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Combining Seismic and CSAMT Methods in a Sinkhole Site Study

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SUMMARY

The Catalan Potasic Basin (Northeast of Spain) has been associated with subsidence and structural failures due to sinkholes influenced by salt mining activities. The study area contains three visible sinkholes developed in 60s, 2000 and 2002. Questions regarding the subsoil extension of the collapse/drainage zone and the mechanism of sinkhole formation are under study. Complex geology and presence of different materials susceptible to dissolution make difficult to understand the process based only on outcrop and borehole information. In this work, we present the combination of two geophysical techniques, seismic and Control Source Audiomagnetotelluric (CSAMT) methods, in order to delineate subsurface anomalies associated with the sinkhole formation. Combining both seismic velocity and resistivity models constrain the interpretation and helps to find high-porosity zones associated with sediment displacement and to define the evaporitic rock top.

Introduction

Understanding sinkhole development in karst areas is critical for trying to reduce the risk related to them. In addition to intrusive methods such as well drilling, geophysical techniques have been introduced as a fundamental tool for subsoil characterization. Dobecki and Upchurch (2006) summarized the applications of geophysical methods in geotechnical studies in karst environments since they can be applied in different stages: risk assessment, forensic evaluation and remediation. The most widely used geophysical methods in these studies are: ground-penetrating radar (GPR), microgravimetry, resistivity methods (ERT) and seismic methods. GPR techniques have been useful in detecting cavities (Beres et al., 2001) and subsoil subsidence evidence (Dobecki and Upchurch, 2006). Microgravimetry methods may be used for detecting areas with mass deficiency related to cavities filled with water, sediment, collapse material, or a mixture of all of these (Styles et al., 2006). Electrical resistivity methods have been applied in order to detect collapse/drainage features (Dobecki and Upchurch, 2006) and filled sinkholes and soil pipes (Ahmed and Carpenter, 2003). Seismic refraction tomography (Sheenan et al., 2005) and surface wave methods (Shtivelman et al., 2005) can map areas with increased porosity compared to the surrounding materials related to drainage zones. A method less extensively applied to sinkhole studies is the Control Source Audiomagnetotelluric method (CSAMT) which provides resistivity models for deeper targets than ERT (Kim et al., 2007).

The study area is located in the Catalan Potasic Basin in Northeast of Spain (Figure 1) that has been targeted by intensive mining activities from the 40s to 70s. This basin is characterized by soil failures and subsidences caused by evaporitics materials dissolutions favoured by mining. In particular, our study area contains three sinkholes, the older one formed before the sixties. Recently, soil failure has occurred in 2000 and 2002 leading to two sinkholes with a maximum diameter of 5 m. One of them presents a depression area around the sinkhole that reaches a diameter of 20 m.

In this paper we focus on the geophysical survey carried out in order to determine the underlying mechanism that controls their formation and detect the extension of the collapse/drainage features associated with sinkholes. Two geophysical methods have been applied to constrain the interpretation in this area characterized by a complex geology and the presence of a variety of materials susceptibles to dissolution. Seismic and CSAMT methods have been chosen since they provide subsoil information for a similar scale and penetration. The results and interpretation for two profiles located in the vicinity of two sinkholes are presented in this work.

Geological Setting

The study area is part of the Catalan Potassic Basin in Northeast of Spain (Figure 1). Evaporitic materials have been

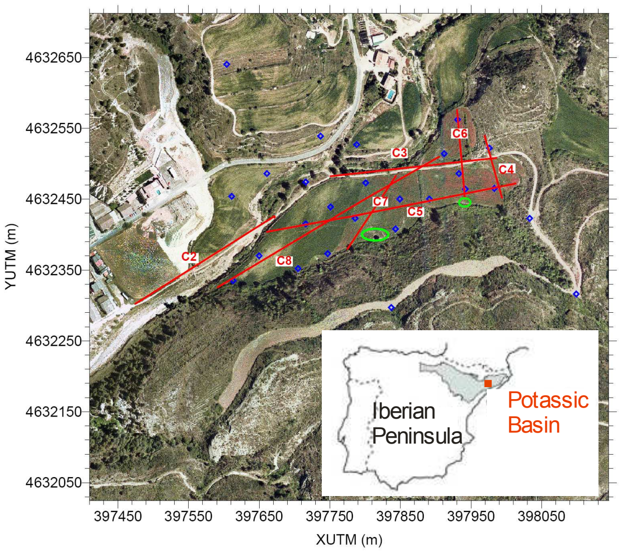

Figure 1 Location of the study area showing the distribution of seismic profiles (red lines) and CSAMT stations (blue diamonds). Green lines indicate the location of the two sinkholes studied in this work.

deposited in the Eocene during the exorreic/endorreic transition of the basin. Subsequently, continental sedimentation evolves from alluvial ambient with conglomerates, sandstones and lutites deposition to a lacustre and palustrine ambient (calcarics, marls and sandstones).

