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Non-invasive characterization of water-bearing strata using a combination of geophysical techniques

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ABSTRACT

Hydrogeological investigations were carried out in an arid area of Inner-Mongolia to determine the locations of future water supply resources. The first geophysical survey was conducted near Baiqi to identify favorable boreholes using magnetic resonance sounding (MRS). The yield capacities of 43 sites were investigated, and the extent of the potential groundwater storage was determined. Previous studies have indicated that a major tectonic structure may have a significant impact on the groundwater flow and well yield in the study area. Therefore, high-resolution seismic surveys were applied in the second stage of the investigation to determine the fault locations. After the regional identification, a major structure was investigated in detail to map the fracture patterns. Based on the assumption that the hydraulic conductivity of this formation is similar along the entire strike of the fracture, we proposed drilling a borehole (BQ3) in the zone. However, this well has a yield of only 0.8 L/s, falling short of the required flow rate of 3.0 L/s. Therefore, the objective of the final stage of exploration was to accurately define the attitude and extension of the aquifer and to select a more favorable borehole site that would meet the required water flow rate. The geophysical exploration was carried out using time-domain electromagnetic (TDEM) and MRS methods. The MRS results suggest optimal locations for water supply boreholes within the subsurface structures mapped by the TDEM inversion method. The data obtained by drilling and coring are in agreement with the predicted aquifer thickness from the TDEM data. Pumping tests indicate that the water discharge of borehole BQ4 was 3.5 L/s. Our results demonstrate that the delineation of the groundwater body using a combined application of three geophysical methods (the MRS, TDEM and 2D seismic methods) was successful.

1. Introduction

The effective management of groundwater resources is of paramount importance in many regions of the world, particularly for those regions that suffer from a lack of fresh surface water and insufficient rainfall. The town of Baiqi in the Chinese province of Inner-Mongolia is typical of such areas, the average annual precipitation is 350.1 mm and groundwater is the only source of fresh water (Liu and Xia, 2004; Liu et al., 2005).

In the 1950s, various geophysical methods and borehole data were used to understand the geophysical features of the area. Consequently, the orientation of the faults within the study area was found to be predominantly ENE–WSW (faults F1 and F2) and E–W (Faults F3 and F4 in Fig. 1). A magnetic resonance sounding (MRS) survey was conducted in Baiqi in May 2002, in response to the request of the Inner-Mongolian government for comprehensive groundwater mapping and water supply planning. Forty-three sites were investigated using MRS, and the potential high groundwater storage area was identified (Fig. 1). There is an artesian well (BQ1) located near fault F1, suggesting that the fractures and faults may form an important groundwater resource in this area. Further, combined methods should be used to optimize the locations of further water supply boreholes within this complex terrain.

The accurate determination of fracture locations would provide important information on groundwater resources. For example, high-resolution reflection method has been developed and used for geotechnical, environmental and groundwater-related studies (Myers et al., 1987; Shtivelman and Goldman, 2000; Shtivelman et al., 1998). However, the method cannot yet predict groundwater locations or estimate total groundwater amounts.

Considering the depths and electrical resistivities of aquifers, MRS is a promising electromagnetic method. It allows for the direct detection of aquifers by assessing the groundwater, as opposed to detecting the electrical properties of the sediments (Jiang et al., 2011a,b; Schirov et al., 1991; Yaramanci et al., 1999). Furthermore, this method can estimate the water content, hydraulic conductivity, transmissivity, and storage-related properties (Lachassagne et al., 2005). The main geophysical constraint for MRS applications is the low level of the MRS

