# Electrical resistivity tomography contribution to the characterization of underground cavities in the region of Safi, Morocco

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**Abstract.** Natural underground cavities represent a major risk that compromises the durability of infrastructures and buildings and requires an urgent evaluation in order to be integrated in urban planning and decision-making. Nevertheless, the assessment of the hazard related to them requires a better understanding of the complexity of karst phenomena that may be well-developed in an area even without the presence of any surface indices. Actually, evolutions of karst underground features are controlled by a set of predisposing factors. The present study aims to contribute to the delineation and characterization of underground cavities in the coastal part between Safi and Oualidia. The choice of the study area was based on a preliminary analysis of site conditions and the main controlling factors of superficial karst especially those related to geology, hydrology and geomorphology. In this part of Safi region, The high salinity of seawater enhances the process of dissolution creating so an aggressive environment and favorable conditions for an accelerated extension of karst networks. In order to detect and estimate the approximate extensions of karst networks and features in this area, results of seven electrical profiles were interpreted in correlation with available geological and hydrogeological information.

## 1 Introduction

During last decades, Safi region has known the occurrence of many surface incidents related to karst and its features especially collapses of underground cavities. In fact, many research works has revealed that the area is underlined by a developed karst network [1, 2, 3 ,4 ,5] and has known the occurrence of sinkholes and land subsidence that affected mainly manmade structures, buildings and agricultural areas [1, 2, 4, 6]. However, the risk related to the presence of underground voids and cavities is still out of consideration in urban planning and geotechnical studies related to infrastructure projects. For this reason, their detection and characterization in the area is crucial and urgent.

**Fig. 1.** Degradations observed in the coastal part of Safi.

Detection of natural underground cavities is a key step in mitigating the risk associated to sinkholes sudden appearance and a key task in making geo-hazard maps especially in highly urbanized areas. In fact, terrains underlined by evaporate and carbonate rocks, known as karst terrains, presenting a distinctive morphology and hydrology and a well-developed secondary porosity and many other predisposing factors form a favorable environment for voids formation that may be the cause of many engineering challenging problems [1, 5]. For instance, the ignorance of an existing deep lying cavity in a construction project may lead to disastrous effects linked to land subsidence or collapses. That is why hazard mapping is nowadays a priority in order to preserve human lives and properties and make favorable conditions for a safe urban construction. The problem becomes more crucial with increasing rates of urbanization in highly populated areas. It requires thus an urgent assessment of the hazard related to karst environment towards reliable risk maps that identify, and delineate areas presenting a high susceptibility to underground cavities formation.

During the last two decades, the problem of detecting cavities has gained more and more interest and many techniques has been proposed to tackle the issue. Nevertheless, it is still a challenging matter because of the inexistence of a standard detection technique. Many studies have used aerial photographs, geomorphologic analysis and in-site data to obtain reasonable hazard maps [7, 8]. The use of such techniques has shown its reasonable reliability for large-scale analysis. The use of

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satellite imagery is becoming more and more an efficient and low cost method with the availability of free data and software [5]. However, the use of such techniques may only serve as a preliminary phase that gives a first appreciation of surface land features and indicates the nature and degree of Karst development. This may serve as a guide to choose specific sites to verify by techniques that are more accurate and have the ability to delineate size and depth of subsurface voids resulting in a more reliable information for hazard mapping [10].

Geophysical methods present a high potential in detecting underground voids and may be considered as one of the best-suited techniques for this matter [10, 11]. They present the advantage of covering large areas in short periods of time and has shown, during the last years, their efficiency in detecting subsurface heterogeneities [10, 12, 13, 14]. In fact, underground cavities can be detected by geophysical techniques because they have significant contrasting in physical properties when compared to the host rock [13, 15]. Their resistivity is usually distinguished from that of the host rock and, regarding their position in the karst system and the piezo-metric level, they may be totally or partially water or air filled as they may be filled with a conductive or nonconductive material.

