Geophysical characterization of a crystalline hard rock using MRS, TEM and ERT methods: A case study

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SUMMARY

The paper presents the results of combined study of electrical resistivity tomography (ERT), transient electromagnetic (TEM) and magnetic resonance sounding (MRS) in an over-exploited granitic terrain at Maheshwaram watershed carried out during 1999-2003 under a collaboration between the CSIR-NGRI, India and BRGM, France. The integrated analysis has helped in assessing the total groundwater resources. The water content in the area is found varying in the range of 0-8% down to the depth of 25 m below ground level (bgl). Maximum percentage of water content is found at around 15 m (bgl). Comparative MRS response in 1999 and 2003 revealed drastic fall of the free water content from 5% to negligible (MRS signal level is less than the instrumental noise of 5 nV). In this weathered granite setting MRS show greater sensitivity to groundwater depletion than ERT.

While the sensitivity of the instrument is sufficient for characterizing the water-saturated saprolite, in the fissured zone (FZ) where the water content is much lower, the magnetic resonance signal is accordingly lower. The method sensitivity may then not be sufficient and this formation cannot be fully resolved.

Key words: Magnetic Resonance sounding, Transient electromagnetic method, Electrical resistivity tomopgraphy, Granite hard rock

INTRODUCTION

The Green Revolution of the seventies in India has led to a complete anastrophe of the irrigation scenario with groundwater sustaining most irrigated land instead of the previously used surface water. Nowadays, the strain on groundwater resources due to the pumping of large quantities of water threatens the sustainability of agricultural development. A joint study of the CSIR-NGRI and BRGM in collaboration with IRD, UMR Sysiphe was carried out to test the efficacy of magnetic resonance sounding method in determining the water content in the weathered-fractured granitic terrain in India and supply input parameter to the groundwater modelling for effective groundwater management. The joint study addresses two maim issues: i) domains and limits of application of the geophysical method in general and MRS in particular for the characterization of weathered granite aquifers, and ii) reliability of the MRS estimation of the aquifer characteristics and hydrodynamic properties.

- Field investigations were carried out on two hydrogeological watersheds i.e. the Maheshwaram and Wailpally in Andhra Pradesh (Figure 1). Subsurface geology in the both the watersheds is composed of weathered granite of Archean age falling in the semi-arid condition. This paper presents a few typical representative results from KB Tanda site of Maheshwaram watershed. Weathered and weathered-fissured layers form aquifer system. The weathered layer structure is result of multiphase process such as: (i) an ancient weathered profile that got partly eroded; (ii) re-weathered profile roughly parallel to the current topography (Dewandel et al., 2006). In addition presence of intrusive in such terrain makes the weathered profile even more complex resulting into compartmentalization of the aquifer system. The weathering profile can be categorized broadly from top to bottom as: saprolite, the Fissured Zone (FZ) and fresh unweathered rock. The global geometry of crystalline rock is mainly controlled by the weathering processes, where such front are parallel to paleo-surfaces and thus lead to a mainly sub-horizontal and stratiform structure (Wyns et al. 2004). However, geological features such as fault and dykes or contrasts in rock mineralogy can locally modify the characteristics of the weathering profile and lead to the development of 2D and 3D structures. The top weathered materials are the principal aquifer system, where and ground water occurs under water table condition. Weathered zone is followed by its underneath weathered-fractured zone, where groundwater is found unconfined to semi-confined conditions. Beneath the weathered horizon, fractures system within the basement surface is also supposed to be potential aquifer zone. But determination of fracture geometry is difficult task and these fracture zones have not been fully exploited.

METHOD AND RESULTS

The proposed methodology is based on the combined use of electric-electromagnetic methods that are used for delineating the subsurface structure and geometry and Magnetic Resonance Sounding (MRS) for defining the hydrodynamic characteristics of the aquifer. Following such a detailed aquifer schema, geophysical field data were carefully compared to borehole lithology and hydrogeological testing data. Numerical study of the sensitivity of applied geophysical methods has led to the following results. ERT is preferred over TDEM because the FZ is too resistive to be distinguished from the underlying compact rock by the latter technique.

Two significant contrasted MRS responses were observed on KB Tanda rice fields (Maheshwaram watershed) in 1999 and 2003, while the water table had respectively deepened from 5 to 12 m below groundwater level (BGL). The KB Tanda site is located in the western part of the Maheshwaram watershed. Seven MRS were carried out along a 900 m long ERT profile. MRS results along the ERT profile in 1999 (**Error! Reference source not found.** show a main water-bearing layer extending from the surface or a few metres depth down to 10-15 m. It is characterized by 1 to 7% water content and a maximum relaxation time constant, T2* of 200 ms. It is moreover interesting to notice (Fig. 2) that the base on the water-bearing layer as drawn by the 1% water content contour is closely delineated by the 200 ohm.m iso-resistivity contour (Krishnamurthy et al., 2003).