The target area is a colluvial plain limited by a Northern outcrop characterized by gypsum and anhydrites rocks. In the Southern margin, calcaric marls and lutites can be observed. According to borehole information, below quaternary materials, marls and calcaric layers are found. The calcaric layers present a maximum thickness of 2 m interbedded with marls. Below this formation marls and gypsum can be found underlain by salt materials with a depth of 70 m in the western part of the study area. Salt top depth in the rest of the area is unknown. Figure 1 shows the location of the two more recent sinkholes which are the target of this study.

Methods

Seismic methods were performed using DMT seismic recorder with 48 channels. Seven P-wave profiles were acquired using low-energy explosives as seismic source. The orientation and length of the profiles were limited by the dimensions of the study area. Therefore, distances between 40-Hz geophones vary from profile to profile with a minimum of 2.5 m and maximum of 5 m (equivalent to 120 m and 240 m total length). C5 and C8 profile were acquired overlapping two 48 channels spreads arriving to a length of 340 m. Source position has varied along a fixed geophone spread in order to have data suitable for refraction analysis. A total of 15 shots were fired for each 48 channel spread. Where data quality allows, low-fold seismic reflection stack has been obtained. *Rayfract* software has been applied to obtain seismic velocity models from first arrivals. A 1D gradient initial model is derived from time-distance slope and subsequent refined with Wavepath Eikonal Traveltime tomography processing.

Control Source Audiomagnetotelluric data has been acquired using a StrataGem EH4 system, a four-channel, natural and controlled-source tensor system recording in the range of 10 to 92000 Hz (Geometrics, 2000). The system is composed of 4 buffered active high-frequency electrodes and 2 induction coils connected to an receiver. To improve the signal-to-noise ratio where cultural noise may be present or where the natural signal is weak, an unpolarized transmitter (800 to 64000 Hz) comprised of two horizontal-magnetic dipoles with a magnetic moment of 400 Am^2 is used. The transmitter needs to be located far enough away from the receiver to fulfil the plane wave assumption, but close enough to provide adequate signal strength. AMT+CSAMT tensor measurements may be treated using standard MT processing techniques. The Determinant of the impedance tensor was inverted using the code of Siripurnvaraporn and Egbert (2000) with the modifications of Pedersen and Engels (2005).

Results

Figures 2 and 3 show the velocity and resistivity models obtained from seismic refraction and CSAM methods respectively for profiles C5 and C8.

C5 is the closest profile to the collapse on surface which location is shown over the models. C8 crosses the depression area associated to sinkhole 2. Seismic models depict low-velocity values (< 1500 m/s) in the shallow section probably related to unconsolidated sediments above the water table in both profiles. The zone below this shallow part is characterized by a low velocity anomaly located around 180-200 m distance in C5 and around 160 m distance for C8 up to a depth of 50 m aproximately. The eastern sector of the C5 model presents a maximum depth of 45 m compared to 90 m in the rest of the profile. This low penetration can be interpreted by the presence of a strong velocity gradient which precludes the rays to travel deeper. High velocity zone is revealed at 80 m depth (>3500 m/s) in the western end in C5 and at both sides of the profile below 60-70 m depth in C8.

The most striking result from the CSAMT models is the presence of high resisitivity structures at depth, which are spatially coincident with the high velocity zones observed in the seismic velocity models

Conclusions

Both seismic velocity and resisitivity sections show an excellent correlation between low velocity and low resistivity zones in the central part of the profiles. This may be related to a water content and porosity increment in the sediments of these zones. In this way, it would help to delineate collapse/drainage sectors associated to sinkholes.

The high-velocity sectors below 60-70 m depth correspond to the resistive zones. The interpretation of these sectors is cumbersome since they could be related with calcaric or evaporitic rocks. However, very high-velocity values combined with borehole information lead us to consider the western high-velocity zones of the profiles as salt.

Combining two geophysical techniques is critical to obtain information in a sinkhole area specially in zones where complex geology make difficult to define the causes of terrain inestabilities. Seismic and CSAMT methods are shown as good complementary techniques in this type of studies.