The use of geophysical techniques helps planning more efficiently further investigations by means of destructive techniques such as drilling. The last present the disadvantage of being expensive and environmentally damaging.

## 2 Geology and location of the study area

Investigation site is located in the northeastern part of Safi region and stretches along about 30 km length towards Oualidia.

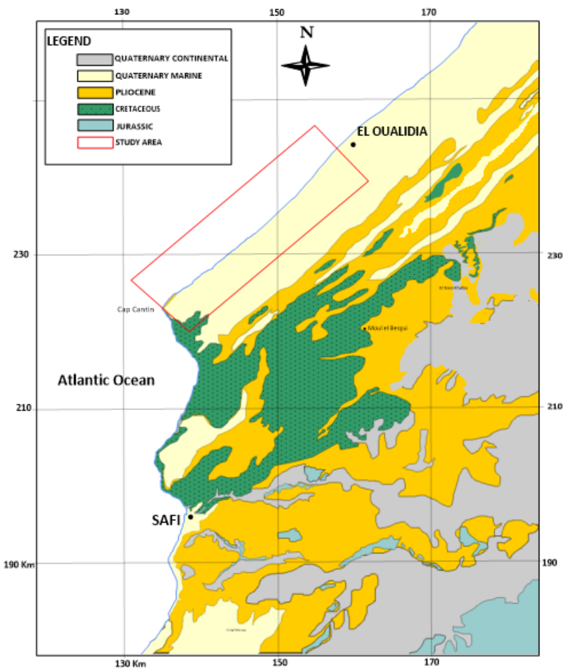


**Fig. 2.** Location and main geologic features of the study area

It belongs to the 'Sahel' that refers to the coastal part highly prone to cavities formation because of seawater intrusion that creates an aggressive environment and accelerates dissolution process in carbonate and evaporate series.

The study area belongs to the Moroccan coastal 'Meseta' that refers to the primary substratum covered with Mesozoic and Cenozoic sediments stretching between Souiria Lequidima to Oualidia and extending until Jamaat Shaim in the south [1, 2, 3, 4, 6]

Since the Mesozoic age, morocco is located in a junction between the African continent, the Atlantic Ocean and an active collision plate. Geodesic and seismologic data reveal that distortions caused by the convergence Africa-Asia-Europe are concentrated in the north edge of Africa and result in strains that have a maximum compression NW-SE [2]. In the study area, folds are mainly oriented SW-NE [2, 6].

In the Sahel, the geomorphology is composed of cliffs with important high levels. The mean geological formations and lithology are shown in figure 2 and the table below:

**Table 1.** Mean geological series and the stratigraphic profile in the study area.

| Geological series | Composition |
|---|---|
| Plio-quaternary | Consolidated sand and dunes of limestones |
| Cretaceous- upper Hautrivian | Red sandy clays containing red clays bedded with sand that forming the base of the Plio-Quaternary series |
| Middle Hautrivian | Dridrat limestones composed of less dolomitic calcareaous sand |
| Lower hautrivian and upper Valangian | Brown Clays of Safi composed of marly sand containing some beds of limestones |
| Upper Jurassic | Marly limestones, marls, clays with gypsum blocs |

Dridrate limestones are considered the only aquifer of interest in the area. They cover about 220 Km² of the 'Sahel' and constitute the base of Plio-Quaternary series along 240 km². What makes this geological formation occupy about 36% of the Sahel surface. Their hydrogeological performance is due to their impermeable base formed by the brown Safi clays. Upper series, composed of red clays, block usually any percolation of water when existing and their permeability remains dependent of their content of sand. While in areas where the Plio-Quaternary series lie directly on Dridrate limestones all water infiltration is oriented to this aquifer [2]. The average permeability of Dridrate limestones is about 5.10-3 m/s.

According to Ferré, Ruhard and Wiersrock [2, 6], geological formations in the area may be classified depending on their susceptibility to karstification as follow: (1) The high fractured marly limestones and gypsum of the upper Jurassic because of the high degree of solubility of gypsum, (2) Dridrat limestones of the upper cretaceous, (3) and series of Plio-Quaternary containing marine bio-calcarenite and detrital limestones.