A few TDEM sounding profiles (1999 survey) were located along ERT profiles on the KB Tanda site and on the Mohabatnagar site. For each sounding, the interpretation was carried out using a multi-layered smooth model with Occam inversion assuming a 1D case. The parameters of the inversion are the same for all the soundings: 8 layers have been taken into account and the depth of interpretation has been limited to 80 m. This value of 80 m can be considered as a maximum depth of penetration of the method with this configuration. Very conductive superficial layers can significantly lower this investigation depth.

On the KB Tanda site, MRS were repeated at about the same location, in a heavily irrigated area of paddy field, during different field surveys in 1999, 2003 and 2005 (Baltassat et al., 2004; Krishnamurthy et al., 2006) while the water level respectively deepened from 5 m to 12 m and 21.5 m below ground level. The MRS measurement (IPMR11) showed a well expressed MRS signal with a maximum amplitude of about 30 nV in November 1999, which was lowered to 7.5 nV during post monsoon in 2003 (Figure 3). A measurement repeated in March 2005 on KB1 (not shown in figure) also did not show any signal emerging from the noise although it was still lowered (4 nV).

CONCLUSIONS

The contrasted observations at KB Tanda (Maheshwaram) were modelled using geometrical constraints provided by detailed borehole lithology and demonstrate that MRS is able to assess the groundwater table depletion over time or spatially, in agreement with piezometric measurements and with local agricultural activities.
In this weathered granite setting MRS sensitivity to ground water depletion appears much higher than ERT one's.

While the sensitivity of the instrument is sufficient for characterizing the water-saturated saprolite, in the FZ where the water content is much lower, the magnetic resonance signal is accordingly lower. The method sensitivity may then not be sufficient and this formation cannot be fully resolved. The MRS screening effect of the saprolite water layer on the underlying FZ is also discussed and the limit of the inversion schema of interpretation in this context is underlined.

From this analysis a geophysical model of the Hyderabad region weathered granite aquifer is proposed, where the different water-bearing zones can be distinguished by their MRS, electrical and magnetic characteristics. MRS water content estimation compared favourably with other MRS observations obtained in Burkina Faso granite, thus suggesting that these results could be extended to similar geological settings around the world.

The observed significant variations in magnetic susceptibility along the weathered profile are an indicator of potential magnetic field inhomogeneities that could appreciably affect the MRS response, but it is not necessary to invoke them for interpreting the observed contrasted MRS responses since they are fully explained by water table variations.

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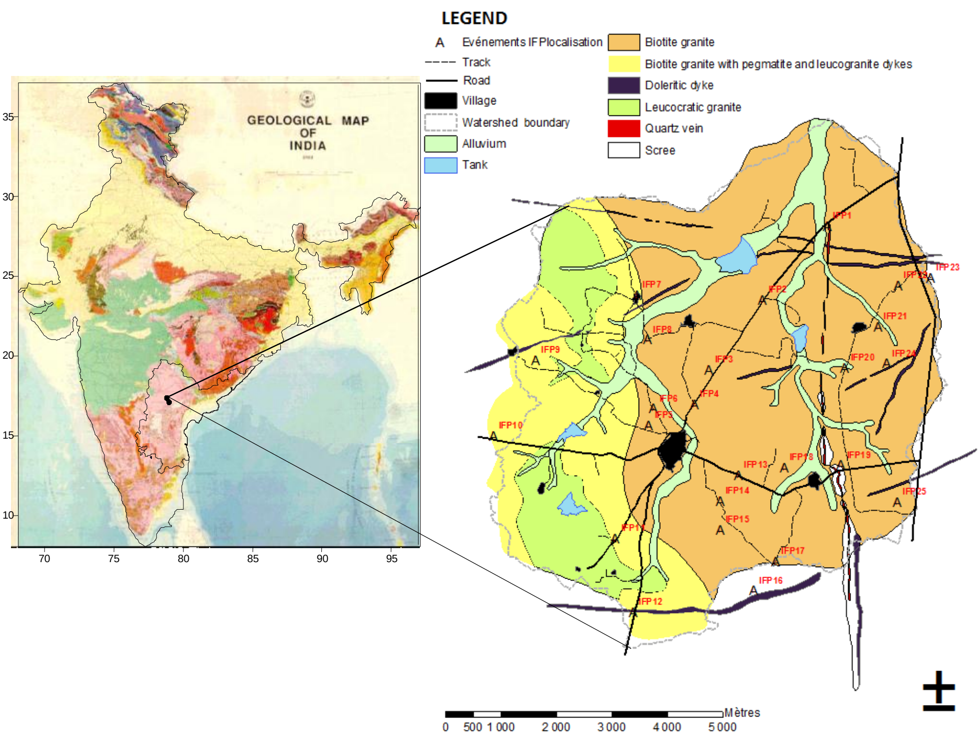

Figure 1: Location of the Hyderabad region and test sites within the Maheshwaram watershed.

