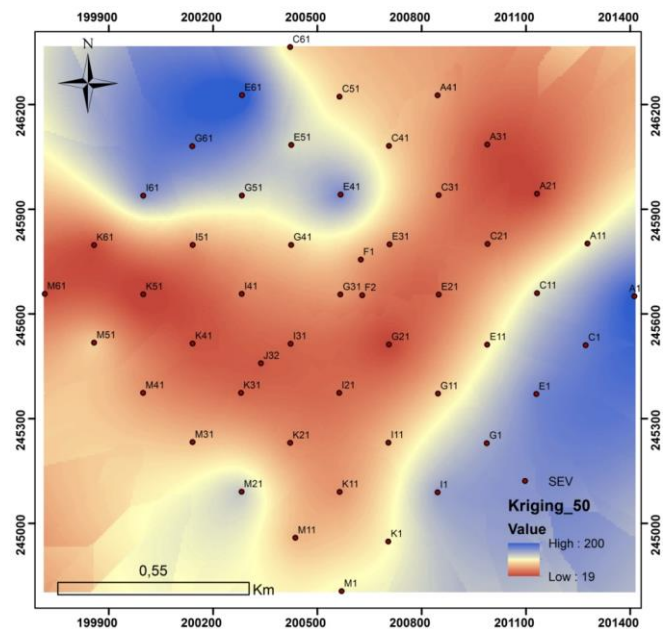


**Fig. 7.** Goelectric section according to profile m1m61



**Fig. 6.** Goelectric section according to profile c1c61

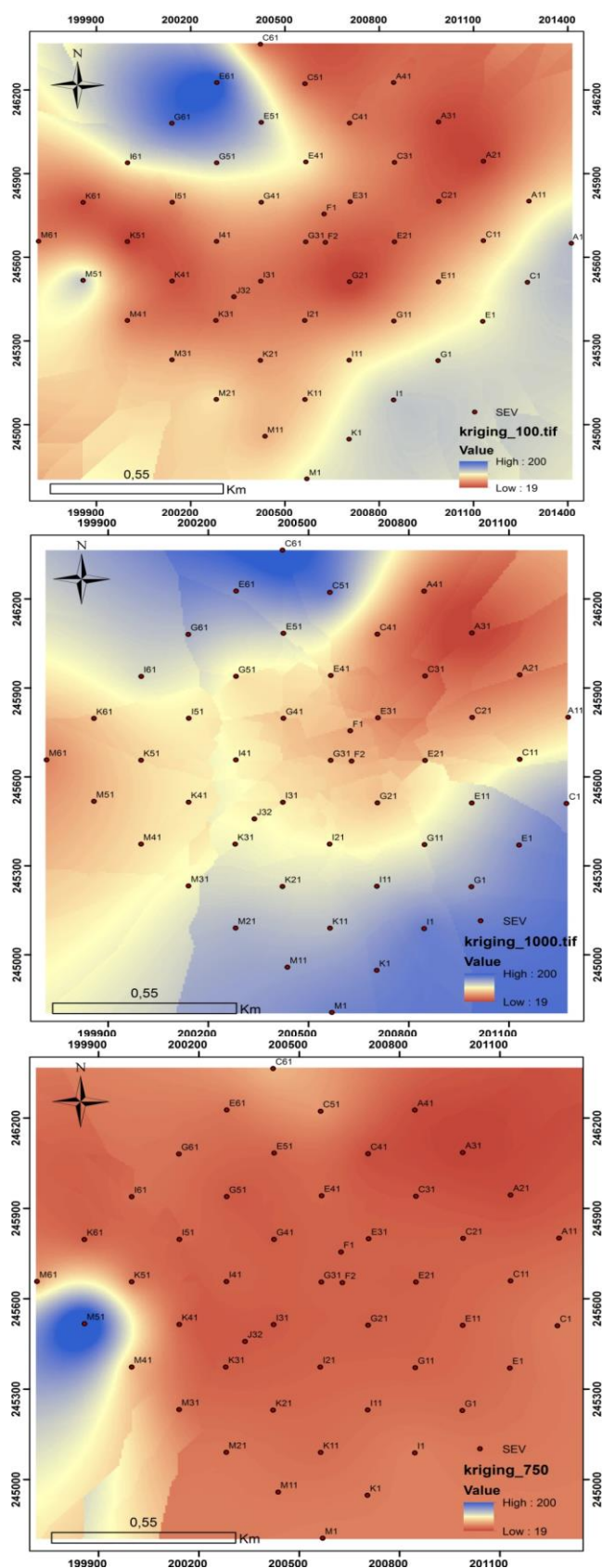
encountered in the region. These maps show a very regular distribution of resistivities, in the middle of the city concentrates the conductive zone and the values become more and more elevated in the South-East and North-West. By comparing the maps we find that the conductive formations are reached in all the maps. These formations are associated with sectors where limestone and gypsum are the main materials. For the spacing  $AB = 1500$  m, ie a depth of ( $\approx 110$  m), we observe that the formations are mainly gypseous, except for the resistant zone under M51, which confirms the presence of a cavity which extends over a depth of 114 m to 174 m. For the spacing  $AB = 2000$  m, is a depth of ( $\approx 125$  m), a very strong zone is observed under the two holes C51 and C61 which confirms a vacuum filled with air detected in the geoelectric map C1C61 which is prolonged on depths of 105 to 120 m. For the small AB spacings = 100 m, 200 m (depth of 10 to 20 m) the most resistive zones are associated with fractured limestones of Plioquaternary (800-1200 ohm.m) under the electrical soundings C1, E1 G1, I1, I61 and G51.



### 4.3. Map resistivity

Four maps of apparent resistivity iso-contour were created using the Krigeage spatial interpolation method, which predicts the apparent resistivity value studied at a non-sampled site by a linear combination of adjacent point data [12].

Figure 9 shows the resistivity maps, one for each  $AB = 100, 200, 1500$  and  $2000$ m spacings. Their utility is to establish a scale of resistivities for the types of materials



**Fig. 9.** Resistivity Maps for AB=100m, 200m, 150m and 2000m

## 5 Conclusion

The results of the inversion of the 50 SEVs made in the city of Sidi Smail enabled us to establish geo-electric sections characterized by a highly conductive level (5-18 Ohm.m), identifying with a sequence of gypsiferous formations of Upper Jurassic spread over lengths of 1696m. This level contains cavities up to 110 m thick at depths between 40 and 110 m. The solubility of the gypsums favored the dissolution and thus assisted the appearance of these empty spaces filled with air. The results of this study show that this method is well adapted to the recognition of the subsoil, they also show the interest of the SEV method in the detection of underground cavities. Of course, the lack of resolution does not allow this method to distinguish the precise dimensions of the cavities. These very interesting results should be the basis of any future prospection in the city of Sidi Smail.

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