## 3 Methodology

The present work aims to delineate and characterize subsurface cavities in the costal line between Safi and Oualidia. For this purpose, the results of seven electrical resistivity tomography profiles that were executed by the Hydraulic Bassin Agency of Oum Errabia were interpreted and correlated with geological and hydrogeological context. Location of those profiles is chown in figure 4 below.

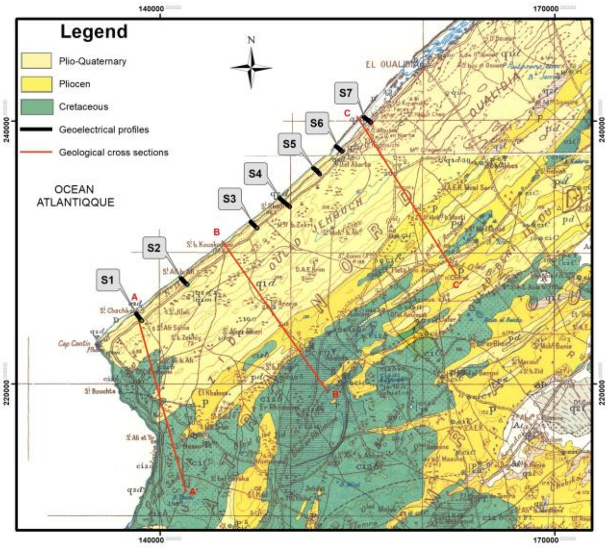


**Fig. 3.** Location of electrical resistivity tomography profiles and geological cross sections with the geological distribution of superficial layers from combined geological maps of the Meseta [16, 17]

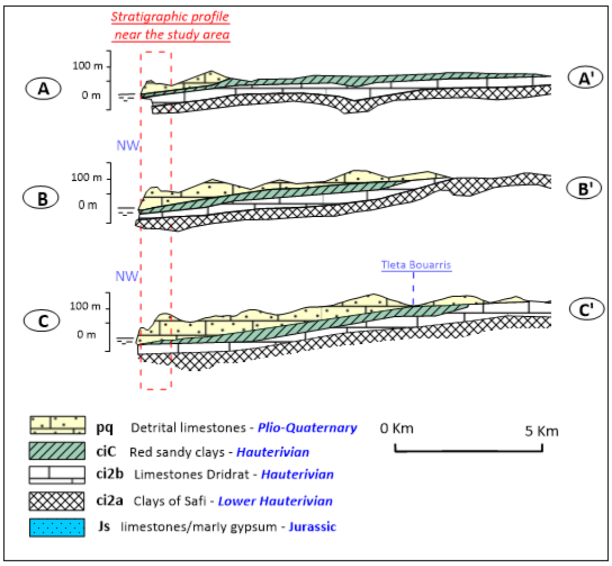


**Fig. 4.** Geological cross sections along the study area as indicated in figure 3. From Ferré and Ruhard modified [1].

Surveys were carried out using 72 electrodes according to a Wenner array with a spacing of 10m. The choice of Wenner array was made because of its high sensitivity to vertical changes in resistivity values what makes it suitable to map horizontal structures [12]

Profiles length ranges between 710 to 1430 m what results in a depth of investigation that reaches 120m. Inversion of apparent resistivity was made using RES2DINV software and obtained results were interpreted and correlated with available geological information derived from the geological cross sections indicated in figure 3 and figure 4 in addition to data from drilling in investigation area.

Electrical resistivity tomography or subsurface imaging is a geophysical technique that is able to detect cavities in subsurface [18, 19, 20 ]. This technique is not time consuming, allows a good investigation depth and has a good resolution [12]. The technique relies on Ohm's law and consists of laying out two ranges of electrodes connected by a single cable, a switching box and a resistance meter. A direct current is injected into the ground by means of two electrodes called 'current electrodes' and the resulting potential is measured by another pair of electrodes called 'potential electrodes' [1, 18]. Horizontal and vertical resolutions are determined by changing the inter-electrode spacing according to the survey objectives [18]. Pore fluid contained in rocks plays the role of electrolyte and is mainly responsible in conducting electric current. This makes sedimentary rock more conductive than ingenious ones that show usually high values of resistivity [18].

