UP-TO-DATE OF SURFACE BASED HYDROGEOPHYSICS IN KARST SYSTEMS.

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ABSTRACT

This essay is a forward-looking evaluation of surface-based geophysical methods applied to karst system hydrogeological exploration. First it describes the most common issues in karst hydrosystems. Second for each issue, it provides an overview of the most relevant geophysical studies being published the last twenty years. Finally, it provides an evaluation on the adequacy of all surface-based geophysical methods used for karst systems hydrogeological exploration. This work is a part of a recently submitted paper [3] that treats in a more general way, based in an exhaustive bibliographic research, all surface based geophysical methods applied for investigation in karst terrains.

INTRODUCTION

Karst is the one of the most challenging environments in terms of groundwater, engineering and environmental problems [5]. Geophysics can provide useful subsurface information in karst regions but suitable characterisation of heterogeneities in the karst environment is challenging for all geophysical methods. Due to its complexity, a karst area produces multiple and time-variable geophysical signatures [3]. Therefore, selection of the correct geophysical method for karst system exploration is not always straightforward, due to the highly variable and unpredictable target characteristics.

During the last years, several efforts were undertaken in order to provide a guideline for geophysical methods in karst system exploration. (**e.g.** [2] provided a first attempt to evaluate the possibilities of using geophysics in karst systems. [8] provided a useful comparison of various geophysical approaches for void detection and [4] established a guide for air-filled caves detection with geophysical methods. [1] described geophysical methods adapted to karst study in a general book about karst hydrogeology. [6] presented an evaluation of geophysical methods for sinkhole detection in evaporate areas based on general proposition of geophysical methods for karst exploration made by [7]).

MAIN ISSUES IN KARST HYDROSYSTEMS

Taking in consideration the complexity of a karst system, an effort was undertaken to identify the main issues related to hydrogeological exploration. Certainly, the list presented in this paragraph is simplified and some issues can be superimposed or even subdivided into more specified ones. Nevertheless, this list is made according to the most frequent issues addressed to geophysicists and also to the available published studies used by [3].

Accordingly five main hydrogeological issues in karst can be recognised:

1. Limits – extension of a karst system: how geophysics can help to define the boundaries of a karst system? (Vertical or lateral limits of an outcropping karst system or of a sedimentary buried karst system). Localisation of the karst substratum, contact with other non karst formations, presence of faults etc.
2. Structural discontinuities: Do geophysical methods can distinguish more fractured zones of a karst system from the massive part of the same formation? Can it define orientation of the fractures?
3. Preferential pathways, concentrated infiltration: Sinkholes are often points of recharge to the karst groundwater system and generally the most vulnerable points of a karst system. Such features often do not have a surface expression, and their presence may go unrecorded. Do geophysical methods can help to localise such preferential pathways?
4. Empty cavities: In what conditions geophysical methods can help to localise air filled cavities? Or voids in a smaller scale?
5. Water-filled cavities: Do geophysical methods can provide with accuracy the position of a water-filled cavity?

ADEQUACY OF GEOPHYSICAL METHODS

Geophysics examines the physical properties of the subsurface, with four parameters – electrical resistivity, density, propagation velocity of elastic waves and magnetic susceptibility- forming the basis of the four fundamental geophysical methods. Numerous measurements techniques exist within this limited number of methods, with the application of a specific technique often being reserved for a well-determined target.

Based on an exhaustive bibliographic research (more than 100 papers published in high rang international journals), [3] states the up-to-date contribution of ground-based geophysical methods in karst exploration

and provides an evaluation of their adequacy regarding various issues (Table 1). This evaluation presents the state of the art of the geophysical methods contribution for karst system exploration, based on the analysis of published scientific results.