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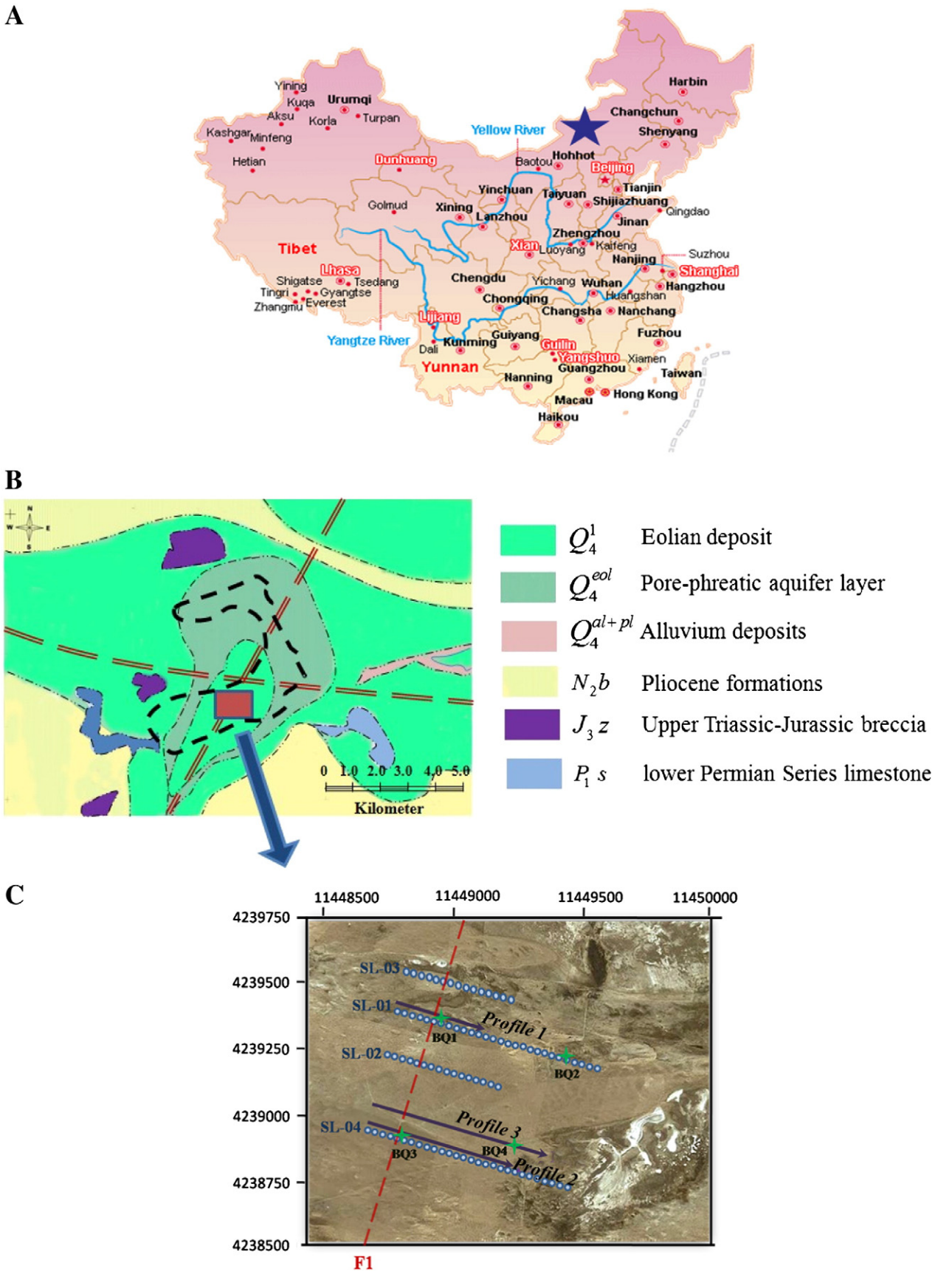

Fig. 1. Location and geological map of the survey area. (A) Maps showing Baiqi (blue star), where geophysical exploration was carried out in 2002. (B) The simplified geological map of the survey area, and an enlarged aerial photo of the exploration site. The black dotted line indicates 43 MRS testing sites, and the potential high groundwater storage area is shown in brown. (C) The locations of the seismic lines (SL), TDEM Profiles, and boreholes BQ1, 2, 3 and 4 are indicated.