Values of apparent resistivity are obtained towards many sets of four electrodes by shifting each time by one electrode the electrode spacing as shown in figure 5.

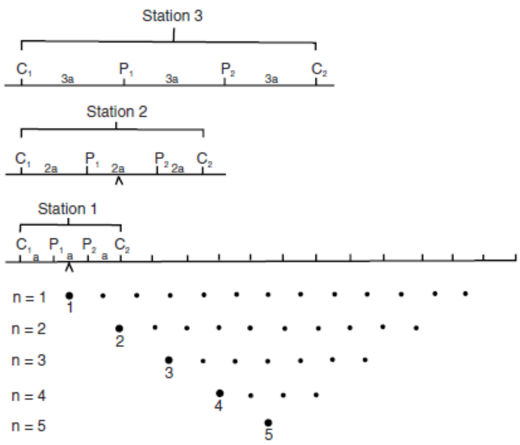


**Fig. 5.** Example of measurement sequence to build a pseudo cross-section [18].

The apparent resistivity obtained represents the measured resistance (R) corrected by a geometric factor (K) that depends on the electrodes arrangement as the equation (1) shows:

$$\rho_a = RK \tag{1}$$

Values of apparent resistivity are then converted to a true resistivity model using inversion technique and the 2D model response is obtained by means of finite element or finite difference method. The process is based on successive iterations until the root mean square misfit between the pseudo-section and observed model is minimal.

Nevertheless, the technique of Electrical resistivity tomography presents some difficulties. In fact, this technique is highly affected by field conditions and the internal resistance of the circuit measuring the potential has to be higher than the ground resistance between potential electrodes [18]. Otherwise, the measured resistance is not accurate because the current flows towards lower resistances offered by the potential circuit. When implanting current electrodes in some kind of materials like gravel or dry sand, electrode contact resistance becomes very high and hinders the injecting of current to the ground what may result in misleading interpretations of high resistivity values.

## 3 Results and discussion

The seven ERT profiles were performed in a buffer zone of about 1km from the northern cliff. Geological sections (figure 4), superficial geology (figure 3) and data derived from drilling show that the stratigraphic profile in this zone is composed of detrital limestones of Plio-Quaternary deposits that has a variable width with topography reaching about 80m in some areas. Those deposits show a high to medium resistivity values depending on their degree of fractures and weathering.

Areas located near the ocean tend to be more conductive because of soil moisture and seawater intrusion. The red clays have a width of about 20 to 30m width and a resistivity value less than 500 Ω.m. They lay on Dridrate limestones that stretches in a depth between 50 to 100 m with a resistivity reaching high values (more than 1300 Ω.m). The base is composed of Safi red clays tending to be conductive regarding the piezo-metric level in the area and the existence or not of seawater.

Resistivity pseudo cross-sections and cross-sections were obtained for the seven profiles of electrical tomography and were qualitatively interpreted according to geological and hydrological known data in the area. Interpretation revealed the existence of many anomalies of low resistivity and high resistivity values in many profiles.

Figure 6 shows an example of resistivity cross section along the profiles S2, S3 and S7. The inverted model of the profile S2 shows that the first 160m of the profile is highly affected by seawater and reacts as a conductive material. The aquifer of Dridrat limestones is submerged with water until a lateral extension of about 200m. At the southeastern part of the profile, resistivity values are considerably increasing. The upper layer of about 20m followed by a thin conductive layer correspond to Plio-Quaternary and red clays layers that cover the Dridrate limestones. At the middle of the profile resistivity show higher values than the surrounding layers. This anomaly may be interpreted as a probable air filled cavity located at about 30m of depth and having a diameter of 15 to 20m.