Ground based geophysics		Adequacy of the method: With sedimentary covering					Adequacy of the method: Without sedimentary covering					Sedimentary covering		Remarks	
Method	Measuring technique	Boundaries	Fractured zone	Preferential pathways	Cavities: Air-filled	Cavities: Water-filled	Boundaries	Fractured zone	Preferential pathways	Cavities: Air-filled	Cavities: Water-filled	nature	thickness	Rent cost per week	Min number of operat.
Electrical	ES	+++	++	+	0	0	+++	+		0	0	++	+++	II	3
	ERT	++	++	++	++	++	+++	++	++	++	++	+++	++	III	2
	Mise-à-la-masse	0	0	++	0	++	0	+	++	0	++	0	0	II	2
	SP	0	++	+++	0	++	0	++	+++	0	++	+	0	I	2
EM	slingram	++	++	++	+	+	++	++	++	++	++	+++	++	II	2
	TDEM	+++	+	0	0	0	+++	+	0	0	0	+++	+++	II	2
	GPR	0	+	+	+	+	+	+++	++	+++	++	+	0	II	3
	CSAMT	+++	++	++	+	+	+++	+++	++	+	+	+++	+++	IV	2
	VLF resistivity	++	++	++	+	+	+++	+++	+++	+	+	+++	+++	II	2
	VLF EM	++	+++	+++	+	+	++	+++	+++	+	+	++	+	II	2
Seismic	Tomography	+++	++	++	++	++	+++	++	++	++	++	++	++	IV	3
	MASW	++	++	++	++	++	++	+++	++	++	++	++	++	IV	3
Microgravity	Profiling or mapping	0	+	+	+++	++	0	+	+	+++	++	0	0	III	2
Magnetic	Profiling or mapping	0	0	0	0	0	0	0	0	0	0	++	0	II	2
MRS	Sounding	0	0	0	0	+++	0	0	0	0	+++	+	0	V	2

*+: adapted but limited, ++: adapted but incomplete, +++: recommended, and 0 not recommended
**I : <300 €, II : 301-600 €, III : 601-1000 €, IV : 1001-2000 €, V : >2001 € (sources : ABEM France, IRIS Instruments, Expins et Georental)

Tab. 1 Adequacy of geophysical methods to karst system exploration by [3].

DISCUSSION

The geophysical response depends on the size of the target in relation to its depth and on the contrast between the physical properties of the target and those of the surrounding rock. The size of karst features is usually small, except for caves. Caves have a larger size but they are often located in more important depth. The amplitude of geophysical anomalies is, moreover, an inverse function of the distance between the measurement point and the structure. However, it is important to remind that the response of each geophysical method is highly dependant to the overburden sediments. Their thickness and consistence (percentage of clay, density, presence of water, etc) can significantly change the geophysical signature of the target as their investigation depth. The presence, the thickness and the structure of the epikarst zone is also extremely important.

CONCLUSION AND PERSPECTIVES

Each karst system is unique, and the geometry of its different parts can be rather complex. Due to very strong lateral and vertical changes of physical and lithological properties in karst regions, the main goal of an exploration is to acquire a precise three dimensional geological model of the underground. Geophysical methods can play an important role in the building of such a model for two main reasons. Firstly, on the basis of geophysical results, the optimum locations and quantities of exploration boreholes can be defined which can have great implications on the total exploration cost. Secondly, geophysical methods can provide for continuous coverage over an exploration area, connecting data from boreholes to build a complete 3D model. High and rapid spatial sampling (dense spatial coverage), low cost and fast data interpretation are the main advantages of geophysical methods compared to traditional geological, hydrogeological and geomorphological studies. Finally, 3D data acquisition and inversion development for many geophysical methods as boreholes geophysics seems to be extremely promising for karst system exploration.

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Hydrogeophysics is a cross-disciplinary area of research that uses geophysics to determine parameters (characteristics; measurements of limitations or boundaries) and monitor processes for hydrological studies of matters such as water resources, contamination, and ecological studies. The field uses knowledge and researchers from geology, hydrology, physics, geophysics, engineering, statistics, and rock physics. It uses geophysics to provide quantitative information about hydrogeological parameters in the different components of karst hydrogeological systems. It is hoped that the book will also provide a basis for scientists and technicians working on the development of new and better investigative methods and there is still much to do! Of course, much more can be said about each method than can be done within the framework of this book.Â In karst aquifers, such model-based predictions are generally problematic (see section 1.4). This is not only because turbulent flow in vadose and phreatic conduits is difficult to model, but mainly because the network of conduits and fractures is rarely sufficiently well known. Nevertheless, models. Due to its karstic nature, the Salento Peninsula is characterized by scarce availability of surface water resources. On the other hand, important volumes of groundwater are hosted in the deep, karst aquifer, which represents a strategic resource for the socioeconomic aspects of this Mediterranean region [25].Â The equivalent porous medium approach is being widely adopted to simulate groundwater flow in karst systems all over the world [46, 55] and in the region under exam [28, 31â€“36]. In this contribution, we made a step forward with respect to the previous modelling studies referred to the deep aquifer of the Salento Peninsula.