ARTICLE IN PRESS

NRIAG Journal of Astronomy and Geophysics (2014) xxx, xxx–xxx

National Research Institute of Astronomy and Geophysics

NRIAG Journal of Astronomy and Geophysics

www.elsevier.com/locate/nrjag

Geophysical assessment of the hydraulic property of the fracture systems around Lake Nasser-Egypt: In sight of polarimetric borehole radar

Khamis Mansour [a], Alhussein A. Basheer [a,*], Taha Rabeh [a], Ahmed Khalil [a], A.A. Essam Eldin [b], Motoyuki Sato [c]

[a] *National Research Institute of Astronomy and Geophysics (NRIAG), 11722 Helwan, Cairo, Egypt*
[b] *Research Institute of Groundwater (RIGW), Kalubia, Egypt*
[c] *Center for Northeast Asian Studies, Tohoku University, Kawauchi, Sendai 980-8576, Japan*

Received 20 August 2013; revised 18 October 2013; accepted 21 January 2014

KEYWORDS

Fracture characterization;
Polarimetric borehole radar;
Polarimetric analysis;
Lake Nasser and Nubian aquifer

Abstract Hydraulic property of the subsurface structures is a complicated mission. In this work, the polarimetric analysis for the measured dataset applied by the polarimetric borehole radar system in order to delineate the characteristics of subsurface fractures. Two different locations in USA and Egypt were selected to perform our investigation. The first polarimetric dataset has been acquired at Mirror Lake, USA which is well known as a standard site for testing the hydraulic properties of subsurface fractures (Sato et al., 1999). The results show the presence of nine fracture zones in one borehole FSE-1. The hydraulic properties were detected and the subsurface fractures were differentiated into four categories fracture zones after deriving the radar polarimetric analysis of alpha, entropy and anisotropy parameters at 30 MHz frequency. The fracture zones at 24.75, 47.8 and 55.2 m depths have the highest hydraulic transmissivity while the fracture zones at 28.5, 36.15 m have the lowest hydraulic transmissivity. These results show a good consistency with the hydraulic permeability tracer test and the structures exist in the area.

Similarly, we used the same technique to characterize the subsurface fracture systems detected by geoelectric and geomagnetic methods around Lake Nasser in Egypt using the previous results of Mirror Lake as a key guide. The results show a great correlation with detected structures prevailed in the sedimentary and basement rocks. These results illustrate an ideal explanation for the prevailed subsurface structures and the recharging of the main Nubian sandstone aquifer from Lake Nasser. Also, these results also show that the northeast fracture zone trends are most probably

* Corresponding author. Address: Geomagnetic and Geoelectric Department, National Research Institute of Astronomy and Geophysics (NRIAG), Egypt. Tel.: +20 1122802222; fax: +20 225548020.
E-mail address: Alhussein007@yahoo.com (A.A. Basheer).

Peer review under responsibility of National Research Institute of Astronomy and Geophysics.

ELSEVIER Production and hosting by Elsevier

http://dx.doi.org/10.1016/j.nrjag.2014.01.002

having the highest hydraulic transmissivity whereas the northwest fracture zones have the lowest one.

The integration of surface geophysical measurements with the polarimetric borehole radar and the polarimetric analysis of its datasets introduce better understanding of the recharging mechanism between surface water and the subsurface aquifer and also can be used as clue for identifying the subsurface structures for different areas.

1. Introduction

Flow interaction between a permeable rock and embedded conductive fractures remains poorly understood since earlier research may have investigated only into fractures (Smith, 1993), focused on idealized synthetic fracture geometries (Bogdanov et al., 2003), or applied a dual porosity approach assuming a stagnant matrix (Dershowitz and Miller, 1995; Kazemi, 1993). It is also difficult to monitor fracture flow in experiments (Renard et al., 2001). Using analytical solutions and finite-element analysis, many authors have been also involved to quantify the fracture connectivity, length distribution and saturation variations with layer thickness and lithology affecting and controlling the hydraulic conductivity of crystalline and tight sedimentary rock (Kranz et al., 1979; Taylor et al., 1999; Wu and Pollard, 1995, 2003).

Borehole radar is a special electromagnetic application of ground penetrating radar for determining the depth and location of subsurface fractures depending on their properties and their filled materials. This tool has limitations due to high attenuation of the electromagnetic waves.