For the profile S3, the upper part shows a medium resistivity value ranging between 400 Ωm to about 1400 Ωm in some points. This distribution that stretches along the profile with in a depth of 10 to 20 m correlates with the Plio-Quaternary deposits. Fluctuations of resistivity are related to the degree of fractures in detrital limestones. This profile shows two anomalous zones: The first one located under the first sounding points at about 20 m of depth and showing a very low resistivity that may be interpreted as a probable cavity filled with sea water. The contact between Dridrate limestones and seawater in this area yields in an accelerating the dissolution process of the last with the presence of an aggressive environment related to the high salinity of water agent. The second anomaly is observed under the point located at 500m from the northwestern part of the profile and located at a depth of about 40m. This anomaly may be interpreted as an air filled cavity located also in Dridrate limestones.

The Profile S7 is located in an area where layers of red sandy clays are thin. The shape of topography results in a high superficial water input that has fractured detrital limestones and consolidated sands of the upper Plio-Quaternary series. In some parts of the profile, Dridrate limestones outcrop and their covering deposits are eroded. This explains partly the important conductive zone in the profile that corresponds in its upper part to weathered limestones and a saturated zone of the aquifer. When heading towards the coast, resistivity tends to decrease in lower parts. This corresponds to areas where seawater melts with rainwater detained in the aquifer.

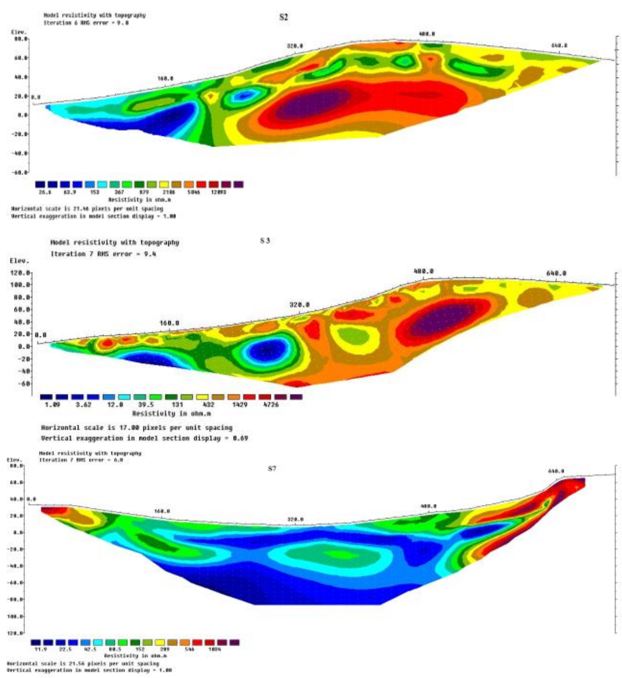


**Fig. 6.** Resistivity cross sections along the profiles S2, S3 and S7.

## 4 Conclusion

The interpretation of ERT results in the northeastern coastal part of Safi region has shown the existence of many low and high resistivity anomalies that were interpreted as possible underground cavities. The most susceptible layer prone to the existence of cavities in this area is the Hautrivian series of Dridrates limestones. The aggressive environment in this area created by seawater and the direct contact between limestones and the ocean in many parts has caused a high degree of dissolution in subsurface layers. As shown in the examples above, probable water filled cavities are likely to stretch along the investigated area. The roof composed of Plio-Quaternary series tend to be resistant when the width of deposits is important. However, in some areas affected by erosion process and acting as water input zones regarding their topography, upper deposits tend to have a decreasing width what leads to a high risk of collapse.

The comparison between drilling data and the results of electrical resistivity tomography has shown the efficiency of the technique in detecting superficial underground cavities. However, interpretation of exact location of layers boundaries is sometimes difficult because ERT sections are not a step function with clear boundaries but a gradient of resistivity values. In addition, the presence of artefacts of the inversion process make it sometimes difficult to distinguish real from ghost anomalies.

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