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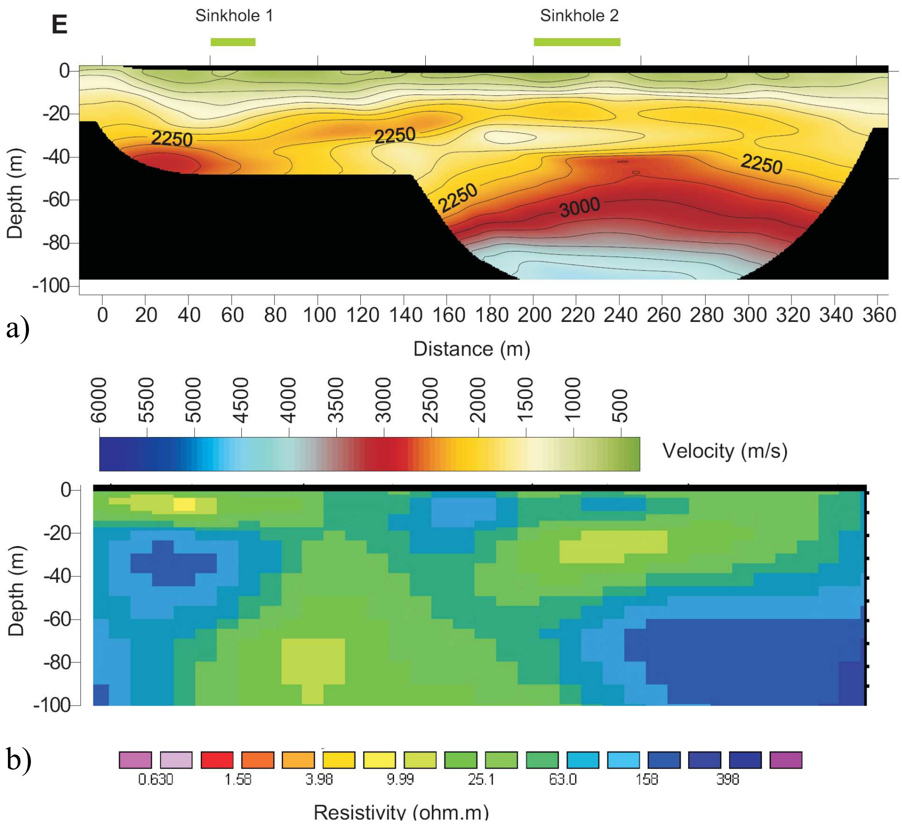

Figure 2. a) Seismic velocity model and b) Resistivity model from CSAMT of C5 profile.

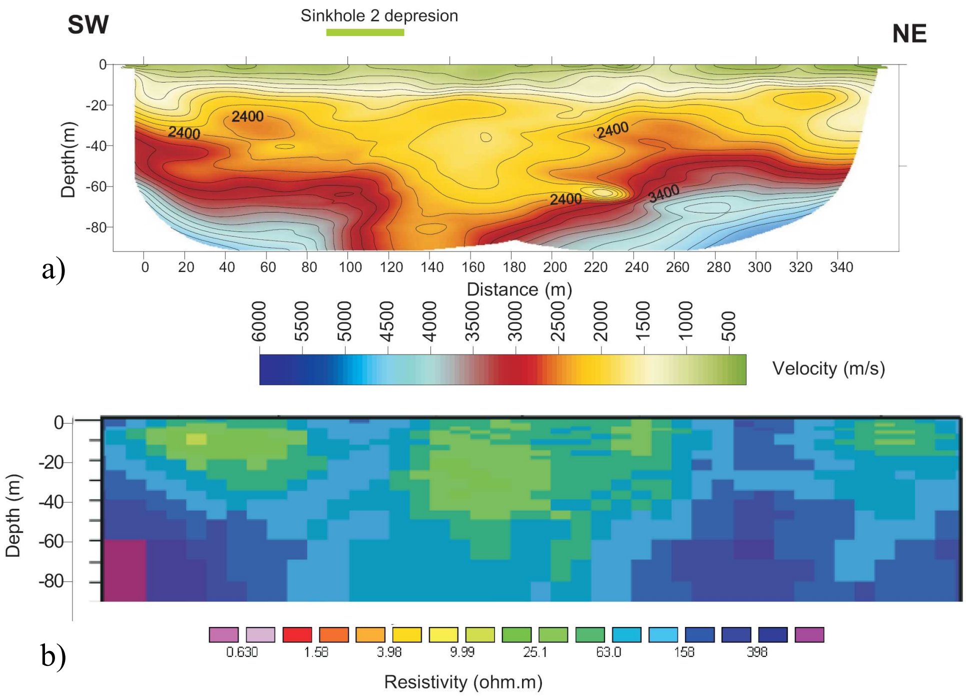

Figure 3. a) Seismic velocity model and b) Resistivity model from CSAMT of C8 profile.