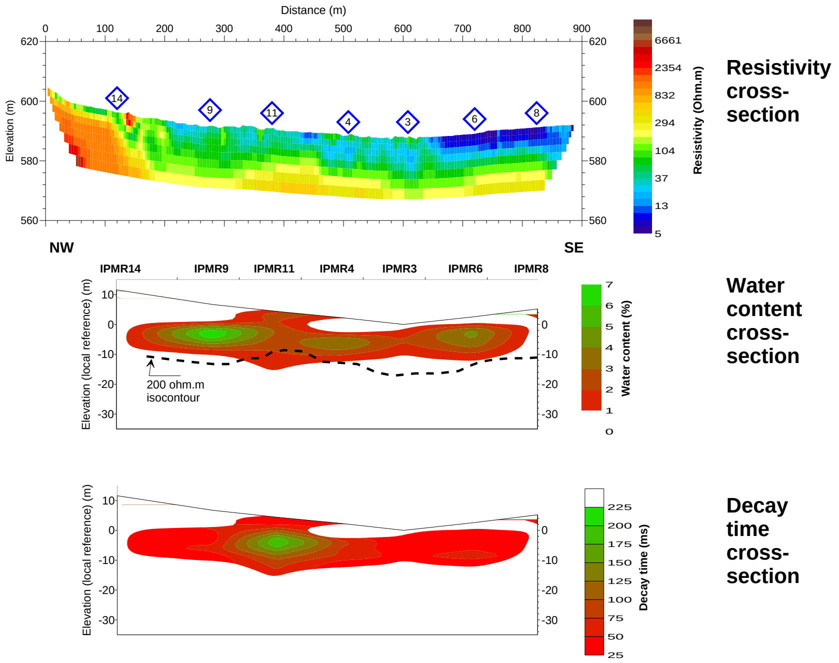

Figure 2: MRS and ERT cross-section on the KB Tanda site (1999 field survey data).

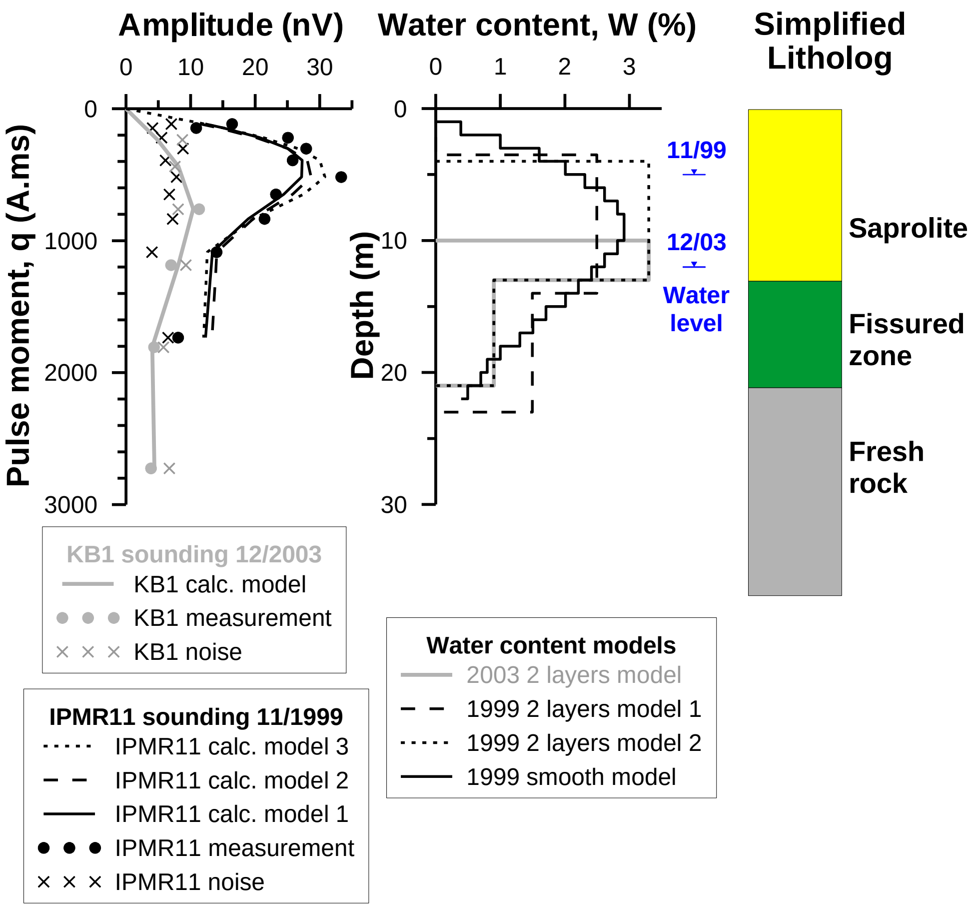

Figure 3: KB Tanda site: amplitude sounding curves measured in 1999 and 2003, calculated sounding curve and corresponding water content models. Note the water level that was at 5 m in 1999, deepened to 12 metres in 2003.