In our work we are accommodating the polarimetric radar technology (Sato et al., 1999) to be used for investigating subsurface structures derived from the borehole measurements. To do that using the full polarimetric borehole radar system, a combination of the dipole and slot antennas as transmitter and receiver for acquiring the full polarimetric information for subsurface fractures was used. The dipole antenna transmits or receives the vertical polarized electromagnetic signals and the slot antenna transmits or receives the horizontal polarized ones. The full polarimetric measurements for a single borehole consist of measuring four times with a pair of antennas if the transmitter and receiver are the same type of antenna we call it Co-polarization measurements (VV and HH). On the other hand, when, the antenna pairs are not of same type we call it Cross- polarization measurements (VH and HV).

The configuration of the polarimetric borehole radar system is shown in Fig. 1. The advantage of this system is that: it overcomes the radar resolution as it measures the full polarization states in the borehole for the vertical backscattered and vertical transmitted electromagnetic signals (VV); vertical backscattered and horizontal transmitted signals (VH); horizontal backscattered and vertical transmitted signals (HV) and horizontal backscattered and horizontal transmitted signals (HH). We tested the method for evaluating the parameters of the known subsurface structures of the standard site at Mirror Lake, USA.

We applied this method to define the parameters of known subsurface structures such at Mirror Lake test site then applying the deduced results to estimate the unknown parameters of the subsurface structures previously detected using land magnetic and geoelectric survey around the artificial Lake Nasser, Egypt.

2. Data acquisition and interpretation

2.1. *Polarimetric data acquisition at Mirror Lake area, USA*

The Mirror Lake test site is a crystalline rock and quite homogeneous except for fracture sets. It is been used in the scientific researches/experiments to study the flow in fractured rocks by the USGS Toxic Substance Hydrology Program since 1990. The joint research group of Tohoku University and USGS carried out the field measurements at Mirror Lake site. These measurements involved a borehole cluster of FSE-1, -2, -3, and -4 (Fig. 2), which form a square (Lane and Haeni, 1998).

The full polarimetric single-hole radar measurements were conducted at FSE-3 and FSE-1 wells, with an antenna separation of 1.6 m. The separation distance between FSE-1 and FSE-3 is 9 m and the frequency-domain of the acquired data was between 2 and 402 MHz with a 2 MHz frequency interval. The single-hole full polarimetric dataset acquired at FSE-1 borehole1 is shown in Fig. 2.

2.2. *Theoretical bases of the polarimetric data analysis*

We are accommodating the polarimetric analysis to be used for investigating the hydraulic characteristics of subsurface structures derived from the polarimetric borehole radar measurements. The implementation of the target decomposition theorem for subsurface fracture characterization is based on the expected value of the coherency matrix T. The coherency matrix formation is based on the introduction of a scattering vector $\overrightarrow{k}_p$ where this vector can be estimated depending on the scattering matrix S elements ($S_{HH}, S_{HV}, S_{VH}, S_{VV}$) at certain single frequency. The scattering matrix S and scattering vector $\overrightarrow{k}_p$ are defined as follows:

$$S = \begin{bmatrix} S_{HH} & S_{HV} \\ S_{VH} & S_{VV} \end{bmatrix} \quad (1)$$

$$\overrightarrow{k}_p = \frac{1}{\sqrt{2}}[S_{HH} + S_{VV}\ S_{HH} - S_{VV}\ 2S_{HV}]^T \quad (2)$$

The coherency matrix T is formed by averaging the outer product of scattering vector $\overrightarrow{k}_p$ as shown in Eq. (3), the averaging window size can be (3×3, 5×5 or 7×7), and it has real non-negative eigenvalues and orthogonal eigenvectors.

$$\langle T\rangle = \frac{1}{N}\sum_{i=1}^{N} k_i.k_i^{*T} \quad (3)$$

Please cite this article in press as: Mansour, K. et al., Geophysical assessment of the hydraulic property of the fracture systems around Lake Nasser-Egypt: In sight of polarimetric borehole radar. NRIAG Journal of Astronomy and Geophysics (2014), http://dx.doi.org/10.1016/j.nrjag.2014.01.002