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Surface geophysics and borehole inspection as an aid to characterizing karst voids and vadose ventilation patterns (Nerja research site, S. Spain)

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ABSTRACT

A combined approach using two surface geophysical methods (capacity-coupled geoelectrics and ground-penetrating radar) and careful inspection by optical televiewer probes in a network of boreholes (<30 m) has been undertaken at an experimental karst site located in the immediate vicinity of the Nerja cave (S. Spain), an important show cave developed in Triassic dolomitic marbles. Our approach has proved helpful in characterizing geometrically and speleologically the vadose zone of these highly heterogeneous environments in that we have been able to identify a considerable number of caves and arrive at an idea of their approximate volume and length. Televiewer logging in the borehole network allowed us to identify a number of karst features: horizontal and vertical openings and cavities, as well as the relative degree of speleothem development. We had previously made a systematic record of the CO_2 content of the air inside these boreholes and the results of this earlier study together with the present one have allowed us to further our knowledge of the ventilation patterns in the vadose zone of the research site, which suggest that high CO_2 contents (up to 60,000 ppm) are directly linked to the degree of karstification. The general geometrical model of karstification in the area suggests a common genesis for the Nerja cave and the numerous cavities revealed during this study. The flows of CO_2-rich air and the ventilation patterns in the vadose zone in general seem to be different in the Nerja cave from those in the network of small cavities surrounding it, a circumstance that most likely derives from the fact that the main cave communicates both naturally and artificially with the outside atmosphere. The air-flow regime in the network of boreholes has still to be studied in detail however.

1. Introduction

1.1. General objectives

Geophysical methods are very useful for studying karst terrains because of the intrinsic heterogeneity of the medium (*cf.* Mochales et al., 2007; Neukum et al., 2010; Smith, 2005; Šumanovac and Weisser, 2001; Van Schoor, 2002; Vouillamoz et al., 2003). A detailed study of the geometry and structure of a karst system (i.e. epikarst, karst conduits and cavities) can lead to an understanding of the different processes taking place. These processes include infiltration from surface to groundwater level, the movement of contaminants, air flow in the vadose zone and/or the evolution and variations in the atmosphere in caves. Our study focuses on the latter of these processes, as will be explained in the second part of this introductory section. The first part contains a brief review of the main geophysical methods used to detect voids, fissures and cavities in karst terrains.

Because the main heterogeneities in karst terrains are due to the existence of voids (minor and major cavities, conduits, fractures and fault zones) any geophysical method must involve void detection as its main objective. Furthermore, the geophysical mapping of karst heterogeneities needs to be able to encompass the many singularities involved: (1) target depths may vary within one to hundreds of metres; (2) karstic void sizes may range from centimetres to tens of metres; (3) the surfaces of karst areas are often rough and consist of a combination of soil and compact rock; (4) investigation sites often belong to protected environmental areas; and (5) groundwater and its seasonal variations plays an important role in that it changes physical parameters at different times. Although all these points might sometimes be disadvantageous, the vadose zone affords the advantage of not being a fully saturated medium and thus provides

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